

ICILSM 2026

5TH INTERNATIONAL CONFERENCE ON IMPACT
LOADING OF STRUCTURES AND MATERIALS

29 JUNE – 3 JULY 2026

NATIONAL UNIVERSITY OF SINGAPORE



NUS
National University
of Singapore

Department of Mechanical Engineering
College of Design and Engineering

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"Welcome to ICILSM 2026 and Singapore!"



Victor Shim
Conference Chair



Vincent Tan
Co-Chair



Leong Hien Poh
Co-Chair

A very warm welcome to ICILSM 2026 (5th International Conference on Impact Loading of Structures and Materials), to Singapore and to the National University of Singapore, particularly for those who are attending ICILSM or here in Singapore for the first time. For those who have attended previous ICILSM conferences, my Co-chairs and I trust that this will be as meaningful and engaging as the ones you have been to.

Thank you all for making the time and effort to come all the way here to this tropical island, and contributing to this time together. As with previous ICILSM conferences, we hope that this one will constitute an effective and productive forum for the sharing of current research activities and outcomes in the field of Impact Mechanics and Dynamic Material Behaviour.

In addition to the presentations, we trust that the conversations and interactions at mealtimes and during informal activities, will provide opportunities for meaningful discussions and foster establishment and enhancement of interpersonal rapport and friendships. Sustained communication beyond the conference, leading to possible future collaborative efforts, would constitute strong evidence that ICILSM has a significant role in linking together the international community working on dynamic stress analysis.

Most of all, we hope that your time in Singapore will result in an academically meaningful and personally enjoyable experience that yields positive memories of ICILSM 2026!

Victor P.W. Shim

NUS Department of Mechanical Engineering
Conference Chair
ICILSM 2026

Plenary Speakers



Professor Wesley Cantwell

Associate Dean for Research and a Professor in
Aerospace Engineering
Khalifa University

He received his BSc in Aeronautical and Astronautical Engineering from the University of Southampton, and MSc and PhD degrees in Aeronautical Engineering from Imperial College, UK. He then worked as a Research Scientist in the Department of Materials at the Ecole Polytechnique Federal de Lausanne for nine years and as a Lecturer/Reader/Professor at the University of Liverpool for eighteen years.

During this time, he directed a research team focusing on the impact behavior of lightweight structures. He joined Khalifa University in 2012 to establish and direct the Aerospace Research and Innovation Center (ARIC). His research interests are in composite materials, additive manufacturing as well as the impact response of structures and smart materials.

He has published more than 320 Scopus-listed journal papers on these topics. He has presented a number of keynote addresses at leading international conferences since joining ARIC, including at the 2014 European Conference on Composite Materials and the 2017 International Conference on Composite Structures. He currently works with a number of international partners on this topic, including the University of Cape Town, Tokyo University of Science and Tongji University.

Plenary Talk:

Energy absorbing properties of composite materials

Composite materials, such as carbon fiber reinforced epoxy resins, are renowned for their relatively poor resistance to localized impact loading and this, along with challenges in repairing such damage, historically resulted in delays in the widespread adoption of these high-performance materials by the civil aerospace sector. Paradoxically, however, composite materials are widely recognized for their outstanding energy-absorbing characteristics, particularly when tested in tubular form and loaded in the axial direction. Early work by Thornton [1] highlighted the impressive crushing characteristics of a range of glass, carbon and Kevlar fiber reinforced epoxy composites and showed that these materials offered specific energy absorbing (SEA) values that greatly exceeded those determined following tests on conventional metal tubes. Whereas the latter were observed to fail in a localized buckling mode, the composite tubes failed as a result of extensive fiber fracture and interlaminar shear, mechanisms that are capable of absorbing considerable levels of energy. Over the years, many other researchers have sought to investigate the outstanding energy-absorbing properties of fiber-reinforced composites and a detailed review of much of the early work was presented in a review article by Jacob et al [2].

This presentation will start by briefly considering some of these earlier studies. The main body of the talk will then focus on more recent work by the author and his colleagues that seeks to benefit from the impressive energy-absorption characteristics of composite tubes by developing a range of lightweight sandwich structures that can be used in engineering applications, such as those for which an outstanding ability to absorb energy is required. Here, the concept of tube-reinforced foams and tube-reinforced honeycomb structures is proposed, profiting from the fact that decreasing the diameter to thickness ratio of a composite tube leads to rapid increases in its specific energy absorbing properties. The presentation will then outline attempts to model the crushing behavior of composite tubes and tube-reinforced foams in order to gain a deeper understanding of the mechanisms of energy dissipation during the crushing process. The final part of the presentation will discuss ways to further enhance the energy-absorbing properties of lightweight sandwich structures.

Keywords: energy absorption, impact loading, crushing, sandwich structures, composite tubes.

References

- [1] D.H. Thornton, "Energy absorption in composite structures" J. Comp. Mats., Vol. 13, pp247-262, 1979.
- [2] G.C. Jacob, J. F. Fellers, S. Simunovic, and J.M. Starbuck, "Energy Absorption in Polymer Composites for Automotive Crashworthiness", J. Comp. Mats., Vol. 36, pp813-850, 2002.

Plenary Speakers



Dr. Christian C. Roth

Senior Scientist at the Chair of Artificial Intelligence in Mechanics and Manufacturing (AIMM)
ETH Zurich's Department of Mechanical and Process Engineering (D-MAVT)

He joined ETH in 2015 after a postdoctoral stay at MIT's Impact and Crashworthiness Lab. Dr. Roth received his PhD from Ecole Polytechnique in Paris for his work on the effect of strain rate on ductile fracture of metals.

While he is particularly interested in the effect of strain rate and temperature, the effect of anisotropy and stress state on the plastic and fracture response of engineering materials are also at the heart of his research. His current focus lies in the development of a fully automated thermo-mechanical high throughput testing laboratory along with the efficient calibration of advanced constitutive models for plasticity and ductile fracture under extreme conditions.

Plenary Talk:

From Data Scarcity to Autonomous Discovery: High-Throughput Thermo-Mechanical Testing and Constitutive Modeling under Extreme Loading

Predictive modeling of structures subjected to impact and extreme loading conditions critically depends on constitutive and fracture models applicable to wide ranges of stress state, strain, strain rate, and temperature. However, the experimental characterization of material behavior under such conditions remains constrained by low-throughput testing methodologies, significant operator dependence, and limited thermomechanical data. This talk presents a research effort to transform dynamic material characterization through the development of autonomous thermo-mechanical testing laboratories and efficient calibration strategies for advanced constitutive and ductile fracture models.

Recent developments towards fully automated, data-rich testing platforms include a fully automated high-throughput Split Hopkinson tensile bar system that enable dynamic testing with minimal operator intervention. Automated specimen handling, synchronized high-speed optical and infrared imaging, digital image correlation, and fully automated post-processing significantly reduce testing overhead while improving repeatability and statistical robustness.

The capabilities of the framework are demonstrated through the characterization of five dual-phase steels using more than 650 experiments. Automated parameter identification of constitutive frameworks is carried out using coupled thermo-mechanical finite element simulations combined with machine-learning-enhanced strain-rate dependent hardening and fracture models. These enhanced models are shown to accurately predict force-displacement responses, local strain fields, and temperature evolution across a wide range of loading conditions.

Plenary Speakers



Professor Andy Tyas

University of Sheffield

Professor Andy Tyas has worked in the field of research into high explosive blast for the past 30 years, mainly focusing on small scale, high quality experimental research.

He has authored or co-authored over 200 technical papers, and given keynote presentations on his blast research at conferences in UK, China, Belgium and Poland. Professor Tyas holds the position of Royal Academy of Engineering/DSTL Chair of Blast Protection Engineering at University of Sheffield, where he heads a team comprising around 25 academics, post-doctoral research associates and PhD students.

He founded the spin out company Blastech Ltd, 23 years ago which provides commercial services to industry and government departments in experimental blast and impact.

Plenary Talk:

Prediction of Loading from High Explosive Detonation: Past Successes and Future Challenges

The problem of predicting the loading from high explosive detonations was the subject of intense interest by some of the finest minds in early-to-mid 20th Century experimental, and numerical modelling research. Giants such as G.I. Taylor and John von Neumann worked on these problems, as did a host of brilliant but lesser-known researchers.

This was driven by armed conflict being a constant existential threat to humanity during much of that time. The result of this work was a profound understanding of the nature and parameters of high explosive blast waves in simple environments. Yet with the downgrading of the importance of this field from the later years of the 20th Century, as the threat of large scale armed conflict between major powers receded, there was a perhaps inevitable loss of some of that understanding.

This talk will cover work conducted over the last decade or so to try to re-establish the scientific fundamentals of blast loading in three scenarios: near-field, far-field and confined explosions. The talk will describe experimental methodologies and the conclusions found, before looking to how this positions the research field to address the next generation of challenges.

Plenary Speakers



Assoc. Prof. Cliff Butcher

Associate Professor in Mechanical Engineering
University of Waterloo
Director of the Waterloo Forming and Crash Lab

He completed his engineering degrees at the University of New Brunswick and worked with Professor Emeritus Michael Worswick, founder of the Forming & Crash Lab, as an NSERC post-doctoral fellow and then as a faculty member in 2016.

His research interests include the plastic deformation, formability and fracture prediction of advanced and high-strength metals, particularly in relation to automotive applications and crashworthiness. Recent focus areas include sheared edge fracture characterization, refinement of digital image correlation techniques for material characterization and the hot forming and crash performance of 7xxx-series aluminum and ultra-high strength steels.

Plenary Talk:

Vehicle Lightweighting with a Novel 7xxx Series Aluminum Alloy: From Thermomechanical Processing to Crash Performance

This talk covers the development of a hot forming process route for 7xxx-series structural automotive components from solutionization and precipitation hardening through to corrosion and crash performance. The focus is on C7M7, a new 7xxx-series alloy developed specifically for automotive hot forming applications with reduced quench sensitivity and an expanded forming window. The work was performed in collaboration with Honda and Cosma using the robotic fast forming cell and crash safety laboratory at the University of Waterloo.

The talk covers development of the solutionization and stabilization treatments, forming operations, die coating and lubricant selection, corrosion performance, fracture characterization, and structural impact testing. Particular attention is given to fracture characterization and prediction across multiple length scales and its application to structural impact simulations using both solid and shell element approaches.

The resulting process route uses a five minute solutionization treatment and two-step stabilization process that can be completed in as little as two hours while remaining insensitive to subsequent paint bake cycles, meeting corrosion targets and achieving improved crash performance relative to AA7075.

Plenary Speakers



Assoc. Prof. Shannon Ryan

Deakin University's School of Engineering in Melbourne, Australia

His research is focused on the development and application of machine learning and artificial intelligence to complex engineering problems, with a focus on protective structures and materials.

A/Professor Ryan has previously worked in various roles at Australia's Defence Science and Technology Group (DSTG), the US Army Research Laboratory (DEVCOM ARL), NASA Johnson Space Center (JSC), and the Fraunhofer Ernst-Mach-Institute (EMI).

Plenary Talk:

Designing Protective Structures in the Age of AI: Physics-Informed Learning and Human–Machine Collaboration

Designing protective systems against ballistic and hypervelocity impact presents a uniquely difficult engineering challenge. Experimental data is scarce and expensive to generate, the underlying physics is strongly nonlinear and multi-scale, and high-fidelity numerical simulations are computationally expensive. These constraints fundamentally limit the direct application of modern data-hungry AI approaches.

This talk will explore how AI and machine learning can, within this data-scarcity paradox, transform the design and evaluation of protective structures. We will discuss predictive modelling under sparse-data conditions by embedding physical knowledge and simulation data within machine learning frameworks. Additionally, we will consider design optimisation for lightweight ballistic and hypervelocity protective systems, including human-machine teaming paradigms in which engineers and AI systems collaborate to explore complex design spaces.

Finally, we will consider emerging research in hybrid computational approaches that combine first-principles physics, explicit finite element solvers, and machine learning to accelerate the design of protective systems for extreme impact loading.

Plenary Speakers



Dr. Joseph Morton

Project Engineer at ATA Engineering

He specializes in materials characterization and high-rate mechanics. He earned his Ph.D. from the Colorado School of Mines, where his research focused on the dynamic response of composites and ceramics under extreme loading conditions.

His expertise spans hypervelocity impact, aerospace ceramics, and energy-absorbing materials, integrating advanced experimental techniques with computational methods to enable predictive modeling. His work combines hypervelocity testing using two-stage light-gas gun platforms with multiscale simulation approaches, including hydrocodes, finite element methods, and molecular dynamics, enabling physics-based insights across length and time scales.

He has held research positions at Sandia National Laboratories and Lawrence Livermore National Laboratory, and has collaborated with the US Air Force Research Laboratory and the Office of Naval Research, among others.

Plenary Talk:

Identifying the Multiphasic Damage Mechanisms Associated with Hypervelocity Impact

Hypervelocity impact is becoming an ever-prevalent risk for space assets and re-entry vehicles due to the increased density of debris in Low Earth Orbit (LEO). Each micrometeoroid and orbital debris (MMOD) impact sheds an order-of-magnitude more fragments, representing an exponential growth in risk for impacts to future space assets. Impacts of this magnitude involve multiphysics behavior that can include phase transformations different from other kinds of dynamic loading.

This talk investigates the response of carbon fiber reinforced polymer (CFRP) annular truss members and silicon carbide plates to hypervelocity impact, leveraging experimental and computational techniques to capture the damage in both materials across solid states and length scales.

The comparison of the two materials illustrates the similarities and differences in how the energy from a hypervelocity impact is dispersed throughout the impact event. Identifying the energy transfer mechanisms during a hypervelocity impact will aid in the design of orbital debris shields for space assets and illustrate the potential strength of a thermal protection system for re-entry vehicles.

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29 JUNE – 3 JULY 2026

CONFERENCE PROGRAM & VENUES



Department of Mechanical Engineering
College of Design and Engineering

CONFERENCE PROGRAM OVERVIEW

29 JUNE 2026, MONDAY



5:30pm ~ 8:30pm
**REGISTRATION &
DINNER RECEPTION**

30 JUNE 2026, TUESDAY

9:00am – 9:30am (30 mins) OPENING SESSION	2:10pm – 2:30pm (20 mins) SESSION TRANSITION
9:30am – 10:10am (40 mins) PLENARY TALK 1	2:30pm – 3:20pm (50 mins) PARALLEL SESSIONS
10:10am – 11:00am (50 mins) PHOTO-TAKING & TEA BREAK	3:20pm – 3:50pm (30 mins) TEA BREAK
11:00am – 12:20pm (70 mins) PARALLEL SESSIONS	3:50pm – 5:50pm (120 mins) PARALLEL SESSIONS
12:20pm – 1:30pm (70 mins) LUNCH	5:50pm – 6:15pm BUS TO NUS U-TOWN
1:30pm – 2:10pm (40 mins) PLENARY TALK 2	6:15pm – 8:30pm WELCOME DINNER

1 JULY 2026, WEDNESDAY

9:00am – 9:40pm (40 mins) PLENARY TALK 3	1:30pm – 2:10pm (40 mins) PLENARY TALK 4
9:40am – 9:50am (10 mins) SESSION TRANSITION	2:10pm – 2:20pm (10 mins) SESSION TRANSITION
9:50am – 10:30am (40 mins) PARALLEL SESSIONS	2:20pm – 3:20pm (60 mins) PARALLEL SESSIONS
10:30am – 11:00am (30 mins) TEA BREAK	3:20pm – 3:50pm (30 mins) TEA BREAK
11:00am – 12:20pm (70 mins) PARALLEL SESSIONS	3:50pm – 5:50pm (120 mins) PARALLEL SESSIONS
12:20pm – 1:30pm (70 mins) LUNCH	FREE EVENING

2 JULY 2026, THURSDAY

9:00am – 9:40am (40 mins) PLENARY TALK 5	1:30pm – 6:30pm CONFERENCE TOUR to GARDENS BY THE BAY
9:40am – 9:50am (10 mins) SESSION TRANSITION	
9:50am – 10:50am (60 mins) PARALLEL SESSIONS	6:30pm – 8:30pm CONFERENCE BANQUET
10:50am – 11:00am (10 mins) TEA BREAK	
11:00am – 12:20pm (70 mins) PARALLEL SESSIONS	
12:20pm – 1:30pm (70 mins) LUNCH	

3 JULY 2026, FRIDAY

9:00am – 9:40am (40 mins) PLENARY TALK 6	12:10pm – 12:30pm (20 mins) CLOSING REMARKS
9:40am – 9:50am (10 mins) SESSION TRANSITION	12:30pm – 1:30pm (60 mins) LUNCH
9:50am – 10:50am (60 mins) PARALLEL SESSIONS	DEPARTURE
10:50am – 11:00am (10 mins) TEA BREAK	
11:00am – 12:00pm (60 mins) PARALLEL SESSIONS	
12:00pm – 12:10pm (10 mins) SESSION TRANSITION	

View the detailed Daily programs
in the following pages.

MAIN CONFERENCE VENUE

9 ENGINEERING DRIVE 1, SINGAPORE 117575
NATIONAL UNIVERSITY OF SINGAPORE



PICK UP / DROP OFF



BUS STOP

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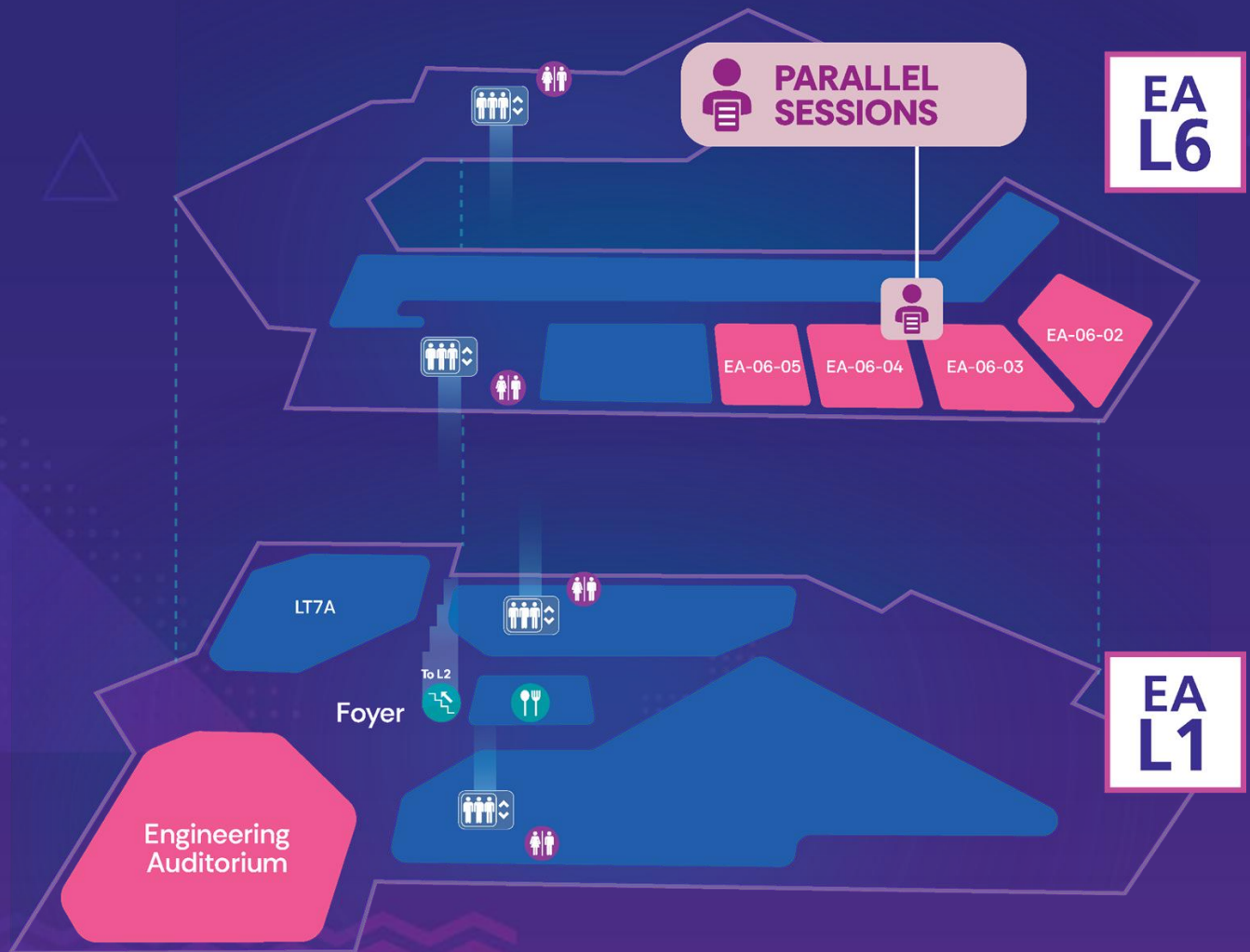
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CP 2B CARPARK 2B



PEDESTRIAN BRIDGE

MAIN CONFERENCE VENUE

9 ENGINEERING DRIVE 1, SINGAPORE 117575
NATIONAL UNIVERSITY OF SINGAPORE



Take lifts to LEVEL 6 for
Parallel Sessions



EA-06-02 | EA-06-03 | EA-06-04 | EA-06-05

DAILY PROGRAM

MONDAY 29 JUNE 2026

Registration & Dinner Reception Venue: Block EA Lobby	
17:30–20:30	Registration & Dinner Reception

TUESDAY 30 JUNE 2026

Plenum – Invited Lecture 1				
Venue: Engineering Auditorium – Chair: Victor Shim				
09:00–09:30	Welcome – Victor Shim (NUS); Poh Seng Lee (NUS Mechanical Engineering Department Head)			
09:30–10:10	Wesley Cantwell (Khalifa University) <i>Energy absorbing properties of composite materials</i>			
10:10–11:00	PHOTO-TAKING & TEA BREAK			
Parallel sessions 11:00–12:20				
	Session A1 - Blast loading and response Venue: EA-06-02 Chair: Andy Tyas	Session A2 - Impact absorption and crashworthiness Venue: EA-06-03 Chair: Cliff Butcher	Session A3 - Dynamic material behaviour and constitutive modelling Venue: EA-06-04 Chair: Sebastian Heimbs	Session A4 - Projectile penetration and perforation Venue: EA-06-05 Chair: Weinong Chen
11:00–11:20	044 - Blast and structural numerical analysis of accidental explosions during the hydrogen operation of the Large Gun of Fraunhofer EMI Stefano Signetti , A. Klomfass, W. Riedel, R. Putzar, P. Müller, A. Heine (Fraunhofer EMI)	029 - Behaviour of steel connections subjected to extreme loading conditions Magnus Langseth (SIMLab, NTNU)	042 - Determination of the Taylor-Quinney Coefficient from Strain and Temperature Measurements in Tensile SHB Tests Amos Gilat , Jarrod L Smith, Jeremy D Seidt, Carter J Fietek (The Ohio State University)	032 - Advanced ballistic protection concepts through experiment–simulation correlation and optimization Giovanni Garofalo , Patrice Longère, Kamel Moussaoui (ISAE-SUPAERO)
11:20–11:40	182 - Optimisation and Experimental Validation of Blast Door Panels with Conventional and Advanced Core Configurations Paolo Del Linz , Le Shen, Sherlene Ng (Singapore Institute of Technology)	067 - Mechanical behaviour of interpenetrating phases composites 316L/PDMS under dynamic loading Paul Jabin Echeveste (University of Bordeaux, CEA), L. Le Barbenchon, L. Heraud (University of Bordeaux, CEA), A. Core (CEA), P. Viot (University of Bordeaux)	082 - High-Cycle Fatigue Modelling of Microarchitected Lattices Sihao Han (University College London, South China University of Technology), I. Christodoulou, PJ Tan (University College London)	156 - Penetration Resistance of Cavity Structures against Shaped Charge Jets Junzhong Zhang , Zihao Wang, Hang Zheng, Zhijun Zheng (USTC)
11:40–12:00	090 - Localised blast loadings of functionally graded metallic plates Ye Yuan , Qiang Suo, Yifan Huang, Yan Liu (Beijing Institute of Technology)	155 - A plate-based shock isolator: Tunable nonlinear restoring forces enabled by boundary control Yuan Li , Y.D. Zhu (USTC), S.F. Liao (Institute of Fluid Physics, China Academy of Engineering Physics), Z.J. Zheng (USTC)	150 - Experimental techniques and dynamic behavior of TPMS lattice structures under high strain rate loading Xinpei Zhang , Yuanyuan Ding , Kebin Li, Mingjun Cui, Yuxuan Zheng (Ningbo University)	255 - Penetration Behavior and Configuration Design of Long-Rod Projectiles under Damage Regulation Shuangqi Li , Yiding Wu, Xinyu Sun, Bingzhuo Hu, Wencheng Lu, Guangfa Gao (NJUST)
12:00–12:20	049 - Arching Effects in Masonry Walls Subjected to Blast Idan E. Edri (Technion - Israel Institute of Technology)	170 - Structural topology optimization of honeycomb sandwich panel under ship side collision impact Guijie Shi (Shanghai Jiao Tong University), Yiqin Gong, Dawei Gao (University of Shanghai for Science and Technology)	085 - Electromagnetic Hopkinson Bar: Basic Principles and Application Yazhou Guo , Ning Li (Northwestern Polytechnical University)	147 - Homogenized modeling of cumulative kill probability for aircraft under multi-munition attacks Yuxiang Feng , Yuan Li, Tao Suo (Northwestern Polytechnical University)
12:20–13:30	LUNCH - Venue: EA Lobby			
Plenum – Invited Lecture 2				
Venue: Engineering Auditorium – Chair: Magnus Langseth				
13:30–14:10	Christian C. Roth (ETH Zurich) <i>From Data Scarcity to Autonomous Discovery: High-Throughput Thermo-Mechanical Testing and Constitutive Modeling under Extreme Loading</i>			
14:10–14:20	Session Transition (Move to 6th Floor)			
Parallel sessions 14:20–17:50				
	Session B1 - Blast loading and response Venue: EA-06-02 Chair: S. Das Adhikary	Session B2 - Artificial Intelligence and Machine Learning in impact/dynamic stress analysis Venue: EA-06-03 Chair: Yuanyuan Ding	Session B3 - Dynamic material behaviour and constitutive modelling Venue: EA-06-04 Chair: Paolo del Linz	Session B4 - Hypervelocity impact Venue: EA-06-05 Chair: Joseph Morton
14:20–14:40	078 - Damage Evolution and Flexural Residual Properties of GFRP Laminates Clamped in Two Sides and subjected to Air-blast S. Mashau, C. J. von Klemperer, Steeve Chung Kim Yuen , G. S Langdon (University of Cape Town)	192 - A Data-Driven Framework for Rapid Impact Deformation Prediction X. Zhang (Zhejiang University, Zhejiang University of Science and Technology), S.Y. Chen (Swinburne University of Technology), Guoxing Lu (Zhejiang University)	185 - Masonry Walls under Dynamic Loading – Analysis of two Lightweight Retrofitting Systems Christoph Roller , Kai Fischer (Fraunhofer EMI)	040 - Space Environment Effects on Hypervelocity Impact Behavior of High Heat-resistant Polyimide CFRP Masahiro Nishida , T. Tsukiokaa, M. Nagayoshi (National Defense Academy), Y. Ishida, Y. Kimoto (Japan Aerospace Exploration Agency)

DAILY PROGRAM

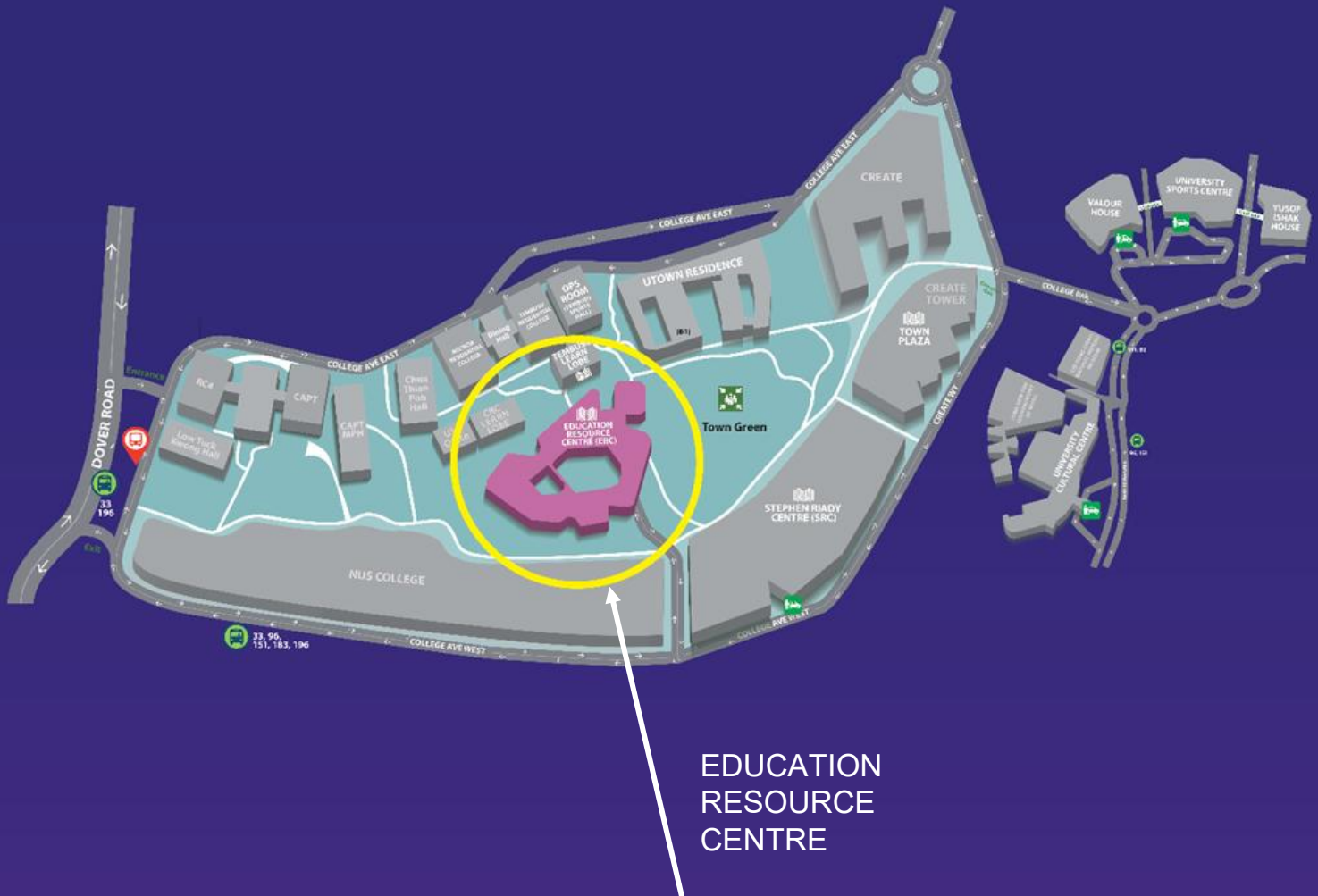
TUESDAY 30 JUNE 2026

14:40–15:00	158 - Anti-blast performances of various auxetic sandwich panels Guojie Chen , Kefeng Peng, Yuan Li, Baixue Chang, Zhijun Zheng (USTC)	135 - Machine learning-aided prediction and customization on mechanical response and wave attenuation of multifunctional kiri/origami metamaterials Sihao Han , C.L. Li, Q. Han, X.H. Yao (South China University of Technology)	149 - Influence of Strain Rate on Mechanical Properties of Ultra-high Molecular Weight Polyethylene Yangbo Guo (NUS), A. Yew, K. Chua (Singapore General Hospital), V.P.W. Shim (NUS, Ningbo University)	148 - Experimental Evaluation of the Mechanical Behavior of Pure Iron at Ultra-High Deformation Rates Chong Gao (Northwestern Polytechnical University), T Iwamoto (Hiroshima University), T Kusaka (Ritsumeikan University)		
15:00–15:20	050 - Blast Response of Hybrid Steel-UHMWPE Composite Panels Haleimah ALAbdouli (University of Sheffield, Technology Innovation Institute), Richard Curry, Genevieve Langdon (University of Sheffield)		124 - Influence of Cross-Sectional Aspect Ratio on the Dynamic Hardening of Li-ion Battery Cells Tuo Fang (Tsinghua University, National University of Singapore), Z.A. Zhuang, B.B. Xing, Y. Xia, Q. Zhou (Tsinghua University)	234 - Numerical Simulation and Experimental Study on the Momentum Transfer Characteristics and Impact Effects of Kinetic Impact on Quartz Sand Jinbao Ma , Tianhong Wang, Zizheng Gong, Xinlu Yu, Yingqian Fu (Ningbo University)		
15:20–15:50	TEA BREAK - Venue: EA Lobby					
	Session C1 - Experimental techniques for impact and dynamic testing Venue: EA-06-02 Chair: Hyunho Shin	Session C2 - Response of 3D-printed components to impact Venue: EA-06-03 Chair: PJ Tan	Session C3 - Failure and fracture under impact and impulsive loads Venue: EA-06-04 Chair: Naresh Thadhani			
15:50–16:10	257 - Dynamic In-Plane Torsion for Large-Strain Thermo-Mechanical Characterization of Sheet Metal and Taylor–Quinney Coefficient Identification Dirk Mohr , Xueyang Li, Christian C. Roth, Vincent Grolleau (ETH Zurich)	063 - Quasi-static and dynamic compression of 4D-printed reusable metamaterials with different Poisson’s ratios S. Huo (Swinburne University of Technology), A. Zolfagharian (Deakin University), F. Xia, S. Xu Swinburne University of Technology), Z. Gao (Tianjin Chengjian University), Dong Ruan (Swinburne University of Technology)	175 - A Combined Blast–Fragment Loading Test with Independent Control of Overpressure, Impact Velocity, and Arrival Time. Results from tests on dry Aramid Fabrics G. Kechagiadakis , D. Lecompte (Royal Military Academy Belgium), V.W. Paepegem (Ghent University)			
16:10–16:30	112 - Impact Testing System for a Mechanically High-Fidelity Anthropomorphic Craniocerebral Model J.Y. Wang, Y.T. Zhang, R. Li, K. He, Z.X. Chen, Z.Y. Lei, L.C. Zhou, Z.J. Liu, Y.P. Liu, B. Yang (South China University of Technology), G. A. Holzapfe (Graz University of Technology), Z.Y. Jiang, T.L. Sun, Liqun Tang (South China University of Technology)	122 - Blast-Like Loading Simulation Performance of Additively Manufactured Open-Cell Metallic Foams Chenglin Gou , Yuanrui Zhang, Yudong Zhu, Yongliang Zhang, Zhijun Zheng (University of Science and Technology of China)	080 - Ballistic Impact Responses of CoCrNi MEA Nanofilm Guiji Wang , Jinlei Dong (Institute of Fluid Physics, China Academy of Engineering Physics)			
16:30–16:50	243 - A thermodynamically consistent initialization approach for driver gas in a large-diameter shock tube: Experimental and numerical study on shock wave dynamics Haoyang Li , Li Chen (Southeast University)	221 - Experimental and numerical comparative study on the crashworthiness of pristine and recycled 3D-printed fiber-reinforced lattice structures Francesco Bandinelli , M Scapin, L Peroni (Politecnico di Torino)	128 - A Development of a DIC-Based Software for Direct Evaluation of the J-Integral in Dynamic Fracture Experiments of SUS304 Ruihe Liu (Hiroshima University), Bo Cao (Northwestern Polytechnical University), Takeshi Iwamoto (Hiroshima University)			
16:50–17:10	108 - Dynamic response of clamped circular plates subjected to graded cellular projectiles: A coupling analysis theory and validation Yuanrui Zhang (Hefei University of Technology), Y.D. Zhu (USTC), T.X. Yu (The Hong Kong University of Science and Technology), J.L. Yu, Z.J. Zheng (USTC)	233 - Microstructural and mechanical properties of CF/PEEK gyroid structures Dejian Zou , Yingqian Fu (Ningbo University)	017 - Failure Behavior Analysis of a Silicon-based MEMS Inertial Switch with Curved Zig-Zag Tracks Mo Yang , Weirong Nie, Baolin Cheng, Yun Cao (Nanjing University of Science and Technology)			
17:10–17:30	062 - Thermal Analysis of Portevin-Le Chatelier Effect in AlMg Alloys Chris Giesige , Antoine Dumont, Stephane Boubanga, Silke Klitschke, Frank Huberth, Ben Saute (Telops-Exosens)	126 - Experimental investigation on the response of sandwich panels with 3D printed biopolymer gyroid structure cores and asymmetric glass fibre face sheets under blast loading Sherlyn Gabriel , J.A. Dicks, M. Christodoulides, L. Luthuli (University of Cape Town)	114 - Probabilistic Fragility Assessment of the Liner Plate in the Reactor Cavity under Steam Explosion-Induced Impulsive Loads Seong-Kug Ha , S.L. Cha, J.C. Park (Korea Institute of Nuclear Safety), Y.H. Yoon, K.T. Lee (Korea Simulation Technologies)			
17:30–17:50	172 - Study on Load-Bearing/Energy Storage Integration Performance of Core-Sheath Structured Lithium-Ion Fiber Battery Composites for Dynamic Load Environments Xin Xia , Yingying Chang (Xin Jiang University)	016 - Compressive-Driven Mechanical Enhancement of Low-Infill FDM Parts Through Liquid Resin Infiltration Chi-Chyuan Kuo , Zhe-Zhi Lin (Ming Chi University of Technology)	123 - Full-Scale Low-Velocity Impact Experiments on Reinforced Concrete Slabs in a High-Temperature State Due to Fire Takuto Nakanishi , Yasunori Mizushima (Kobe University), Junichi Suzuki (National Institute for Land and Infrastructure Management), Wararu Yamasaki (Dot Corporation), Tomohiro Naruse (National Institute for Land and Infrastructure Management), Yoko Hirano (Hokkaido University)			
17:50–18:15	Bus to NUS UTown					
18:15–20:30	Welcome Dinner at NUS UTown					

29 JUNE 2026

WELCOME DINNER VENUE

EDUCATION RESOURCE CENTRE



DAILY PROGRAM

WEDNESDAY 01 JULY 2026

Plenum – Invited Lecture 3				
Venue: Engineering Auditorium – Chair: Leong Hien Poh				
09:00–09:40	Andy Tyas (University of Sheffield) Prediction of Loading from High Explosive Detonation: Past Successes and Future Challenges			
09:40–09:50	Session Transition (Move to 6th Floor)			
Parallel sessions 09:50–12:20				
	Session D1 - Blast loading and response Venue: EA-06-02 Chair: Christoph Roller	Session D2 - Dynamic material behaviour and constitutive modelling Venue: EA-06-03 Chair: Petr Hála	Session D3 - Experimental techniques for impact and dynamic testing Venue: EA-06-04 Chair: Takeshi Iwamoto	Session D4 - Impact absorption and crashworthiness Venue: EA-06-05 Chair: Tracy Dong Ruan
09:50–10:10	083 - ECC overlay Concrete system under Contact Detonation Aniket Kumar, Satadru Das Adhikary (Indian Institute of technology (Indian School of Mines), Dhanbad), Aditya Rana (CSIR-Central-Institute of Mining and Fuel Research)	199 - Dynamic Mechanical Characterization and Constitutive Modeling of 3D-Printed Polyurethane: An Infill-Dependent Study Xinyue Huang, Z.W. Guo, G.Y. Huang (Beijing Institute of Technology)	242 - Additively Manufactured SS316L–W Impedance-Gradient Flyers for Controlled Ramp-Wave Loading Xiaofeng Wang, Jinlin Xu, Yonggang Wang, Zhaoxiu Jiang (Ningbo University)	141 - Testing, modelling and optimisation of aluminium extrusions for side-crash protection of battery trays in electric vehicles Eduard Teixido, E.Teixidó-Marquès, D. Morin, O. S. Hopperstad, T. Børnvik, M. Costas (SIMLab - NTNU)
10:10–10:30	210 - Experimental and Numerical Study of Steel-concrete-steel Composite Walls with CFST Boundary Elements under Near-fault Explosions Yuxuan Wang, Lu Gan, Zhouhong Zong (Southeast University)	153 - A Macroscopic Constitutive Model for Polycarbonate Subjected to Impact Loading Haicheng Xu, Heming Wen (USTC)	048 - Impact Deformation Behavior of AA6063 Sheets Subjected to A Six-Stage Reluctance Electromagnetic Launch System Miaomiao Wan, Fuguo Li, Nianxuan Hu (Northwestern Polytechnical University)	237 - Dynamic Mechanical Behavior and Wave Propagation Analysis of Lattice Structures under High-Velocity Impact Xinpei Zhang, Yuanyuan Ding (Ningbo University)
10:30–11:00	TEA BREAK - Venue: EA Lobby			
	Session E1 - Blast loading and response Venue: EA-06-02 Chair: Steeve Chung Kim Yuen	Session E2 - Failure and fracture under impact and impulsive loads Venue: EA-06-03 Chair: Ye Yuan	Session E3 - Experimental techniques for impact and dynamic testing Venue: EA-06-04 Chair: Christian C. Roth	Session E4 - Artificial Intelligence and Machine Learning in impact/dynamic stress analysis Venue: EA-06-05 Chair: Shannon Ryan
11:00–11:20	208 - Blast Analysis of Underground Structures and Metro Stations Subjected to Internal Explosions Tin V. Do, Asher Gehl (Karagozian & Case)	115 - Insights from Machine Learning based Predictions of Spall Strengths of Metals and Alloys Naresh Thadhani, Keara Frawley, Hari Sahu, Nakul Shah, Jackson Smith, Greg Kennedy, Rampi Ramprasad (Georgia Institute of Technology)	020 - Vehicle Excitation Identification Based on the Dynamic Response of Bridges Tommy H.T. CHAN, K. Jeyamohan, Khac-Duy Nguyen, David P. Thambiratnam (QUT)	191 - A Dual-Network Framework to Optimize Lattice Protective Structures Under Impact Loading Conditions Salvatore Annunziata (Politecnico di Milano), L.A. Tellier (NTNU), L. Lomazzi (Politecnico di Milano), V. Aune (NTNU), A. Manes (Politecnico di Milano)
11:20–11:40	014 - From vent sizing to structural response: a logarithmic congestion model for dust explosion loads on industrial filter structures Francesco Pinna, Marco Zucca (University of Cagliari), Marco Simoncelli (Politecnico di Milano), Flavio Stochino (University of Cagliari)	092 - Calibration of Strain Rate- and Temperature-Dependent Constitutive and Fracture Models Using Results from a Single SHPB Test with a Compression-to-Tension Converting (CTC) Specimen Structure Hyunho Shin, Gyeonggeun Shin, Jinwoong Jeon (Kangwon National University), Jaehyuck Lee (Dyn Tech), Sanghoon Kim (Chonnam National University), Wooseok Sung, Jae Sakong, and Jaeyi Oh (Hanwha Aerospace Co. Ltd.)	046 - Hybrid Metallic Ceramic Interfacial Engineering for Enhanced Thermo-Mechanical Performance of CFRP Laminates under High Strain-Rate Loading Md Newaz Sharif, Pengfei Wang, Kassaw D. Jibrel, Songlin Xu (University of Science and Technology of China)	093 - Machine learning based predictions on the mechanical performance and inverse design of lattice metamaterials Lijun Xiao (Beijing Institute of Technology), X.C. Zhang (North China Electric Power University), W.D. Song (Beijing Institute of Technology)

DAILY PROGRAM

WEDNESDAY 01 JULY 2026

11:40–12:00	214 - Experimental study on impulse saturation of metal plates under shock wave loads and the application of pulse equivalent method Lanren Tian (Central South University), L. Zhu (Wuhan University of Technology), V.P.W. Shim (NUS)	159 - From Impact to Blast: An Integrated View on Laminated Glass Response, Fracture and Residual Capacity Petr Hála , A. Zemanová, P. Konrád, P. Kheml (Czech Technical University in Prague)	151 - Research Progress on the Development of Ultra-large Size Split Hopkinson Torsion Tube Xiquan Jiang (Hefei Jiangshui Dynamic Mechanics Experiment Equipment Co., Ltd., China), Qin Fang, Li Chen (Southeast University), Peng Yu (Guangxi University)	069 - Application of machine learning models to predict residual velocity of rigid projectiles on monolithic metallic targets Prince Jeya Lal Lazar (Rajalakshmi Institute of Technology), Kota Muralidhar (SSN College of Engineering), Ramesh Sengottuvelu (Presidency University)
12:00–12:20	060 - Dynamic Response Characteristics and Parametric Study of Reinforced Concrete Blast-Resistant Structures under Internal Explosion Loads Yongyang Xing , H.B. Wang, M. X. Wang, N. Lv (Anhui University of Science and Technology)	072 - State-Dependent Structural Integrity of Li-ion Batteries During Mechanical Abuse Kangpei Meng (Ningbo University of Technology)	245 - Damage Mechanism and Mechanical Response of Composite Subjected to High-Velocity Sand Erosion Jia Huang , Shaorui Wang, Qianzhu Mao, Chao Zhang, Zhongbin Tang, Yulong Li (Northwestern Polytechnical University)	059 - Data-Driven Modeling and Optimization of a 4D-Printed Shape Memory Polymer-Based Crash Absorber Yingbo Zhu, Feng Zhu (Johns Hopkins University)
12:20–13:30	LUNCH - Venue: EA Lobby			
Plenum – Invited Lecture 4 Venue: Engineering Auditorium – Chair: Dirk Mohr				
13:30–14:10	Cliff Butcher (University of Waterloo) Vehicle Lightweighting with a Novel Txxx Series Aluminum Alloy: From Thermomechanical Processing to Crash Performance			
14:10–14:20	Session Transition (Move to 6th Floor)			
Parallel sessions 14:20–17:50				
	Session F1 - Impact absorption and crashworthiness Venue: EA-06-02 Chair: Wesley Cantwell	Session F2 - Impact on brittle materials – concrete, rock, ceramics, etc. Venue: EA-06-03 Chair: Longhui Zhang	Session F3 - Projectile penetration and perforation Venue: EA-06-04 Chair: Xin Zhang	Session F4 - Computational modelling of impact and high-rate loading Venue: EA-06-05 Chair: Zoran Ren
14:20–14:40	019 - Crashworthiness Enhancement of Inverted Honeycomb Auxetic Panels: Experimental and Computational Study Nejc Novak (University of Maribor), Hasan Al-Rifaie (Poznan University of Technology), Alessandro Airoidi (Politecnico di Milano), Matej Vesenjak, Zoran Ren (University of Maribor)	022 - Dynamic Properties of UHPFRC Under Extreme Loading Ezio Cadoni , D. Forni (University of Applied Sciences and Arts of Southern Switzerland)	171 - The damage transition mechanism induced by interface effects during the penetration of concrete/rock double-layer targets Shushu Zhao , Jianguo Ning, Xiangzhao Xu (Beijing Institute of Technology)	027 - Mesh-free simulation of microparticle rebound, bonding, jetting, and adiabatic shear instability during high-velocity impacts: An experimentally validated study John Magliaro , Mankam Sandhu (University of Waterloo), Ahmed Tamiyu (University of Calgary)
14:40–15:00	225 - Topologically Integrated Helical Sponge Bio-Hybrid Lattice with Enhanced Dynamic Strength and Energy Absorption Dongdong Guo , ZX Jiang, YG Wang (Ningbo University)	229 - Impact Mechanical Behavior and Energy Dissipation Analysis of Rock-Concrete Composites with Different Interface Roughness Yushan Liu , Weijing Yao, Qinghe Zhang, Haiming Chen (Anhui University of Science and Technology)	256 - Data-driven Lightweighting and Terminal Lethality Enhancement of PELE Projectiles: A Comparative Machine Learning and Multi-objective Optimization Framework Zhanxuan Wang (NJUST), H.L. Zheng (Shenyang Ligong University), M.Y. Wang, X.T. Li, C.W. Luo (NJUST), Z.H. Du (NJUST, Shenyang Ligong University), L.Z. Xu (NJUST)	127 - A Three-Dimensional Explicit Direct FE² Framework for Dynamic Analysis of Lattice Structures Pei Li (University of Southern Denmark), Heng Zhang, Zhe Liu (Xi'an Jiaotong University, NUS), Vincent B. C. Tan (NUS)
15:00–15:20	116 - Performance Study of Sound-Absorbing and Blast-Resistant Integrated Metamaterials Wenjie Lu , L. Chen (Nanjing University of Science and Technology), C.Q. Chen (Nanjing University of Science and Technology, Nanjing University), X. Li (Nanjing University of Science and Technology), M.H. Lu, Y.F. Chen (Nanjing University)	065 - Low-Velocity Impact Response of Rubberized One-part Geopolymer Concrete with Varying Rubber Contents under Extreme Temperatures Shunyin Wan , Chaobin Yang, Yuanzheng Lin (Southeast University)	166 - Correlation between dynamic mechanical properties and ballistic resistance of spray-formed 7055 Aluminum Alloy against 7.62 mm ball projectiles Zekun Wang , Yangwei Wang, Lingxiang Shi, Rui An, Jiawei Bao (Beijing institute of technology)	119 - In-structure shock assessment for precast components Jia Yuan Lim , K.W. Kang (Defence Science and Technology Agency, Singapore)
15:20–15:50	TEA BREAK - Venue: EA Lobby			

DAILY PROGRAM

WEDNESDAY 01 JULY 2026

	Session G1 - Impact absorption and crashworthiness Venue: EA-06-02 Chair: Nejc Novak	Session G2 - Dynamic material behaviour and constitutive modelling Venue: EA-06-03 Chair: Ezio Cadoni	Session G3 - Response of 3D-printed components to impact Venue: EA-06-04 Chair: John Magliaro
15:50–16:10	215 - Impact response of Cassini Oval Aperture Auxetic Metamaterials Arash Soleiman Fallah (Oslo Metropolitan University), N. Mehreganian (Imperial College London), X.P. Zhang, Z.P. Sun, Y.Y. Ding (Ningbo University), V.P.W. Shim (NUS)	012 - Numerical Modeling of Dynamic UHMWPE Behavior Robin Paul , A. Lion, M. Johlitz (University of the Bundeswehr Munich)	235 - Understanding 3D Printed Concrete (3DPC) against Projectile Impacts Utami Yerikania (NUS), Zhang Jie (Taiyuan University of Technology), Poh Leong Hien (NUS)
16:10–16:30	011 - A similarity technique for predicting the dynamic response of stiffened plates under impact loading Xinzhe Chang , Fei Xu (Northwestern Polytechnical University), Wesley J. Cantwell (Khalifa University of Science and Technology)	253 - Modeling and Validation of 95W Tungsten Heavy Alloy Considering Stress State, Strain Rate, and Temperature Effects Xinyu Sun , Yiding Wu, Rui Zhu, Wencheng Lu, Shuangqi Li, Bingzhuo Hu, Guangfa Gao (Nanjing University of Science and Technology)	207 - Behaviour of Multi-Layer 3D Printed Reinforced Concrete Components under High Dynamic Load Vahan Zohrabyan , Thomas Braml (University of the Bundeswehr Munich)
16:30–16:50	162 - Anisotropic response of additively-manufactured polymeric strut-based lattices to compression along different directions Zhengping Sun (Nanjing University of Science and Technology, Ningbo University), Y.Y. Ding (Ningbo University), V. P. W. Shim (NUS, Ningbo University)	018 - Post-yield and Damage Response of Polyurethane Foam – Effects of Loading Direction and Strain Rate Shaohua Wang , Hanyang Li, Yangbo Guo (NUS), V.P.W. Shim (NUS, Ningbo University)	138 - Impact Behaviors and Damage Mechanisms based on Mechano-electrical Monitoring for Additively Manufactured CFRP Laminates coated by Elastomer Guo Wang , Haoyang Yin, Yuanrun Zhang, Yinggang Miao (Northwestern Polytechnical University)
16:50–17:10	113 - Multiscale Investigation of impact resistance and energy absorption mechanisms of node-enhanced gradient Lattices fabricated from $Al_0.5CoCrFeNi$ Shijia Li , Yixiang Gao, Shunhui Luo, Longhui Zhang, Xiaohu Yao (South China University of Technology)	174 - The Parallel Hardening Paradox in High Strain Rate Deformation of 316L Stainless Steel Micro-mechanisms and Thermo-mechanical Coupling Dianqiang Shu , Huanran Wang (Ningbo University)	239 - Integrated Design of Origami-Based Structural Metamaterials for Tailored Dynamic Mechanical Properties and Electromagnetic Stealth Yiming Lei , YG Wang (Ningbo University)
17:10–17:30	088 - Stability of multi-body system under axial pulse load: an idealised model for collision stability of rail vehicles Kai Liu , L. Jing (Southwest Jiaotong University), Q.M. Li (The University of Manchester)	077 - Constitutive Modeling, Failure Criterion and Equation of State for the High-Entropy Alloy $Ti_3Zr_{1.5}Nb_{0.5}V_{0.9}Al_{0.5}$ Yunfei Yin , H. Chang, Z.Q. Li (Taiyuan University of Technology)	131 - Dynamic shear behavior and microstructural evolution of additively manufactured AISi10Mg alloy Xianzhe Zhong , Zhehao Liu, Lin Jing (Southwest Jiaotong University)
17:30–17:50	154 - Theoretical Study on Dynamic Response of Foam Core Sandwich Structure Under Repeated Impacts Wen Xiao , Yinggang Li (Wuhan University of Technology), Ser-Tong Quek (NUS)	106 - A new high-strain-rate characterization method and its application to automotive component crash analysis Xiangfan Fang , Chongyang Zeng (Institute of Automotive Lightweight Design, University Siegen)	054 - Enhancing flexible transparent electrodes fabrication via laser-induced optical-thermal-mechanical coupled nanowire welding Yaowu Hu (Wuhan University)
FREE EVENING			

DAILY PROGRAM

Thursday 02 JULY 2026

Plenum – Invited Lecture 5				
Venue: Engineering Auditorium – Chair: Guoxing Lu				
09:00–09:40	Shannon Ryan (Deakin University) <i>Designing Protective Structures in the Age of AI: Physics-Informed Learning and Human–Machine Collaboration</i>			
09:40–09:50	Session Transition (Move to 6th Floor)			
Parallel sessions 09:50–12:20				
	Session H1 - Dynamic material behaviour and constitutive modelling Venue: EA-06-02 Chair: Amos Gilat	Session H2 - Impact biomechanics & Stress/shock waves Venue: EA-06-03 Chair: Liqun Tang	Session H3 - Failure and fracture under impact and impulsive loads Venue: EA-06-04 Chair: Zoran Ren	Session H4 - Computational modelling of impact and high-rate loading Venue: EA-06-05 Chair: Jean-Philippe Ponthot
09:50–10:10	041 - Characterization and modeling of plasticity and fracture behavior in steel sheets under multiaxial dynamic loading Chongyang Zeng , Xiangfan Fang (University of Siegen), L. Leotoing, D. Guines (Université de Rennes)	178 - Vertebra-Specific Lumbar Fracture Tolerance Under Dynamic Vertical Loading Kwong Ming Tse (Swinburne University of Technology, The University of Melbourne), D. Robinson (The University of Melbourne, University of Queensland), M. Franklyn, P.V.C. Lee (The University of Melbourne)	164 - Mechanical properties of carbon fiber reinforced shear stiffening gel composite under impact Xin Zhang , Yajing Miao (Southern University of Science and Technology)	038 - Validating VIPERFSI: Modelling blast against steel and concrete structures James Wurster , Peter McDonald, Andrew Nicholsona (Viper Applied Science)
10:10–10:30	130 - Numerical study of nanoparticle effect on compressive flow stress of magnesium alloys with strain rate Yang Chen (Guilin University of Electronic Technology), Y.B. Guo (NUS), S. Tekumalla (University of Victoria), M. Gupta (NUS), V.P.W. Shim (NUS, Ningbo University)	165 - Enhancement Effect of Underwater Explosion Shock Waves Influenced by Seabed Topography Yujie Xie , Zhiming Liu, Hailong Li, Zhifan Zhang (Dailian University of Technology)	184 - Failure and Fragmentation of a Brittle Beam under Pure Bending Fenghua Zhou, Zhiqiang Wang , Hongsheng Yang (Ningbo University)	075 - Machine learning-driven prediction of the conditions for shock-induced phase transformations in tin Marti Puig Fantauzzi (University of Oxford), Simon Wilkinson (AWE), Patrick Heighway, Antoine Jerusalem, Daniel Eakins (University of Oxford)
10:30–11:00	TEA BREAK - Venue: EA Lobby			
	Session I1 - Dynamic material behaviour and constitutive modelling Venue: EA-06-02 Chair: Pei Li	Session I2 - Blast loading and response Venue: EA-06-03 Chair: Lijun Xiao	Session I3 - Impact on brittle materials – concrete, rock, ceramics, etc. Venue: EA-06-04 Chair: Kwong Ming Tse	Session I4 - Projectile penetration and perforation Venue: EA-06-05 Chair: Stefano Signetti
11:00–11:20	137 - Dynamic Responses of Tape Spring Structures Jianjun Zhang (Western Sydney University), Guoxing Lu (Zhejiang University)	144 - The influence of geometric fidelity in blast-obstacle interaction: Experimental and CFD studies of the Beirut grain siloes Jack Denny (University of Southampton), D.G. Farrimond (University of Sheffield), S. Gabriel, S. Chung Kim Yuen (University of Cape Town), S. Rigby (University of Sheffield), S. Al-Hajj (American University of Beirut), G.S. Langdon (University of Sheffield)	238 - A rapid method for measuring the rock brittleness index Rapid characterization of rock brittleness based on LIBS technology Qinghe Zhang , Haiming Chen, Weijing Yao, Yushan Liu (Anhui University of Science and Technology)	232 - Projectile–Target Coupled Fragmentation and Energy-Partition Mechanisms of Ceramic/Metal Composite Armor under High-Velocity Penetration Yilei Yu (Ningbo University, NJUST), M.H. Ma (NJUST), Z.X. Jiang, L.B. Wang (Ningbo University), G.F. Gao (NJUST)
11:20–11:40	024 - Multiphysics characterization of Polycarbonate under medium strain rates Dayou Ma , Chiara Colombo, Andrea Manes (Politecnico di Milano)	241 - A Scaling Prediction Method for Structural Dynamic Response under Blast Loading Based on Equivalent Static Loads Sijia Liu , Li Chen (Southeast University)	120 - Experimental Characterization of Energy Dissipation and Fragment Morphology in Rock Fragmentation Jiangshuai Meng , Xu Li (Sydney University), Sheng Jiang (Hohai University), Daniel Dias-da-Costa, Luming Shen (Sydney University)	152 - Quantitative parameters analysis of ignition damage caused by reactive fragments impacting aircraft fuel tanks Haokai Li , Yuan Li, Tao Suo (Northwestern Polytechnical University)
11:40–12:00	091 - Research on the dynamic mechanical behavior and mesoscale constitutive model of porous titanium based on in-situ multiscale characterization Boshi Wang , Y.X. Zheng, F.H. Zhou, J.Y. Huang (Ningbo University)	240 - Intelligent identification and quantification method of rockburst behavior characteristics based on vision and 3D laser point cloud Haiming Chen , Qinghe Zhang, Weijing Yao, Yushan Liu (Anhui University of Science and Technology)	230 - Dynamic behavior and damage mechanism of white sandstone under cyclic impact and acid-base erosion Weijing Yao , Yushan Liu, Qinghe Zhang, Haiming Chen (Anhui University of Science and Technology)	167 - Ballistic impact response of basket-weave near a titanium alloy Zhaoguo Zhang , Longhui Zhang (South China University of Technology)
12:00–12:20	248 - Dynamic behavior and a phenomenological elastoplastic model of metal fiber sintered sheet Yifei Meng , Ping Xia, Tao Suo, Bing Hou (Northwestern Polytechnical University)	055 - Study on cross-sectional shape effect on blast performance of CFDST columns under contact explosions Qian Zang , Li M H, Zong Z H (Southeast University)		099 - Cohesive zone modelling of boulder-mortar interface in multi-layered composite target under projectile impact Shashwat Kapoor , Sonalisa Ray (Indian Institute of Technology, Roorkee, India)
12:20–13:30	LUNCH - Venue: EA Lobby			

CONFERENCE DINNER

Marina Bay Sands & Convention Centre

Thursday 02 JULY 2026

Conference Tour & Banquet 13:30–20:30			
Conference Tour to Gardens by the Bay (GBTB)		Conference Banquet at Marina Bay Sands (MBS) Expo & Convention Centre	
13:30	Leave NUS for GBTB	18:00	Pre-dinner soft drinks
14:30	Visit GBTB	18:30	Presentation of Tokens to Plenary Speakers
17:30	Leave for MBS	19:00	Dinner commences
18:00	Arrive at MBS	21:00	Dinner ends

TOUR – 13:30



BANQUET – 18:00



DAILY PROGRAM



Friday 03 JULY 2026

Plenum – Invited Lecture 6				
Venue: Engineering Auditorium – Chair: Vincent Tan				
09:00–09:40	Joseph Morton (ATA Engineering) <i>Identifying the Multiphasic Damage Mechanisms Associated with Hypervelocity Impact</i>			
09:40–09:50	Session Transition (Move to 6th Floor)			
Parallel sessions 09:50–12:20				
	Session J1 - Blast loading and response Venue: EA-06-02 Chair: Masahiro Nishida	Session J2 - Dynamic material behaviour and constitutive modelling Venue: EA-06-03 Chair: Shaohua Wang	Session J3 - Failure and fracture under impact and impulsive loads Venue: EA-06-04 Chair: Shiqiang Li	Session J4 - Impact on brittle materials – concrete, rock, ceramics, etc. Venue: EA-06-05 Chair: Arash S. Fallah
09:50–10:10	102 - Research on impact similarity law of elastic composite laminate based on ODLV scaling framework Fei Xu, Xinzhe Chang (Northwestern Polytechnical University), Xiaocheng Li (Aircraft Strength Research Institute of China)	161 - Influence of Strain Rate and Combined Tension - Torsion loading on the Mechanical Performance of Ti0.7Al4V Govind Gour (University of Oxford), Yuan Xu (Newcastle University), Antonio Pellegrino (University of Bath)	033 - Warhead fragmentation prediction methods Clément Chausse (CEA)	211 - Influence of water saturation on concrete under extreme ballistic loading Théo Calmels (Université Grenoble Alpes, CEA), Pascal Forquin (Université Grenoble Alpes), Magali Arlery (CEA)
10:10–10:30	101 - A Fast-Running Engineering Tool for Assessing Fluid-Structure Interaction in Blast-Loaded Plates Giovanni Marchesi, L. Lomazzi (Politecnico di Milano), V. Aune (NTNU), S. Gabriel, T. J. Cloete, G. Nurick, S. Chung Kim Yuen, A. Manes (University of Cape Town)	249 - Errors and influencing factors caused by area mismatch in SHPB devices: Decoupling analysis of generalized wave impedance Yiding Wu, Wencheng Lu, Minghui Ma (NJUST), Yilei Yu (Ningbo University), Xuan Zhou, Lin Chen, Guangfa Gao (NJUST)	125 - Effect of High-Frequency Pulsed Current Treatment on the Dynamic Mechanical Behavior of SiC/6061 Aluminum Matrix Composites Xiaozhe Sun, Z.Q. Li, R.F. Liu (Taiyuan University of Technology)	250 - Study on the Anti-Penetration Performance of SiC Ceramic-Fiber Composite Armor Wencheng Lu, Yiding Wu, Xinyu Sun, Bingzhuo Hu, Suangqi Li, Guangfa Gao (Nanjing University of Science and Technology)
10:30–11:00	TEA BREAK - Venue: EA Lobby			
	Session K1 - Blast loading and response Venue: EA-06-02 Chair: Chong Gao	Session K2 - Dynamic material behaviour and constitutive modelling Venue: EA-06-03 Chair: Zhengping Sun	Session K3 - Failure and fracture under impact and impulsive loads Venue: EA-06-04 Chair: Yang Chen	Session K4 - Computational modelling of impact and high-rate loading Venue: EA-06-05 Chair: Yazhou Guo
11:00–11:20	081 - Capturing Fragments Inside Dense Explosion Clouds Using a Multi-Beam DIH Technique Arpit Joglekar, Devashish Chorey (Indian Institute of Technology Indore), Viwek Mahto, Kusumkant. D. Dhote (DRDO), Devendra Deshmukh (Indian Institute of Technology Indore)	133 - Strain rate and temperature dependent deformation response and microstructural evolution of U75V rail steel Yanxiang Liang, Lin Jing (Southwest Jiaotong University)	037 - Experimental evaluation of the hydrodynamic ram effect on water tanks Ewan Leroy, Vincent Momboisse (CEA)	058 - Comparison of the Arbitrary Lagrangian-Eulerian and Smoothed Particle Hydrodynamics to Simulate Bird Impacts Jean Philippe Ponthot, N Quettier, E Smeyers, R Boman (University of Liège), B Toussaint, G Marichal (GD&T), R Barale, JS Ruess (Safran Aero Boosters)
11:20–11:40	180 - Dynamic Response and Energy Absorption of Polyurethane-Filled Folded Conical Dome Core Sandwich Structures Yingjing Liang, Yijie Liu, Jianzhang Huang, Shuxin Huang, Zeming Pan (Guangzhou University)	139 - Rate-dependent Mechanical Behaviors of PVA Composite Hydrogel enabled as Articular Cartilage Daxin Zhang, J.P. Yin, Z.Z. Fan, Y.G. Miao (Northwestern Polytechnical University), C.H. Luo (North Minzu University)	117 - The influence of W and V elements on the mechanical properties and fracture ignition behavior of TiZrNb-based high-entropy alloys Jiahao Huang, Y.X. Zheng, C. Cheng (Ningbo University)	109 - Impact equivalent static load based on a dynamic load factor formulation Jaesoon Jung, Sang-Mok Shin (Agency for Defense Development)
11:40–12:00	168 - Analysis of Damage Characteristics of Spherical Shell Structures Under Underwater Array Charge Explosion Yuxi Zhao, Z.M. Liu, P. Huang (Dalian University of Technology), X. Huang (Northwestern Polytechnical University), Z.F. Zhang (Dalian University of Technology)	224 - Effect of impact velocity on deformation mechanism of SAC305 lead-free solder Feiyang Chen, Zhaoxiu Jiang, Xiaofeng Wang, Yonggang Wang (Ningbo University)	140 - Experimental and numerical investigation of repeated impact damage and residual strength of foam-core composite sandwich panels Lihao Ding, Yinggang Li (Wuhan University of Technology)	219 - Finite Element Modelling of ceramic-based composite ballistic armour under high-velocity impact: design comparison and sensitivity analysis Lorenzo Paleari, Federico Danzi, Alessio Bassano, Lorenzo Moroni, Abhishek Kumar (Leonardo S.p.A.)
12:00–12:10	Session Transition (Move to Engineering Auditorium)			
Closing Remarks				
Venue: Engineering Auditorium – Chair: Victor Shim				
12:10–12:30	Closing Remarks			
12:30–13:30	LUNCH - Venue: EA Lobby			

ICILSM 2026

5TH INTERNATIONAL CONFERENCE ON IMPACT
LOADING OF STRUCTURES AND MATERIALS

29 JUNE – 3 JULY 2026

ABSTRACTS



Department of Mechanical Engineering
College of Design and Engineering

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A similarity technique for predicting the dynamic response of stiffened plates under impact loading

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Abstract

Scaled model testing has long been recognized as an efficient approach for investigating the dynamic response of large stiffened plate structures subjected to impact loading, owing to its advantages of reduced cost, shorter duration, and experimental feasibility [1, 2]. Nevertheless, conventional similarity laws often lose validity when thin-walled stiffened plates are considered, since thickness cannot be scaled proportionally to length, inevitably leading to geometric distortion. In addition, most existing similarity methods neglect elastic effects, which can strongly affect predictive accuracy. The present work addresses these challenges by establishing similarity laws that incorporate both geometric distortion and elastic-plastic behavior for stiffened plates under impact loading.

In the present work, a relative plastic capacity equivalence technique is introduced, allowing stiffened plates to be transformed into equivalent double-plate models. On this basis, the similarity framework of the ‘Oriented-Density-Length-Velocity’ (ODLV) dimensionless system is extended from single plates to stiffened plates through the introduction of a Response Number [3, 4]. The corresponding similarity laws are derived for both co-direction and hetero-direction distortion. The latter requires the relative plastic capacity of the stiffeners to remain unchanged between the prototype and the scaled model, which can be achieved by adjusting the yield stress or the distribution of stiffeners. Employing thin plate theory and Euler-Bernoulli beam theory, similarity conditions are obtained, and displacement compatibility constraints are imposed at the plate-stiffener interface. A correction technique is then proposed, in which the elastic modulus and density of stiffeners are corrected to extend applicability into both elastic and plastic regimes.

Verification against numerical simulation results of a stiffened plate (as shown in Fig. 1) subjected to impact by a rigid sphere clearly demonstrates that the proposed scaling laws allow scaled models, incorporating geometric distortion and elastic-plastic behavior, to accurately reproduce the prototype response, including displacement, velocity, energy, and impact force, as presented in Fig. 2. These findings confirm that the developed similarity technique effectively overcomes the limitations of conventional scaling methodologies by integrating geometric distortion with elastic effects, thereby enhancing the applicability of scaled model testing in aerospace, marine, and civil engineering structures.

Keywords: stiffened plate, impact loading, geometric distortion, elastic-plastic behavior, scaled model.

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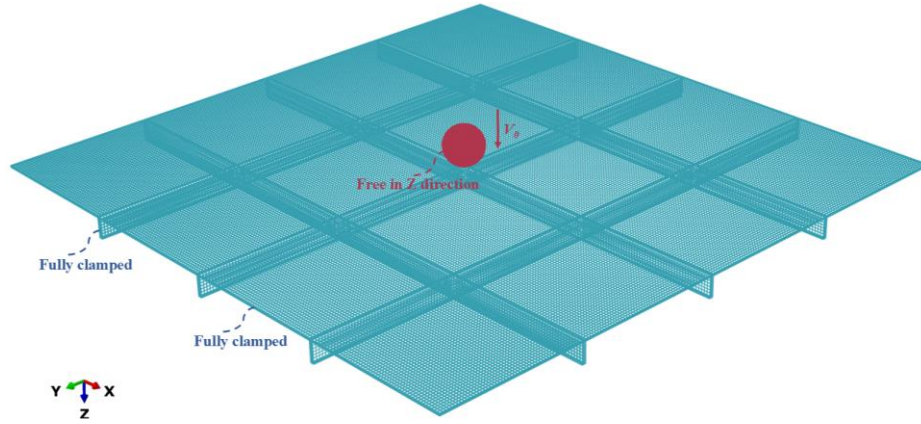


Fig. 1. A stiffened plate subjected to impact by a rigid sphere.

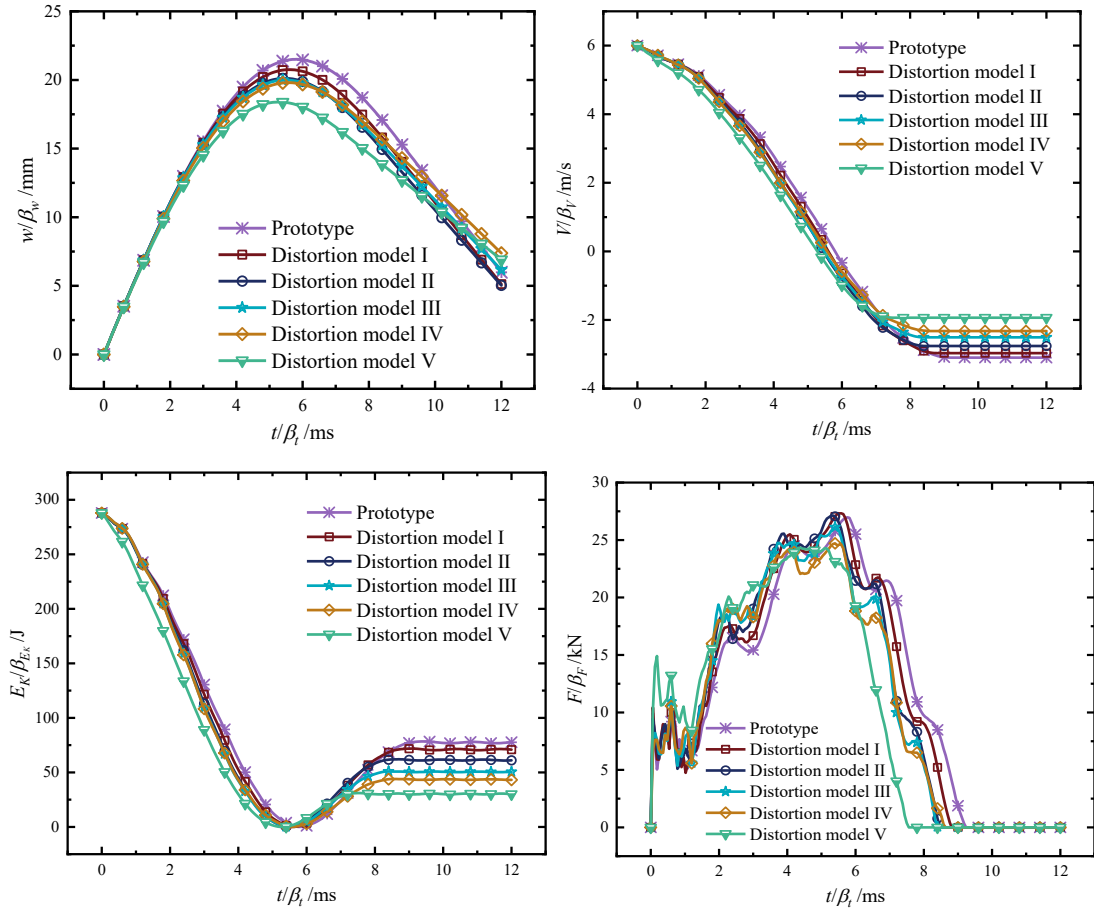


Fig. 2. Dynamic variable response curves for the prototype and scaled models: (a) Rigid sphere displacement-time curve; (b) Rigid sphere velocity-time curve; (c) Rigid sphere kinetic energy-time curve; (d) Stiffened plate force-time curve.

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Numerical Modeling of Dynamic UHMWPE Behavior

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Abstract

Ultra-high molecular weight polyethylene (UHMWPE) has gained significant attention as a high-performance composite material due to its exceptional specific strength, low density, and high energy absorption capability. These properties make it particularly suitable for lightweight structural and protective applications subjected to dynamic loading [1]. However, its complex, rate-dependent mechanical behavior poses challenges for accurate numerical prediction.

In this study, UHMWPE laminates were experimentally characterized under tensile loading at multiple strain rates and different fiber orientations to capture both fiber-dominated and combined fiber–matrix deformation mechanisms. The experimental results provided the basis for the development and calibration of a numerical simulation model in LS-DYNA. The model employed the MAT_058 material formulation and a ply-wise composite modeling approach, where each unidirectional (UD) layer was represented using the PART_COMPOSITE keyword.

This modeling strategy enabled a detailed description of the anisotropic and rate-dependent behavior of UHMWPE laminates under dynamic conditions. The calibrated model successfully reproduced key experimental trends across strain rates and orientations, demonstrating its capability to predict the complex mechanical response of UHMWPE. The developed framework provides a foundation for further simulation-based investigations of UHMWPE structures exposed to dynamic and impact loading.

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From vent sizing to structural response: a logarithmic congestion model for dust explosion loads on industrial filter structures

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Abstract

Dust explosions in industrial filter units are typically treated from a process-safety perspective, focusing on vent sizing and compliance with existing standards such as EN 14491 [1] and NFPA 68 [2]. However, the way venting conditions and internal congestion affect the actual loading on filter housings, vent panels and supporting frames remains only partially addressed in current design practice. This work proposes a simple, engineering-oriented framework that links improved reduced pressure predictions for dust deflagrations to the structural response of key components.

First, we introduce a new logarithmic congestion model for the prediction of reduced explosion pressure in congested filter vessels [3]. The model is calibrated and validated against a database of vented dust explosions, including highly obstructed configurations, and it systematically reduces the scatter and bias observed when applying standard correlations in the same conditions. The proposed formulation provides closed-form expressions for the reduced pressure as a function of vent area, congestion level and dust explosibility parameters.

The predicted pressure–time histories are then used as input for an equivalent single-degree-of-freedom (SDOF) [4] model representing critical structural elements of filter systems, such as vent panels, casings and anchorage systems. By combining the logarithmic congestion model with the SDOF formulation, we directly assess displacement demands, damage thresholds and demand-to-capacity ratios under realistic dust deflagration loads.

The results show that neglecting congestion or relying on standard venting correlations may lead to a significant underestimation of impulsive actions on structural components [5]. Conversely, the proposed framework offers a fast, transparent design tool that allows practising engineers to move consistently from vent sizing to structural checks under dust explosion scenarios, without the need for full CFD–FEM simulations in the early stages of design.

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Compressive-Driven Mechanical Enhancement of Low-Infill FDM Parts Through Liquid Resin Infiltration

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Abstract

To evaluate the reinforcement effectiveness of liquid resin infiltration on low-infill FDM structures, this study designs three representative test parts. PU resin is infiltrated into 3D printed parts with 20 % infill density using a vacuum casting technique. For performance comparison, reference parts with 100 % infill density and without resin treatment are also fabricated and subjected to compression testing. The experimental data indicate that resin infiltration significantly improves the compressive strength of all three test parts. The compressive strength of the stool increases from 3.26 MPa to 3.96 MPa, the snap-fit rises from 3.46 MPa to 14.21 MPa, and the car shell improves from 6.94 MPa to 17.46 MPa. These findings confirm that liquid resin effectively fills intra-layer voids generated during the printing process. Even under low infill conditions, the infiltration process forms a robust internal support structure that facilitates efficient load transfer and stress distribution [1]. This result shows that the infiltration technique can significantly enhance the mechanical properties of additively manufactured structures. The key conclusions are found. PU resin infiltration effectively fills voids in low-infill printed structures and increases the tensile strength by approximately 21 % to 310 % compared to untreated printed parts using conventional method with 100 % infill density. A 20 % infill density structure with infiltration reaches or exceeds the mechanical strength of a conventional 100 % infill density structure. This process also reduces material usage and printing time. It provides high efficiency and strong application potential, especially for the development of complex geometries and functional prototypes [2].

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Failure Behavior Analysis of a Silicon-based MEMS Inertial Switch with Curved Zig-Zag Tracks

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Abstract

MEMS inertial switches are miniature devices fabricated by microelectromechanical systems (MEMS) technology and used for response to movement of mechanism. When going through the special environments such as impact, vibration or rotation, the inertial switch can sense inertial characteristics and turn “on” or “off”. In recent years, MEMS inertial switches have been employed in a multitude of fields and industries, including consumer electronics, medical devices, automotive transport, aircraft and spacecraft. Multiple functions including sensing, actuation, and control, can be integrated into a small volume [1]-[6]. The failure mechanisms of inertial switches in high impact overload are particularly complex. Researchers worldwide have actively pursued related studies [7]-[9]. However, these studies rarely conduct detailed failure analysis of inertial switches, leading to overly idealized assumptions about device performance. Through failure analysis, the root causes of device failures can be identified, enabling subsequent design improvements. This approach facilitates the recognition and elimination of potential safety hazards, thereby enhancing device reliability and safety.

This research presents a failure analysis of a novel silicon-based MEMS inertial switch. It is composed of the frame, mass block, micro-spring, curved zig-zag tracks and fixed anchor latching beams. The mass block, microspring, and curved zig-zag tracks make up the inertial mechanism for load differentiation. The results of the finite element method (FEM) confirm that the inertial switch with curved zig-zag tracks is effective in detecting and distinguishing impact loads with similar energy sum. The strength analysis using FEM simulation identified damage-prone locations. It was determined that the micro-spring connection part fracture is more prone to damage than the tooth of the zig-zag track. The micro-spring connection part is the main fracture area of the micro spring. The failure behavior of the inertial switch has been investigated by the impact experiment. 88 times impacts on 57 devices in different directions, and 198 times failure behaviors are obtained. The causes of failure behavior are investigated in a very detailed way. The study shows that it has two types of failure: non-function failures (68.18%) and function failures (31.82%). The main function failures are spring damage (including beam fracture, connection part fracture and root fracture) and unexpected locking, which account for 87.30% of the function failures. Among non-function failures, the mass block has the highest number of failure behaviors, with 82 times (60.74%). However, these failure behaviors do not cause complete damage to the device, and the inertia switch can still perform the locking function normally. The experiment validated the accuracy of FEM analysis, indicating that FEM can be used as a preliminary criterion for predicting function failures. It was illustrated that machining errors in tooth height and width of the spring constituted a significant factor in the device's failure, resulting in an unexpected locking and spring damage. While non-function failures do not affect the basic function of the device, which are acceptable without cumulative damage. Finally, a fault tree analysis was performed to summarize the failure behaviors of the inertial switch, and the methods for subsequent improvements are proposed.

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Post-yield and Damage Response of Polyurethane Foam – Effects of Loading Direction and Strain Rate

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Abstract

Polyurethane (PU) foams with an anisotropic cell geometry, exhibit mechanical responses that are notably direction-dependent. Information on the effects of loading direction and strain rate on the post-yield response and damage development in PU foam appears limited. This study systematically characterizes the elastic, plastic, and damage response of PU foam subjected to uniaxial compression at five angles (0°, 30°, 45°, 60°, 90°) relative to the foam-rise direction, and over a range of quasi-static to dynamic strain rates. Incremental cyclic compression tests and dynamic impact were applied to elicit the responses. Three primary deformation modes were identified: localized cell buckling and crushing for compression along the foam-rise direction, stable cell-wall bending for loading along the transverse direction, and cell buckling coupled with rotation for loading between these two directions. An effective damage parameter is defined to describe the evolution of the elastic stiffness with plastic deformation. The elastic stiffness first decreases following initial yield, as a result of cell material damage; it drops to a minimum, and subsequently recovers partially when crushed cell wall material begins to be compacted together. This observed decrease-increase in the elastic modulus is a consequence of competition between stiffness degradation associated with cell wall damage, and hardening linked to compaction of crushed cells. For compression along the transverse direction, the elastic stiffness decreases to a plateau phase earlier than for compression along the foam-rise direction, because of stable cell wall flexure. This effort provides a deeper insight into the anisotropic post-yield and damage response of PU foam, as well as the associated deformation modes. In addition, the relationships describing such anisotropic behavior, derived from experiments, constitute a useful basis for future establishment of constitutive models.

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Crashworthiness Enhancement of Inverted Honeycomb Auxetic Panels: Experimental and Computational Study

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Abstract

This study details the fabrication, testing, and modelling of macro-scale auxetic crash absorbers based on inverted honeycomb structures. Unlike most auxetic crash absorbers that rely on additive manufacturing, this work demonstrates a scalable and low-cost manufacturing route with industrial feasibility. Aluminum panels were corrugated, adhesively bonded, and—depending on the configuration—either selectively or entirely filled with polyurethane (PU) foam to introduce multi-scale auxetic reinforcement. Fabrication was low-cost and suitable for meter-scale structural components.

Quasi-static compression and 10 m/s drop-tower impact tests were performed. Key crash metrics—including stress–strain response, deformation modes, Specific Energy Absorption (SEA), Crash Force Efficiency (CFE), and Poisson’s ratio—were benchmarked against validated non-linear FE simulations.

Foam-filled panels outperformed unfilled counterparts, improving SEA by +23% (full-fill) and +9% (auxetic-fill) vs. graded panels, while maintaining a negative Poisson’s ratio (up to -0.8) and ensuring stable progressive collapse [1]. Increasing sheet thickness from 0.8 to 1.2 mm provided a further $\sim 29\%$ SEA gain, without proportional weight penalty. Dynamic CFE exceeded the quasi-static response for graded designs, demonstrating superior crash robustness under impact loading.

The experimentally validated FE framework accurately captures both mechanical response and auxetic deformation, enabling the accelerated virtual design of next-generation foam-filled auxetic crash absorbers for road safety equipment and blast protection applications.

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Vehicle Excitation Identification Based on the Dynamic Response of Bridges

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Abstract

Accurate identification of vehicle excitation on bridges using dynamic bridge responses is critical for continuous structural performance monitoring and real-time condition assessment. To address this need, this study presents a comprehensive inverse identification methodology based on a Lagrangian polynomial load-shape function, enabling vehicle excitation identification in the presence of prestress force using only dynamic displacement measurements [1].

A simply supported prestressed concrete box-girder bridge model with a 6-m span was constructed and tested experimentally. The excitation was applied at mid-span using a Moog controlled dynamic loading system, and the resulting dynamic displacement responses were captured through LVDT sensors. For validation, the externally applied dynamic excitation from the Moog actuator was recorded and compared against the forces identified through the proposed approach. To validate vehicle excitation identification under varying prestress forces, several prestress levels were applied. The vehicle excitation was identified for each level, and the actual prestress force was measured using a load cell. To establish the bridge-vehicle system matrix, impact (hammer) tests were conducted to extract modal parameters. These parameters were processed using ARTEMIS modal analysis software and subsequently used to calibrate the finite element model of the prestressed concrete box girder bridge model [2].



Figure 1: Experimental arrangement for the simply supported box-girder bridge model [2].

The integration of experimental validation, inverse formulation, and modal-based model calibration demonstrates that the proposed methodology can effectively identify vehicle excitation with a maximum error margin of only 3%, while requiring a minimal number of sensors, low data volume, and reduced monitoring cost. This outcome highlights the potential of the method as a scalable and practical solution for long-term bridge structural performance monitoring and life-cycle safety management.

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Dynamic Properties of UHPFRC Under Extreme Loading

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Abstract

This paper presents the results of a comprehensive experimental investigation into the dynamic behaviour of Ultra-High Performance Fiber-Reinforced Concrete (UHPFRC) and its matrix under high strain rates. The mechanical testing campaign employed multiple setups based on the Split Hopkinson Bar (SHB) technique, enabling direct tensile tests, punching tests, and compression tests on specimens with various geometries, including both notched and unnotched samples [1-4].

The UHPFRCs examined were commercial formulations characterized by a highly resistant matrix and reinforced with 1%–4% by volume of straight, high-carbon steel fibers, each measuring 13 mm in length and 0.16–0.20 mm in diameter.

The experimental results revealed substantial increases in peak strength and energy absorption capacity. The strain-rate sensitivity of the material was quantified using the Dynamic Increase Factor (DIF). Furthermore, the findings were compared with other UHPFRC formulations, including tests on similar materials [5]. These results provide valuable insights into the dynamic mechanical behavior of UHPFRC, supporting the design of protective structures by highlighting key material properties.

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Multiphysics characterization of Polycarbonate under medium strain rates

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Abstract

Polycarbonate has been widely used as a safety guard due to its transparency and outstanding mechanical performance under impact and blast loading [1]. Although its mechanical properties, including strain-rate-dependent behaviour, have been extensively characterised, the large deformation and the sensitivity of the strain-rate effect [2] continue to attract significant attention in research. Additionally, given the varied working conditions for polycarbonate as safety guards, its mechanical performance at medium strain rates remains a concern, and the dynamic response of polycarbonate can be further refined.

In the present study, the mechanical properties of polycarbonate were characterised under medium strain rates, specifically between 10 and 100 /s, incorporating both mechanical and thermal properties as part of a multifield characterisation. Tensile tests involving different levels of triaxiality were conducted using a drop tower. To precisely measure strain during loading with large deformation, a high-speed camera was employed, while a thermal camera monitored temperature changes. During dynamic loading, temperature variations in polymer materials can indicate energy distribution, thereby supporting the characterisation of polycarbonate. The thermal field can be used to locate sample failure, while the photoelastic properties were also observed at their breaking points before failure from the shadow of the samples, as shown in Figure 1. On the mechanical side, the strain rate effect was characterised, and a sudden jump in strength was observed during strain rate increases. Regarding the thermal properties, the Taylor Quinney coefficient was calculated based on experimental data to describe the energy released to the environment, where a decrease was found at medium strain rates, but the dynamic ones are higher than the static ones. With the Multiphysics characterisation in the current work, the mechanical properties of polycarbonate can be determined, especially under medium strain rates. As a validation, low velocity impact tests were performed to support the results from the multifield characterisation.

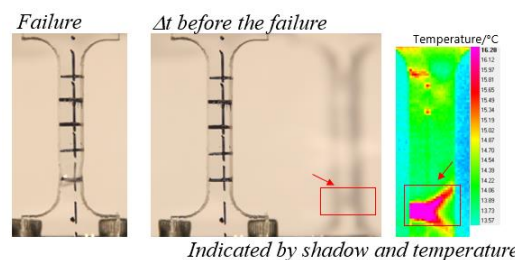


Figure 1: The failure location indicated by shadow and thermal field.

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Mesh-free simulation of microparticle rebound, bonding, jetting, and adiabatic shear instability during high-velocity impacts: An experimentally validated study

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Abstract

High-velocity microparticle impacts involving ductile metals underpin both destructive events (e.g., debris strikes) and additive processes such as cold spray [1]. The latter represents an interesting case of constructive impacts with solid-state deposition on a substrate. Low-velocity impacts cause the particles to inelastically rebound from the substrate (regime I). The impact velocity, V_i , must be sufficient to achieve particle flattening and induce jetting (regime II) via adiabatic shear instability to achieve bonding [2], shown in Fig. 1(a). However, excessive velocities cause particles to hydrodynamically penetrate the surface (regime III) and form destructive craters [3].

The underlying mechanisms involve high strain, strain rate ($\gg 10^6/s$), and temperature plasticity, occurring over nanosecond timescales that are difficult to experimentally characterize. Mesh-free simulation methods such as smoothed particle hydrodynamics (SPH) are suited to modeling the extreme deformation and debris arising from high-velocity impacts [4,5]. Fundamental studies of impact-induced bonding require single-particle experiments, recently enabled by the laser-induced projectile impact tester [6–8]. These results provide essential data to validate advanced material models that capture adiabatic effects and the shock-induced upturn in dynamic flow strength [9]. In this study, SPH modeling of the distinct mechanistic regimes of microparticle impacts was performed in LS-DYNA, with in-depth validation against published data from Schuh's group [3,6-8].

A modified version of the Johnson-Cook constitutive model with Cowper-Symonds rate sensitivity was calibrated over twelve decades of strain rate, up to $10^{10}/s$, and coupled with a Mie-Grüneisen equation of state. Impact velocities ranging from 50-1300 m/s were considered for copper (Cu) and aluminum (Al) microparticles with 10-30 μm diameters, D_p , involving Cu-Cu and Al-Al impacts and mismatched Al/Cu particle-substrate pairs. The experimental and simulated post-impact cross-section morphologies are compared for each mechanistic regime, I through III, in Fig. 1(a-c), respectively.

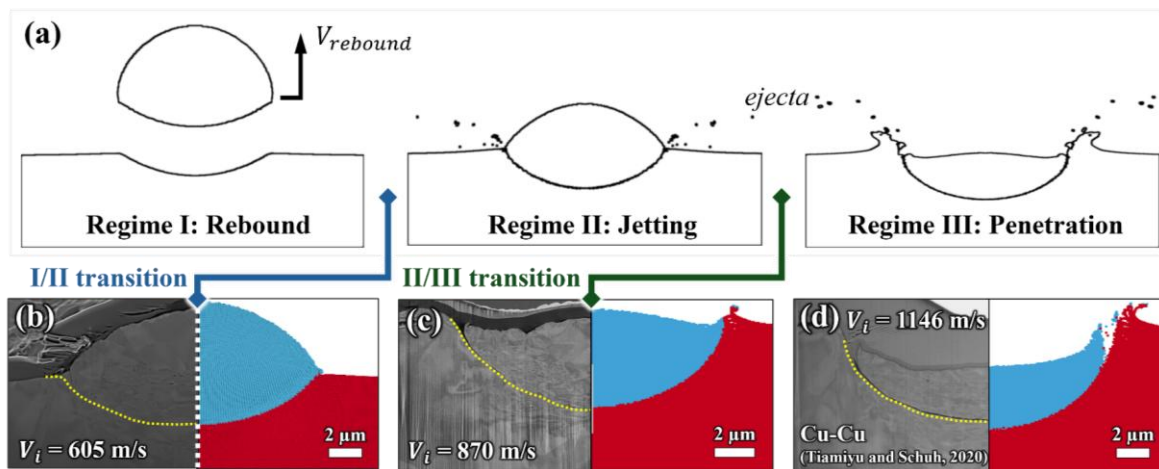


Fig. 1. (a) Schematic of the distinct mechanistic regimes associated with metal-on-metal microparticle impacts with comparisons between Cu-Cu experiments [7] and SPH simulations for (a) the regime I/II transition associated with bonding, (b) the regime II/III transition, (c) a hypervelocity impact case with hydrodynamic penetration.

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An average error of 21% was achieved for the coefficient of restitution (COR) in regime I, as shown in Fig. 2(a), with the critical bonding velocity (I/II transition) predicted within 11%. The complete scope of CORs is compared in Fig. 2(b). Contact, interactions, and mechanical interlocking between the particle and substrate nodes were computed through the governing energy and momentum conservation equations of the SPH kernel. The true global strain from particle flattening was simulated with an average error of 23%. Qualitative features such as material rim curling (Fig. 1(c)) and debonding under hypervelocity impacts (Fig. 1(d)) closely resembled the experimental observations, reinforcing confidence in the high-rate constitutive model and SPH approach.

Consideration for particle rebound, jetting, flattening, and hydrodynamic penetration particle diameters between 10-30 μm over two orders of magnitude in impact velocity represents one of the most in-depth validated numerical investigations to date. The full scope of validation included CORs, true strain via flattening, and regime-specific post-impact surface morphology. The outcomes of this study underscore the importance of accurately quantifying the dynamic material-flow strength upturn in shock-induced impact phenomena and present an efficient approach to probe the material and geometric conditions that govern site-specific microparticle impacts across distinct regimes, from low-velocity rebound to hypervelocity-induced penetration and embedment.

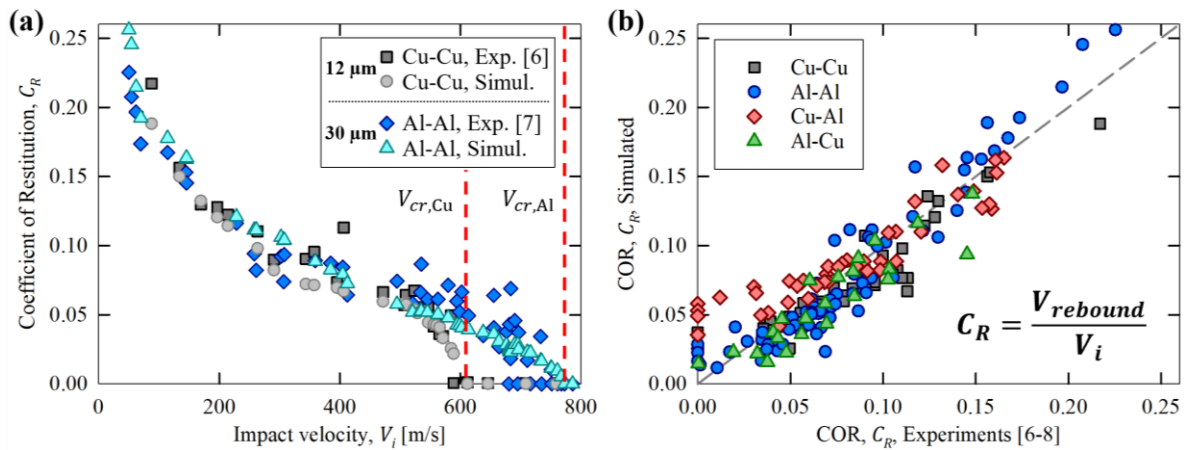


Fig. 2. (a) Experimentally measured [6-7] and simulated coefficient of restitution (COR) with respect to impact velocity for representative Cu-Cu and Al-Al impact microparticle impacts, annotated with the critical velocity when bonding is initiated, and (b) comparison for the full Cu/Al scope, including matched and mismatched pairs.

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Behaviour of steel connections subjected to extreme loading conditions

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Abstract

The behaviour of beam-to-column joints subjected to quasi-static and impact loading have been studied. H-sections beams and columns were joined by bolted endplate connections. The experiments showed that inertia effects induced a pronounced shearing action of the joints in the impact tests, which was not observed in the quasi-static test. The FE simulations were able to capture most of the behaviour observed in the tests. Moreover, the simulations demonstrated that the failure mode of the joints can be completely altered by taking the inertia introduced by notional floor slabs into account.

Experiments and FE simulations of various bolt and nut assemblies subjected to quasi-static tension loading were also studied. The main objective of this part was to investigate how the position of the nut along the bolt shank affected the failure mode of the assemblies. Both the tests and the simulations demonstrated that placing the nut close to the thread run-out of the bolt shank increased the chance of thread failure. The simulations revealed that when the nut was close to the thread run-out, necking of the bolt shank reduced the effective overlap between the threads of the bolt and nut, which further induced thread failure.

Fillet welds subjected to impact loading were also studied. Two different types of test specimens were designed; one with longitudinal welds and one with transverse welds. The design of the specimens allowed measuring the forces acting on the welds as well as the deformation of the welds during testing. In addition to the impact tests, corresponding quasistatic tests were performed for comparison. The test results showed that the resistance of the welds was practically unaffected by the applied displacement rate. On the other hand, the deformation capacity of the specimens with longitudinal welds was significantly reduced as the displacement rate was increased. This effect seemed to be due to thermal softening of the material. In the simulations of the tests, a comprehensive material model incorporating porous plasticity was employed. The simulations captured well the response observed in the quasistatic tests. In the impact test simulations, the force and weld deformation at failure were considerably over-predicted

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Advanced ballistic protection concepts through experiment–simulation correlation and optimization

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Abstract

The evolution of threats across terrestrial, maritime, aeronautical, and space domains has stimulated the development of advanced lightweight protective systems with improved ballistic performance and durability. These systems employ diverse materials, including steels, ceramics, composites, and functionally graded materials [1]. Their assessment often relies on costly experimental testing. [2] Most studies focus on experimental and numerical analyses of explosions or standard projectile impacts (whose penetration mechanisms are listed in [3]), addressing material modelling and ballistic performance, while fewer works investigate numerical optimisation strategies to improve energy absorption [4,5].

The objective of the present study is to model and optimise the impact behaviour of a passive protection system, represented by two different square plates, under the impact of a conical non-standard projectile. By adopting a multi-objective functional approach, the functions employed to frame the ballistic threat include projectile destabilisation and erosion, kinetic energy and shock wave absorption, the reduction of fragment generation, and subsequent fragment collection. [6] A finite element framework is developed by means of Simulia® Abaqus/Explicit to model high-velocity impact configurations, followed by a numerical optimisation process by means of Simulia® ISIGHT plugin. The numerical methodology incorporated simplified material models and contact formulations to capture the system performance, characterized by the terminal ballistic velocity, denoted v_{bl} . Parametric analyses are conducted by varying material properties throughout the thickness and their distribution to assess their influence on the overall response and weight, enabling a “virtual” evaluation.

The results reveal correlations between material distribution, structural configuration, and energy absorption capability. Compared to the baseline solution, the optimised configurations exhibit promising improvements in ballistic resistance; however, a reduction in structural mass is not always achieved. This limitation is primarily associated with the optimisation algorithm employed and the thickness constraint required to retain minimum overall mass. Despite these constraints, the numerical outcomes support more informed design choices and reduce reliance on extensive trial-and-error experimentation. Overall, the results highlight the potential effectiveness of numerical optimisation strategies as a tool to guide the design of advanced protective systems. Nevertheless, while the numerical findings are encouraging, further experimental testing and validation are required to fully assess the robustness of the proposed solutions and to confirm their performance under a wider range of loading conditions.

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Warhead fragmentation prediction methods

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Abstract

In order to evaluate the lethal performance of a given weapon, it is necessary to determine the characteristics of the spray of fragments that are generated by the detonation. Those trials are carried out by the CEA using static detonation tests, also known as arena tests [1]. Then, the results of those experimentations are concatenated in a matrix containing the fragments mass, number and ejection velocity.

The objective of this analysis is to compare different methods to predict the natural fragmentation of a warhead. For example, the fragmentation of the warhead can be computed using a commercial code, a natural fragmentation FREM [2] or through hydrodynamic simulations. Then, all the results will be compared to the experimental results from arena test. In particular, the analysis will focus on the number and mass of fragments.

Furthermore, an assessment is conducted to compare the differences in number of perforations on a thin steel plate. This study can be done with a numerical software called PROMETER (*PRO*gramme de *Modélisation de l'Eff*ficacité *TER*minale: terminal effectiveness modelling software) [3]. The goal is to quantify the spread between experimental results and numerical predictions from the different methods in terms of perforations.



Warhead detonation during arena trial



Hydrodynamic simulation of fragmentation

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Experimental evaluation of the hydrodynamic ram effect on water tanks

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Abstract

The penetration of a projectile in a liquid filled tank (e.g. kerosene or water) induces a damage process called hydrodynamic ram. The projectile transfers its kinetic energy to the liquid, which causes a rise of the internal fluid pressure that acts on the tank walls [1]. The hydrodynamic ram generates structural damages of varying degrees up to the integral rupture of the tank and must therefore be considered for survivability and vulnerability studies of aircrafts or missiles. For the purposes of studying this phenomenon, water-filled tanks were impacted by different parallelepiped projectiles weighing between 70 and 100 g using a powder gun. These experiments follow and complete a small-scale study carried out in the 2000s-2010s by the CEA. The instrumentation implemented consisted of several pressure sensors and high-speed cameras used for, inter alia, image correlation. The results brought out, beyond the projectile kinetic energy, a correlation between projectile impact attitude and tank damage level. The exploitation of image correlation and pressure levels allowed the characterization of the damage dynamics. Moreover, the analysis of the fragmentation of different projectiles has demonstrated no influence on the damage to the target. The experimental evaluation of the hydrodynamic ram effect on water tanks will be followed by a numerical study enabling the simulation of complex impact scenarios.

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Validating VIPERFSI: Modelling blast against steel and concrete structures

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Abstract

Modelling the interaction between fluid and structures is vitally important in scenarios where a structure's reaction is nearly as quick as the blast. Although numerous software codes and algorithms exist (e.g., [1, 2, 3]), numerically modelling fluid-structure interaction (FSI) can often be challenging, due to the complexity of initialising and running the simulations and due to the requirements of supercomputers. Given its importance, modelling FSI should not mean sacrificing efficiency, or ease of use, or accuracy.

In this presentation, we introduce VIPERFSI, a powerful yet user-friendly solution for fast and accurate FSI simulations. By leveraging VIPER BLAST for fluid dynamics on the GPU and OPENRADIOSS for structural analysis on the CPU, VIPERFSI optimizes the strengths of each platform to utilise the entire computer. This dual approach enables large, fully coupled simulations to run efficiently (even on a personal laptop!) without compromising accuracy or user experience. Here, we will demonstrate the ease of use of VIPERFSI in validation cases that model blast against structures of steel and concrete. We will first compare the results of our coupled simulation to that of an uncoupled simulation, both in terms of results and computational performance. We will then compare our results to experimental and numerical results in the literature to demonstrate the efficiency and accuracy of VIPERFSI.

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Space Environment Effects on Hypervelocity Impact Behavior of High Heat-resistant Polyimide CFRP

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Abstract

Non-governmental space development in low Earth orbit is progressing, and there is a need for materials that can be used for extremely long periods in space. Plastics and plastic-based materials exhibit substandard resistance to the space environment [1]. Carbon fiber-reinforced plastic (CFRP) possesses high specific strength and specific rigidity, which renders them well-suited for use in spacecraft. However, their application in exposed areas is precluded.

The Japan Aerospace Exploration Agency (JAXA) has developed high heat-resistance polyimide-based CFRP plates for use in aircraft engines. This group of CFRP also includes materials that are expected to be resistant to the space environment. The authors are currently conducting experiments to examine the space environment resistance of the high heat-resistant polyimide CFRP, including ultraviolet, electron beam, atomic oxygen, heat cycle, micro-meteoroids and orbital debris impact and so on.

In this study, the effects of electron beam and atomic oxygen irradiation, including sequential effects on the fracture behavior of polyimide CFRP were examined in terms of hypervelocity impacts. We used polyimide CFRP plates of quasi-isotropic laminates consisting of prepregs provided by JAXA [2, 3] were used as the target materials with a thickness of 1.1 mm. A total of 20 MGy of electron beams were irradiated at the Takasaki Institute for Advanced Quantum Science and a total atomic oxygen fluence of 2.7×10^{20} atoms/cm² were irradiated at Kobe University. To examine space debris collisions, hypervelocity impact tests [4] were carried out using aluminum alloy spheres with a diameter of 1.6 mm at a velocity of 3 km/s. Perforation holes, peeling-off area of outermost surface and front and rear ejecta were examined.

The results of the hypervelocity impact were compared with static tensile tests on film materials and three-point bending tests on CFRP. To investigate changes in molecular structure FT-IR of polyimide film were measured after electron beam and atomic oxygen. The degradation mechanism due to electron beam irradiation and atomic oxygen was discussed. It was confirmed that polyimide CFRP has high resistance to electron beams and atomic oxygen.

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Characterization and modeling of plasticity and fracture behavior in steel sheets under multiaxial dynamic loading

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Abstract

To accurately model vehicle crash events using the finite element method, reliable characterization of the plasticity and fracture behavior of automotive sheet metals under high strain rates (up to 1000 s^{-1}) and various stress states is required. In this study, a comprehensive mechanical characterization of the automotive high-strength steel HX340LAD was conducted using specimens with different geometries, covering stress states ranging from uniaxial to biaxial loading and a wide range of loading rates. Fig. 1 illustrates the experimental setups, including a servo-hydraulic tensile testing machine for uniaxial tensile tests [1] and an in-plane biaxial tensile testing machine for biaxial tests [2].

Strain-rate sensitivities under different loading conditions were calibrated and compared, revealing a pronounced dependence on the loading direction, as shown in Fig. 2a. This observation enabled a more accurate calibration of a non-uniform strain-rate-dependent hardening model (YldSRH), as illustrated in Fig. 2b. In particular, comparisons between simulations based on experimentally measured biaxial tensile data and those obtained using the averaging approach, where the equi-biaxial stress state is approximated by averaging uniaxial tensile tests at 0° , 45° , and 90° , clearly demonstrate the necessity of incorporating biaxial data for reliable plasticity characterization. Furthermore, the calibrated fracture strain under equi-biaxial loading was implemented in a damage mechanics model (e^2 MBW [3]), revealing that the fracture strain in the equi-biaxial stress state is significantly lower than that in uniaxial tension. This finding motivated the adoption of a six-parameter asymmetric Bai-Wierzbicki model to more accurately describe the fracture behavior. In addition to previously reported strong negative strain-rate effects in the SH specimen and negligible sensitivity in the CH-R3, NDB-R8, and PS-R4 specimens [4], a positive strain-rate effect was observed for the cruciform specimen.

Overall, the combined YldSRH+ e^2 MBW framework, accounting for both strain-rate dependence and adiabatic heating effects, demonstrated excellent predictive capability for dynamic plasticity and fracture behavior under both uniaxial and biaxial stress states (see Fig. 2c-f). These results highlight the importance of including biaxial tensile data for the robust calibration and modeling of sheet metals subjected to multiaxial dynamic loading.

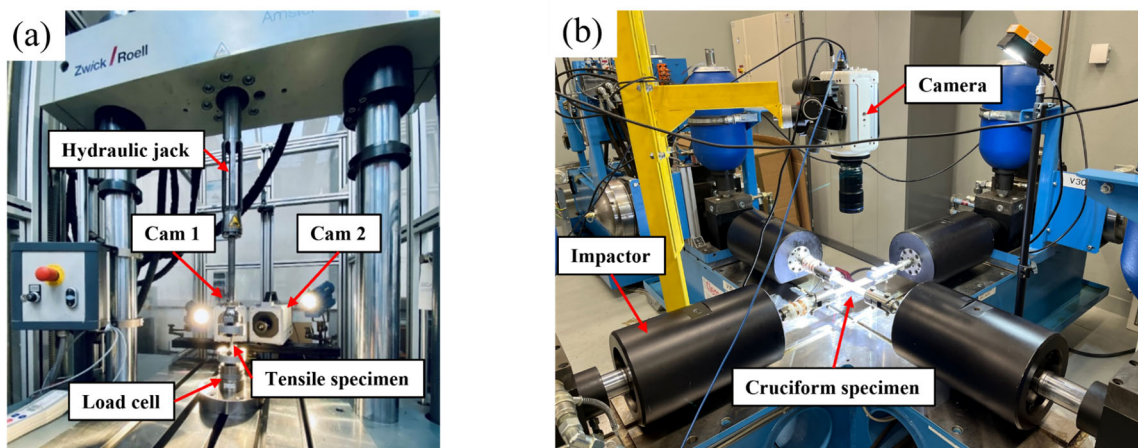


Fig. 1. (a) Zwick HTM 5020 servo-hydraulic tensile testing machine setup for the uniaxial tensile tests. (b) In-plane biaxial tensile machine equipped with four independent servo-hydraulic actuators for the biaxial tests.

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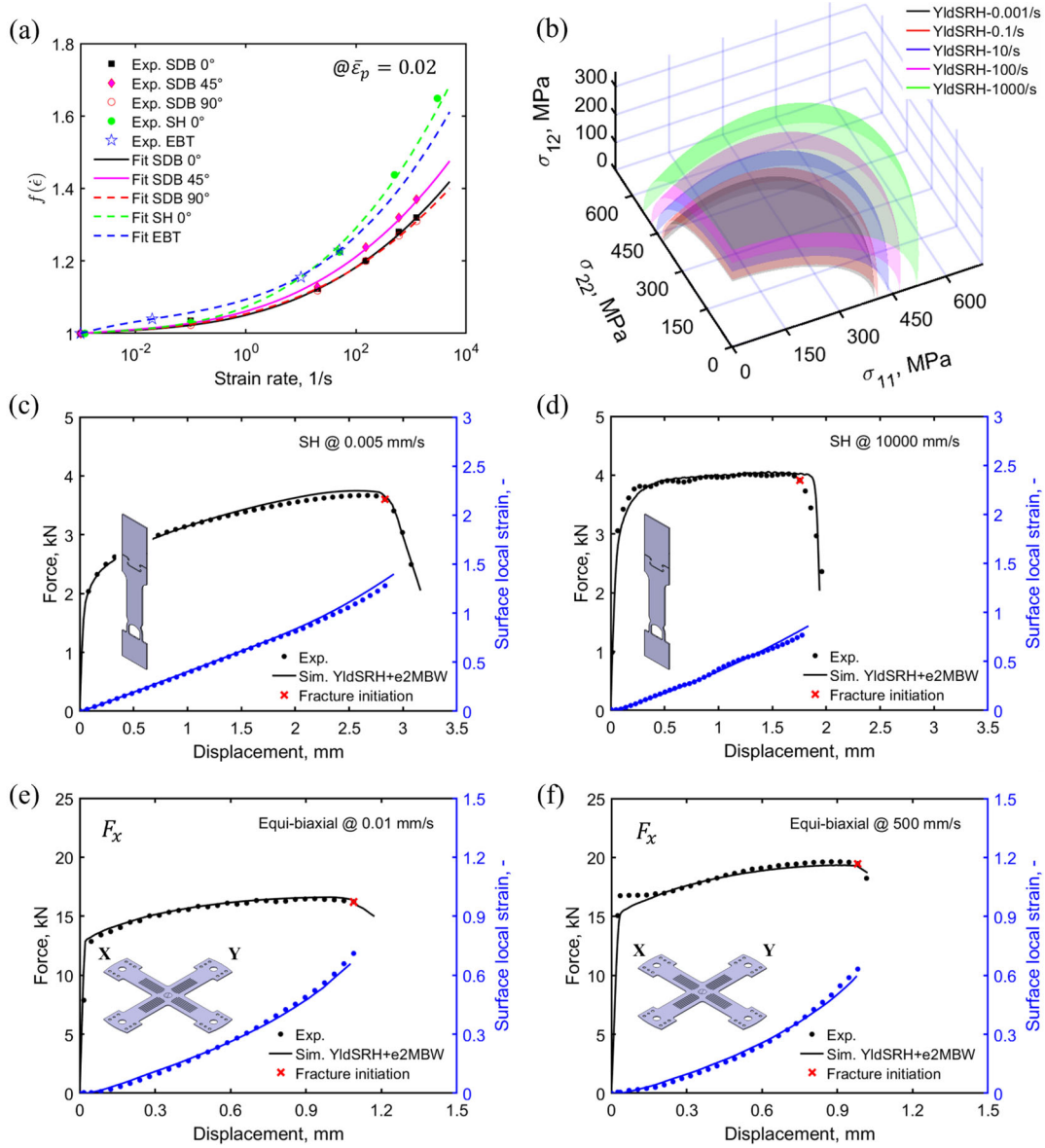


Fig. 2. (a) Comparison of strain-rate sensitivities under different loading conditions at a plastic strain of 0.02. (b) YldSRH yield surface (1/8 section) at a plastic strain of 0.02 for strain rates of 0.001, 0.1, 10, 100, and 1000 s^{-1} . (c-f) Experimental and numerical force-displacement curves and local strain evolution for simple shear and cruciform specimens at quasi-static and dynamic loading conditions.

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Determination of the Taylor-Quinney Coefficient from Strain and Temperature Measurements in Tensile SHB Tests

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Abstract

The split Hopkinson bar (SHB) technique is used for determining the value of the Taylor-Quinney coefficient (TQC), [1]. Most investigations used the compression version of the technique since in the compression test the deformation and the associated temperature increase are uniform, e.g., [2], [3]. In tensile SHB tests, necking typically develops relatively early during the test. Consequently, determination of the TQC from the average values of strain and temperature is limited to small strains during the early part of the test where the deformation is uniform, e.g., [4], [5]. In the present paper the determination of the TQC in tensile SHB tests is extended for large strains by analyzing the deformation and temperature increase in the necking region. Simultaneous full-field deformation and temperature measurements are used to determine the TQC at every point along the specimen, including in the necking region where the strain and temperature increase are much larger than the values during the uniform deformation. Results from testing Inconel 718 show that during the uniform deformation portion of the tests (up to a strain of about 0.15 before necking initiation) the conditions at the center region of the specimen's gage section are adiabatic. Large strains and significant increase in temperature are observed in the necking region once it develops. Analysis of the nonuniform deformation and temperature within the necking region show that at the edges of the necking region the condition is not adiabatic (heat is conducted from the necking region to the rest of the specimen). The center of the necking, however, deforms under adiabatic conditions and the determination of the TQC can accurately be extended up to a strain of 0.36.

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Blast and structural numerical analysis of accidental explosions during the hydrogen operation of the Large Gun of Fraunhofer EMI

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Abstract

There is growing interest towards the operation of two-stage light-gas guns with hydrogen to achieve the acceleration of projectiles to hypervelocity. Inevitably, safety aspects must be addressed. This is also motivated by the catastrophic event that occurred in 2012 at the testing facility of The University of Texas at Austin [1]. For the various hypervelocity accelerators of Fraunhofer EMI [2] safety risks have recently been reviewed as well.

As a case study, we present a combined blast and structural simulation procedure to quantify the effects of hydrogen combustion as a consequence of leakage scenarios during the operation of the EMI “Large Gun” [3]. The facility, located in the basement of a 65+ year-old concrete building hosting the headquarters of the Institute, employs up to 69 g of hydrogen, which are potentially enough to cause a detonation. For the analysis, the EMI in-house CFD code APOLLO Blastsimulator [4] has been used in combination with LS-Dyna, cf. Figure 1.

With respect to empirical models, numerical simulations provide time-resolved and enriched information of blast effects, enabling tailored, more effective and cost-saving countermeasures. Examples of recently implemented risk mitigation solutions at the EMI “Extra Large Gun” –currently the largest of its kind in Europe [2]– are shown.

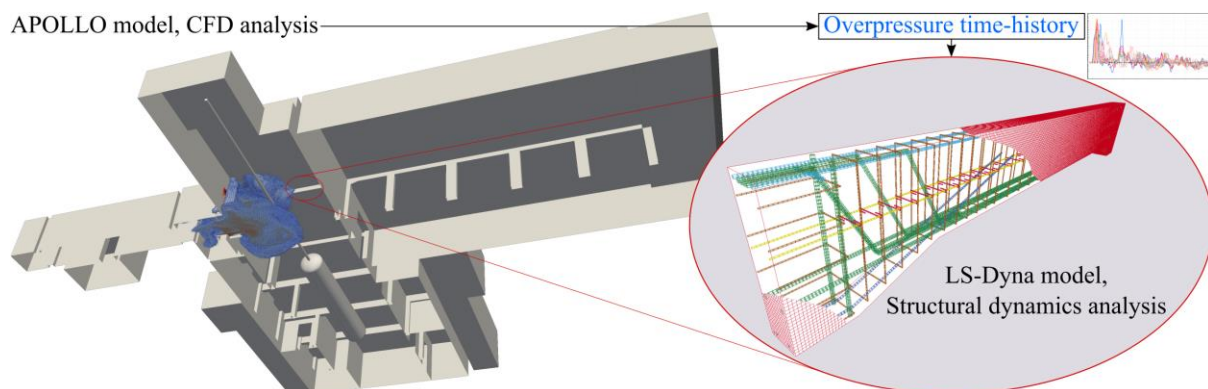


Figure 1. Cloud of combustion products for a leakage scenario along the launch tube simulated with APOLLO and details of an exemplary reinforced concrete beam modeled in LS-Dyna for the dynamics structural analysis, which is based on the CFD-derived overpressure time-history. Images adapted from Ref. [3].

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Hybrid Metallic Ceramic Interfacial Engineering for Enhanced Thermo-Mechanical Performance of CFRP Laminates under High Strain-Rate Loading

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Abstract

Carbon fiber–reinforced polymers (CFRPs) are increasingly deployed in aerospace and high-speed transportation systems, where components are subjected to coupled high strain-rate loading and elevated temperatures. However, conventional epoxy-based CFRPs suffer from rapid thermal softening, interfacial debonding, and loss of energy-absorption capability under such extreme conditions [1-4]. In this work, we present a scalable hybrid interfacial engineering strategy that significantly enhances the dynamic thermo-mechanical performance of CFRPs through the integration of a ductile metallic nanolayer and a thermally stable ceramic interphase. A conformal Au/Pd nanocoating was deposited on carbon fiber surfaces, followed by a sol–gel-derived SiO₂ interphase, forming a hierarchical interface that couples nanoscale ductility with microscale thermal rigidity. Dynamic compressive behavior was evaluated using split Hopkinson pressure bar testing at a strain rate of $\sim 3000 \text{ s}^{-1}$ across a temperature range of 25–225°C. The hybrid-modified laminates exhibit markedly improved post-yield ductility, delayed softening, and enhanced energy dissipation compared to unmodified and single-phase coated composites. At 225 °C, the hybrid interface delivers over 200% improvement in peak strain energy density and maintains substantial load-bearing capacity beyond the epoxy glass transition temperature. Multiscale characterization using scanning electron microscopy, X-ray computed tomography, and nanoindentation reveals suppressed fiber–matrix debonding, reduced delamination, and stabilized crack evolution in the hybrid system. Finite-element simulations incorporating temperature-dependent cohesive zone modeling reproduce the experimental trends and elucidate the cooperative roles of the metallic and ceramic layers in stress transfer and damage mitigation. These results demonstrate that hybrid metallic–ceramic interfacial architectures provide a robust and scalable pathway to improve the impact tolerance, thermal stability, and energy-absorption capability of carbon fiber composites, offering promising potential for aerospace structures operating under extreme thermo-mechanical environments.

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Impact Deformation Behavior of AA6063 Sheets Subjected to A Six-Stage Reluctance Electromagnetic Launch System

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Abstract

The AA6063 aluminum alloy sheet, commonly used in the aerospace and automotive applications, exhibits a remarkable strength-to-weight ratio. A comprehensive investigation into the impact deformation behavior of AA6063 sheet is imperative to enhance the effectiveness of processing technologies and ensure the reliability and longevity. To enhance the stability of impact velocity during medium and low velocity impacts, which are affected by the complexity, nonlinearity and random effects in experimental contexts and practical applications [1-3], there is a compelling need for an advanced multi-stage electromagnetic drive. This paper presents a novel impact testing platform that integrates a six-stage magnetic resistance electromagnetic launch system, enabling the precise control of the impact velocity stability of three projectiles within 10% accuracy. The optimal parameters of the electromagnetic system, as determined by Maxwell's simulation, were as follows: projectile length of 20-30 mm, initial voltage of 400-450 V, capacitance of 150 μ F and coil count of 150-250 turns. It was observed that the degree of deformation increased non-linear with the impact energy when a thin sheet of AA6063 was subjected to impact. The damage failure modes corresponding to spherical, conical and cylindrical projectiles were penetration, piercing and shear damage, respectively. A significant observation was the substantial influence of altering the impact angle on the thickness of the target plate. Microscopically, as the impact energy increased, the hardness of the impact area also increased. The conical projectile demonstrated the greatest degree of deformation and grain refinement, followed by the spherical projectile, while the cylindrical projectile exhibited the least deformation and refinement.

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Arching Effects in Masonry Walls Subjected to Blast

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Abstract

The blast response of arching masonry walls is governed by multiple interacting mechanisms, including crack opening and closure, unloading-reloading cycles, time-dependent boundary reactions, rocking, and coupled in-plane and out-of-plane dynamics. This study investigates the complex behavior of such walls under blast loading through an integrated theoretical and experimental approach.

The theoretical component presents a previously developed analytical model formulated within the principle of virtual work, incorporating equilibrium conditions, joint cracking, geometrically nonlinear kinematics, and nonlinear constitutive behavior. These features are unified within a variational framework that captures the nonlinear response of the wall and the geometric nonlinearity associated with large displacements and moderate rotations.

The experimental part consists of controlled laboratory tests on one-way masonry walls conducted using an advanced blast simulator and an extensive monitoring system. The tests provide a robust basis for validating the presented analytical model. The first experiment examines a non-arching masonry wall and demonstrates its limited blast resistance. The second test focuses on an arching wall, highlighting the significant influence of the arching mechanism on the dynamic response and failure mode under blast loading.

Comparisons between experimental observations and analytical predictions demonstrate the ability of the model to capture the complex dynamic behavior of masonry walls. The results further emphasize the critical role of support conditions and confirm the substantial contribution of arching action to enhancing blast resistance.

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Blast Response of Hybrid Steel–UHMWPE Composite Panels

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Abstract

High-hardness steels are widely employed in blast-resistant structures due to their high strength and stiffness, which enable effective resistance to high pressures and limit global deformation. Under sufficiently severe localised blast loading, however, they can undergo a characteristic failure mode in which a central bulge develops and separates from the main plate as a high-velocity “cap” fragment [1]. This capping phenomenon presents a significant secondary hazard due to the high momentum of the detached fragment. In contrast, ultra-high-molecular-weight polyethylene (UHMWPE) composites such as Dyneema® exhibit excellent ballistic performance because of their high specific strength and energy absorption capacity. Under explosive loading, however, their performance can be limited, particularly in close-in conditions where detonation-induced heating (and associated thermal softening/melting) can degrade mechanical response [2].

Motivated by the complementary response characteristics of these materials, the present study investigates the blast response of hybrid protective systems comprising an Armox steel front face backed by a Dyneema® composite layer. Experimental tests were first conducted on Armox steel and Dyneema panels as standalone systems to examine their deformation and failure behaviour. Two hybrid configurations were then examined: a direct-contact arrangement and a configuration incorporating a controlled air gap between the steel and the composite. The response of the hybrid systems was assessed relative to the standalone behaviour of each material.

The results showed that, in the direct-contact configuration, the Dyneema backing restricted cap development in the steel, delayed deformation, and reduced permanent out-of-plane deflection by approximately 5–8 mm. However, shock transmission through the steel induced an extreme dynamic response in the Dyneema, with peak displacements exceeding 50 mm, leading to significant laminate damage. Introducing an air gap markedly reduced damage by decoupling the layers and shielding the Dyneema from the initial blast wave. In this configuration, the steel plate was allowed to cap, and the Dyneema was primarily subjected to impact loading from the detached fragment. The composite successfully arrested the cap, with peak displacements of approximately 30 mm. These findings highlight the potential of Dyneema® to act as an effective fragment-mitigating layer in hybrid steel-composite systems under localised blast conditions.

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Enhancing flexible transparent electrodes fabrication via laser-induced optical-thermal-mechanical coupled nanowire welding

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Abstract

Silver nanowire (AgNW) networks are highly regarded for their exceptional electrical conductivity and optical transparency, establishing them as key materials for developing high-performance, stable, and multifunctional flexible conductive films. To enhance the electrical properties and service life of AgNW-based films, it is essential to achieve high-quality welding and effective protection of the nanowire network. This study examines the fundamental characteristics of laser shock welding of AgNWs across different scales, evaluates the ability of hot-plate-assisted laser shock welding to suppress mechanical damage at welded junctions, and introduces a novel AgNW welding strategy based on dual-laser optical-thermal-mechanical multi-field coupling induced by laser shock. By synergistically combining laser shock effects with localized optical enhancement generated by laser-induced plasma, this approach enables real-time control of optically driven processes at nanowire gaps under laser shock loading, leading to high-quality welding at the nanowire junctions. The proposed efficient and controllable multi-field coupling method offers considerable potential for industrial applications, providing a viable new pathway for nanomaterial welding in next-generation flexible electronic devices.

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Study on cross-sectional shape effect on blast performance of CFDST columns under contact explosions

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Abstract

The blast resistance of structural columns is strongly influenced by cross-sectional geometry. This study investigates the response of concrete-filled double-skin steel tube (CFDST) columns with circular and square cross-sections subjected to contact explosions. Field explosion tests were conducted on circular and square CFDST columns, and high-fidelity finite element models were developed using LS-DYNA. The numerical simulation results and experimental results showed good agreement. Taking a circular CFDST column as the benchmark, three square column configurations were designed considering geometric equivalence. Their blast performance was comparatively evaluated in terms of dynamic response, damage evolution, energy absorption. The results indicated that, among the square configurations, the column with an equivalent concrete cross-sectional area exhibited the best blast resistance, but its blast performance remained significantly inferior to that of the circular column. Square columns were subjected to more severe blast loading, leading to intensified concrete crushing and steel tube fracture. As a result of the increased extent of plastic damage, the blast energy absorbed by the square columns was more than 40% higher than that absorbed by the circular column. Therefore, circular CFDST columns are more suitable for the blast-resistant design of protective structures exposed to potential contact explosion threats.

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Comparison of the Arbitrary Lagrangian-Eulerian and Smoothed Particle Hydrodynamics to Simulate Bird Impacts

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Abstract

Bird strikes, defined as collisions between birds and aircraft, have remained one of the most persistent hazards in aviation since the earliest days of flight. This risk has driven the establishment of stringent certification procedures requiring engines and critical structures to demonstrate tolerance to specified bird masses and impact conditions through full-scale experimental tests. However, because these tests are extremely costly, numerical simulation has become an indispensable tool for predicting structural responses under large deformation and high strain-rate conditions.

In this work, we present recent advances in bird strike simulations using the commercial solver LS-Dyna. In particular, we investigate the accuracy and computational performance of modeling a bird impactor with the Multi-Material Arbitrary Lagrangian–Eulerian formulation, and compare this approach with the well-established Smoothed Particle Hydrodynamics (SPH) method. Given the variety of SPH options available in LS-Dyna, a detailed comparison among these formulations applied to bird strike problems is also provided.

The numerical results are assessed against experimental tests conducted on representative substructures. We compare the formulations to gelatin impact experiments carried out on a flat dummy vane, representing a simplified aeroengine blade. Additional simulations involving two consecutive impacts are presented, where a gelatin surrogate first strikes a plate obliquely, rebounds, and subsequently impacts a second orthogonal plate. This configuration reproduces multi-stage loading scenarios typical of booster (compressor) environments, in which impact fragments interact sequentially with engine components. Finally, we show validations against tests performed on a real blade, demonstrating that the models not only capture projectile bifurcation and trailing debris flow patterns, but also quantitatively reproduce leading and trailing edge displacements during impact.

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Data-Driven Modeling and Optimization of a 4D-Printed Shape Memory Polymer-Based Crash Absorber

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Abstract

Shape memory polymers (SMPs) offer tunable thermomechanical behavior and enable the development of recoverable energy-absorbing structures for crashworthiness applications. This study presents a data-driven computational framework for the design and optimization of a 4D-printed SMP-based crash absorber incorporating periodic auxetic microstructures. A finite element (FE) model is first developed and validated against experimental measurements of crushing response and shape recovery. A comprehensive parametric study is then conducted by systematically varying key microstructural parameters, including wall thickness, unit-cell size, and re-entrant cell geometry. Structural performance is assessed using metrics such as specific energy absorption (SEA), peak crushing force, and recoverability.

To efficiently explore the high-dimensional design space, machine-learning-based surrogate models are constructed and integrated with a multi-objective optimization scheme to identify Pareto-optimal designs that balance competing performance objectives. Results indicate that microstructural geometry plays a dominant role in governing both energy absorption and recovery behavior. Increasing wall thickness improves stiffness and peak force but degrades recoverability due to increased residual deformation, while larger re-entrant angles enhance auxetic behavior and promote more uniform stress distribution. An optimal structural configuration achieving a balanced combination of moderate peak load, high energy absorption, and substantial shape recovery is identified, demonstrating the effectiveness of the proposed framework for designing recoverable crashworthy structures.

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Dynamic Response Characteristics and Parametric Study of Reinforced Concrete Blast-Resistant Structures under Internal Explosion Loads

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Abstract

Reinforced concrete structures, a primary component in modern construction, are extensively utilized in hazardous material production and storage facilities owing to their high strength, fire resistance, and superior blast performance. Typical applications include blast-resistant design in manufacturing workshops, protective storage warehouses, blast walls, and pressure-relief structures [1]. Accidents at such sites can lead to catastrophic consequences. Incorporating pressure-relief openings in the roof, designed to fail preferentially during an explosion, can significantly mitigate blast wave damage to the primary structure and surrounding buildings. Therefore, investigating the blast resistance of concrete structures is of considerable importance.

Scaled models serve as a key method for studying the dynamic response and damage behavior of full-scale prototypes. However, structures under dynamic loading often deviate from conventional scaling laws due to size effects and strain-rate sensitivity [2,3]. In this study, a simplified blast-resistant reinforced concrete model suitable for roof pressure relief was developed based on realistic operational layouts. The roof was designed with variable-sized relief openings covered with lightweight panels. Numerical simulations were performed to examine the effects of explosive mass, detonation location, and charge geometry on structural response [4,5].

The results indicate distinct damage patterns across roof slabs and walls. Roof damage concentrated near the junctions between relief openings and side walls, whereas wall damage was most pronounced in the upper-middle sections. Among different charge shapes, a cubic charge induced the most severe structural damage and displacement. For elongated charges, structural damage initially increased and then decreased with increasing aspect ratio. Both the amplitude and growth rate of roof displacement rose significantly with larger charge masses. Moreover, the detonation location markedly influenced local damage and displacement distribution.

By quantifying these response patterns, this study provides a useful reference for blast source localization and yield estimation in complex industrial explosion scenarios.

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Thermal Analysis of Portevin-Le Chatelier Effect in AlMg Alloys

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Abstract

Portevin–Le Châtelier (PLC) bands are a classic indication of plastic instability occurring in metal deformation. As these dislocations are intrinsically exothermic, it is possible to monitor the PLC bands displacement and specific energy output with a high-speed infrared camera. This technique allows for non-invasive, real-time monitoring of temperature variations corresponding to PLC band propagation, enabling a deeper understanding of the spatio-temporal aspects and energy exchange of these localized strains [1]. Thermal measurements can enable improved modeling of material behaviour and properly isolate the heat produced by the PLC effect, discerning between the three main sources of heat in strained materials: (i) thermoelastic coupling, (ii) the mechanical dissipation due to homogeneous plasticity, (iii) the heat source due to the PLC effect [2]. The high-speed thermal data on an AlMg alloy was obtained at the Fraunhofer IWM institute in Germany with a Telops FAST M3k camera. The acquisition was done at a rate of 31 000 Hz with a window of 128x36 pixels.

The unique displacement of the PLC strain bands as well as their specific 55° angle were clearly observed through the M3k image with a high temporal resolution. The unstandard fracture point following the PLC bands movement is also studied, demonstrating a two-step increase in temperature and an asymmetrical energy release from either side of the gauge region. The fracture point following the PLC effect is thermally analyzed in Fig. 1. Just before the fracture, the peculiar angular dislocation aggregation first generates a large amount of heat in a uniform manner along the band. The heat then increases drastically to the edge appearing as the last two points of contact before the sample is fully split in two, with two distinct heat increasing steps seen in Fig. 1a. The angle associated with the PLC effect impacts the alloy rupture behaviour with an unbalanced strain causing one side of the sample (A) to generate more heat during the fracture compared to the other side (B).

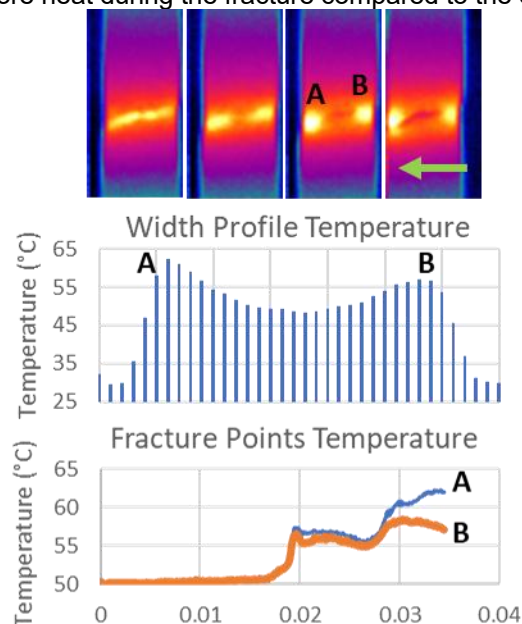


Fig. 1. a) Infrared images at the moment of fracture showing the double release points. b) Temperature line profile of the fracture line. c) Temperature over time for the last two points of contact before the separation of the sample two halves.

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While the PLC bands dynamics does not require a particularly high frame rate, the high-speed imaging from these measurements enables the in-depth study of the fast fracture process following the oscillating band displacement and unveils its unconventional features. These findings underscore the continued relevance of infrared imaging as a non-invasive and effective approach for characterizing mechanical phenomena.

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Quasi-static and dynamic compression of 4D-printed reusable metamaterials with different Poisson's ratios

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Abstract

Four-dimensional (4D) printed cellular metamaterials offer new opportunities for impact energy absorption with programmable deformation and recovery. In this work, metamaterials with positive (PPR), negative (NPR), and near-zero (ZPR) Poisson's ratios were fabricated via fused deposition modelling using polylactic acid as a shape-memory polymer. The metamaterials were subjected to uniaxial compression under quasi-static (0.025 mm/s) and dynamic (25 mm/s) loadings along two orthogonal in-plane directions (X and Y, as defined in Fig. 1), followed by cyclic cold-programming and thermal recovery.

Axial compressive test results reveal pronounced directional dependence in the crushing response across all metamaterials, which exhibit higher stiffness, plateau force, and specific energy absorption under compression in the X direction than those along the Y direction. In contrast, compression along the Y direction is characterised by earlier deformation localisation and reduced energy-absorption efficiency. An increase in the loading rate leads to pronounced strain-rate strengthening, with the ZPR honeycomb showing the most stable rate-dependent performance among the three types of metamaterials.

Cyclic cold-programming tests demonstrate that mechanical properties initially improve after the first recovery cycle, particularly under dynamic loading. The possible reasons include the relieved residual stress, closure or reduction of the initial defects/voids/gaps originated from the printing process, and alignment of polymer chains in the cell wall material. With increasing cycle number, progressive degradation occurs owing to possible plastic hinge formation, inter-filament debonding, and geometric misalignment. Nevertheless, high shape-recovery ratios are maintained over multiple cycles, especially for the NPR and ZPR honeycombs, indicating good functional reusability. Catastrophic fracture is observed in the ZPR honeycomb in the sixth cycle and thus tests are terminated.

These results provide experimental insight into the coupled roles of the topology of metamaterials, loading direction, strain rate, and cyclic recovery in governing the mechanical response of 4D-printed cellular metamaterials.

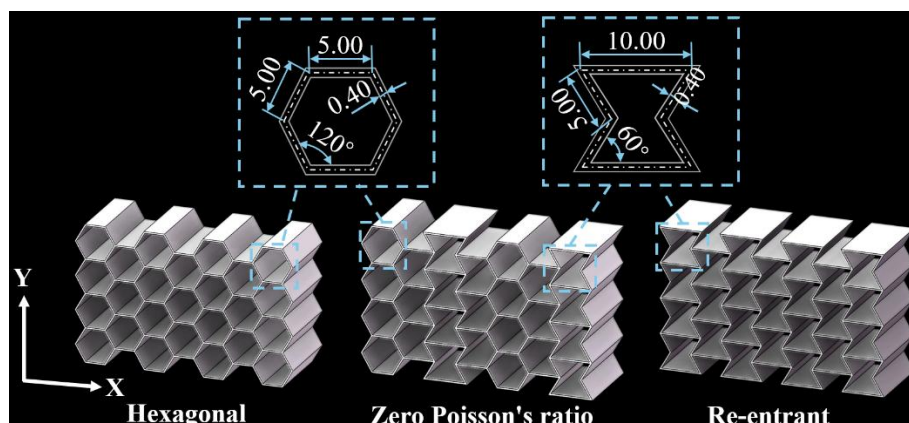


Fig. 1. Geometric configurations of metamaterials with positive, zero, and negative Poisson's ratios, together with the geometries and dimensions (in mm) of unit cells. Compressive tests are conducted along the two orthogonal in-plane directions (X and Y).

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Low-Velocity Impact Response of Rubberized One-part Geopolymer Concrete with Varying Rubber Contents under Extreme Temperatures

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Abstract

This study investigates the low-velocity impact behavior of rubberized one-part geopolymer concrete (ROPGC) under a wide range of temperature conditions. Rubber particles were incorporated as partial replacements of fine aggregates at volume ratios of 0%, 10%, 20%, 30%, and 40% to evaluate the influence of rubber content on impact resistance. Drop-weight impact tests were conducted on ROPGC specimens exposed to five temperature conditions, namely $-196\text{ }^{\circ}\text{C}$, $-78.5\text{ }^{\circ}\text{C}$, ambient temperature, $100\text{ }^{\circ}\text{C}$, and $200\text{ }^{\circ}\text{C}$, aiming to clarify the combined effects of rubber incorporation and thermal environment on dynamic impact performance. The experimental results indicate that the inclusion of rubber particles significantly altered the impact response of one-part geopolymer concrete. Compared with the reference specimens without rubber, ROPGC exhibited reduced peak impact force but improved deformation capacity and damage tolerance, particularly under repeated impact loading. With increasing rubber content, the specimens generally showed enhanced energy absorption capability and delayed damage accumulation, accompanied by more distributed cracking patterns and less brittle failure modes. Temperature was found to play a critical role in governing the impact behavior of ROPGC. Under cryogenic conditions, ROPGC maintained relatively stable impact resistance, while elevated temperatures led to a gradual degradation of stiffness and impact-bearing capacity. Nevertheless, the presence of rubber particles effectively mitigated temperature-induced brittleness, especially at extremely low temperatures. Overall, the results suggest that an appropriate rubber content can improve the impact resistance and thermal adaptability of one-part geopolymer concrete by balancing strength reduction and toughness enhancement. This study provides experimental insights into the impact performance of rubberized one-part geopolymer concrete subjected to extreme temperature environments and supports its potential application in structures requiring enhanced impact resistance and thermal resilience.

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Mechanical behaviour of interpenetrating phases composites 316L/PDMS under dynamic loading

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Abstract

In the field of architected materials mechanics, interpenetrating phase composites (IPCs) have recently attracted increasing attention due to their multifunctional capabilities and the tunability of their properties through intrinsic IPC parameters [1]. In particular, the combination of a metallic reinforcement with an incompressible polymer matrix has been actively investigated, demonstrating significant potential for energy absorption under both low- and high-velocity impact loading conditions [2-4]. However, the current understanding of matrix–reinforcement interactions remains limited because of pronounced edge effects, which limit optimal matrix confinement and consequently restrict energy absorption efficiency. Moreover, most studied TPMS-based IPCs feature fully filled phases, making the specimens nearly incompressible and further complicating the interpretation of the interaction mechanisms between the matrix and the reinforcement [5]. The aim of this work is therefore to investigate the influence of complete or partial infiltration of an incompressible hyperelastic matrix into a TPMS-based metallic reinforcement on the dynamic mechanical behavior of the resulting IPCs. To address this objective, quasi-static and dynamic experiments, covering strain rates from 0.001 s^{-1} to 200 s^{-1} , are conducted on IPC specimens composed of an additively manufactured 316L metallic reinforcement and an incompressible hyperelastic PDMS filling matrix. Different filling configurations are investigated—namely empty, partially filled, and fully filled—based on a TPMS Primitive geometry. ABAQUS/Explicit numerical simulations are conducted to correlate the mechanical responses and elucidate the underlying deformation mechanisms within the reinforcement. Mechanical tests indicate that the presence of the matrix promotes deformation homogenization throughout the entire structure, leading to an enhanced mechanical response compared to the empty reinforcement. Dynamic experiments further show that the mechanical behavior of IPCs is sensitive to the applied strain rate, with both the deformation response and the specific energy absorbed being strongly influenced by the matrix filling configuration. These observations suggest that matrix infiltration improves load transfer and deformation stability by modifying the local deformation modes of the metallic reinforcement, a trend further supported by numerical simulations highlighting the role of the matrix in governing local deformation mechanisms within the TPMS architecture, particularly under dynamic loading conditions.

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Application of machine learning models to predict residual velocity of rigid projectiles on monolithic metallic targets

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Abstract

For the design of protective armour and ballistic evaluation, accurately predicting the residual velocity of projectiles is essential. Conventional approximate models, such as the Lambert–Jonas and Recht–Ipson formulations, are analytical solutions. The accuracy of these models declines in the presence of complex material behaviour and impact conditions. High-fidelity finite element simulations are more accurate at predicting outcomes, but they require significant time for extensive studies or real-time evaluations. To overcome the limitations mentioned above, this study develops a combined machine learning framework for predicting the residual velocity of rigid projectiles on monolithic Al6061-T651 aluminium plates. Optuna hyperparameter optimization was performed for eleven machine learning algorithms, and the results were compared using cross-validation. Of all the models, CatBoost produced the most accurate predictions, with a test-set RMSE of ~0.7 m/s and an R^2 value of 1.00, indicating no evidence of overfitting. The derived SHAP for explainability analysis showed that the model captured physically meaningful trends. The initial velocity had the most significant influence on the residual velocity, followed by the plate thickness and the projectile mass. The CatBoost model was deployed in a standalone graphical user interface for real-time prediction and visual interpretation of feature contributions based on SHAP values. According to the results, machine learning can offer a reliable computationally efficient alternative to repeated ballistic testing and repeated finite element simulations. Future work may extend it to mixed-material targets, oblique impacts, and physics-informed architectures.

Keywords: Residual velocity; Ballistic impact; Machine learning; CatBoost; SHAP explainability; Al6061-T651 aluminium

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State-Dependent Structural Integrity of Li-ion Batteries During Mechanical Abuse

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Abstract

Lithium-ion batteries (LIBs) face critical safety challenges when subjected to mechanical abuse during electric vehicle operation. This work systematically explores the causal relationship between operational electrochemical states and structural vulnerability. Experimental evidence establishes that actively discharging LIBs exhibit substantially compromised load-bearing capacity and elevated thermal runaway propensity compared to rested states, with post-discharge rest effectively mitigating internal stress accumulation. Multiphysics simulations deconvolute the underlying coupling mechanism: electrochemical drivers (ionic concentration polarization, kinetic overpotentials) and mechanical consequences (localized stress intensification) engage in a deleterious feed forward cycle during discharge, precipitating premature structural failure. For latent damage assessment in abuse-survived batteries, we establish a multimodal interrogation protocol combining electrochemical impedance characterization, microstructure tomography, and novel ultrasonic frequency-domain spectroscopy—demonstrating superior sensitivity to subcritical internal defects under operando conditions. The derived state-dependent failure criteria delineate electrochemical-mechanical safety boundaries across operational envelopes. Collectively, this work advances a fundamental paradigm for predicting LIB structural integrity through electro-chemical state monitoring, providing theoretical foundations for collision-safe battery design and field-deployable diagnostic frameworks.

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Machine learning-driven prediction of the conditions for shock-induced phase transformations in tin

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Abstract

Thanks to its unusual mechanical properties, tin has recently attracted significant attention across a variety of engineering fields. It is, however, a complex material, exhibiting a variety of deformation mechanisms under dynamic loading due to its low-symmetry β crystal structure. In particular, the β - γ phase transformation significantly influences tin's dynamic behaviour owing to its onset at relatively low shock pressures. However, the orientation dependence of this phase transformation is still not well characterised, with modelling efforts to date remaining very limited. To this end, non-equilibrium molecular dynamics simulations of shock compression in single-crystal tin were performed across five orientations to identify the mechanical conditions under which β -tin transforms to γ -tin. These simulations utilised a recently proposed machine learning-based interatomic potential [1], trained on density functional theory data across a wide range of pressures, to resolve the mechanisms driving orientation-dependent phase transitions. The results suggest that γ -tin nucleates in coexistence with β -Sn at lower pressures than experimentally measured, with the transformation occurring at higher pressures when the material is shocked in the [100] direction. However, the pressure at which the material fully converts to γ -tin, with no residual β -Sn, is found to be around 10 GPa regardless of orientation, in good agreement with experimental data. The results from the atomistic simulations were then used to train a variety of machine learning classifiers to predict the set of necessary conditions for γ -tin to start nucleating. The resulting machine learning-based framework predicts phase transformations in tin accounting for orientation dependence. This will eventually complement current state-of-the-art experimental investigations and allow for further upscaling at the continuum scales for the establishment of continuum models for real components.

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Constitutive Modeling, Failure Criterion and Equation of State for the High-Entropy Alloy $\text{Ti}_3\text{Zr}_{1.5}\text{Nb}_{0.5}\text{V}_{0.9}\text{Al}_{0.5}$

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Abstract

High-entropy alloys (HEAs) have garnered significant attention in recent years due to their exceptional mechanical properties. However, most existing studies focus on the fabrication methods and microstructural characterization of HEAs[1–3], with limited progress in developing comprehensive models to describe their mechanical behavior under practical applications.

In this study, we utilized Laser Directed Energy Deposition (LDED) technology to fabricate the $\text{Ti}_3\text{Zr}_{1.5}\text{Nb}_{0.5}\text{V}_{0.9}\text{Al}_{0.5}$ high-entropy alloy and designed various sample types for systematic investigation. The mechanical behavior of this alloy was comprehensively characterized through quasi-static tensile tests, dynamic compression using a Split Hopkinson Pressure Bar (SHPB), and plate impact experiments conducted with a two-stage light-gas gun. These tests were performed across a wide range of strain rates and temperatures. Additionally, digital image correlation (DIC) and microstructural analysis were employed to investigate the interaction mechanisms between the alloy's dynamic mechanical behavior and its microstructure.

The results indicate that $\text{Ti}_3\text{Zr}_{1.5}\text{Nb}_{0.5}\text{V}_{0.9}\text{Al}_{0.5}$ HEA exhibits superior mechanical performance under various loading conditions, especially under high strain rates and across a wide temperature range. The alloy demonstrates remarkable plastic deformation capacity and high compressive strength, with significant strain rate sensitivity. Quasi-static tensile tests revealed that the alloy possesses high yield strength and ductility at room temperature, with a notable increase in elongation at elevated temperatures, indicating excellent temperature dependence. As the temperature increases, the alloy's plasticity significantly improves, with no brittle fracture observed. Under varying strain rates, the alloy exhibits a pronounced strain rate sensitivity, where peak stress increases substantially with the strain rate, reflecting a significant dynamic strengthening effect. Particularly, under high strain rates, the alloy can withstand large stresses and strains, showing excellent impact resistance. Plate impact tests using a two-stage light-gas gun further revealed that the alloy exhibits excellent impact toughness and energy absorption at different impact velocities.

Based on these findings, a comprehensive mechanical behavior model was developed to accurately describe the mechanical response of $\text{Ti}_3\text{Zr}_{1.5}\text{Nb}_{0.5}\text{V}_{0.9}\text{Al}_{0.5}$ HEA under high strain rate and wide temperature conditions. This model integrates the Johnson-Cook (JC) constitutive model, JC damage criteria, and the Grüneisen equation of state to fully characterize the alloy's mechanical behavior, addressing plastic deformation, dynamic strengthening, and damage evolution under extreme conditions.

Keywords: High-entropy alloys (HEAs), Strain-rate, Compressive behavior, Constitutive model

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Damage Evolution and Flexural Residual Properties of GFRP Laminates Clamped in Two Sides and subjected to Air-blast

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Abstract

This paper examines changes to the flexural properties of Glass Fibre Reinforced Polymer (GFRP) laminates when impulsively loaded by the detonation of a cylindrical explosive charge. Different masses of explosive were detonated to generate a range of uniform blast loads causing different responses in the laminates. Four-point flexural tests were performed to quantify the residual flexural strength and stiffness of the blasted laminates. When dynamically loaded with relatively low impulses, the laminate experienced comparatively little damage, and consequently the flexural properties remained unchanged. Increasing the shock wave pressure beyond a threshold value caused notable damage, resulting in an appreciable loss of residual flexural strength and stiffness.

Introduction

Fibre-reinforced polymer (FRP) composites have been extensively preferred as a replacement to metals due to their excellent mechanical properties^{1,2}. This choice allows for the design of structures with desirable strength to weight properties. When subjected to explosive loading (either accidental or intentional), composites can exhibit unpredictable damage patterns, such as fibre breakage or matrix fragmentation, which can compromise the overall structural integrity of the material². One of the primary challenges with composites is the difficulty in detecting damage, especially internal defects. Depending on the load intensity, composites can experience internal delamination damage which is not always visible². To ensure the safety and reliability of composite materials, it is important to understand how they fail and their residual properties after being exposed to damage. This paper thus reports on the residual flexural strength of GFRP laminates that were subjected to uniform blast loads.

Material Manufacturing and Characterisation

The GFRP laminate was made from WOVITEX 400P E-glass fibres and Prime-27 epoxy polymer together with an appropriate slow hardener. The continuous glass fibre used in the laminate were of a 0°/90° plain weave with an areal density of 200 g/m². The fibres were vacuum infused with the epoxy to produce 5.6 mm thick laminates consisting of 18 layers. The laminates were post cured according to manufacturer specifications² before being CNC-routed or cut by water jet to produce the required samples for the mechanical tests. Four point-bend flexural tests and tensile tests were performed according to the relevant ASTM standards^{3,4} for polymer matrix composite materials to confirm manufacturing repeatability. The properties of the manufactured GFRP panels obtained from the material tests are presented in Table 1. A span to thickness ratio of 20:1 was used for the flexural tests. The flexural test data was also the baseline data for assessing post blast flexural properties later. Complex stress states occur in composite materials during flexural tests due to tensile, compressive and shear stresses being set up simultaneously⁵. Flexural tests are relevant for assessing residual properties as various structures are typically loaded in bending and not in compression, which is traditionally used to assess residual properties⁵.

Table 1: Flexural and Tensile Properties.

PROPERTY	MEAN	STD DEV
Flexural Strength	327 MPa	3 MPa
Flexural Modulus	32.1 GPa	0.8 GPa
Tensile Strength	362 MPa	17 MPa
Tensile Modulus	28.4 GPa	1.3 GPa

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Blast Testing

The blast test panels of size 200 mm x 300 mm were clamped between a square steel blast tube and a clamp frame on two opposite short sides to present an exposed area of 200 mm x 200 mm. The bolts were torqued equally to ensure uniform clamping pressure along the clamped region. The blast tube assembly shown in Figure 1 was attached to a horizontal pendulum, used to determine the impulse imparted onto the panels. The panels were blast loaded by detonating cylindrical discs of Plastic Explosive 4 (PE4). A 22 mm diameter was used for charge masses less than 8 g and a diameter of 28 mm for charge masses larger than 8 g. Different diameters were chosen to optimize the impulse imparted to the panel and ensure complete detonation⁶. The PE4 cylinder was attached to a polystyrene pad that was placed at the end of the blast tube and detonated at a stand-off distance of 300 mm to generate a uniform blast load. The response of the panels was captured using high speed cameras and analysed using Digital Image Correlation (DIC). The blast loaded panels were cut by waterjet into smaller rectangular specimens of 220x15 mm² for four-point flexural tests to determine of the residual flexural properties of the material.

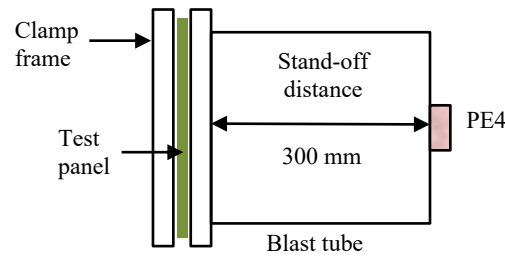


Figure 1: Blast tube assembly.

Results

The blasted tested panels were visually inspected to establish the evolution of damage in the panels with increasing load. The following damage was noted, listed in order of occurrence: clamp boundary damage (CBD), matrix damage along the centre (MDC) and bolt hole damage (BHD), delamination (D) and in-plane cracking, and through thickness cracking (TTC) along the clamp boundary. The damage visible on the face of the panel is shown in Figure 2.

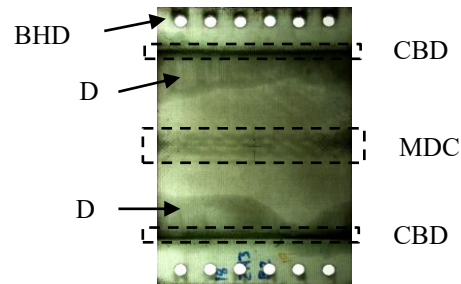


Figure 2: Panel damage at 47.8 Ns.

The panels were photographed on a backlit lightbox to help quantify panel delamination after the blast tests. The delamination damage visualised by this technique included the superposition of all the delamination damage through all the layers and interfaces in the panel. Delamination was visible as the darker regions, cannot be easily identified by layer. The delaminated regions were traced and their projected areas calculated, to determine the delamination area as a percentage of the exposed area. The evolution of the delamination and other damage is presented in Table 2.

Table 2: Damage progression with increasing impulse.

Impulse (Ns)	28.8	39.7	47.8
CBD	Yes	Yes	Yes
MDC & BHD	No	Yes	Yes
Delamination	0%	35%	41%
TTC	No	Yes	Yes

Four-point flexural test specimens were waterjet cut from these blasted panels to determine residual properties of the damaged material. The specimens were assigned an image-based brightness value related to the degree of delamination. Delamination makes the specimen less translucent resulting in lower brightness values from the photographs. The results for the residual properties of specimens against specimen brightness are shown in Figure 3. This may provide an easy method of quantifying the damage in a part.

The DIC data provided the transient response of the panels during the blast. The initial displacement of the panels confirm that they were uniformly loaded by the blast. The maximum displacement of centre of the panels increased with an increase of impulse, the panels rebounded and oscillated at lower impulses but tended to slip between the clamp frame and blast tube at higher impulses resulting in crushing at the bolt holes. The panels did not rebound when slippage occurred.

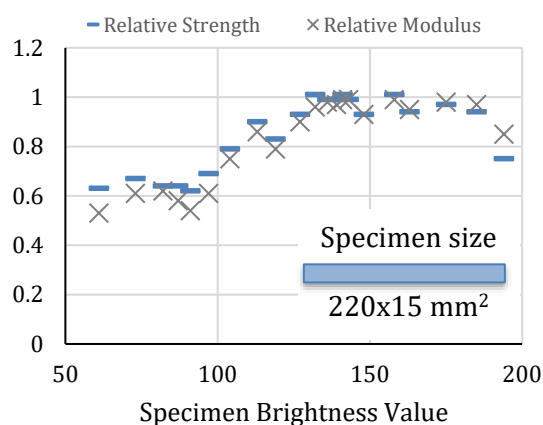


Figure 3: Residual properties (normalised by flexural strength and modulus) vs specimen brightness value.

Conclusions

The damage progression for panels clamped on two opposite sides and subjected to increasing blast impulses was evaluated. A correlation was found between an image-based damage evaluation and residual properties; this has the potential of being implemented in image processing techniques for rapid damage assessment for translucent materials. The transient response of the panels was assessed using DIC showed that the displacement of the centre of the panels was directly proportional to the applied impulse.

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Ballistic Impact Responses of CoCrNi MEA Nanofilm

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Abstract

Ion beam-assisted deposition (IBAD) was used to deposit CoCrNi MEA nanofilm on Si substrates. The results of nanoindentation (strain rate: $5 \times 10^{-2} \text{ s}^{-1}$) show that the elastic modulus and hardness of the CoCrNi MEA films are $200.8 \pm 11.3 \text{ GPa}$ and $8.86 \pm 0.9 \text{ GPa}$, respectively. The high hardness and elastic modulus are conducive to the enhancement of their impact resistance. We used LIPIT to measure the ballistic impact responses of CoCrNi MEA nanofilm. The results revealed that the CoCrNi MEA nanofilm exhibits high specific penetration energy (up to 0.882 MJ/kg) and excellent impact resistance, significantly surpassing traditional protective materials. For instance, the specific penetration energy of CoCrNi MEA nanofilm is about 1.8 to 2.2 times that of steel, and the specific penetration energy of CoCrNi MEA nanofilm is about 1.2 to 1.4 times that of Kevlar/PVB composite. Based on the post-impact analysis, we observed abundant energy dissipation pathways including multiple cracks, bending of cracking-induced petals, mechanical twins, and, of particular note, amorphization for the nanocrystalline CoCrNi MEA nanofilm. Such solid-state amorphization, stemming from severe lattice distortion, activates a new mechanism for impact energy dissipation. The versatility and synergy of deformation mechanisms contribute to the exceptional protective performance of the nanocrystalline CoCrNi MEA nanofilms. The specific penetration energy of the nanocrystalline CoCrNi MEA nanofilm is about 21% higher compared to that of the amorphous CoCrNi MEA nanofilm due to the additional energy dissipation mechanisms arising from mechanical twins and amorphization.

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Capturing Fragments Inside Dense Explosion Clouds Using a Multi-Beam DIH Technique

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Abstract

Understanding the motion of preformed fragments within a dense explosion cloud is critical for characterising controlled fragmentation systems. Conventional imaging techniques, such as Flash X-ray and Shadowgraphy, are ineffective at tracking fragments within a dense explosion plume. Scattering, occlusion, and insufficient penetration of conventional illumination systems hinder the accurate mapping of fragment trajectories and velocities under these conditions. This paper presents a Multi-beam Digital Inline Holography (DIH) imaging technique with a sub- μ s effective exposure to address these issues. Experiments were conducted with 33 g Plastic Explosive (PEK-1) as a base charge filled inside an Aluminium casing. For preformed fragmentation, 84 cuboidal Tungsten Alloy (TA) fragments with edge length 6 mm x 6 mm x 4.5 mm were attached to the outer surface of the casing. Results showed superior performance of the developed imaging technique to map fragment motion inside dense explosion clouds. In addition, the captured fragments showed significant deceleration within the cloud due to variations in the effective density (ρ_{eff}) of the post-detonation medium. This results in a significant increase in drag force on the fragments, reducing their velocities within the explosion cloud. The velocities were found to be constant as the fragment crossed the dense particulate luminous zone. Microstructural analysis through SEM of the soft recovered fragments revealed spalling and brittle fractures resulting from high-impact loads. Overall, the developed imaging system improves fragment mapping and velocity measurements for fragments inside the explosion cloud, offering enhanced insights into explosion physics.

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High-Cycle Fatigue Modelling of Microarchitected Lattices

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Abstract

High-cycle fatigue typically occurs under low stress amplitudes over long lifetimes and often develops without observable macroscopic precursors. Nevertheless, it can lead to sudden and catastrophic failure of materials and structures, thereby governing their effective service life. A mechanistic understanding of high-cycle fatigue is therefore essential for ensuring structural safety and reliability.

In this work, a predictive computational framework [1] for high-cycle fatigue modelling of architected lattices is developed by coupling a non-linear continuous damage (NLCD) model [2] with finite element (FE) simulations. The framework is applied to investigate the cyclic shear and compression fatigue behaviour of microarchitected lattices. The proposed NLCD–FE approach captures stress evolution and progressive fatigue damage accumulation at the strut level, enabling the prediction of macroscopic stiffness degradation, damage localisation, and accelerated failure. To eliminate the mesh dependency associated with strain-softening damage, a non-local damage formulation [3] is adopted to regularise the damage field. In addition, a jump-in-cycle strategy [4] is implemented to substantially improve computational efficiency, making simulations over very high fatigue lifetimes computationally feasible.

The accuracy and robustness of the NLCD–FE framework are validated through systematic calibration against experimental data and multi-scale benchmark models. The results show that lattice microarchitecture and initial topological imperfections exert a strong influence on fatigue life, damage evolution, and failure mechanisms, particularly under cyclic shear loading. Differences in fatigue performance among lattice architectures are attributed to variations in strut-level stress states, damage-induced load redistribution, and pronounced boundary-layer and size effects. Overall, this study provides new methodological insights and mechanistic understanding of high-cycle fatigue in architected lattices, and establishes a reliable numerical tool and theoretical basis for the design and optimisation of high-performance, fatigue-resistant architected lattices for engineering applications.

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ECC overlay Concrete system under Contact Detonation

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Abstract

Due to the rising occurrence of accidental and intentional explosions, the focus of researchers has increased significantly in improving the blast resistance of engineering structures, particularly, protective systems and critical infrastructure such as nuclear power plant, bridges, tunnel, military and government buildings. Engineered Cementitious Composites (ECC), due to their superior mechanical properties and high tensile ductility, provides an effective means of enhancing the blast resilience of structural components, hence can be used as a retrofitting material to enhance the concrete system performance. From that motivation, in this study, a series of three-dimensional non-linear Finite Element Method-Smoothed Particle Hydrodynamics (FEM-SPH) numerical models were developed and simulated to reproduce the response of ECC-strengthened concrete slab under contact explosion of spherical TNT charge, focusing on the strengthening layer of ECC in such conditions. Total of five slab configurations were analyzed: one conventional concrete slab and four retrofitted slabs. Two retrofitting schemes were considered: application of ECC only on the distal (back) surface, and application on both the blast-incident (front) and distal surfaces. First, numerical models are performed and validated with the existing literature data to characterize the material behavior of ECC. Subsequently, blast wave parameters were validated under near-field explosion. Based on the simulation results, the control specimen is completely damaged under contact explosion of 5 kg TNT spherical charge. For the slab with a 20 mm ECC layer on both the blast and distal surfaces, the crater diameter decreased by 25 % while the spalling and breaching diameter also increased by 8.8 % and by 5.12 %, respectively. Similarly, when a 10 mm ECC layer is used on both surfaces, the crater diameter reduced by 32.0 % and the spalling and breaching diameter increased by 17.10 % and 13.8 %, respectively. Among the five configurations, the specimen with a 40 mm ECC layer applied on the distal surface gave the best overall performance, achieving the largest reduction in spalling and breaching failure.

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Electromagnetic Hopkinson Bar: Basic Principles and Application

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Abstract

Hopkinson bar, since being invented by Hopkinson in 1914[1], has become the most popular experimental apparatus in the field of impact dynamics. This apparatus had widely applied to test the mechanical properties of materials at strain rates ranging 10²-10⁴s⁻¹. However, in light of the original design of split Hopkinson bar is to load the specimen by one single stress wave (compression, tension or torsion)[2], its makes it difficult to measure the material behavior under multi-pulse or multi-axial loadings. Plenty of researchers have been put into the multi-axial dynamic tests through modification of the traditional Hopkinson bar apparatus and the design of special shaped specimens. Recently, we reported a new technique similar to the traditional Hopkinson bar, the E-Hopkinson bar, except that the stress waves are generated directly by electromagnetic forces. This electromagnetic force is adopted to generate stress pulse directly instead of gas gun or elastic energy release. The stress pulse generator is in contact with the incident bar and there is no mechanical motion of projectile (in fact, there is no projectile) during the whole loading process. Moreover, the generation of stress wave is controlled by electronic unit. As a result, the repeatability of loading time can be as good as less than few microseconds. With such time accuracy, two or more stress pulse generators can be combined together to loading one specimen. In this investigation, we introduced briefly the basic principles of the E-Hopkinson bar technique and some recent experimental works which cannot be performed by traditional Hopkinson bar apparatus using this technique.

The basic idea of the proposed E-Hopkinson bar system in this work is based on the principles of the RLC (Resistance-Inductance-Capacitance) circuit. In general, an E-Hopkinson bar system should include three main units: the charging unit, the discharging unit and the Hopkinson bar unit, as shown in Figure 1. Details of the components and design of each unit can be found in our previous works [3]. Based on the principles we apply the E-Hopkinson bar technology to symmetric dynamic compression/stretching of materials, interlaminar fracture of composites, dynamic Bauschinger effect of metals, mechanical testing at moderate strain rates (10⁰-10²s⁻¹) and dynamic multi-axial testing. In this work, we introduced a technique called E-Hopkinson bar that proposed for testing the dynamic mechanical behavior of materials. The E-Hopkinson bar use electromagnetic force to generate stress pulse directly, rather than air gun or elastic energy release. Therefore, the time point at which the specimen is loaded by the stress wave can be accurately controlled (within several microseconds). By far, this technique has been applied in symmetrically dynamic compression/tension of materials, interlaminar fracture of composites, dynamic Bauschinger effect of metals, intermediate strain rate tests and dynamic multi-axial test.

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Stability of multi-body system under axial pulse load: an idealised model for collision stability of rail vehicles

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Abstract

The longitudinal collision stability and critical instability criteria of rail vehicles is investigated herein, using an idealised model with multi-bodies connected by Shanley cells under axial pulse load. In this model, the car bodies of rail vehicles are idealized as rigid bodies, and their interactions are represented by Shanley cells, with two-dimensional motion being taken into account. Based on this model, the vertical and axial responses of the multi-body system before the occurrence of buckling are presented and discussed. Influences of key parameters (i.e., the shape, duration and intensity of the pulse load) on the collision stability of rail vehicles are revealed. An equivalent non-dimensional p_e-i_e diagram is drawn for arbitrary form of pulse loadings, by introducing two non-dimensional indices of effective impulse and effective peak load, to predict the instability of rail vehicles during the longitudinal collision process. Finally, the critical instability criteria of rail vehicles in longitudinal collision are presented. It is shown that the collision stability of rail vehicles is highly sensitive to loading parameters, and the distance between two flanges of Shanley cells significantly influences the critical instability boundary. The proposed theoretical model and the findings can be used to guide the optimal design of collision safety for rail vehicles.

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Localised blast loadings of functionally graded metallic plates

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Abstract

Functionally graded multi-layered metallic (FGMM) plates integrated with gradation of constituent, lightweight, high-strength and customised properties are highly desired as blast-resistant structures. Meanwhile, very limited investigation on their dynamic response to localised blast loading involving large deflection and damage has been reported. This study investigates the deformation and failure mechanisms of FGMM, subjected to localised air blast loading. A primary objective is to characterise their dynamic response, including large inelastic deformation and failure modes, and to elucidate the underlying mechanisms for their superior blast resistance compared to monolithic plates of equivalent weight. To this end, an integrated analytical, experimental, and numerical approach is adopted.

A new theoretical model is developed to analyse the large deformation response. The model incorporates key nonlinearities, such as localised blast pressure with exponential temporal decay, strain rate sensitivity, and material hardening. The governing equations of motion are derived via the extended Hamilton's principle, providing analytical predictions for transient and permanent deflections which are validated through blast tests. Results demonstrate that metallic laminates exhibit significantly enhanced blast resistance. For instance, functionally graded plates show a 14.9% reduction in permanent deflection, while steel-titanium-aluminium laminates achieve reductions up to 34.3% and resist perforation under conditions that fail monolithic steel. The performance enhancement is attributed to two synergistic mechanisms: (1) a higher effective specific strength and collapse moment, reducing inelastic deflection, and (2) a wave management effect where impedance gradation and high wave-speed layers (e.g., aluminium) promote a wider distribution of deformation. This mitigates critical displacement gradients and localised plastic strain, thereby delaying failure initiation.

This work provides fundamental insights into the deformation mechanics of blast-loaded laminated plates, highlighting their potential for lightweight, damage-tolerant protective structures. The developed analytical framework offers a valuable tool for optimising their design against localised impulsive threats.

Research on the dynamic mechanical behavior and mesoscale constitutive model of porous titanium based on *in-situ* multiscale characterization

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Abstract

Porous titanium represents a new type of structure-function integrated material, exhibits broad application prospects in fields such as biomedical engineering and aerospace [1-2]. However, research on the deformation mechanisms of porous titanium under impact remains at an early stage, largely due to the lack of *in-situ* characterization techniques capable of probing the microscale and penetrating porous architectures [3]. This research focuses on the strain rate effect and microstructural effect of porous titanium, conducting quasi-static and dynamic compression experiments on porous titanium materials with different porosities. Furthermore, dynamic *in-situ* X-ray diagnostic techniques are employed to observe the collapse process of pores under dynamic and static loading conditions, analyzing the pore collapse modes and the microstructural deformation mechanism of the matrix. Utilizing the three-dimensional configuration obtained from CT, predictive mesoscale numerical models and dynamic constitutive models are constructed and compared with experimental results, showing good agreement. With the validated mesoscale model, the effects of strain rate, initial density, and pore size on the stress-strain distribution of the titanium skeleton are revealed.

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Calibration of Strain Rate- and Temperature-Dependent Constitutive and Fracture Models Using Results from a Single SHPB Test with a Compression-to-Tension Converting (CTC) Specimen Structure

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Abstract

A large number of stress–strain curves obtained over a wide range of strain rates and temperatures are necessary to calibrate a constitutive model [1]. Additionally, multiple fracture strain values derived from various fracture tests conducted under different stress states, strain rates, and temperatures are essential for calibrating a fracture model [2]. However, these procedures are costly and prone to errors due to the extensive testing required, particularly at high temperatures and strain rates.

Recently, compression-to-tension converting (CTC) structures have been utilized as specimen configurations in SHPB tests [3–6]. The CTC–SHPB setup combines the advantages of both SHPB [7,8] and SHTB [9] methods while mitigating their respective drawbacks. Typically, the CTC–SHPB setup is integrated with a simulation-based inverse identification technique, which iteratively simulates the measured bar signals by assuming sets of constitutive and fracture model parameters until the simulated signals closely match the experimental data. Because the adiabatic temperature rise in the tension-receiving portion of the CTC structure is simulated, the CTC–SHPB test conducted at ambient temperature enables the accurate determination of not only strain rate parameters but also temperature-dependent parameters of the constitutive and damage-fracture models.

The geometry and functionality of the Type I CTC structure are detailed in references [3–6]. This structure has been used to calibrate a strain rate- and temperature-dependent constitutive model. Although it enables constitutive model calibration, inducing fracture during the first couple of passages of the stress pulse through the incident and transmitted bars is challenging. The geometry and feasibility of the Type II and Type III CTC structures are described in references [3–6]. Unlike the Type I structure, the tension-receiving sections of the Type II and Type III structures can be fabricated with a narrower cross-sectional area at the center than at the ends, thereby promoting artificial necking and fracture during the first passage of the stress pulse. These structures enable calibration of both constitutive and fracture models from a single CTC–SHPB test conducted at ambient temperature.

Here, we fabricated the Type II CTC structure using an aluminum alloy and conducted the CTC–SHPB test at ambient temperature. The strain signals measured on the incident and transmitted bar surfaces served as targets for repeated simulations. The Johnson–Cook constitutive model, with parameters A , B , n , C , and m [1], along with the Johnson–Cook damage–fracture model, with parameters D_1 – D_5 [2], were employed to characterize the specimen's behavior.

Two types of repeated simulations were conducted. The first type focused on calibrating the constitutive parameters by matching the magnitude of the measured bar signals, without employing any fracture model. To obtain the initial values of A , B , and n , a quasi-static test was performed using the method described in [10,11], which involves determining the equivalent stress versus equivalent plastic strain curve without assuming a constitutive model. The resulting curve was then fitted using the Ludwik model to determine these parameters. The initial values of C and m were set by referring to literature on similar materials. The parameter set for the subsequent finite element analysis was optimized using the MATLAB function `fminsearch`. Constitutive

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parameters were considered calibrated when the simulation profile closely matched the magnitude of the measured signals.

The second type of repeated simulations was conducted for fracture model calibration. In this stage, all calibrated constitutive parameters were consistently applied throughout the simulations, while the D_1 – D_5 values were varied using the `fminsearch` function to match the duration of the transmitted pulse with the experimental results. To obtain the initial values of D_1 – D_5 , data from quasistatic fracture tests on round specimens, round-notched specimens, and hat specimens were utilized. The initial values of D_4 and D_5 were set by referencing literature on similar materials. The fracture model parameters were considered calibrated when the simulation profile closely matched the duration of the transmitted bar signals.

The investigation of strain rate, temperature, and triaxiality in the simulation—using calibrated values of A – m and D_1 – D_5 —demonstrates that these parameters can effectively model deformation and fracture events occurring at strain rates up to approximately $15,000\text{ s}^{-1}$, temperatures up to 125.5 K , and triaxialities ranging from 0.4 to 1.0 . Future research will include expanding the triaxiality range to include negative values. It is anticipated that the CTC–SHPB technology, combined with the inverse identification method, can be applied to other types of constitutive and fracture models. This potential application warrants further testing and validation of the proposed approach.

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Machine learning based predictions on the mechanical performance and inverse design of lattice metamaterials

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Abstract

Predicting the mechanical properties of lattice-based metamaterials and designing their mesoscopic structures according to specific demands is crucial for their application. Nevertheless, the complex nonlinear relationship between the mesoscopic structure of lattice metamaterials and their macroscopic mechanical behavior makes prediction and design challenging [1,2]. Herein, the lattice metamaterials with various cell configurations were described by a graphic representation method. Two machine learning models, i.e. a GCN-LSTM framework and a multi-task variational autoencoder (VAE) with a residual predictor, were built to predict the stress-strain response of lattice metamaterials under compression. The models were trained and validated based on the database obtained from finite element (FE) simulations. Meanwhile, compressive experiments were conducted on several lattice configurations randomly selected and 3D printed to verify the FE results as well as the model predictions. Furthermore, lattice metamaterials with customized stress-strain responses were generated by the VAE framework. It can be demonstrated that the data-driven framework provides a more efficient pathway for the prediction and on-demand design of architected metamaterials compared with conventional strategies.

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Cohesive zone modelling of boulder-mortar interface in multi-layered composite target under projectile impact

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Abstract

In this study, a multi-layered composite target has been used to design protective structures, comprising five distinct layers, each serving a specific function to enhance overall protective performance. The top sandy soil layer has acted as a camouflage, blending with environmental conditions. The boulders–mortar layer has primarily functioned as an anti-penetration layer due to its enhanced energy absorption characteristics. Due to its higher ductility, a steel plate has served as the energy absorption and load-distribution layer, supporting the randomly distributed boulders. The subsequent UHPC layer has provided resistance against spalling and tensile cracking, while the bottommost reinforced concrete slab has acted as the structural base supporting the entire assembly. The boulders have been randomly distributed using Fuller’s distribution curve in MATLAB, and their radii and center coordinates have been transferred to ABAQUS/Explicit via Python scripting. To capture the heterogeneous anti-penetration response of the boulder–mortar layer, a cohesive zone model has been implemented at the boulder–mortar interface using a bilinear traction–separation law, with damage initiation having been defined by the maximum nominal stress quadratic criterion and damage evolution having been governed by the mixed-mode Benzeggagh–Kenane fracture criterion. The mesoscale boulder–mortar interface model has been validated against similar studies reported in the literature, confirming improved accuracy in capturing interfacial fracture mechanisms under dynamic loading conditions. Comprehensive meso-scale finite element analyses have been conducted under projectile impact, and key performance indicators, including residual velocity, penetration depth, and energy balance, have been systematically analyzed to quantify layer-wise contributions to energy absorption and dissipation. The results indicate that the proposed meso-scale multi-layered configuration, designed using impedance-mismatch techniques, provides higher impact resistance and energy absorption than conventional single-layered systems.

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A Fast-Running Engineering Tool for Assessing Fluid-Structure Interaction in Blast-Loaded Plates

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Abstract

Fluid-structure interaction (FSI) can modify the response of blast-loaded structures, especially in lightweight or flexible configurations where the structural motion influences the pressure field [1,2]. For blast-loaded plates, FSI effects typically mitigate the structural response, in terms of peak mid-point velocity and out-of-plane displacement, as illustrated in Figure 1(a). In practice, however, FSI is often neglected because fully coupled simulations are computationally expensive and there is no widely accepted objective criterion to decide when they are required [3]. As a consequence, FSI effects can only be quantified by comparing the results of coupled and uncoupled simulations a posteriori [4], which is inefficient and not always compatible with realistic design workflows.

This work presents a unified framework for the rapid estimation of FSI effects in blast-loaded plates, with the dual objective of (i) guiding the selection of the most appropriate simulation method between uncoupled and coupled numerical strategies and (ii) quantifying the influence of FSI effects. The approach builds on one-dimensional theories that incorporate non-linear compressibility and inertia, as schematically illustrated in Figure 1(b). It leads to a set of dimensionless error estimates Δv and Δw that can be extracted from a single uncoupled simulation. The procedure is applied to two representative classes of blast-loading scenarios: plates subjected to constant reflected pressures over the main deformation phase [1,4], and plates for which the reflected pressure decays significantly while the structure is still in motion.

The methodology is validated against high-fidelity numerical and experimental benchmarks covering a wide range of blast intensities and plate areal masses, for clamped metallic plates in membrane-dominated, large-inelastic regimes. For the constant pressure case, Figure 2 shows that the dimensionless error estimates lead to simple linear correlations that are valid across multiple materials, thicknesses and loading conditions, with good agreement between predicted and observed values. Across all the cases examined, the trends predicted by the framework are consistent with the reference high-fidelity results, correctly reflecting the tendency of uncoupled simulations to overestimate plate velocities and deflections when FSI is relevant. The proposed fast-running engineering tool enables rapid, objective and operator-independent assessment of FSI effects suitable for practical use, and it supports informed selection of the appropriate numerical strategy for subsequent detailed analyses.

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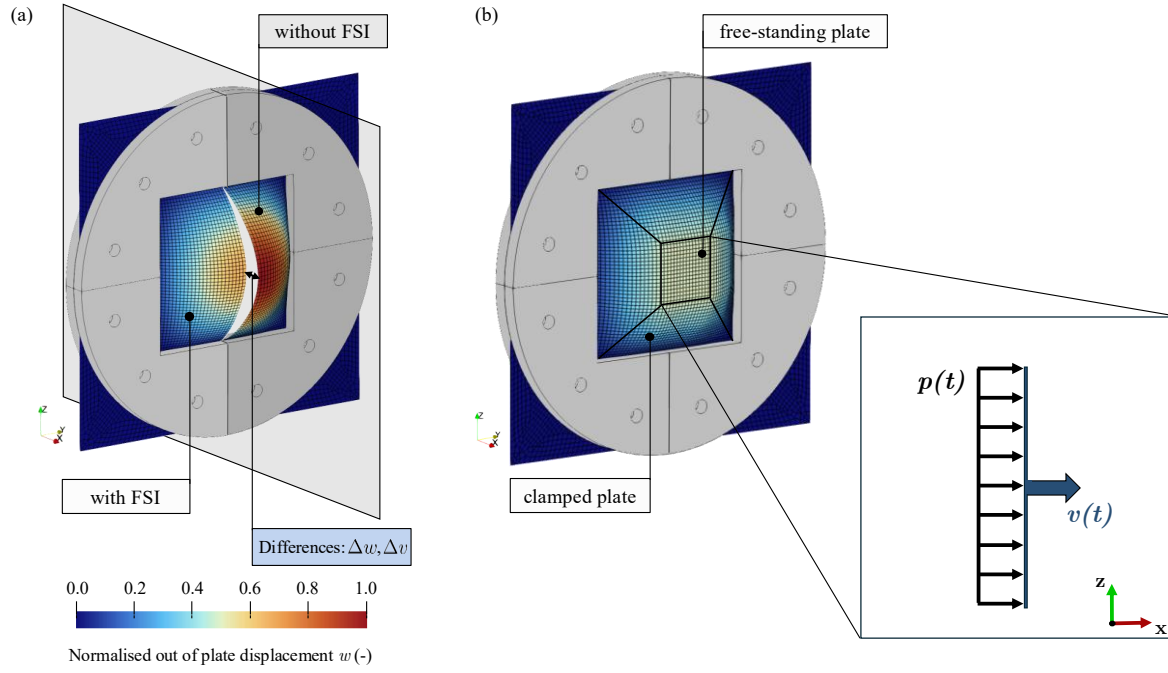


Figure 1, Illustration of the problem and modelling concept. (a) Comparison between uncoupled and coupled simulations for a clamped blast-loaded plate, highlighting the reduction in normalised out-of-plane displacement when FSI is included and the corresponding differences Δw and Δv . (b) Idealisation of the plate centre as a free-standing plate subjected to a uniform reflected pressure history $p(t)$, which enables a one-dimensional analytical description of the velocity response $v(t)$.

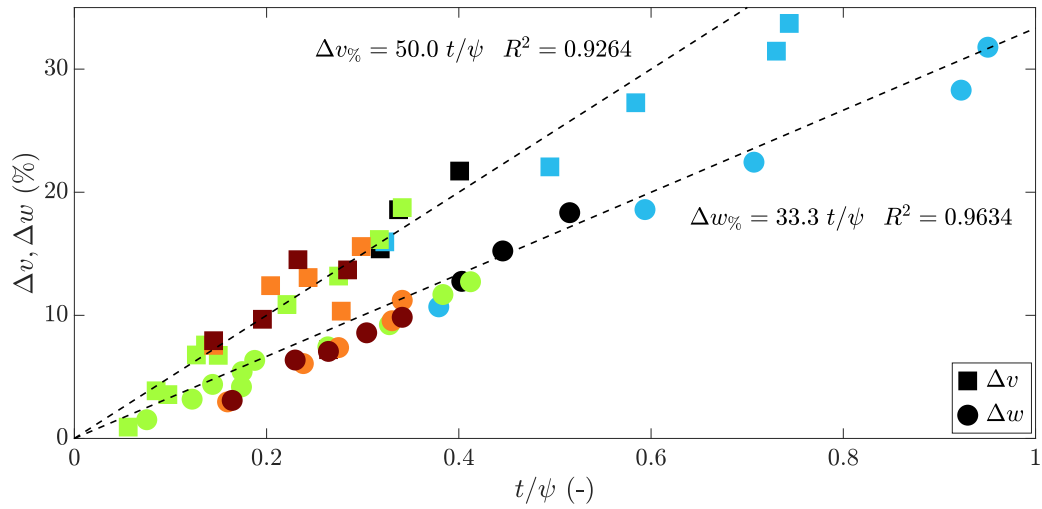


Figure 2, Percentage differences in peak mid-point velocity and deflection between coupled and uncoupled simulations, $\Delta v_{\%}$ and $\Delta w_{\%}$, plotted against the dimensionless parameter t/ψ for clamped blast-loaded plates. Squares and circles denote $\Delta v_{\%}$ and $\Delta w_{\%}$, respectively, while different colours correspond to different combinations of material, thickness and loading intensity. Dashed lines represent the linear correlations provided by the engineering tool.

Research on impact similarity law of elastic composite laminate based on ODLV scaling framework

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Abstract

Similarity theory has been applied to the design of scaled models in many fields of impact engineering. As the lightweight, high strength composite materials are widely used in large-scale aerospace structures, the requirement of the similitude theory and the scaling methods for composite materials is increasing.

This study develops the DLV (Density-Length-Velocity) [1] scaling framework to the directional similarity system ODLV (Oriented-DLV) [2] and derives the similarity law for the elastic an-isotropic laminates plate under transverse impact loading [3]. The distinct feature of the ODLV framework is to define dimensionless numbers and scaling factors for all basic quantities are explicitly expressed by three characteristic lengths of spatial directions L_x , L_y and L_z , which overcomes the inherent defects only with one scalar length in the traditional dimensional analysis. Meanwhile, similarity laws for the directional stresses, strains and displacements are expressed by different power law relationships of the ratios of characteristic lengths. Therefore, the ability of similarity theory to express structural geometric characteristics are effectively developed.

Based on the above similitude relationships, the distortion correction of material properties by adjusting ply-angle and impact velocity or material density of the scaled laminate model is proposed and the Particle swarm optimization algorithm is used to determine the stacking angles. Finite element models of the prototype and the scaled laminate plate subjected to a rigid ball impact are established. The correction of scale models with thickness distortion, material distortion, and thickness-material-width distortion are verified. Simulation results show that the scaled model have good similarity with the prototype in displacement, impact force, and energy etc.

Keywords: similarity laws, elastic composite laminate, structural impact, distortion scaled model.

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A new high-strain-rate characterization method and its application to automotive component crash analysis

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Abstract

Accurate determination of plastic deformation properties under high strain rates is critical for modeling automotive crash events. However, tensile testing in a conventional servo-hydraulic machine is often compromised by structural vibrations or system ringing, which deteriorate force measurements and hinder precise characterization of yield loci, strain hardening, and fracture strain. In this work, the ringing effects of the entire tensile testing system, including machine, sample, sample clamping, and load cell, were analyzed using finite element (FE) simulations and verified with simple bar models with known analytical physical solutions [1]. Inspired by the split Hopkinson bar principle, a novel tensile specimen, referred to as the Gen. III specimen (see Fig. 1a), was developed featuring an additional minor plastic deformation region, as shown in Fig. 1b in cut-off area. In this locally restricted region, a small secondary plastic deformation occurs, which absorbs elastic vibrations and enables oscillation-free force measurements using strain gauges in the elastic deformation zone above. Fig. 1c shows the measured stress-strain curves of a DC04 steel, which exhibit no oscillations at strain rates up to 1000 s⁻¹. Simplified analytical one-dimensional stress wave models implemented in MATLAB were used to explain the specimen functionality and accurately predict the specimen geometry [2].

Using this method, a comprehensive high-strain-rate characterization of automotive dual-phase sheet steel DP1000 was performed using specimens with various geometries (see Fig. 2a) and orientations relative to the rolling direction at strain rates from quasi-static to 1000 s⁻¹. The results reveal pronounced strain rate sensitivities and non-uniform strain rate hardening across loading directions, particularly in shear. Therefore, a non-uniform strain rate hardening model (YldSRH) [3] and a rate- and temperature-dependent damage model (e²MBW) [4] were applied and successfully calibrated using these data. Finally, the calibrated YldSRH + e²MBW model was applied in component-level simulations, as shown in Fig. 2c, demonstrating excellent predictive capability for DP1000 components under both quasi-static and dynamic crash loading (see Fig. 2d). These results highlight the model's ability to capture the influence of strain rate on material behavior and fracture, thereby directly linking high-strain-rate material characterization to structural crash performance and providing a reliable basis for automotive lightweight component design and safety assessment.

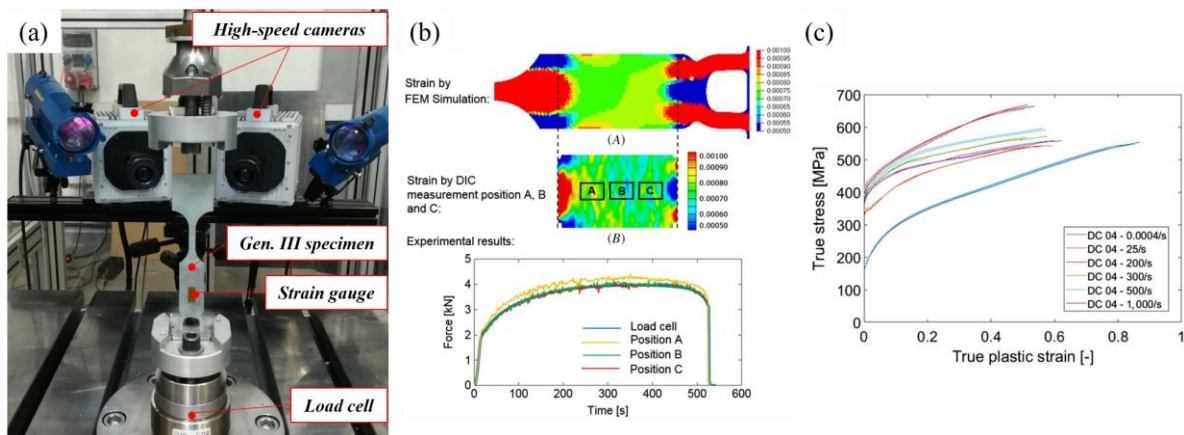


Fig. 1. (a) New specimen in servo-hydraulic tensile testing machine. (b) Homogeneous elastic stress distribution in the measurement area (A, B and C: strain gauge sensor area) of the new specimen. (c) Measured stress-strain curves of a DC04 steel using the new specimen [5].

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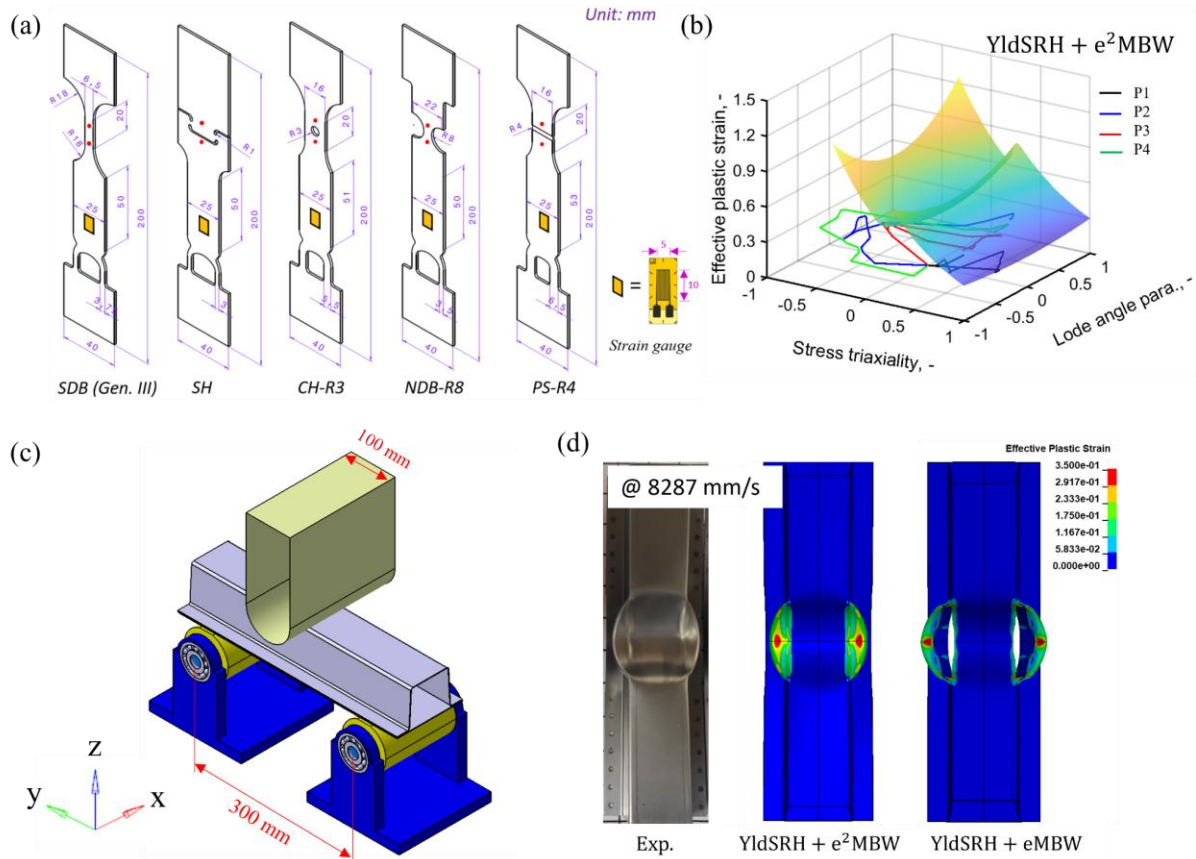


Fig. 2. (a) Gen. III SDB specimen [5] and additional specimen geometries designed for different stress states ($\eta, \bar{\theta}$) [6]. (b) Calibrated fracture locus under dynamic loading conditions. (c) CAD of the three-point bending test. (d) Comparison of sample profiles after testing and FE simulation.

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Dynamic response of clamped circular plates subjected to graded cellular projectiles: A coupling analysis theory and validation

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Abstract

Graded cellular projectiles (GCPs) with well-designed density gradients have emerged as promising blast simulators due to their controllable impact loads, offering potential for rapid evaluation of anti-blast performance of structures [1, 2]. The deformation and force coupling relation between GCPs and the tested targets plays a critical role in determining the impact load of GCPs, which has been incorporated into the density design of GCPs when testing two-dimensional beam structures. However, for the more ubiquitous plate structures, the coupling response process between GCPs and plates has not been formally modeled, which limits the density design of GCPs and their application in testing the blast resistance of plates. This work establishes a coupling analytical theory by integrating the shock wave model of GCPs, the membrane factor methodology for plates, and the projectile–plates interface coupling conditions [3]. Theoretical predictions demonstrate that under equivalent momentum and kinetic energy, GCPs with negative density gradients or metal matrix material exhibit higher kinetic energy transfer efficiency and impact intensity compared to GCPs with uniform/positive density gradients or plastic matrix material, consequently inducing greater permanent deformation of plates. Dimensionless analysis indicates that the “areal mass ratio” ξ of GCPs to the plate is the key parameter governing the projectile–plate effect. Increasing the “areal mass ratio” ξ intensifies the projectile–plate effect and amplifies the influence of the projectile density gradients on the impact process and plate response. Finite element simulations employing the 3D Voronoi technique and impact tests of 3D-printed GCP were carried out. The comparison between the theoretical, numerical, and experimental results validates the accuracy of the theory in predicting the GCP loads and the dynamic response of monolithic and sandwich plates. The proposed analytical framework advances blast simulation and anti-blast evaluation by resolving the key interaction mechanisms between projectiles and deformable plates, which provides a theoretical foundation for designing the density gradient of GCPs to reproduce blast-like loads on plate targets.

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Impact equivalent static load based on a dynamic load factor formulation

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Abstract

Here, we present a method for obtaining a static load equivalent to an impact load using the dynamic load factor (DLF) approach. The DLF quantifies the amplification of structural response under dynamic loading relative to a corresponding static load. This approach has attracted considerable research interest because it significantly reduces computational cost by eliminating the need for full time-history transient response analyses. In this study, a strain energy–equivalent DLF formulation is developed. The proposed theoretical formulation is applied to a rocket launch system subjected to an impact load during liftoff. The results confirm that the DLF approach provides an upper bound on the strain energy response.

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Impact Testing System for a Mechanically High-Fidelity Anthropomorphic Craniocerebral Model

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Abstract

Experimental study on mechanical responses of human brain during impact is extremely challenging due to the lack of high-fidelity human-like craniocerebral model and the difficulty in measuring deformation of brain inside the skull. This paper demonstrates the impact tests of human head using a mechanically high-fidelity craniocerebral model. The model consists of a transparent polycarbonate skull and a brain-mimetic hydrogel model immersed in artificial cerebrospinal fluid. The mechanical properties of hydrogel are adjusted to be like porcine brain tissue under the mechanical tests at various strain rates. An impact system is built to impose strikes on the model at velocities ranging from 0.83 m/s to 3.3 m/s and from various directions. The strain field on brain surface is measured using a home-made single-camera stereo digital image correlation system with millisecond resolution. The testing results reveal highly heterogeneous deformation of brain during impact, including relative rotation and regional strain concentration. These findings can be well reproduced through the simulation of finite element model. It is the first time that the deformation field of human brain during the impact is accurately measured, which provides high quality data to guide theoretical modelling and numerical simulation. The work is believed to substantially stimulate the exploration of mechanical responses within the brain and the research on traumatic brain injury.

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Multiscale Investigation of impact resistance and energy absorption mechanisms of node-enhanced gradient Lattices fabricated from $\text{Al}_{0.5}\text{CoCrFeNi}$

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Abstract

In this study, by taking advantage of the high strength and high ductility of $\text{Al}_{0.5}\text{CoCrFeNi}$ high-entropy alloy (HEA) and combining it with structural design, a node-enhanced gradient lattice structure is prepared and investigated. The mechanical responses and microstructural evolution of four configurations including BCC, node-enhanced BCC (NBCC), decreasingly graded (DGNBCC) and increasingly graded (IGNBCC) are systematically evaluated through quasi-static compression and Split Hopkinson Pressure Bar (SHPB) experiments, complemented by finite element method (FEM) simulations. The results reveal that INBCC configuration demonstrates superior crashworthiness under dynamic impact. At a dynamic strain of 0.13, the specific energy absorption (SEA) of INBCC increased by approximately 37% compared to the uniform BCC lattice. Notably, the HEA lattice achieved a remarkable SEA of 28.8 J/g at a relative density of 0.203, placing it at the performance frontier compared to conventional 316L steel and Ti6Al4V lattices [1][2][3]. INBCC also exhibited outstanding strain rate sensitivity with a dynamic yield strength 167% higher than its quasi-static value. Microstructural characterization via EBSD revealed the underlying mechanisms. Quasi-static loading induced grain refinement due to dislocation accumulation, while high-speed impact triggered dynamic recovery and partial recrystallization, evidenced by a moderate increase in grain size and a continuous rise in Kernel Average Misorientation (KAM) values. The node-enhancement strategy effectively mitigated stress concentration, while the gradient design delayed overall buckling. This research provides a robust framework for designing next-generation energy absorbers utilizing the high strength and high ductility advantages of high-entropy alloys.

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Probabilistic Fragility Assessment of the Liner Plate in the Reactor Cavity under Steam Explosion-Induced Impulsive Loads

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Abstract

When molten corium contacts cooling water in the reactor cavity during a severe accident, an ex-vessel steam explosion may occur. This event generates steam explosion-induced impulsive pressure waves that can challenge the structural integrity of reactor cavity components, including concrete, reinforcement, and liner plates [1,2]. While previous studies have mainly relied on deterministic evaluations under such impulsive loading conditions, the structural capacity of reactor cavity components remains inherently uncertain due to material property variability. Such variability is generally not quantified in deterministic assessments [3]. This study applies an uncertainty-informed numerical framework to assess the structural reliability of the reactor cavity through probabilistic fragility analysis under steam explosion-induced impulsive loading. Material strength and elastic modulus of concrete, reinforcement, and liner plates are treated as aleatory uncertainties, whereas epistemic uncertainties associated with modeling assumptions are not considered. These uncertainties are propagated through nonlinear finite element analyses using the Latin Hypercube Sampling (LHS) technique, which enables efficient sampling for computationally demanding analyses. Fragility curves are constructed assuming lognormal distributions, and conditional probabilities of failure are evaluated as functions of reflected shock-wave-induced pressure and impulse. Liner plate failure is defined by exceeding a membrane principal strain limit of 5.0% specified in NEI 07-13 [4]. The results show that the liner plate exhibits steep fragility curves with low dispersion, indicating limited sensitivity to material uncertainty. The derived median and high-confidence-low-probability-of-failure (HCLPF) values indicate that liner plate failure occurs only at reflected steam explosion-induced shock wave pressures on the order of 1,000 MPa and impulses exceeding 2,400 MPa·ms. Accordingly, the reactor cavity liner plate is expected to maintain its structural integrity under severe impulsive loading conditions, even when material uncertainties are explicitly considered.

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Insights from Machine Learning based Predictions of Spall Strengths of Metals and Alloys

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Abstract

Spall strength is a critical property that characterizes a material's resistance to dynamic tensile failure under impact or shock compression loading [1]. Accurate prediction and control of spall strength is essential for designing materials used in armors, vehicle components, structural barriers, and mining. Traditional methods for spall strength measurements are slow, destructive, and expensive [2], while existing theoretical models offer limited predictive accuracy [3]. This presentation introduces a machine learning (ML) based regression model that rapidly and accurately predicts the spall strength of metals and alloys at strain rates in the range of 10^5 – 10^6 s⁻¹. Trained on a dataset of over 70 metals and alloys and validated with recent data of generally available elastic, plastic, and fracture properties, the ML based predictive model identifies quasi-static tensile yield strength and bulk modulus as key properties correlating with increased spall strength [4]. ML model predictions also offer insight into effects of the structural characteristics of different metals and alloys on their spall response. In particular, the predictions enable an efficient method for screening metals and alloys for use in extreme conditions of impact loading, as well as for probing effects of material behavior and structural changes that can influence induced spall failure.

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Performance Study of Sound-Absorbing and Blast-Resistant Integrated Metamaterials

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Abstract

Blast shockwaves and noise typically occur together, and the emergence of metamaterials has effectively addressed the need for such multifunctional integration [1–5]. Among them, acoustic metamaterials based on Helmholtz resonators have been extensively studied for their strong resonance-induced sound absorption performance under subwavelength conditions, serving as an effective solution for low-frequency noise control [6]. In the field of blast and impact resistance, honeycomb sandwich panel mechanical metamaterials have been systematically and thoroughly investigated due to their lightweight nature and excellent energy absorption capabilities [7,8]. However, there has been no progress yet in simultaneously studying both blast/impact resistance and noise control. Therefore, we integrated traditional honeycomb structures with resonant cavities to design a metamaterial panel that combines blast resistance and sound absorption functions. By perforating the face sheets of the honeycomb sandwich panel and embedding circular tubes as the necks of Helmholtz resonators, sound waves are dissipated. Three structural variants with different face sheet configurations were designed and subjected to standing wave tube tests and blast experiments. The standing wave tube tests verified that the sound absorption peaks of the specimens were at 100 Hz and 200 Hz. The blast experiments investigated their dynamic responses, elucidating the failure mechanisms and deformation processes of the face sheets. The results show that the extent of damage to the metamaterial panel is influenced by the scaled distance and the location of blast loading. Compared to an aluminum box, the metamaterial panel exhibits superior blast resistance. These findings establish an experimental foundation for the design of integrated acoustic and mechanical metamaterials.

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The influence of W and V elements on the mechanical properties and fracture ignition behavior of TiZrNb-based high-entropy alloys

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Abstract

TiZrNb-based high-entropy alloys are a type of promising energetic structural material with broad application potential in kinetic energy armor-piercing and reactive material applications [1-5]. However, the regulation of their mechanical properties and fracture-induced ignition behavior through element doping, as well as the underlying mechanism, still requires in-depth exploration. This study focuses on the effects of W and V additions on TiZrNb-based high-entropy alloys, and conducts quasi-static and dynamic compression experiments to investigate their phase composition, microstructure, mechanical properties, and fracture-induced ignition behavior. Various characterization techniques including XRD (X-ray Diffraction), SEM (Scanning Electron Microscope), EDS (Energy Dispersive Spectrometer), TEM (Transmission Electron Microscope), and XPS (X-ray Photoelectron Spectroscopy) were employed to analyze the phase structure, elemental distribution, fracture morphology, and oxidation products of the alloys. Additionally, high-speed cameras and infrared thermal imagers were used to record the energy release process and thermal field distribution during fracture. The results show that W addition enhances the alloys' strength but reduces toughness, while V addition improves toughness; the co-addition of W and V achieves a balanced strength-toughness profile. Moreover, the energy release intensity of the alloys is positively correlated with fragmentation degree and strain rate. XPS and EDS analyses reveal that oxidation reactions (forming TiO₂, ZrO₂, Nb₂O₅, V₂O₅, WO₂, and WO₃) constitute the core mechanism underlying the alloys' energy release and ignition.

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In-structure shock assessment for precast components

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Abstract

Traditionally, protective structures adopt cast in-situ design. However, there is increasing interest to pivot to use of precast design, due to the enhanced construction efficiency and safety. As in-structure shock arising from an external explosion can produce high frequency accelerations with large magnitudes, the structural response of precast concrete (PC) hollow core slabs and wall panels to the in-structure shock loads is investigated via numerical analysis. The numerical analysis was conducted in two stages: the first stage to model the in-structure shock loading from the external explosion, and the second stage to access the structural response of the precast components from the shock loading. This study focuses on the second stage of analysis of the structural response of the precast components. The in-structure shock accelerations were extracted from the model of the first stage, and was applied as a force-time function to detailed models of the precast components that uses Lagrangian formulations. Subsequently, the precast components were checked for damage and also failure criterions established in conventional codes like UFC 3-340-02 [1].

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Experimental Characterization of Energy Dissipation and Fragment Morphology in Rock Fragmentation

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Abstract

Dynamic fragmentation of brittle materials under high strain-rate loading dissipates energy through several pathways, including the creation of new fracture surfaces, fragment kinetic energy, acoustic emissions, and heat or friction. Among these mechanisms, fracture surface generation and fragment kinetic energy play dominant roles and can be directly quantified in our laboratory-scale experiments.

To investigate the fundamental mechanisms of energy dissipation during high strain-rate brittle fragmentation, we designed a self-developed drop-weight test (DWT) that enables controlled impact loading and direct measurement of post impact fragment ejection velocities. The DWT provides a simplified and repeatable experimental framework to study single impact fragmentation behaviour, allowing the kinetic energy of individual fragments to be quantified.

Experimental results show that fragment ejection is strongly concentrated near the impact source, and fragments exhibit diverse geometric characteristics after impact. To further explore the relationship between energy dissipation and post impact fragment morphology, all collected fragments were analysed using high-resolution micro-CT scanning. The results indicate that most post-impact fragments exhibit a shell-like morphology, characterized by relatively large major and intermediate axes and a significantly shorter minor axis. Moreover, fragments with higher ejection velocities tend to exhibit increased major and minor aspect ratios, revealing a systematic dependence of three-dimensional fragment shape on kinetic energy.

These observations suggest that post-impact fragment morphology can serve as an effective indicator of energy dissipation mechanisms in high strain-rate brittle fragmentation processes.

Blast-Like Loading Simulation Performance of Additively Manufactured Open-Cell Metallic Foams

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Abstract

Explosion is a common dynamic failure phenomenon that frequently occurs in military confrontations, industrial production, and civilian environments, posing severe threats to life and property. While anti-blast protective structures have advanced rapidly, the current challenge lies in the efficient assessment and optimization of these structures. Graded cellular projectiles have emerged as a promising laboratory alternative due to their designability and great potential for simulating blast loads [1, 2]. This study presents a multiscale design method to precisely control the density distribution of open-cell metallic projectiles to achieve high-intensity blast-like impact loads. By varying the unit cell size, a projectile with a relative density distribution exhibiting nonlinear decay was obtained and fabricated through selective laser melting. Finite element simulations combined with impact experiments were performed to assess the blast load simulation capability of the graded cellular projectiles. The results reveal that the effective simulation duration is primarily governed by the initial momentum of the graded cellular projectile. Meanwhile, the maximum attainable initial momentum depends on the initial velocity V_0 of the projectile. The fabricated graded cellular projectile successfully simulated a targeted blast load with a peak value of 60 MPa under laboratory conditions. The achievable impact loads of graded cellular projectiles made of different matrix materials were obtained through finite element simulations. The present findings provide a practical testing method and material selection guideline for a wide range of blast simulation scenarios.

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Full-Scale Low-Velocity Impact Experiments on Reinforced Concrete Slabs in a High-Temperature State Due to Fire

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Abstract

Recent revisions to Japan's Building Standards Act permit the partial use of wood as structural members, under the condition that fire safety and evacuation are ensured. Under fire conditions, these wooden elements may burn, potentially causing the collapse of upper structural members and impact loading on the reinforced concrete (RC) slab below, posing a serious hazard to occupants evacuating on lower floors. If the resistance of slabs to impact during a fire can be clarified, the risk of collapse of upper structural members under the fire condition can be reduced. However, to the best of the author's knowledge, no low-velocity impact experiments accounting for fire-induced temperature effects have been reported. Therefore, this study conducted full-scale impact experiments in which a single structural member was dropped onto a fire-heated slab to provide the fundamentals of RC slabs' impact resistance during fire.

The full-scale experiments simulated a scenario in which a rectangular steel tube, representing an upper structural member, was dropped onto a RC slab. The slab consisted of a 150-mm-thick base slab with an additional 30-mm-thick fire-resistant layer. The concrete slab specimen was first placed on a mounting frame, and a similar mounting frame was installed next to the frame supporting the specimen. Connected rails were mounted on top of the two frames. A heating box was fabricated, and flames were generated inside the box using a burner in order to simulate fire conditions representative of an actual fire. The heating box was equipped with wheels at its bottom, allowing it to be placed on the rails installed on the mounting frames and to move across both frames. During slab heating, the heating box was moved along the rails to cover the slab. The slab was heated from the top surface until the time integral of the slab surface temperature was equal to that of the ISO standard fire curve for 90 minutes of heating. After heating, the heating box was immediately moved away, and the impactor was dropped before any significant temperature reduction of the slab occurred. The drop heights of 2.8 m and 8.5 m were determined based on FEM analysis considering the temperature dependence of material properties, i.e., strength and Young's modulus.

After slab heating, cracks were observed in the support direction prior to impact due to the thermal expansion of the slab. The experimental results showed that the slab was locally damaged in the shape of the impacting object, and that the deck plate fell off and fragments scattered from the bottom of the slab at both drop heights of 2.8 m and 8.5 m. In the study by Mizushima et al. [1], similar impact experiments were conducted on RC slabs at ambient temperature without a 30 mm fire-protection layer. In comparison with their results, it was found that, despite the presence of a 30 mm fire-protection layer in the present experiment, the resistance against the impact of the slab was significantly reduced due to the effects of fire. This reduction in impact resistance could not be explained by the degradation of material stiffness and strength considered in the FEM analysis, suggesting that cracking induced by thermal expansion of the slab had a substantial influence.

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Influence of Cross-Sectional Aspect Ratio on the Dynamic Hardening of Li-ion Battery Cells

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Abstract

With the rapid growth of the electric vehicle industry, the safety of power Li-ion batteries under mechanical abuse has attracted significant attention. The complex dynamic response of battery cells, governed by constituents with contrasting mechanical properties and the interactions between fluid (electrolyte) and multi-layer porous solid structures (active coatings of electrodes), requires in-depth investigation.

In this study, both quasi-static and dynamic compression tests were conducted on prismatic battery cells using cylindrical indenter. Results reveal that the cross-sectional aspect ratio (defined as the length along the loading direction relative to the lateral thickness) of the cell has a significant influence on the hardening behavior under in-plane dynamic loading. Specifically, cells with a large cross-sectional aspect ratio exhibit a markedly lower dynamic hardening effect compared to those with a smaller aspect ratio.

Component-level experiments across various strain rates were further conducted to compare the dynamic responses of wet and dry electrodes. The strain rate effect of the dry porous solid structure was investigated alongside the influence of the fluid. Results indicate that while the dry electrode demonstrates minor strain rate sensitivity, the wet (electrolyte-infiltrated) electrode exhibits significant strain rate dependent strengthening. This effect is moderate at an engineering strain rate of 0.2/s but becomes dominant at 400/s, implying a high strain rate sensitivity regime ranging from approximately 10⁰/s to over 10²/s.

Based on these component-level results, a detailed heterogeneous structural model was established for finite element analysis to uncover the mechanisms by which the cross-sectional aspect ratio affects dynamic strengthening. Statistical analysis of the equivalent strain rates reveals that a considerable proportion of the active coating enters the high strain rate sensitive regime locally, even when the global macroscopic strain rate remains at the order of 10⁰/s. Furthermore, it is concluded that the cross-sectional aspect ratio governs a shifting between structural buckling (with low strain rate sensitivity) and local densification (with high strain rate sensitivity) by altering the deformation mode of compressed jellyrolls.

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Effect of High-Frequency Pulsed Current Treatment on the Dynamic Mechanical Behavior of SiC/6061 Aluminum Matrix Composites

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Abstract

Silicon carbide particle-reinforced 6061 aluminum alloy (SiC/6061) composites have garnered significant attention in the aerospace and transportation sectors due to their excellent specific strength and stiffness. Their critical components are often subjected to extreme loads involving the coupling of impact and elevated temperatures. However, the inherent physical property differences between SiC and the aluminum matrix can lead to poor interfacial bonding, triggering premature failure under dynamic loading and thus limiting their application potential. Recent studies have shown that high-frequency pulsed current (HFPC) treatment, as an efficient non-thermal/electroplastic technique, can significantly enhance the static tensile properties of SiC/Al composites by promoting static recrystallization, refining grains, and healing microcracks. Nevertheless, how this technology affects the dynamic mechanical behavior and failure mechanisms of the material under coupled conditions of high strain rates ($1000\text{--}6000\text{ s}^{-1}$) and a wide temperature range ($20\text{--}300^\circ\text{C}$) remains unclear.

This study aims to systematically reveal the regulatory effect of HFPC treatment frequency on the dynamic tensile performance and underlying micro-mechanisms of SiC/6061 composites. We applied HFPC treatments at four different frequencies (10, 50, 100, 200 kHz) to composite specimens prepared by powder metallurgy, using untreated specimens as a baseline. A split Hopkinson pressure bar (SHPB) system equipped with a high-low temperature environmental chamber, combined with high-speed digital image correlation (DIC) technique, was employed to in-situ obtain the dynamic stress-strain response and full-field strain evolution of the material at different temperatures (20, 100, 150, 200, 250, 300°C) and strain rates. The microstructural evolution of specimens before and after treatment, as well as after deformation, was comparatively analyzed using scanning electron microscopy (SEM) and electron backscatter diffraction (EBSD).

Preliminary results indicate a significant frequency dependence of the HFPC treatment effect. Specimens treated at specific frequencies (e.g., 100 kHz) exhibited a synergistic improvement in both strength and plasticity under dynamic loading. DIC analysis revealed that the strain localization process was delayed, and deformation uniformity was enhanced in the optimally treated specimens. Microstructural characterization confirmed that this performance enhancement originated from HFPC-induced matrix grain refinement, enhanced interfacial bonding, and optimization of dislocation structures due to the electroplastic effect. This study establishes, for the first time, a correlation between HFPC treatment parameters and the dynamic performance of composites under high strain rates and varying temperatures, providing an innovative processing route and theoretical basis for designing the next generation of impact-resistant, high-temperature-tolerant lightweight metal matrix composites..

Keywords: High-frequency pulsed current; Aluminum matrix composites; Dynamic mechanical properties; Strain rate effect; Digital image correlation

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Experimental investigation on the response of sandwich panels with 3D printed biopolymer gyroid structure cores and asymmetric glass fibre face sheets under blast loading

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Abstract

Due to the high resolution and near-isotropic material behaviour of parts made via vat photopolymerisation additive manufacturing (AM), there has been significant development in generating affordable yet highly complex 3D structures suitable for a variety of applications, including robotic actuators, aerospace products and biomedical components [1-3]. However, as the materials used in vat photopolymerisation are largely limited to photosensitive thermosetting polymers, adding face sheets could increase the structural rigidity of an optimised lightweight core (subsequently making it a sandwich panel) and improve the overall strength [4]. Few studies have investigated the blast resistance of sandwich panels incorporating 3D-printed cores and have remained limited to using thermoplastic polymeric materials printed via fused filament fabrication AM and utilised metal face sheets [5, 6]. This study aims to determine the potential of non-metal, gyroid-based lattice core sandwich panels as a high-performance and light-weight protective solution in transportation and defence applications.

Previous research has shown that front face sheet damage appears to be the main instigator for the failure of a sandwich panel [7, 8]. Thicker front glass fibre face sheet on the blast facing side was used as shown in Figure 1 similarly to work conducted by Gabriel et al [8]. Two sheet-gyroid lattices were investigated, which had the same unit cell size but varied relative density and hence lattice wall thickness of 132 and 660 microns. The sandwich composites were subjected to a uniform blast load and compared to ref [8], where a closed cell PVC foam with a nominal density of 80 kg/m³ and 19-layer glass fibre reinforced polymer (GFRP) laminate (with no core) was used. The same core thickness of 25 mm was maintained; hence, the different sandwich panels were dimensionally similar to one other another rather than maintaining a similar overall mass. The gyroid core sandwich panels were manufactured in a multi-stage process, where the two face sheets were initially infused with bio-based epoxy resin (tradename Gurit Prime 37) under vacuum for 3 hours, and thereafter a thin film of same resin was used to adhere the core to the face sheets.

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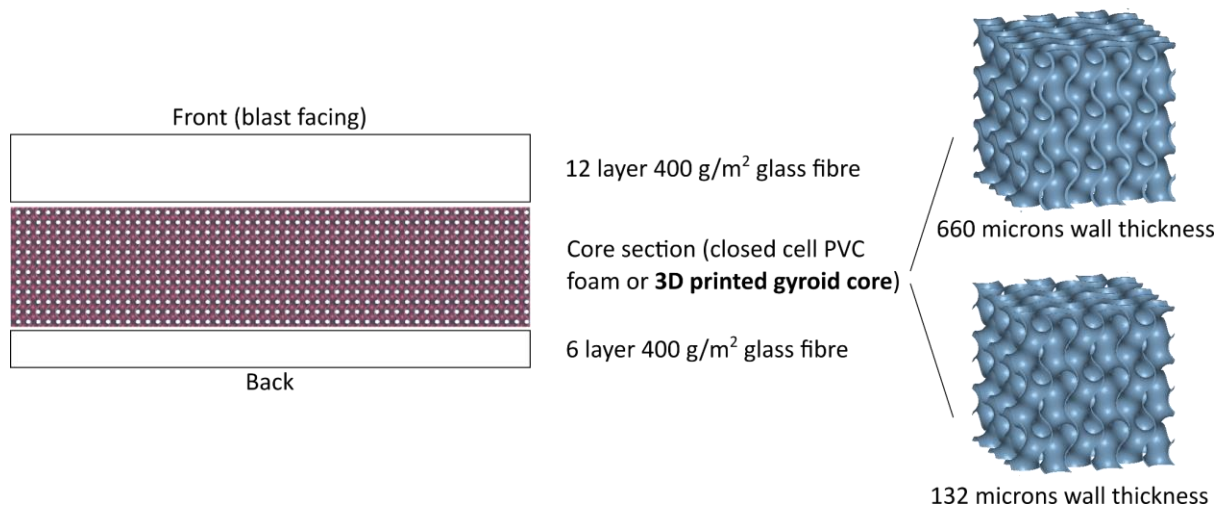


Figure 1: Cross-sectional schematic of asymmetric sandwich specimen used for blast testing with various core sections used

While the laminates (without a core) demonstrated viscously damped elastic behaviour, the sandwich panels exhibited a more complex transient response, most notably in the post-peak displacement regime. As expected, core density and core topography was found to influence the failure mechanisms. Brittle failure was observed in internal gyroid membrane structure, with significant cracking on the thicker membranes at a relative density of 20%. Crushing and progressive cracking were observed in the closed cell PVC and 5% relative density specimens. The combined influence of the differences in stiffness and the speed of stress wave propagating through the components (front face and core) alters the deformation behaviour of the back face sheet.

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A Three-Dimensional Explicit Direct FE² Framework for Dynamic Analysis of Lattice Structures

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Abstract

Lightweight lattice structures offer exceptional potential for energy absorption, wave manipulation, and thermal insulation owing to their high degree of architectural freedom. However, the performance-driven design and numerical analysis of sophisticated lattice architectures remain highly challenging, particularly under dynamic loading conditions where strong geometric and material nonlinearities are involved. Direct single-scale finite element simulations of large-scale lattice systems are computationally intractable for such problems. Multiscale finite element approaches therefore provide an attractive alternative, among which the Direct FE² (DFE²) method—originally proposed by Tan [1] and subsequently extended by Liu and co-workers [2, 3]—has demonstrated strong capabilities for concurrent multilevel analysis.

In this work, a three-dimensional explicit DFE² framework is developed and implemented within a stress- and density-scaling formulation to alleviate potential contact issues between representative volume elements embedded within a single macroscopic element. The proposed method is applied to investigate both global and local impact responses of additively manufactured lattice structures. Corresponding drop-weight impact experiments are conducted to validate the numerical predictions. Good agreement is obtained between simulations and experiments in terms of engineering stress–strain responses and deformation modes. The remaining discrepancies are mainly attributed to the use of simplified beam-based lattice representations and the neglect of inter-cell interactions.

The engineering applicability of the proposed framework is further demonstrated through the simulation of a simplified automotive bumper filled with lattice structures subjected to oblique impact loading. The method successfully captures the sequential deformation mechanisms with favorable accuracy while achieving a significant reduction in computational cost compared to single-scale modeling. These results highlight the strong potential of the explicit DFE² framework as an efficient and reliable tool for predicting the dynamic mechanical performance of lattice-based structures.

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A Development of a DIC-Based Software for Direct Evaluation of the J-Integral in Dynamic Fracture Experiments of SUS304

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Abstract

For the fabrication of automotive steel plates and development of structural components with excellent energy absorption capability, it is necessary to clarify the fracture toughness of transformation-induced plasticity (TRIP) steels under dynamic loading conditions. Previous experimental works typically evaluate the J-integral by combining full-field measurements [1]. In such approaches, deformation fields are obtained using digital image correlation (DIC) [2], and the J values are subsequently calculated through finite-element discretization or post-processing frameworks. At present, the experimental evaluation of the J-integral under dynamic loading conditions remains challenging, primarily due to the higher strain rates involved, the associated inertia effects, pronounced plastic deformation and geometric nonlinearity, as well as the difficulty in accurately identifying crack initiation and propagation during rapid fracture. Cao et al. [3] investigates the fracture behavior of SUS304, i.e. typical TRIP steel, under dynamic tensile loading using a split Hopkinson pressure bar (SHPB) apparatus. However, the J-integral is not calculated from full-field experimental measurements in their study. Therefore, it is necessary to develop a direct J-integral evaluation method based on full-field measurements. Unlike conventional methods that compute the J-integral through finite-element discretization, the present study develops a C++ software based on an open-source DIC engine [2], which enables direct evaluation of the J-integral by processing deformation fields obtained from DIC. Specifically, this method computes the J value by performing weighted integration over discrete pixel points within a rectangular domain. It eliminates the need for finite-element meshing and provides a more direct experimental route for fracture parameter evaluation. Following the work by Cao et al., SUS304 is selected in this study, and dynamic fracture tensile tests are conducted to verify the developed method under dynamic loadings. Fig. 1 shows the strain increment distribution at a certain moment during an impact test, as well as the J-integral value calculated by the developed software at the same moment. The left diagram indicates the crack initiation moment identified by pronounced strain localization near the crack tip, while the right diagram presents the corresponding critical value of J-integral, J_{IC} , at 0.067ms on the J-Time plot.

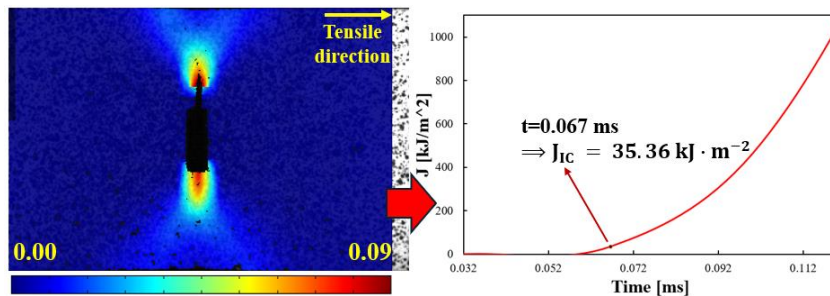


Fig. 1 Strain increment distribution and the time dependent J-integral

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Numerical study of nanoparticle effect on compressive flow stress of magnesium alloys with strain rate

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Abstract

Negative strain rate sensitivity (SRS) for the compressive flow stress of magnesium alloys was found experimentally during the initial phase of plastic deformation, especially with addition of nanoparticles [1]. What is the fundamental mechanism behind such interesting observation is unclear and worth further investigation. A model to describe the onset of tension twinning during the initial plastic deformation of magnesium alloys, which incorporates the influence of nanoparticles and strain rate, is proposed in this work [2]. This model is employed in conjunction with crystal plasticity framework, to study the compressive flow stress of magnesium alloys at strain rates from $10^{-3}/s$ to $10^3/s$. The results show negative SRS for the flow stress, which is consistent with experimental results. The influence of nanoparticles on restraining twinning is demonstrated to diminish with strain rate, and regarded as the underlying mechanism for the negative SRS of magnesium alloys. The combined effects of nanoparticle presence, strain rate, grain size and initial texture on the compressive flow stress of nanoparticle-reinforced magnesium alloys, are investigated using the proposed model.

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Dynamic shear behavior and microstructural evolution of additively manufactured AlSi10Mg alloy

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Abstract

Aluminum alloys are extensively used in engineering applications owing to their outstanding properties, including high specific strength, corrosion resistance, and excellent machinability. However, traditional processing methods are increasingly difficult to manufacture complex-shaped parts with superior mechanical properties. Additive manufacturing (AM) technology offers a novel approach for the one-step forming of complex structural parts. AlSi10Mg is well suitable for AM due to its good fluidity, low shrinkage, and narrow solidification range. Furthermore, additively manufactured AlSi10Mg demonstrates overwhelming strength advantages over its as-cast counterpart, making it highly attractive for applications in aerospace, rail transportation, and weaponry. During service, they are highly susceptible to failure caused by the adiabatic shear band (ASB) during processes like explosive impact, armor penetration, and high-speed cutting. Research on the shear behavior of additively manufactured AlSi10Mg, especially under dynamic loading, is extremely limited.

In this study, the quasi-static and dynamic mechanical response and adiabatic shear sensitivity of four types of shear specimens were first compared, followed by dimensional optimization of the cap-shaped specimen exhibiting the highest adiabatic shear sensitivity. Taking additive manufactured AlSi10Mg alloy as the research subject, dynamic shear tests were conducted on specimens with different build directions at strain rates up to 10^4 s^{-1} . Employing strain freezing technology, multiscale characterization of ASB initiation and propagation was performed using optical microscope, scanning electron microscope, electron backscattered diffraction, and transmission electron microscopy. The influence of strain and strain rate on ASB initiation was determined, the key factors dominating ASB initiation and the intrinsic mechanisms of ASB evolution were revealed. Furthermore, an ASB initiation criterion under shear stress conditions was also proposed.

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Strain rate and temperature dependent deformation response and
microstructural evolution of U75V rail steel

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Abstract

To investigate the effects of high strain rate and temperature on the dynamic mechanical properties of U75V rail steel, experiments were conducted over a wide range of strain rates (700 s^{-1} to 2300 s^{-1}) and temperatures (293 K to 873 K). The results show that the true stress of the material is sensitive to both temperature and strain rate, a response attributed to the interplay between work hardening and dynamic softening mechanisms. Specifically, when the deformation temperature exceeds 673 K or the strain rate surpasses 2300 s^{-1} , a steady-state plastic deformation stage is reached, in which strain-rate strengthening, work hardening, and the structural softening induced by environmental temperature and adiabatic heating attain a dynamic balance. Consequently, the flow stress no longer increases with further strain. Microstructural observations reveal that, with increasing strain rate, cementite lamellae undergo bending, spheroidization, and fragmentation in localized regions, accompanied by a reduction in pearlite interlamellar spacing. Dynamic recovery (DRV) and dynamic recrystallization (DRX) are observed when the deformation temperature exceeds 673 K or the strain rate reaches 2300 s^{-1} . Furthermore, under higher strain rates, the emergence of numerous shear bands leads to the disruption of the lamellar structure of pearlite. The intense plastic deformation within these shear bands triggers DRV and DRX, which is a key factor in the reduced hardening capacity of the material under high strain rates. Molecular dynamics (MD) simulations further indicate that higher strain rates promote dislocation nucleation at the cementite/ferrite interface, resulting in increased dislocation density. In contrast, elevated temperatures alter the preferred nucleation sites of dislocations, allowing them to form in regions away from the interfacial dislocations. Additionally, both transmission electron microscopy (TEM) characterization and MD simulation results confirm that slip transmission across the ferrite/cementite interface leads to the shearing of cementite.

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Machine learning-aided prediction and customization on mechanical response and wave attenuation of multifunctional kiri/origami metamaterials

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Abstract

Multifunctional metamaterials have attracted increasing interest for providing protection against mechanical and vibratory intrusions under impact and dynamic loading. In this work [1], an elegant kresling based kirigami/origami metamaterial is developed, integrating the compression-twist coupling of kresling origami with the strong local resonance of kirigami split-rings. This synergy enables efficient elastic wave polarization, plastic hinge formation, and energy absorption, providing continuous protection from elastic to plastic regimes. Kirigami split-rings offer a fabrication-friendly strategy for constructing local resonators to regulate dynamic wave propagation. Then, we propose a machine learning-aided framework for the design and dynamic loading analysis of a multifunctional kiri/origami metamaterial with tunable elastoplastic responses and broadband ultra-low-frequency wave attenuation. Experimental tests and numerical analyses validate the mechanical responses and wave mitigation performance of the proposed metamaterial. To overcome the high computational cost and complexity of dynamic stress analysis, the machine learning-aided design framework is established to rapidly predict and customize key mechanics-related performances, including wave attenuation, energy absorption, plateau stress fluctuation, deformation triggering force, and load-bearing/plateau force under various impact intensities. Without requiring prior physical assumptions, the machine learning model enables fast multi-objective prediction and end-to-end performance customization for quasi-static and dynamic loading scenarios. This study demonstrates the effectiveness of artificial intelligence and machine learning in dynamic loading analysis and impact-resistant metamaterial design, and provides a general strategy for the development of multifunctional, multiscale, and multiphysics metamaterials.

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Dynamic Responses of Tape Spring Structures

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Abstract

This work investigates the dynamic responses of tape spring structures, specifically focusing on the complex characteristics of hinge propagation during deployment. Tape springs are essential components in deployable space structures, valued for their ability to store strain energy and self-deploy, yet their transient behavior involves highly non-linear transformations. Analytical modeling is established for fundamental governing equations for the propagation of tape spring hinge. Finite Element (FE) analysis is employed to simulate transient buckling and strain energy release. Also, deploying tests are conducted on tape spring structures, and their deformation and deployment kinematics are recorded with high-speed camera. The results elucidate how geometric curvature and thickness influence the steady-state velocity and stability of the hinge front. By correlating theoretical predictions with numerical and empirical data, this work provides a important framework for optimal deployment reliability of satellite components like solar arrays and antennas, ensuring predictable performance in space environments.

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Impact Behaviors and Damage Mechanisms based on Mechano-electrical Monitoring for Additively Manufactured CFRP Laminates coated by Elastomer

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Abstract

Carbon fiber-reinforced polymers (CFRP) have been increasingly applied in advanced equipments such as aerospace and automotive industries due to their superior mechanical properties. However, out-of-plane impact loading tends to cause significant attenuation of their load-bearing capacity, making the research on impact protection mechanisms of great engineering value. In this work, CFRP laminates were additively manufactured and reinforced by back-coating with polyurethane elastomer. Based on the load-dependent resistance characteristic of carbon fibers, a mechano-electrical monitoring system was established to systematically investigate the protection effect of the coated elastomer on impact resistance and mechano-electrical response of CFRPs^[1]. Traditional split Hopkinson Pressure Bar (SHPB) was improved to construct a dynamic impact and an in-situ electrical measurement system suitable for this composite structure. Combined with quasi-static compression and controlled dynamic impact experiments, the strain, displacement, and resistance evolution histories during the impact process were synchronously collected using the mechano-electrical testing system and three-dimensional Digital Image Correlation technology. Coupled with failure morphology characterization, the impact resistance and damage evolution laws were analyzed, and the impact protection mechanisms and damage evolution paths were further explored based on the material characteristics of the laminates and the elastomer-backed composite structure. It is indicated that the coating polyurethane elastomer can significantly enhance the impact resistance of CFRPs and inhibit destructive failure by dispersing the impact-induced displacement and strain fields and reducing local stress concentration effects. CFRP fiber resistance variation increases with the increase of impact velocity, while the coated elastomer can effectively alleviate this resistance mutation behavior. This study provides technical support for the impact protection and in-situ monitoring of CFRP structures.

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Rate-dependent Mechanical Behaviors of PVA Composite Hydrogel enabled as Articular Cartilage

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Abstract

Articular cartilage of human body is usually experienced complex mechanical loadings and conditions, including compression during wide strain rate impact from walking, and accidental collisions, and even cyclic loading from multiple-jumping activities. After long-term service, its performances are decaying and even damaged, which is medically replaced by a synthetic composite hydrogel to repair and even plant for damaged articular cartilage. The mechanical preparties of hydrogel should be enable to survive the complex mechanic loading above-mentioned.

In this work, a composite hydrogels was synthetized based on polyvinyl alcohol (PVA), aiming as articular cartilage substitutes, and series of mechanical tests were performed to obtain its mechanical behaviors, to check their properties to adapt to potential service loading environments. Low strain rate loadings under compression were performed using a universal testing machine to obtain fundamental elastic modulus, compressive strength and residual strain after multiple loadings. Traditional split Hopkinson pressure bar (SHPB) was improved to evaluate its dynamic mechanical properties of the material under high strain rates of 10^2 - 10^3 s⁻¹. Its extended technique was enabled for dynamic compression cyclic loadings, and the Mullins effects under wide strain rate loading was obtained to assess the strength degradation and damage behaviors. The results showed that the elastic modulus and compressive strength were within the range of natural articular cartilage of 0.1–10 MPa, 0.35–0.45 MPa, respectively. After multiple loadings, the resilience rate conformed to the characteristics of natural cartilage. However, the elastic modulus did not exhibit distinct strain rate effect under high strain rate, which is rather preferred as the replacement of articular cartilage. The Mullins effect revealed that after cyclic loading, the stiffness and mechanical property of the composite hydrogel were rather superior to the available commercial materials. The results demonstrates that PVA-based composite hydrogel is qualified as articular cartilage, under the fundamental wide strain rate loading, and long-term cyclic loading conditions.

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Experimental and numerical investigation of repeated impact damage and residual strength of foam-core composite sandwich panels

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Abstract

Composite sandwich structures are increasingly applied in marine and offshore engineering structures due to their high specific strength, high specific stiffness, and excellent design flexibility, enabling lightweight design under complex loading conditions [1,2]. During service, these structures are frequently subjected to impact loading, and repeated impact events may induce barely visible impact damage, significantly compromising structural integrity and safety [3,4]. In this study, the damage behavior of composite sandwich structures under repeated impact loading was investigated through a combined numerical and experimental approach. A finite element model for repeated impact was developed using ABAQUS, and repeated drop-weight impact tests were conducted on composite sandwich panels using an INSTRON 9350 impact testing system. The damage characteristics and damage evolution mechanisms under multiple impacts were systematically analyzed. Furthermore, a finite element model for compression after impact was established to evaluate the residual compressive strength of composite sandwich structures after repeated impact damage. The evolution mechanism of residual strength degradation was clarified, providing insight into the impact tolerance and post-impact load-bearing capability of composite sandwich structures used in marine applications.

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Testing, modelling and optimisation of aluminium extrusions for side-crash protection of battery trays in electric vehicles

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Abstract

The mechanical performance of thick-walled multi-chamber aluminium extruded profiles intended for side-impact protection of electric vehicles is assessed. A material testing campaign is performed to evaluate the mechanical properties of the base material and calibrate a material model for finite-element simulations. The mechanical response of thick-walled extruded profiles is tested in quasi-static and dynamic pole-crushing tests. The experimental results are compared with explicit numerical simulations and serve as a validation of the constitutive model.

This work presents two alternative strategies for the structural optimisation of these components. Owing to the complex crushing behaviour and the relatively large wall thicknesses typical of such profiles, the numerical model employs three-dimensional solid elements, which results in substantial computational cost. Two optimisation procedures were therefore performed: one based on a plane-strain crushing representation and another using a full three-dimensional pole-impact model of the profile. The resulting optimal designs are compared in terms of similarity, robustness, and computational efficiency. The optimal solution was extruded, tested and compared to the numerical predictions.

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The influence of geometric fidelity in blast-obstacle interaction: Experimental and CFD studies of the Beirut grain siloes

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Abstract

In the field of blast protection engineering, it remains challenging to validate large, geometrically complex numerical models, and the implications of modelling assumptions relating to obstacle representation, particularly geometric fidelity, are not well understood. This study presents reduced-scale experimental work addressing these issues in the context of the 2020 Beirut port explosion, which remains an important case study for understanding blast effects in urban environments.

A series of 1:250 scale blast experiments were conducted to examine shielding effects caused by the Beirut grain siloes and to investigate the influence of obstacle geometric fidelity on blast loading. Rigid obstacles were constructed at two geometric fidelities: a simplified cuboidal representation and a geometrically accurate model capturing the cylindrical form of the siloes. Pressure histories were recorded at multiple locations surrounding and behind the obstacles at fixed blast scaled distances, enabling comparison of peak overpressure, specific impulse, and arrival time. Complementary computational fluid dynamics simulations were performed to aid interpretation of the experimental observations.

Experimental results confirmed significant localised shielding behind the siloes, characterised by reduced overpressure and specific impulse at near-field scaled distances. However, blast wave parameters did not exhibit significant differences between the simplified and geometrically accurate representations, except for minor localised variations in peak overpressure of approximately 10%. Numerical analyses indicate that these differences arise from modified blast wave scattering, diffraction, and superposition behaviour associated with the outer geometry of the obstacle.

Overall, the findings suggest that city-scale blast loading assessments can yield reliable predictions through idealised representations of structural obstacles. The results are directly relevant to researchers and practitioners in the impact and high-rate loading community concerned with experimental validation and numerical modelling of blast wave propagation in complex urban environments.

Homogenized modeling of cumulative kill probability for aircraft under multi-munition attacks

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Abstract

Aircraft vulnerability assessment constitutes a core component of survivability analysis and provides the foundation for evaluating combat resilience and guiding aircraft design improvements. Under realistic munition attack scenarios, the probability of a direct hit is generally low, and blast overpressure decays rapidly with distance. Consequently, damage induced by munition-generated fragments becomes the dominant kill mechanism acting on aircraft targets [1]. Early vulnerability studies focused primarily on single-hit scenarios and established classical probabilistic models based on redundancy and overlap assumptions. These models were subsequently extended through generalized frameworks integrating shot-line tracing, equivalent physical modeling, penetration equations, and kill-tree representations, enabling accurate vulnerability analysis for single-hit and limited multiple-hit conditions [2, 3]. However, exact solutions based on Markov chains or tree-graph formulations suffer from severe combinatorial explosion as component redundancy and hit numbers increase. To improve computational efficiency, various simplified approaches—such as binomial, Poisson, and equivalent vulnerable area methods—have been developed. While effective for rapid assessment, these methods typically rely on conditional independence assumptions and constant hit-to-kill probabilities, neglecting the nonlinear mapping between component-level damage and target-level kill probability. As a result, they tend to underestimate cumulative kill probability for redundant aircraft systems, particularly under multiple-hit conditions.

For single-munition attacks, the present study has demonstrated that aircraft vulnerability evolves continuously with increasing hit numbers due to the progressive degradation of functional redundancy. This vulnerability evolution can be captured using both exact Monte Carlo sampling and efficient simplified formulations, and has been shown to significantly influence cumulative kill probability [4]. In contrast, vulnerability assessment under multi-munition attacks remains largely dependent on conditionally independent formulations, in which cumulative kill probability is obtained by combining single-munition results or kill matrices associated with different engagement conditions. Such formulations implicitly assume that damage states induced by different munitions are statistically independent, thereby truncating the continuous evolution of target vulnerability across successive engagements. In realistic combat scenarios, however, multiple munitions may strike a target from different directions and under different impact conditions, as illustrated schematically in Fig. 1(a). Each successive hit further degrades system redundancy and alters the conditional kill probability of subsequent hits. Neglecting this state dependency inevitably introduces non-negligible errors in cumulative kill probability prediction and limits the applicability of existing simplified methods.

To overcome these limitations, the present study proposes a homogenization theory for aircraft vulnerability assessment under multi-munition attacks, under which multi-munition and single-munition damage processes are unified within a consistent computational framework. An exact sequential Monte Carlo method based on shot-line tracing and kill-tree analysis (Fig. 1(b)) is first employed as a reference solution. This method explicitly accounts for target state evolution under multiple hits by sequentially sampling fragment impact locations associated with different engagement conditions and accumulating component-level damage through kill-tree evaluation. Building on this reference, a refined formulation based on component-level average kill probability is developed for multiple-hit scenarios under a single munition. This formulation is subsequently extended to multi-munition attacks by treating all fragment hits generated by different munitions as a unified hit set, rather than as independent engagement waves. In this manner, the continuous inheritance of prior damage effects is preserved within the homogenization framework, while avoiding wave-by-wave vulnerability recalculation.

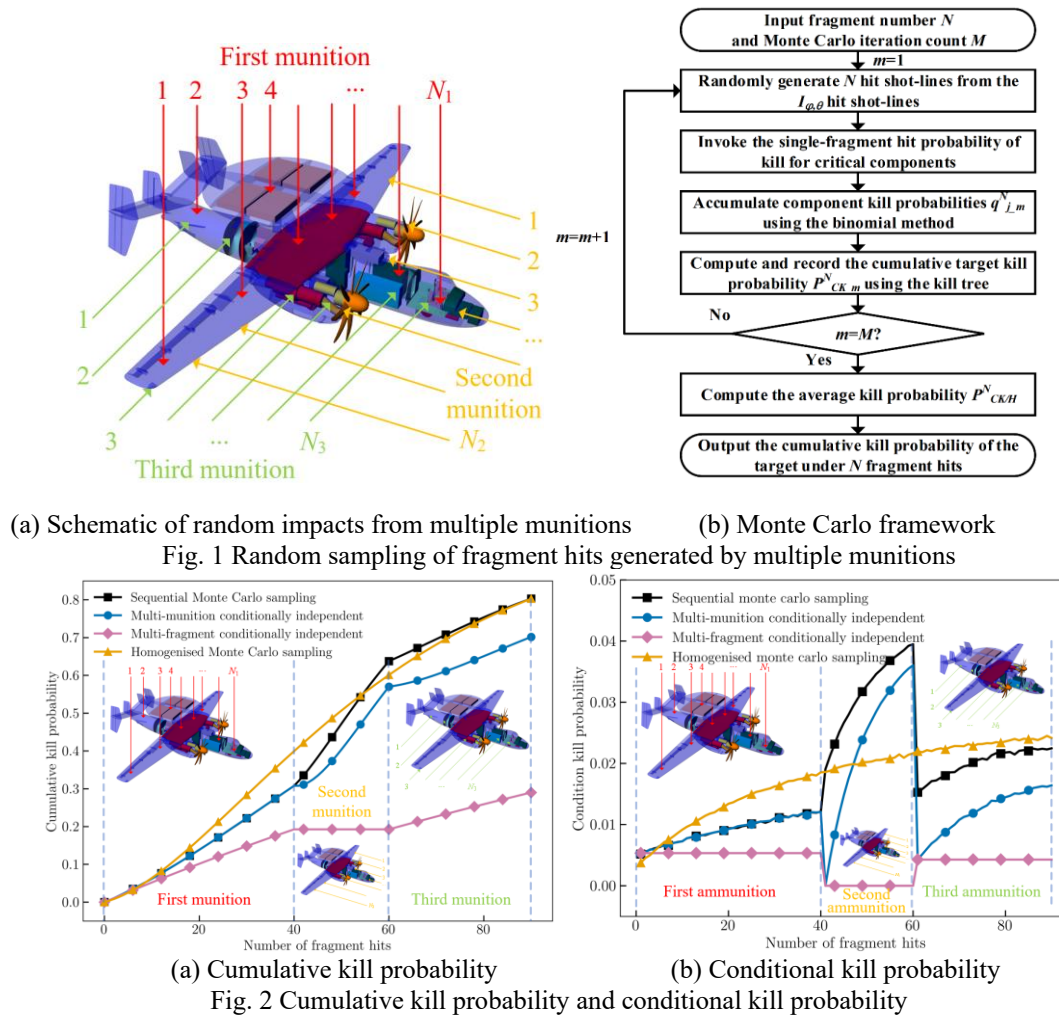
Extensive case studies involving successive munition engagements are conducted to quantify the modeling errors introduced by conditional independence assumptions. Relative to the sequential Monte Carlo reference solution, hit-level conditionally independent formulations underestimate cumulative kill probability by more than 60%, while munition-level independent formulations still exhibit deviations exceeding 10%. These discrepancies

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emerge after the second munition engagement and increase with successive attacks due to the neglect of vulnerability evolution induced by prior damage, as illustrated by the differences in cumulative kill probability obtained using the sequential Monte Carlo, munition-level independent, and hit-level independent methods in Fig. 2. In contrast, the proposed homogenized formulation produces cumulative kill probabilities that are statistically equivalent to those obtained from sequential Monte Carlo sampling, with relative deviations below 0.1%. The results demonstrate that cumulative kill probability depends solely on the final component kill probability vector and the kill-tree structure, and is independent of the order of munition engagement. By eliminating the need for wave-by-wave calculations while retaining the physical and probabilistic meaning of cumulative damage, the proposed homogenization theory provides a computationally efficient, low-cost, and highly generalizable solution for aircraft vulnerability assessment under complex multi-munition attack conditions.

Keywords

Aircraft vulnerability assessment; Multi-munition attack; Cumulative kill probability; Homogenization theory



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Experimental Evaluation of the Mechanical Behavior of Pure Iron at Ultra-High Deformation Rates

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Abstract

The authors previously developed an instrumented Taylor impact (ITI) test to characterize the mechanical behavior of pure aluminum (Al) at ultra-high deformation rates [1]. While the method successfully demonstrated its capability for pure Al, it relies on the assumption of a linear internal force distribution within a specific region of the specimen, and its applicability to other materials remains unverified. Furthermore, mechanical properties can be identified only within a restricted time interval, which must be redefined for each material system. By contrast, the deformation behavior of pure iron at ultra-high deformation rates remains poorly understood, primarily due to the velocity limitations of conventional experimental techniques. Its characterization, therefore, presents substantial experimental challenges. In addition, unlike pure Al, pure iron exhibits pressure-induced magnetic phase transitions [2], which are expected to significantly affect its mechanical response. In this study, ITI tests are performed on pure iron specimens to assess the applicability of the previously proposed mechanical property identification method [1]. Its validity is first examined using digital image correlation (DIC), after which the mechanical behavior of pure iron at ultra-high deformation rates is systematically evaluated.

Fig. 1 shows the impact force histories measured using a piezoelectric film (green curve) and a strain gauge (black curve), together with the temporal evolution of the plastic region length (orange curve). The rising portion of the force waveform is enlarged in the lower-right inset. As highlighted by the pink outline, an abrupt change in slope is clearly observed and attributed to a magnetic phase transition [2]. This feature is not captured by the strain gauge, indicating that the piezoelectric film provides a broader frequency response. Furthermore, similar to pure Al [1], pure iron exhibits a three-phase deformation behavior, which remains valid despite the magnetic-phase-induced FCC-to-HCP transformation. Fig. 2 illustrates the internal force distributions calculated from acceleration fields obtained using the DIC technique. The red, orange, yellow, green, blue, and purple curves correspond to results at 4.76–28.56 μ s, respectively. As shown in the figure, the internal force distribution within a certain region can be well approximated by a linear function, confirming that the method proposed in Ref. [1] remains effective when the application of DIC is impractical.

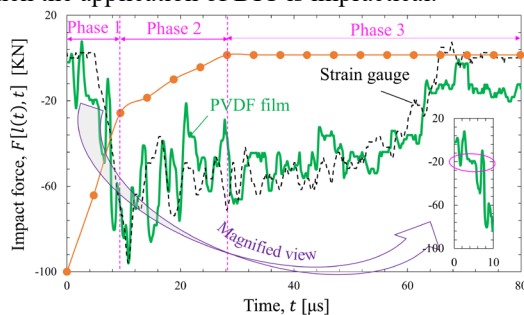


Fig. 3. Impact force wave for pure iron in ITI test.

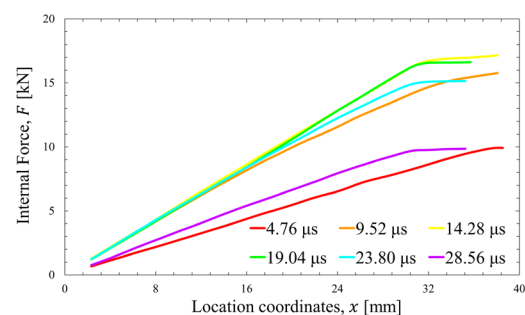


Fig. 4. Internal force distribution.

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Influence of Strain Rate on Mechanical Properties of Ultra-high Molecular Weight Polyethylene

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Abstract

Ultra-high molecular weight polyethylene (UHMWPE) possesses good biocompatibility, superior wear resistance and low friction, and is therefore widely used in orthopaedic implants – e.g. acetabular liners of hip replacements and tibial inserts of knee replacements. During walking/running/jumping, these liners/inserts are frequently subjected to impact loads; hence, an understanding of the dynamic mechanical properties of UHMWPE is essential for effective usage in applications. However, there appears to be limited efforts in examining these aspects, particularly for strain rates below 1000 s^{-1} . In this study, uniaxial compression/tension was applied to UHMWPE specimens at strain rates ranging from 100 s^{-1} to 1000 s^{-1} , using split Hopkinson bar devices. From the stress-strain responses obtained, the influence of strain rate on yield, and post-yield hardening were analyzed. This provided data for constitutive modelling of UHMWPE over a wide range of strain rates, which is crucial for the design of UHMWPE components to meet the requirements of different types of implants.

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Experimental techniques and dynamic behavior of TPMS lattice structures under high strain rate loading

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Abstract

Lightweight lattice materials possess excellent macroscopic mechanical and physical properties due to their unique microstructure, and have wide applications in aerospace, automotive engineering, and biomedicine. Optimizing mechanical properties by controlling the microstructure has become a key research focus for lattice materials. However, progress in optimizing the dynamic performance of these materials has been slow due to limitations in experimental analysis methods. Currently, while Taylor-Hopkinson bar and Taylor impact tests can achieve high strain rate loading, traditional analytical methods based on nominal stress-strain curves cannot accurately reflect the true stress-strain behavior of materials under dynamic conditions. Especially during high-speed impacts, lattice materials often exhibit significant localized deformation, leading to a significant difference between nominal and true strain. Therefore, this report establishes an inversion method for the dynamic stress-strain curves of lightweight porous materials based on stress wave propagation information at high strain rates and the conservation condition of stress wave propagation, in order to further explore their dynamic mechanical behavior.

A representative triply periodic minimal surface (TPMS) Gyroid lattice was selected to investigate quasi-static and dynamic mechanical responses. Planar compression experiments were conducted using an MTS testing system and a direct-impact Hopkinson pressure bar (DIHPB) to achieve quasi-static, intermediate-velocity, and high-velocity loading. The validity of DIHPB data reduction and stress equilibrium assumptions was evaluated using high-speed imaging combined with full-field digital image correlation (DIC), considering two different specimen mounting configurations. The results demonstrate significant rate sensitivity and a distinct shift in deformation mode as impact velocity increases. Compared to quasi-static loading, impact at 34 m/s increases the initial crushing stress by 59.7% and the plateau stress by 17.7%. Stress equilibrium is largely satisfied after the initial transient at 34 m/s but is substantially violated at 80 m/s. This indicates that inertia-driven stress non-uniformity dominates and that conventional DIHPB-derived global stress-strain curves are unreliable. At higher velocities, a compaction wave response is observed. High-rate stress-strain curves were extracted from DIC velocity fields using both shock-wave theory and Lagrangian analysis [1, 2], highlighting the velocity-dependent applicability of these two approaches to TPMS lattice.

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Research Progress on the Development of Ultra-large Size Split Hopkinson Torsion Tube

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Abstract

Shear failure is a common failure mode of engineering structures under extreme loads, such as earthquake, explosion and impact. Once the key components fail by shear, it will lead to disastrous consequences. Concrete is the most widely used engineering material. At present, the shear failure mechanism of concrete under extreme loads is still unclear, and there still is a lack of suitable constitutive model to describe the pure shear characteristics of concrete under high strain rate. The core challenge lies in the absence of experimental setups capable of conducting pure shear tests that can grab the useful stress-strain data on concrete-like heterogeneous materials at high strain rates. This research aims to develop an experimental apparatus for such tests. A preliminary success has been achieved in creating a ultra-large size electromagnetic driven Split Hopkinson Torsion Tube with a diameter of approximately 1000mm and a shear stress wave rise time of about 150 μ s.

Quantitative parameters analysis of ignition damage caused by reactive fragments impacting aircraft fuel tanks

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Abstract

Aircraft combat survivability is primarily compromised by fuel tank fires and explosions triggered by projectile impacts [1]. The advent of reactive fragments—a high-efficiency damage element—poses new challenges to fuel tank vulnerability [2]. To enhance survivability, this study quantifies how projectile/target parameters influence ignition outcomes. In this study, using the established BC_{RM} ignition judging criterion and ignition criterion, we analyzed: (1) reactive/inert fragment lethality against full/partially full tanks; (2) effects of fuel vapor concentration, oxygen concentration, and fuel volume; (3) fragment diameter/mass; and (4) fuel tank shell thickness/density. Then, we compared the conclusions obtained from the analysis with the test results of published literature to verify the validity. Results quantitatively revealed that reactive fragments impacting full fuel tanks induce significantly stronger ignition enhancement effects than reactive fragments impacting partially full fuel tanks. Results show that the establishment of the ignition criteria for a reactive fragment impacting a fuel tank must consider three conditions of penetration, reaction, and ignition together. Based on the above three conditions, the damage area of a fragment impacting full and partially full fuel tanks is divided into five criterion zones (I-V). Only zones II and III reliably ignite tanks. The influence of each parameter on the ignition damage of the fuel tank caused by reactive fragments is consistent with the test results and research conclusions in the literature. The research results provide a quantitative analysis basis for the vulnerability reduction design of aircraft fuel tanks and the improvement of the lethality of reactive fragments.

Keywords: Reactive fragment impact; aircraft fuel tank; vulnerability; ignition criterion; quantitative parameters analysis

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A Macroscopic Constitutive Model for Polycarbonate Subjected to Impact Loading

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Abstract

As a glassy polymer, polycarbonate (PC) finds wide application in areas such as lightweight transparent armor and aircraft windshields. This study proposes a macroscopic constitutive model for polycarbonate subjected to impact loading on the basis of the analysis of existing material test data. The constitutive model incorporates the essential characteristics of polycarbonate, such as pressure dependence, strain-rate sensitivity, strain softening and hardening, and temperature effects. Its predictive capability was first verified via single element simulations, uni-axial and tri-axial test simulations which accurately predict the stress-strain curves at different temperatures, strain rates and confining pressures. To further assess its predictive capability, numerical simulations were then conducted on the perforation of polycarbonate plates loaded by both hemispherical and flat-nosed projectiles at different velocities. Numerical results show good agreement with available experimental data in terms of load-displacement curve, ballistic limit and failure morphology, thereby demonstrating the accuracy and robustness of the proposed model.

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Theoretical Study on Dynamic Response of Foam Core Sandwich Structure Under Repeated Impacts

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Abstract

Ship and marine engineering structures are inevitably subjected to repeated impact loads during its service life, such as ice impact loads [1], slamming loads [2-3], and aircraft landing loads [4]. These repeated impact loads can lead to the accumulative plastic deformation and severe structural damage, which has an adverse influence on service life and structural safety. Foam core materials and sandwich structures, have extensive potential application in the lightweight design and impact resistance of ship and marine engineering structures, owing to their superior mechanical properties, such as excellent specific stiffness and strength as well as impact resistance [5-6]. In this paper, a rigid-perfectly plastic theoretical model of foam-core sandwich plates under repeated impacts was proposed based on the exact yield surfaces and the changing initial conditions after each impact. By employing the membrane factor method (MFM) and energy conservation law, the transient phase responses and modal solutions of foam-core sandwich plates under repeated impacts were derived. Horizontal impact tests and numerical calculations of PVC foam-core sandwich plates were carried out to verify the accuracy of the theoretical model. In addition, the relationship between structural plastic deformation, peak impact force, as well as the dynamic responses and repeated impact number was studied to understand the mechanical mechanism of plastic cumulative deformation under repeated impact loads on lightweight sandwich structures. The influences of membrane force and bending moment on the repeated impact response of plastic energy dissipation were also investigated. The theoretical predictions on transient phase responses and accumulative plastic deformation responses of foam-core sandwich plates under repeated impacts obtained showed good agreements with experimental and numerical results. As the number of impacts increase, the influence of membrane action gradually dominates, the PVC foam-core sandwich plate gradually behaves like plastic membrane, and the structural dynamic bearing capacity is enhanced. The membrane force induced by accumulative plastic deformation of PVC foam-core sandwich plate has an increasing effect on the energy absorption.

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A plate-based shock isolator: Tunable nonlinear restoring forces enabled by boundary control

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Abstract

Complex dynamic loads during cargo transportation, such as vibrations and impacts, pose a significant threat to cargo and personnel safety. We propose a plate-based vibration isolation system with actively tunable boundary constraints for adaptive protection. By adjusting the boundary constraints, this system can continuously change the equivalent linear stiffness and the nonlinear Duffing-type restoring force of the plate, enabling active control over the dynamic response of protected objects. Through integrated theoretical modeling and finite element analysis, this study systematically reveals the quantitative relationships among the boundary parameters, Duffing coefficients, and the system dynamics response under both vibrational and impact loads. The results indicate that this continuously tunable Duffing nonlinearity can not only significantly broaden the vibration isolation bandwidth and suppress system resonance, but also confine the critical displacement within a safety threshold under impact conditions. Numerical simulations further verify that the introduced nonlinear mechanism provides superior adaptability and performance compared to conventional linear isolation. Consequently, this system provides a tunable elastic vibration isolation solution for adaptive protection against combined vibration and impact loads. This study offers a theoretical foundation and design strategy for developing multi-condition intelligent protection systems.

Keywords: Impact protection; Duffing isolation; Tunable nonlinearity; Adaptive structure; Impact resistance

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Penetration Resistance of Cavity Structures against Shaped Charge Jets

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Abstract

Shaped charge jets pose a severe threat to armoured vehicles; consequently, there is an urgent demand for protective structures that combine high efficiency and low areal density. To address this challenge, we propose an innovative steel target incorporating deliberately designed cavity structures to disrupt the penetration process of shaped charge jet and thereby enhance resistance. The protective performance is quantitatively evaluated through the mass efficiency factor (MEF). Compared with a homogeneous 603 steel target (a yield strength of ~830 MPa, MEF = 1.0), the cavity-structured target achieves an MEF of 1.27, corresponding to a 27% improvement. As the strength of the matrix material increases, the MEF of homogeneous target shows some improvement, but the MEF of the cavity-structured target shows a more significant enhancement. This trend indicates that the enhancing effect of the cavity structure becomes more pronounced as the material strength increases. Numerical simulations reveal two key mechanisms: the cavity structure perturbs jet penetration by inducing cratering, thereby destabilizing it; concurrently, the asymmetric forces from the inclined cavity walls deflect the jet tip by altering its velocity vector, significantly intensifying the disruptive effect. These findings confirm that a rationally designed cavity structure can significantly enhance the anti-jet capability of metallic targets, offering a practical design direction for developing lightweight, high-performance armor systems.

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Anti-blast performances of various auxetic sandwich panels

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Abstract

Novel auxetic sandwich structures demonstrate excellent anti-blast performance; however, their performance relative to traditional honeycomb structures remains insufficiently investigated. Numerical simulations were employed to evaluate the anti-blast performance of honeycomb sandwich panels, auxetic structure sandwich panels and solid plates with equivalent mass. The deformation characteristics of the core layer were analyzed, and the anti-blast performance of these structures was systematically compared. Additionally, the influence of structural parameters on the anti-blast performance of sandwich panels was explored. The results indicate that in most scenarios, honeycomb sandwich panels still exhibit superior anti-blast performance, whereas solid panels show poor performance in this regard. The thickness ratio of blast board to backboard, core height, and core strength can be optimized to minimize the deflection of the sandwich panel. The optimal value of the thickness ratio of blast board to backboard increases with escalating explosion loads. When the load exceeds a critical threshold, solid plates demonstrate the best anti-blast performance. This study provides valuable guidance for the design of sandwich panels under explosive loading conditions.

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From Impact to Blast: An Integrated View on Laminated Glass Response, Fracture and Residual Capacity

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Abstract

Laminated glass (LG) is widely employed in structures exposed to extreme loading scenarios, where controlled fracture, energy dissipation and post-breakage capacity are essential for safety and robustness. This talk presents an integrated view on the dynamic response of LG subjected to impact and blast loading, combining full-scale experiments and numerical simulations. The response of LG is first discussed from the perspective of its dynamic characteristics. Experimental modal analysis demonstrated the decisive role of polymer interlayers in governing vibration frequencies and damping, providing a basis for understanding subsequent impact behavior [1]. Drop-weight impact experiments on freely hanging specimens further revealed how interlayer type and temperature influence contact forces, damage initiation and load redistribution between glass plies [2]. Progressive fracture under repeated impact loading showed that multilayer laminates can exhibit pronounced damage tolerance, with fracture evolving gradually rather than catastrophically [3]. Projectile impact tests demonstrated that multilayer LG is capable of arresting ballistic threats while often retaining substantial residual bending capacity, provided damage to inner plies remains limited [4]. Blast loading experiments on freely hanging and simply supported specimens highlighted the influence of laminate configuration and boundary conditions on deformation, fracture patterns and residual strength, supporting the sacrificial-glass-ply design concept for blast-resistant glazing [5,6]. Throughout the presentation, experimental observations are confronted with numerical simulations using industry-standard explicit solvers, including a critical assessment of commonly used glass failure models and their ability to reproduce observed fracture sequences [7]. The presented results provide a coherent insight into the behavior of LG from impact to blast loading and illustrate how carefully designed experiments can support both safer structural design and the development of more reliable predictive models.

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Influence of Strain Rate and Combined Tension - Torsion loading on the Mechanical Performance of Ti0.7Al4V.

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Abstract

Ti0.7Al4V (Ti407) is an alpha/beta titanium alloy developed for applications demanding resistance to impact, explosive blast, and other dynamic loading conditions, while also offering substantial reductions in machining and processing costs without compromising mechanical performance and structural integrity [1, 2]. This study investigates the mechanical response of Ti407 under combined tension - torsion loading. An experimental campaign was conducted under quasi static (QS) and high strain rate (HR) conditions to evaluate strain rate sensitivity and failure mechanisms. Various combinations of stress states were examined, including uniaxial tension, pure shear, and combined tension shear loading, also including both tension and shear dominated regimes.

A novel ligament specimen geometry consisting of four flat dog bone arranged circumferentially was employed [3, 4]. Quasi static experiments were performed at a strain rate of 10^{-3} s^{-1} using a screw-driven universal testing machine equipped with four cameras operating at 1 fps were used. The high strain rate experiments were carried out using a novel Tension Torsion Split Hopkinson Bar (TTHB) apparatus [5, 6] and two high speed cameras operating at 100,000 fps to acquire real time images. Digital image correlation (DIC) analysis was employed to evaluate the deformation and failure mechanism. The high strain rate results confirm the achievement of force and torque equilibrium, as well as approximately constant strain rate loading. The analysis of the loading paths demonstrates proportional strain histories in the combined loading experiments.

Experimental data obtained across quasi static and high strain rate regimes were used to construct multiaxial failure envelopes, highlighting the material strength, strain rate sensitivity, and the influence of combined tension - torsion loading.. This study presents, for the first time, the strain rate dependent combined tension – torsion failure loci of Ti0.7Al4V. It also provides a comparison with Ti6Al4V and promotes the development of more accurate and realistic failure models.

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Anisotropic response of additively-manufactured polymeric strut-based lattices to compression along different directions

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Abstract

Lightweight strut-based lattice structures have been extensively studied, with the objective of enhancing their energy absorption performance. Consequently, a wide variety of different constituent cell geometries have been designed to yield high and stable stress plateaus during crushing. Much effort has been directed at fulfilling cubic symmetry of cell architecture, i.e., identical geometry when viewed from three orthogonal directions, to approximate quasi-isotropic compressive responses. Compared to other cellular materials that focus on enhancement of properties along a single direction, such as honeycombs, lattices with cubic symmetry are envisaged to provide better omnidirectional performance in protective applications, whereby the shielded object may sustain impact from any or multiple directions [1].

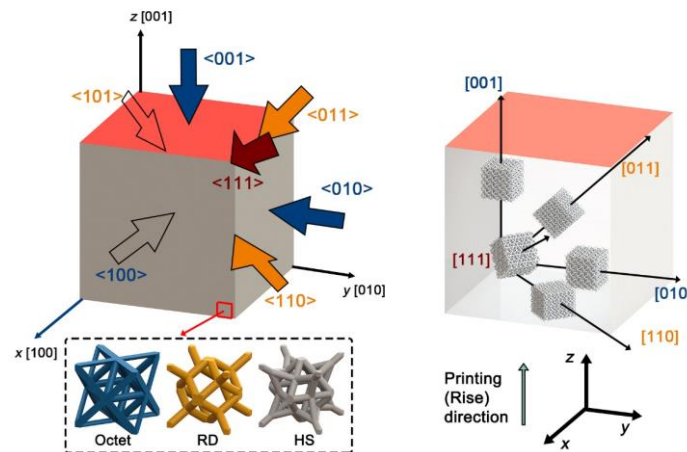


Fig. 1 Schematic diagram of lattices with different constituent cells, subjected to compression from directions other than along orthogonal axes of symmetry; configurations of cubic lattice test specimens subjected to compression along various directions.

Both the lattice cell strut material properties and cell geometry govern the compressive responses of lattices [2]; hence, an understanding of the combined effects of these two factors is crucial. Firstly, orthogonal symmetry in the constituent cubic cell geometry does not ensure similar compressive responses of lattices loaded in directions not aligned with the geometrical principal axes. Moreover, although advancements in additive manufacturing have enabled fabrication of lattices comprising sophisticated cell architectures, the layer-wise material deposition process involved results in non-uniform cell strut material properties. Thus, the compressive responses along the three orthogonal geometrical principal axes are not identical, because the material properties of each cell strut depend on the angle to the direction of printing. Hence, attaining consistent omnidirectional crushing responses to achieve direction-independent energy absorption characteristics is challenging for lattices comprising cells with only cubic geometrical symmetry. Most previous studies have focused on the compressive response of lattices

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along a single geometrical principal axis, i.e., the printing direction [3]; hence, it is instructive to gain an insight into the degree of anisotropy in response, for compression in different directions.

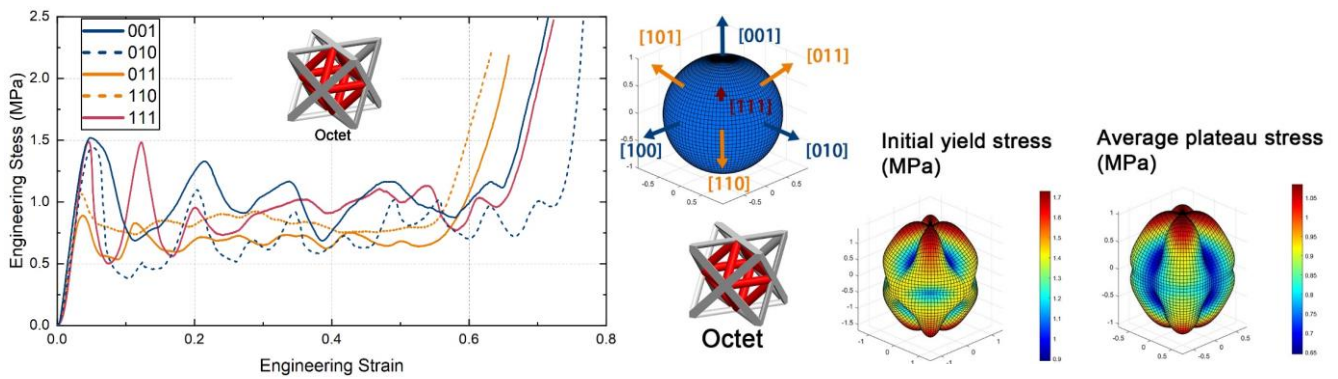


Fig. 2 Example of different stress-strain responses for an Octet lattice compressed in various directions; three-dimensional envelopes illustrating the degree of anisotropy in the initial yield stress and average plateau stress.

In this study, samples of Octet and Rhombic Dodecahedron lattices, as well as a hybrid descendant (HS) lattice, are additively manufactured and subjected to quasi-static and dynamic planar compression along two oblique directions – the face diagonal and body diagonal with respect to the lattice cube. Comparison of these responses with those for compression along the lattice geometrical principal axes, reveals significantly dissimilar global stress-strain responses and crushing patterns, indicating directional sensitivity associated with cell geometry and angle-dependent strut material properties. The proposed novel HS lattice displays less anisotropy, demonstrating its advantage in yielding more consistent, direction-independent behaviour. Meso-scale analysis of the different deformation patterns observed on adjacent sides of lattices subjected to oblique impact, is undertaken via finite element modelling of Octet and RD lattices. Incorporation of rate-dependent properties derived from tensile tests on cell strut materials, yields simulation results for quasi-static and dynamic compression that correlate well with experiments, in terms of the global stress-strain responses and deformation modes. Examination of strut-level deformation indicates that differences in lattice deformation are linked to changes in the mode of loading on cell struts.

Keywords: Lattice, compression, energy absorption, anisotropy, large deformation.

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Mechanical properties of carbon fiber reinforced shear stiffening gel composite under impact

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Abstract

The need for lightweight, high-performance multifunctional composite materials is increasingly prevalent today. This research examines the impact resistance and force-sensing performance of polyborosiloxane (PBS) integrated into carbon fiber structures. Two types of PBS with different crosslinking densities were synthesized, and their rheological and mechanical behaviors were studied under varying strain rates and impact conditions. The findings indicate that when PBS is in a rubbery state, the peak force shows a strong correlation with impact energy rather than impact velocity. Notably, under high-strain-rate dynamic compression, PBS exhibits a yielding stage followed by a strengthening stage. Compared with traditional epoxy/carbon laminates, PBS65/carbon composites demonstrated significantly better impact energy absorption, enduring up to seven repeated impacts. This performance is attributed to the brittle cracking of PBS, its transition to a stiffened state, and its self-healing capability. Furthermore, incorporating carbon nanotubes into the PBS matrix allowed the creation of a force-sensing composite capable of detecting and measuring impact forces. The PBS/carbon laminates also showed improved flexibility, making them well-suited for advanced protective applications that demand both repeated impact resistance and real-time force monitoring.

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Enhancement Effect of Underwater Explosion Shock Waves Influenced by Seabed Topography

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Abstract

The propagation and evolution of near-seabed underwater explosion shockwaves are significantly modulated by seabed topography[1]. The focusing, scattering, and superposition of wave systems induced by complex terrain are key physical mechanisms that enhance shockwave damage effectiveness and interfere with underwater acoustic detection[2]. This paper investigates the shockwave enhancement effect generated by underwater explosions under typical seabed topographies—such as slopes, ridges, and depressions—using an integrated approach of experimental observation and high-order discontinuous Galerkin (DG) numerical simulation. The study systematically examines the evolution of wave structures and the distribution of overpressure under topographic modulation. First, small-yield explosive experiments were conducted under simplified topographic conditions to obtain time-resolved pressure data and spatial distribution characteristics of shockwave propagation. On this basis, to accurately capture multiphase interface evolution and complex wave interactions, a compressible multiphase flow RKDG high-resolution computational model was established based on the Level Set method and the Ghost Fluid method, enabling high-fidelity simulation of underwater explosion processes involving complex seabed boundaries. Comparison between experimental data and numerical results verifies the reliability of the model in predicting shockwave arrival time, peak overpressure, and waveform characteristics. The findings indicate that seabed topography can induce significant local enhancement effects by guiding shockwave reflection and convergence: raised terrains such as ridges tend to cause wavefront focusing, leading to a notable increase in overpressure in specific areas, while depressed terrains may trigger multiple reflections and time-delayed superposition, resulting in sustained high-pressure pulses. The high-precision experimental–numerical framework developed in this study, along with the revealed physical patterns, can provide reliable theoretical support and data references for shockwave damage assessment, underwater structure protection design, and geoacoustic inversion in seabed topographic environments.

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Correlation between dynamic mechanical properties and ballistic resistance of spray-formed 7055 Aluminum Alloy against 7.62 mm ball projectiles

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Abstract

Establishing a correlation between the dynamic mechanical properties of lightweight alloys and their ballistic resistance supports the selection and design of armor materials. In this study, dynamic compression, dynamic shear, Charpy V-notch impact, and ballistic impact tests were conducted on 20 mm spray-formed 7055 (SF7055) aluminum alloy plates prepared by hot extrusion and hot rolling. When impacted by a 7.62 mm ball projectile (with a truncated ogive core), both type plates exhibited a discing damage mode. Analysis shows that discing occurs via a two-stage damage mechanism. The first stage involves crater formation and stable penetration, governed mainly by the in-plane dynamic compressive strength and failure strain of SF7055. The second stage is defined by the projectile approaching the mid-thickness of SF7055, where large bending deformation in the undamaged material initiates rapidly propagating interlaminar shear cracks along the main spalling plane. These cracks interconnect to form a spalling disk, resulting in structural separation. This stage is primarily controlled by the dynamic shear strength and shear failure strain perpendicular to the thickness direction, as well as the dynamic fracture toughness along the thickness direction. By linking dynamic mechanical properties to the ballistic resistance of finite thickness aluminum alloy plates, this work provides theoretical and experimental support for the selection and ballistic-resistant design of armor aluminum alloys.

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Ballistic impact response of basket-weave near α titanium alloy

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Abstract

This study provides a systematic investigation of the ballistic impact response of a near α titanium alloy (TA18) with a basket-weave microstructure over a wide velocity range (599.4–1135.4 m/s). Although basket-weave microstructures are well known for their excellent plasticity and toughness, their ballistic response has not yet been thoroughly explored. A multi-technique approach combining in situ high-speed photography, 3D laser scanning, electron microscopy (SEM, EBSD, TEM), and finite element simulation (FEM) was employed to elucidate the velocity-dependent failure mode transition, microscopic deformation mechanisms, and impact-energy-release behavior. Results indicate a failure mode transition from cratering and projectile rebound at low velocities, to embedding and back-face bulging with cracking at intermediate velocities, and finally to complete penetration at the highest velocity. Quantitative analysis of high-speed imagery identified a critical velocity threshold (~ 1000 m/s) beyond which the spatial extent and intensity of impact-induced energy release surge and plateau, indicating a saturation of the material's reactive capacity. Microstructural analysis reveals a mixed ductile-brittle failure mechanism, characterized by the coexistence of shear/equiaxed dimples and cleavage river patterns, governed by the competition between adiabatic thermal softening and strain-rate hardening. At the highest velocity, localized melting confirms the dominance of thermal effects. Deformation is primarily accommodated by prismatic $\langle a \rangle$ slip and multiple twinning modes (T1, T2, C1), with dynamic recrystallization observed within adiabatic shear bands. Furthermore, the preservation of the Burgers orientation relationship at α/β phase boundaries facilitates effective slip transfer, enhancing damage tolerance. The FEM simulations corroborate the experimental findings, resolving the evolving stress, strain, and temperature fields. This work establishes the structure-property relationships underpinning the superior ballistic performance of basket-weave titanium alloys, highlighting their potential for advanced armor applications.

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Analysis of Damage Characteristics of Spherical Shell Structures Under Underwater Array Charge Explosion

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Abstract

To meet the research demand for damage investigation of underwater vehicle sonar dome structures under underwater array explosion loads, this study adopts the Arbitrary Lagrangian-Eulerian (ALE) multi-material fluid-structure interaction method to carry out a numerical study on the damage of a typical spherical shell structure subjected to simultaneous explosions of three charges. After validating the model effectiveness with experimental data from multiple charge explosion tests, the bubble pulsation characteristics under three arrangement conditions (horizontal, vertical, and equilateral triangular) are systematically analyzed. Special focus is placed on exploring the influence laws of arrangement patterns on bubble merging morphology, pulsation period, and jet direction. Combined with the response time-history curves and plastic deformation contour clouds of the spherical shell structure, the correlation mechanism between the spatial distribution characteristics of explosion loads and the damage characteristics of the spherical shell under different arrangement patterns is revealed.

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Structural topology optimization of honeycomb sandwich panel under ship side collision impact

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Abstract

The side structure of a ship is the most vulnerable region in collision scenarios, often undergoing large deformation or even rupture under severe impact. However, traditional stiffened panels—composed of plating and stiffeners—may not represent the optimal design when lightweight requirements are considered. In this study, a conventional single-side shell with stiffened panels is first selected as the baseline to assess its crashworthiness under impact loading. Subsequently, the side shell is idealized as a solid block of extreme thickness and subjected to topology optimization to determine the optimal material distribution. The optimization results reveal that a honeycomb sandwich panel—featuring an outer skin plate and a core of hexagonal prisms—exhibits superior mechanical performance. Further topological optimization is then applied to this honeycomb sandwich panel to refine the material layout. Based on damage extent and energy absorption criteria, a honeycomb core with variously shaped holes on its inner skin proves to be the most effective configuration, offering improved stiffness-to-weight ratio and enhanced crashworthiness. The findings of this paper provide useful guidance for the design of lightweight ship side structures.

The damage transition mechanism induced by interface effects during the penetration of concrete/rock double-layer targets

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Abstract

Under strong impact loading, the interfacial effect between target layers of different media can alter wave impedance matching and stress wave time histories, thereby affecting the penetration response and damage mechanism of double-layer targets[1,2,3]. In this study, projectile penetration into concrete/rock double-layer targets is studied experimentally, with emphasis on the interfacial effect on reshaping the damage stages of the front and back targets: the shear plugging stage of the front target is weakened or even disappears, the cratering stage of the back target is suppressed, and more target material participates in the tunnel expansion stage with stronger energy dissipation, thereby improving the overall penetration resistance performance. Based on the stress wave reflection and transmission laws caused by the wave impedance difference at the interface, the modified expressions of the interfacial effect on the loading time histories of the front target and back target are established; and the projectile penetration process into double-layer targets is divided into four damage stages, i.e., front target cratering, front target tunnel expansion, back target tunnel expansion, and back target shear plugging, and the calculation method for the stage transition and damage regions under the interfacial effect is provided. Based on these, by combining the principles of energy conservation and minimum potential energy, a penetration prediction model for double-layer targets considering the interfacial effect is established, and it is verified through comparative analysis using the experimental data obtained from this study, experimental results in published literature[2], and traditional classical theoretical models. The results show that the present model can well predict the penetration depth under different conditions, and it is superior to existing models in terms of accuracy and applicability. The model further indicates that the interfacial effect improves the penetration resistance performance of double-layer targets by weakening the front target shear plugging, suppressing the back target cratering, and increasing the proportion of the tunnel expansion stage.

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Study on Load-Bearing/Energy Storage Integration Performance of Core-Sheath Structured Lithium-Ion Fiber Battery Composites for Dynamic Load Environments

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Abstract

To address the challenges of lightweight design and reliability faced by electric vehicles (e.g., aircraft, unmanned aerial vehicles) under dynamic loads such as impacts and vibrations, structural energy storage materials offer an innovative solution[1]. Traditional energy storage devices are prone to structural failure and electrochemical performance degradation under high-speed impacts[2]. Therefore, this study proposes a composite design strategy based on core-sheath structured lithium-ion fiber batteries: fiber electrodes with a core-sheath structure were fabricated by integrating active materials with carbon fibers. Subsequently, an integrated load-bearing and energy storage composite structure was constructed via three key processes: weaving fiber full cells with carbon cloth, lamination, and epoxy resin encapsulation. This design enables carbon fibers to serve the dual functions of conductive current collectors and structural reinforcement phases. Systematic mechanical-electrochemical coupling characterization reveals that the structural battery exhibits relatively excellent comprehensive performance: a tensile strength exceeding 150 MPa, a capacity retention rate higher than 90% after 500 cycles, stable synergistic effects under dynamic stresses of 0 – 150 MPa and simulated impacts tests, intact interfaces, and no significant attenuation in ion transport properties. As an application validation, the prepared structural battery was assembled into the integrated platform of a quadrotor unmanned aerial vehicle, demonstrating reliable power supply performance under dynamic operating conditions. This study not only verifies the feasibility and performance advantages of the structural battery but also provides a new paradigm for next-generation energy storage structures targeting impact resistance and high reliability from the perspective of synergistic design across material, structure and performance, promoting a fundamental transformation of battery systems from independent components to "load-bearing/energy storage" integrated core structures.

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The Parallel Hardening Paradox in High Strain Rate Deformation of 316L Stainless Steel: Micro-mechanisms and Thermo-mechanical Coupling

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Abstract

The dynamic mechanical response of metastable austenitic stainless steels (e.g., 316L) is governed by a complex interplay between strain rate hardening, adiabatic thermal softening, and phase transformation kinetics. A longstanding debate persists regarding the suppression of the Transformation-Induced Plasticity (TRIP) effect under impact loading: is it thermodynamically stabilized by adiabatic heating, or kinetically suppressed by the high strain rate?

This study addresses this fundamental question by employing a novel experimental strategy that decouples temperature and rate effects. By comparing quasi-static (0.0001 s^{-1}), dynamic-adiabatic (1000 s^{-1} , continuous), and dynamic-quasi-isothermal (1000 s^{-1} , incremental) loading paths, we isolate the kinetic limitations from thermodynamic factors.

Experimental results reveal a striking "Parallel Hardening Paradox": the macroscopic strain hardening rate under dynamic loading remains remarkably parallel to the quasi-static regime, despite significant differences in phase evolution. Quantitative EBSD analysis demonstrates that while quasi-static deformation induces approximately 2.3% volume fraction of new martensite, dynamic loading results in an almost fully austenitic structure ($<1\%$ martensite), even when adiabatic heating is minimized ($\Delta T_{\max} \approx 15^\circ\text{C}$). This finding provides compelling evidence that the suppression of the TRIP effect is dominated by kinetic locking—where the extremely short deformation time window limits martensitic nucleation—rather than thermodynamic stabilization.

To resolve the paradox of sustained hardening in the absence of the TRIP effect, we propose a Dynamic Self-Compensation mechanism. Modified Williamson-Hall analysis and GND density mapping reveal that the dynamic regime triggers an explosive proliferation of dislocations (with ρ_{GND} significantly exceeding static conditions) and the formation of nanotwins. This enhanced dislocation accumulation and dynamic Hall-Petch strengthening precisely compensate for both the loss of phase transformation hardening and the onset of adiabatic thermal softening, ensuring the structural stability of 316L under impact.

Keywords

316L Stainless Steel; High Strain Rate; Parallel Hardening Paradox; Kinetic Suppression; Dislocation Compensation

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A Combined Blast–Fragment Loading Test with Independent Control of Overpressure, Impact Velocity, and Arrival Time. Results from tests on dry Aramid Fabrics

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Abstract

Explosions are complex multi-physics phenomena whose effects on materials and structures require a multidisciplinary approach. Historically, the problem has been simplified by separating it into two independent analyses: the assessment of ballistic resistance against fragment impacts and the evaluation of structural response to blast loading. Recent studies have reported synergistic effects arising from the combined action of blast waves and fragment impacts, indicating that the response under combined loading cannot always be inferred from the individual load components [1-6]. However, these interactions have not yet been investigated using a consistent experimental methodology that allows the governing parameters to be independently controlled and systematically evaluated. An experimental setup has been developed to generate the synchronised arrival of a planar blast wave and a Fragment Simulating Projectile (FSP), enabling the realistic simulation of an explosive event corresponding to a specific charge and stand-off distance. The proposed methodology offers independent control of blast overpressure, fragment impact velocity, impact location, and the time interval between the two loads, allowing systematic investigation of their combined effects on material response. The proposed setup is used to evaluate the ballistic resistance of plain-weave aramid fabrics in the presence of blast. The results reveal a time-dependent, phase-sensitive impact resistance, indicating a strong relationship with the target's dynamic response and natural frequencies. The dominant mechanisms are identified as: (i) the kinetic state of the target following blast-induced acceleration, which modifies the relative impact velocity between the projectile and the fabric [7,8]; and (ii) the reduction in the material's load-bearing capacity due to the distributed stress field generated by the blast overpressure.

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Vertebra-Specific Lumbar Fracture Tolerance Under Dynamic Vertical Loading

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Abstract

Underbelly (UB) blast events from improvised explosive devices have led to a rising incidence of lumbar spinal injuries among military vehicle occupants, with compression and burst fractures now predominating [1]. Despite their clinical and operational significance, current spinal injury criteria are largely derived from whole-spine or multi-segment testing and provide limited insight into level-specific fracture susceptibility within the lumbar spine [2]. Moreover, the combined effects of spinal posture, vertebral geometry, and bone quality on injury risk under high-rate vertical loading remain poorly understood.

In this study, level-specific lumbar vertebral fracture tolerance was investigated through a combined experimental and computational approach.

Five cadaveric three-segment functional spinal units spanning L1–L5 were tested under dynamic axial compression to failure and used to validate corresponding specimen-specific finite element (FE) models. The models were validated, accurately reproducing experimental force–displacement responses ($R^2 = 0.93$ – 0.98) and fracture loads (within 10–34%). Parametric simulations were then conducted to quantify the influence of sagittal and coronal spinal postures (flexion, extension, and lateral bending), vertebral geometry (height and cross-sectional area), and areal bone mineral density (aBMD) on fracture tolerance.

The results demonstrate strong level-dependent injury behaviour. Flexion generally reduced the risk of compression fractures at L1, L2, and L4, whereas extension increased susceptibility, while L3 and L5 exhibited distinct responses. Lateral bending significantly increased fracture risk, particularly at L5. Increased vertebral height reduced axial stiffness and fracture load at most levels, whereas greater cross-sectional area consistently enhanced mechanical resistance. Areal BMD emerged as a robust positive predictor of compressive fracture tolerance across all lumbar levels. Survival analysis enabled the derivation of vertebra-specific injury prediction curves, revealing increased resistance in inferior lumbar levels, with L5 remaining uniquely vulnerable.

These findings provide the first vertebra-specific injury tolerance curves for the lumbar spine under dynamic loading and offer critical insights for improving injury prediction models and informing protective system design in defence and aviation environments.

Keywords: Underbody blast; Lumbar spinal injury curve; Biomechanical predictor; Posture; Geometry; Bone mineral density

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Dynamic Response and Energy Absorption of Polyurethane-Filled Folded Conical Dome Core Sandwich Structures

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Abstract

Sandwich structures are widely used for blast and impact protection, yet conventional cores (e.g., foam and honeycomb) often face a trade-off between high energy absorption and an undesirably large initial peak load, which may trigger premature face-sheet damage. This work proposes a polyurethane (PU) foam-filled folded conical dome (FCD) composite sandwich concept aimed at achieving stable progressive collapse, controllable load transfer, and improved blast mitigation.

A novel FCD core with curved crease lines and tailored supporting ribs is designed and fabricated. The mechanical response of FCD units is examined via quasi-static compression and drop-weight impact tests, and then extended to explosive loading through blast experiments and validated finite-element (FE) simulations. Under quasi-static compression, FCD exhibits a relatively low peak force and a stable, symmetric progressive folding mode with uniformly migrating plastic hinges. Parametric studies show that adding three to four constraints effectively suppresses undesired facet unfolding and improves compressive capacity; a three-constraint scheme is selected considering performance and cost. Increasing the number of ribs promotes a more continuous hardening response while preserving progressive collapse characteristics.

Compared with a folded square dome (FSD) core, FCD demonstrates superior load-carrying and energy-absorption performance. Mechanistically, FCD avoids pronounced stress concentration and corner-induced instability and maintains more uniform hinge evolution, leading to better deformation stability and higher specific energy absorption. In axial and oblique drop-weight impacts, FCD shows higher stiffness/peak force and a more continuous energy-absorption path, whereas FSD is more prone to early local buckling due to corner defects, reducing its efficiency.

For the multifunctional composite design, PU foam formulation is optimized by varying the A/B component ratio. Higher ratios improve strength and absorbed energy but increase brittleness; an A:B ratio of 1:1.25 is identified as a balanced solution, yielding a specific energy absorption of 6.226 J/g for the foam material. PU filling significantly enhances the overall resistance and stabilizes the load response of FCD units, with more pronounced strengthening at larger wall thicknesses.

Blast tests and FE analyses indicate that increasing face-sheet thickness improves blast resistance and that FCD sandwiches deform more uniformly than honeycomb and FSD counterparts. Importantly, PU filling markedly reduces back-face deflection; across 30–50 g charge equivalents, peak deflection reduction reaches ~37.5%–56.3% relative to unfilled FCD sandwiches, while also alleviating peak loads by mitigating stress concentration. Partial filling strategies can further balance deformation space, core energy absorption, and face-sheet load reduction, offering a practical route for lightweight, high-performance blast-mitigation design.

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Optimisation and Experimental Validation of Blast Door Panels with Conventional and Advanced Core Configurations

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Abstract

Blast protection is a critical requirement for the safety and resilience of sensitive infrastructure. Blast doors are key protective components for this, and they are often designed with high safety margins. This can lead to excessive weight, increased material consumption, and elevated costs. Traditional designs using steel [1] and concrete [2] are well proven to provide the required protection, however they are heavy. More novel designs, incorporating more complex sandwich cores have been developed in research, aiming to improve the efficiency of the systems [3].

This study furthers the investigation of blast door panels subjected to bare-charge blast loading, using both finite element analysis (FEA) models and experimental validation. Two complementary design strategies are examined. The first focuses on conventional steel blast door configurations, consisting of dual steel plate skins reinforced by stiffeners, and explores the influence of key parameters such as panel thickness, number of stiffeners, and the presence of ironmongery. The second strategy examines alternative core configurations, replacing traditional stiffeners with engineered honeycomb cores with the aim of improving energy absorption and deformation control.

Finite element models were developed using OpenRadioss. Model validation was initially carried out using data from published experimental studies, with good agreement achieved in terms of peak deflections. A comprehensive parametric study was then performed to identify efficient configurations, considering performance metrics such as central deflection, rotation, internal energy, and permanent deformation.

Based on the numerical investigations, eight representative panel designs were selected for experimental assessment: four panels based on optimized conventional stiffener layouts and four panels incorporating advanced honeycomb core configurations. Full-scale blast tests are being conducted to enable direct performance comparisons between the different design approaches. The experimental programme involved a 8 kg TNT equivalent charge detonated at an approximate stand-off distance of 2.5 m. The test results were used to assess overall structural response and to refine the numerical models.

The results provides valuable guidance for the development of lighter, more material-efficient blast door systems. The outcomes of this work contribute to the ongoing optimisation of protective structures and support the adoption of advanced core technologies in future blast-resistant design.

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Failure and Fragmentation of a Brittle Beam under Pure Bending

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Abstract

When a slender brittle beam is subjected to bending loads approaching its ultimate strength, it typically fails instantaneously, accompanied by the release of bending waves. Under rapidly applied bending loads, the beam may fracture into multiple segments, leading to its dynamic fragmentation. The resulting fragment lengths depend on the beam's stiffness, flexural strength, fracture toughness, as well as the rate at which bending load is applied.

In this study, a theoretical analytical framework is developed to investigate the dynamic fragmentation of brittle beams under rapid bending. Timoshenko beam theory is employed to describe the beam's dynamic bending deformation and the associated propagation of bending waves, while a cohesive fracture model incorporating flexural strength and fracture toughness is adopted to characterize the bending fracture mechanism. Based on these formulations, a system of governing equations describing the bending-induced failure and fragmentation of the beam is derived.

The governing equations are hyperbolic by nature. A numerical algorithm based on finite-difference discretization along the characteristic lines is developed, and the corresponding computational code is implemented. Numerical simulations are conducted to capture fracture initiation, bending-wave propagation, fragmentation, and unloading of a brittle beam subjected to a uniform bending strain rate. These simulations yield the mean fragment length and the characteristic features of the fragment-length distribution generated by bending fragmentation.

The numerical results demonstrate that the nondimensional fragment size decreases monotonically with increasing nondimensional bending strain rate, a trend that is qualitatively consistent with fragment-size scaling laws derived from the principle of local energy conservation. Furthermore, the fragment-size distribution associated with bending fragmentation can be reasonably approximated by a three-parameter Weibull distribution.

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Masonry Walls under Dynamic Loading – Analysis of two Lightweight Retrofitting Systems

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Abstract

Masonry, besides timber and glass, is one of the oldest building materials. Masonry walls made of natural stones or bricks have shaped cityscapes over centuries and can still be found in many urban areas. At the present time the well-established material represents a new challenge for building designers: how to upgrade its resistance against extreme lateral loading?

Due to several serious explosion events in the last decades, there is an increasing demand for protective structures in urban areas, especially for existing buildings. The various events showed that masonry walls are relatively vulnerable structural members in case of blast loading. In addition, debris flight emerged as one of the major hazards for people that witness such an incident. Thus, retrofitting concepts need to be found that meet several requirements such as strengthening the brickwork with minimum effort in planning and design, preserving the architectural appearance and basic structure, and minimizing additional dead loads.

The proposed paper addresses this demanding task. It presents the analysis of two lightweight retrofit systems under blast loading. Advanced blast wall panels as well as the integration of CFRP-straps are investigated using a series of shock tube tests. Both systems show significant improvement of the explosion resistance of the tested masonry wall elements and thus validate their applicability for protective structures.

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A Dual-Network Framework to Optimize Lattice Protective Structures Under Impact Loading Conditions

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Abstract

Protection against low- to high-velocity impact increasingly rely on architected materials to reduce mass and increase energy absorption. Periodic Lattice structures are particularly attractive because their response can be tuned working on unit-cell topology, yet practical design remains challenging. In fact, the design space is high-dimensional, and the link between unit-cell geometry and full-lattice performance is strongly nonlinear.

Recent advances illustrate the potential of data-driven design. Graph-based generative models can unify large truss design spaces into continuous latent representations for fast inverse design [1], curvature-based mechanics can provide geometric metrics for shell-like architectures [2], and graph neural networks can learn structure–property relations from large FE databases [3]. In parallel, hypernetwork-driven constitutive models have shown how adaptable, physics-informed neural surrogates can generalize across metamaterial geometries under finite deformation [4].

Building on these ideas, an integrated lattice framework for impact-oriented energy absorption that couples automated dataset generation, surrogate training, and design exploration within a single workflow is here presented. The framework is constituted of a dual-network architecture (Figure 1): a Unit-cell Optimization Network (UON) acting as an inverse surrogate that maps target lattice-level performance descriptors to candidate unit-cell geometries, and a Performance Surrogate/Optimization Network (PSON) acting as a forward surrogate that predicts the corresponding structural response and validates candidates. Both networks are trained on automatically generated FE datasets spanning geometry, relative density, and loading conditions. Material dependence is handled through re-training on experimentally characterized polymer properties, and the predicted responses are assessed against dedicated experimental impact tests. Representative inverse-designed unit cells and their forward-validated responses (Figure 2) illustrate how the proposed generator–validator scheme accelerates topology exploration and enables end-to-end optimization from unit-cell design to lattice-level performance.

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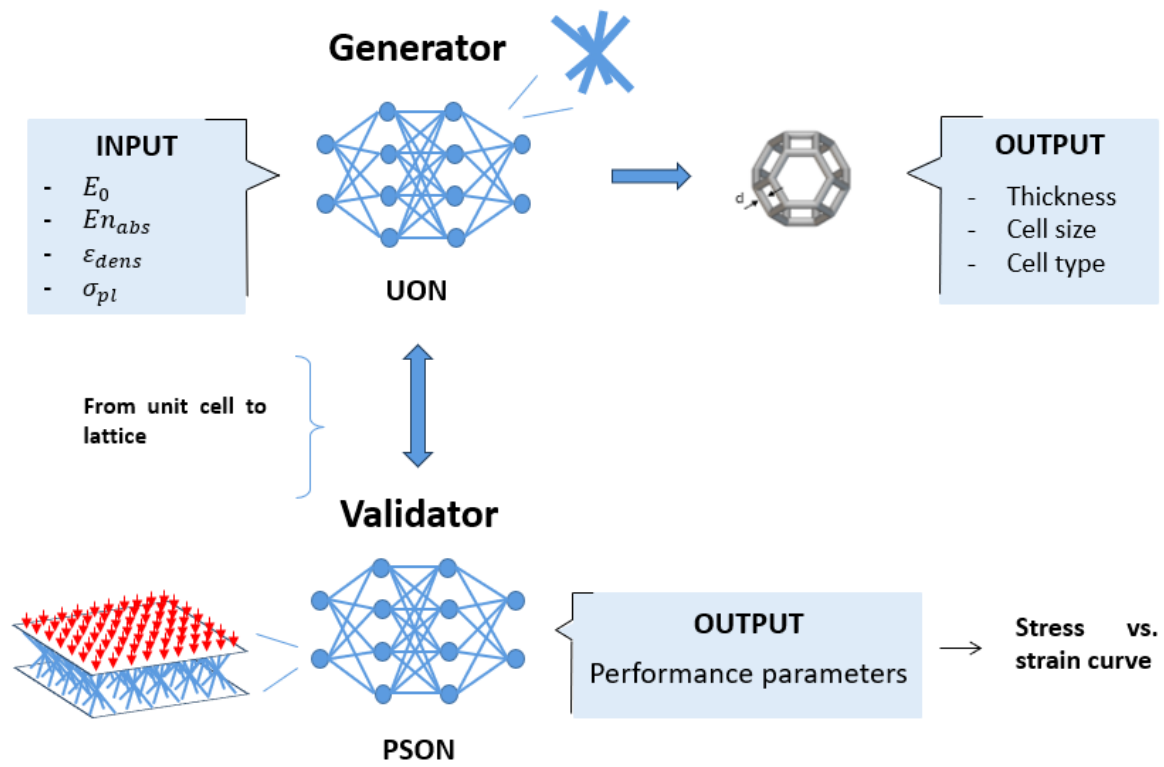


Figure 1, illustration of the dual network framework.

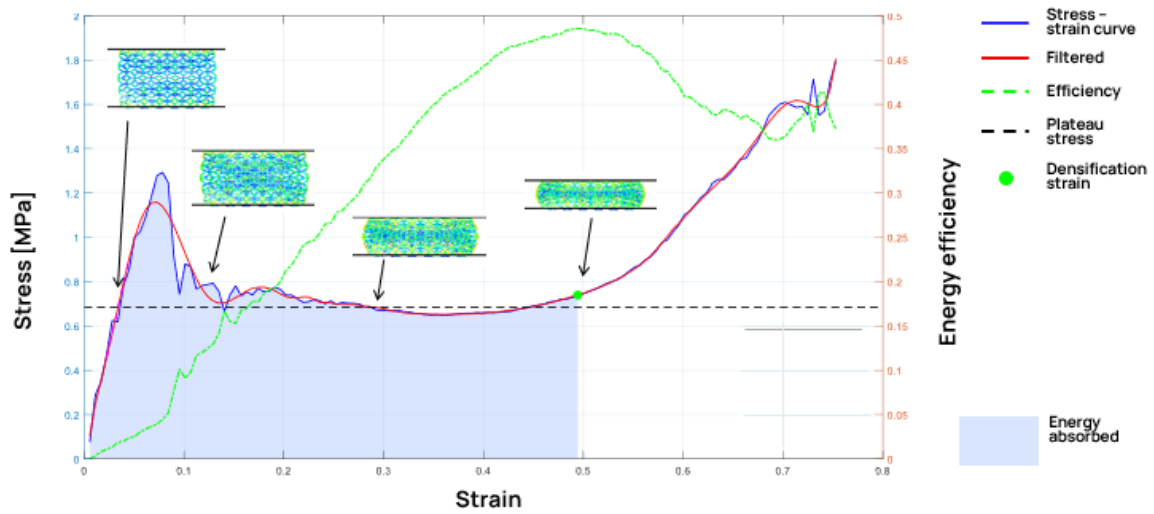


Figure 2, lattice response to high-strain rate loading condition.

A Data-Driven Framework for Rapid Impact Deformation Prediction

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Abstract

Rapid and reliable prediction of structural deformation under impact loading is critically needed for impact-resistant design and safety assessment, particularly in applications where extensive experimental testing is impractical. This study proposes a machine-learning-based collaborative framework that integrates impactor material classification and plate deformation prediction, enabling efficient and reliable estimation of the maximum central deformation of plates subjected to impact.

A impact database is established by integrating experimental data from multiple impact scenarios covering a wide range of velocities and material responses. To improve model generality and reduce platform-dependent variability, physically motivated dimensionless parameters are introduced alongside conventional geometric and material descriptors. These parameters form multiple input schemes for machine learning models based on ensemble methods and neural networks.

The results demonstrate that prior classification of impactors according to their dominant mechanical response significantly enhances deformation prediction accuracy. Compared with direct regression approaches and conventional semi-empirical models, the proposed framework achieves enhanced predictive performance and robustness. Further analysis indicates that the inclusion of dimensionless groups is critical for capturing the underlying impact mechanics and enhancing model interpretability. The potential of data augmentation techniques for small-sample impact datasets is also explored.

The proposed framework provides a practical alternative to extensive experimental testing, allowing rapid estimation of deformation limits and offering insight into impactor target material interactions. This work highlights the capability of data-driven methods to complement classical impact mechanics and supports their application in transportation, aerospace, and infrastructure safety design.

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Dynamic Mechanical Characterization and Constitutive Modeling of 3D-Printed Polyurethane: An Infill-Dependent Study

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Abstract

Additively manufactured thermoplastic polyurethane (TPU) structures are increasingly utilized in impact protection systems due to their tunable energy absorption capabilities [1]. However, optimizing these structures requires a deep understanding of how infill density influences dynamic mechanical response and structural efficiency [2]. This study investigates the dynamic compressive behavior of 3D-printed polyurethane with four specific infill rates (20%, 36.9%, 64%, and 100%) using the Split Hopkinson Pressure Bar (SHPB) technique tailored for soft materials [3]. The experiments were conducted over a strain rate range of approximately 700 to 4500 s⁻¹. Experimental results reveal that the material exhibits significant strain-rate sensitivity and varying degrees of plastic hardening. A distinct trade-off between structural strength and ductility was observed: while the fully dense specimens (100%) exhibit the highest peak stress, reducing the infill rate significantly extends the failure strain. To theoretically describe these dynamic responses, a rate-dependent elastic-plastic constitutive model was employed. The model assumes a linear elastic response defined by the dynamic Young's modulus, followed by plastic flow described by the Johnson-Cook (J-C) plasticity model [4]. The model parameters, including the yield strength, strain hardening modulus, and strain rate sensitivity coefficient, were calibrated individually for each infill rate based on the experimental data. Validation results demonstrate that this macroscopic J-C model can accurately predict the flow stress and dynamic hardening behavior of the 3D-printed TPU structures, consistent with modifications for polymeric materials [5]. This work confirms the applicability of the J-C framework for variable-density soft lattices and provides essential parameters for impact simulation.

Keywords

3D-printed polyurethane; SHPB; Infill rate; Johnson-Cook model; Dynamic constitutive modeling.

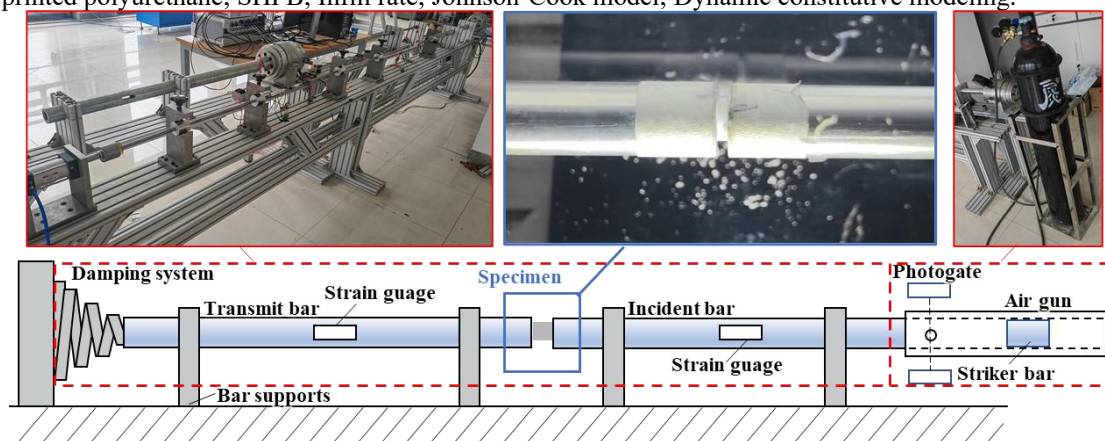


Fig. 1. Schematic diagram and physical experimental setup of the Split Hopkinson Pressure Bar (SHPB) system used for dynamic compression testing.

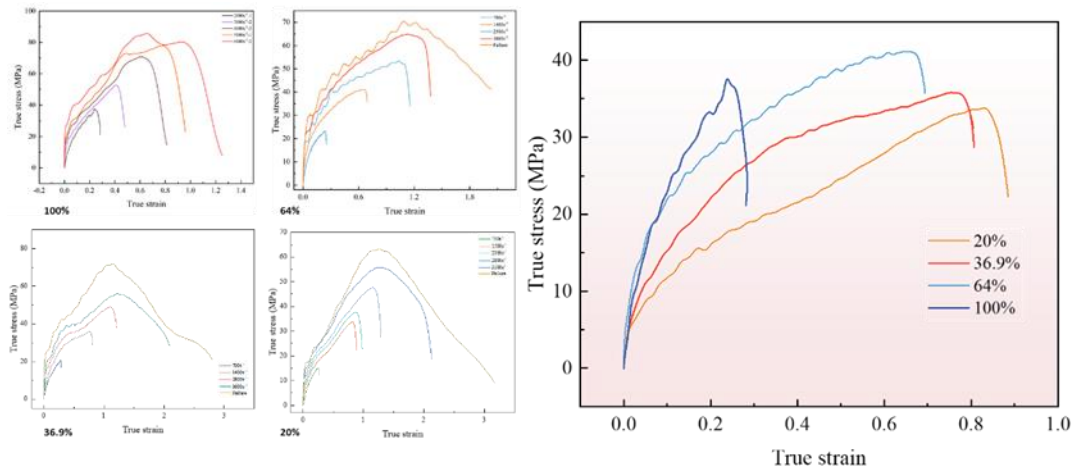


Fig. 2. Dynamic compressive experimental results of 3D-printed TPU: (Left) True stress-strain curves at various strain rates for each infill density; (Right) Comparison of mechanical response across different infill rates at a strain rate of 2000 s^{-1} .

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Behaviour of Multi-Layer 3D Printed Reinforced Concrete Components under High Dynamic Load

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Abstract

In recent years, 3D printing has established itself as an innovative method in the construction industry, particularly to produce complex geometries and customised components. The use of innovative manufacturing technologies in the construction industry supports the realisation of fully automated manufacturing processes with the aim of improving the execution time, individuality and quality of the components. This study investigates the behaviour of multi-layer 3D printed reinforced concrete components after contact detonation, an issue of increasing importance for applications such as protection structures for critical infrastructure. As part of the research, four reinforced concrete slabs with different layer structures and compression orientations (vertical and horizontal) were fabricated and tested under contact detonation. The main objective was to evaluate the mechanical properties such as strength, ductility and energy absorption capacity of the 3D printed samples and compare them with conventionally fabricated reinforced concrete components [1]. The contact detonation results show that the coating structure (thickness and filler) and the orientation of the internal structure have a significant influence on the behaviour of the component at high loading rates. It was also found that the interlayer bond plays a critical role: weaknesses in the interlayer bond can lead to premature failure, especially at high loading rates. Damage analysis of the blasted 3D printed plates using high-speed cameras and non-destructive and destructive testing methods provided detailed insights into the failure mechanisms of the component [2]. By adapting the component structure and combining different materials inside the component, the resistance of the components to highly dynamic stresses can be further optimised using the advantages of the 3D printing process. The study thus makes an important contribution to the understanding and further development of 3D printing technology in the construction industry and provides valuable approaches for practical applications in highly dynamic environments.

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Blast Analysis of Underground Structures and Metro Stations Subjected to Internal Explosions

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Abstract

Metro stations and underground rail structures are considered attractive targets of terrorist activities in the recent decades as they are typically public areas with high density of population and limited opportunity for effective security access controls. The previous terrorist attacks on rail systems have produced significant consequences ranging from issues to evacuation and service disruption to property collapse, injuries, and fatalities by large-scale attacks. For instance, the bomb at Victoria Station, London on February 18, 1991, caused 51 injuries including one fatality. The series of bombings exploded on four trains in and around Atocha Station in the city's centre of Madrid, Spain in 2004 caused the death of 191 people and more than 1800 injuries. In 2003, a bomb placed on a bicycle exploded near the Vile Parle train station in Mumbai, India injured 28 people and caused one fatality. These attacks have raised enormous concerns on security controls and protective designs of railway stations and underground structures under the effect of a blast event during its service life. Recently, with the development of computational power and experimental systems, dynamic performance of structure under the effect of blast pressure has been fairly well understood but mainly at a component level, e.g., reinforced concrete beams or columns, or steel elements, whilst the blast performance of the global building structure still needs to be further investigated. Study on the blast performance of underground structures and underground metro stations under blast loads is still very limited in the open literature due to lack of understanding of structure-soil interaction during the blast event and the availability of numerical modelling tools. Underground structures typically consist of complex structural elements where they are used to support structure and buildings above. The collapse of these structures may also lead to a catastrophic consequence with the collapse of the station and surrounding buildings. Additionally, as these structures are under ground level, the local effect of the blast event, i.e., concrete flexural cracks through the thickness of structural elements, may also produce a flooding risk to the entire railway system with significant economic impacts. Therefore, in this study, lessons learned from the design of metro stations in previous projects undertaken by K&C will be presented. Key considerations that need to be considered in the design of underground structures and railway stations including material model for soil/ rock components, structure-soil interaction, post-blast performance of structure, flooding risks produced by a blast event will be reported and discussed. An example of a High-Fidelity Physics-Based (HFPB) numerical simulation developed for a tunnel boring machine (TBM) lining and structural caverns subjected to a blast event will also be presented in this study.

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Experimental and Numerical Study of Steel-concrete-steel Composite Walls with CFST Boundary Elements under Near-fault Explosions

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Abstract

The threats of blast loading involved in accidental and intentional events have attracted more public concerns over the past decades. Steel-concrete-steel (SCS) composite structures have shown considerable potential promise in the field of protective engineering. This paper investigates the dynamic response and blast resistance of SCS composite walls reinforced with two different types of CFST boundary elements under near-field blast load. Six specimens, including five SCS specimens and one normal concrete (NC) specimen, were fabricated with the same geometric dimensions and tested in the field with cylinder charges under the scaled distances of 0.25 m/kg^{1/3} and 0.29 m/kg^{1/3}. The incident/reflected overpressure, the velocity and the displacements of specimens were measured during the experiment. Finite element models with the implementation of multi-material Arbitrary-Lagrangian-Eulerian (MM-ALE) algorithm were built to demonstrate the spatial distribution of shock waves and the failure modes of SCS panels. The results indicate the composite specimens exhibit superior blast resistance compared to the NC specimen. In addition, the CFST boundary elements can effectively improve the blast resistance of SCS composite walls, which can promote the application of SCS walls in the real protective structures.

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Influence of water saturation on concrete under projectile impact

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Abstract

Concrete behavior has been extensively studied over the past 30 years. However, due to its porous and highly heterogeneous nature, significant uncertainties remain regarding its mechanical response, particularly under extreme loading conditions. The unreacted water remaining after hardening phase has shown to strongly influence the limit state curve of the material during quasi-static triaxial tests [1] and dynamic quasi-oedometric tests [2]. In saturated samples, the shear resistance is significantly lower than in dry ones. It has been proposed that these observations are due to an increase in water pressure within the saturated material porosities. However, to date, this effect has only been observed at material scale or via numerical simulations of striker impacting plain concrete target and considering different material properties for dry and saturated concrete [3].

This study aims to highlight the importance of water content during impact tests by using high velocities, ranging from 600 to 650 m/s, and a hemispherical projectile, allowing to reach hydrostatic pressure levels greater than 1 GPa. Two concrete formulations exhibiting the same static uniaxial compression limit (40 MPa) but different porosity levels are investigated under both saturated and dried conditions. The experiments are conducted using a gas launcher and monitored with high-speed cameras and a doppler radar, allowing accurate tracking of the projectile deceleration within the concrete target. Two effects are investigated: first, the presence of water in concrete porosities by comparing the same concrete formulation in dried and saturated conditions, and secondly, the level of water content by comparing the two saturated concretes with different porosities. The results are then compared with predictions from FEM simulations performed using the software Abaqus and the DFH-KST model. The material parameters are deduced from quasi-oedometric tests conducted under quasi-static and dynamic loading for both saturation conditions.

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Experimental study on impulse saturation of metal plates under shock wave loads and the application of pulse equivalent method

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Abstract

Theoretical analysis on impulse saturation in shock loading of metal plates continues to be a topic of focus. Approaches based on employment of a membrane factor have been proposed to determine the large plastic deformation of beam/plate structures[1–4]. However, in simplifying analysis, many such studies typically focus on pulse loads corresponding to simple analytical forms. While direct theoretical analysis is difficult for loading pulses of complex time histories, the progressive equivalent method [5] proposed in recent years serves as an effective tool to address this. To further verify the effectiveness of the saturation analysis method and the progressive equivalent method, experiments on pulse-loaded plates were conducted. First, static and dynamic stress-strain curves of plate materials were obtained respectively using a universal testing machine and Hopkinson bar tests, and the material parameters were then derived based on fitting the Johnson-Cook constitutive model. Subsequently, the large plastic deformation response of aluminum alloy and mild steel plates subjected to shock waves of different intensities was systematically investigated experimentally using a shock tube arrangement. The pressure-time history of the shock waves and the deformation-time history of the plate center were measured, and the phenomenon of impulse saturation was analyzed. Based on the loading parameters obtained from experiments, as well as structural material and dimensional parameters, a method for rapid estimation of the large plastic deformation response of structures under intense dynamic shock wave loading was established. It takes into account material strain rate and strain hardening effects, and incorporates saturation analysis and the progressive equivalent method. The plastic deformation of metal plates subjected to actual complex pulse loads was calculated using the proposed methods, and the theoretical results display good agreement with experimentally measured deformations and finite element simulations based on both the actual and the simplified equivalent load pulses. This indicates that assumption of rigid-plastic material behavior together with employment of the equivalent pulse load method, constitutes a highly effective analytical tool for rapid preliminary engineering design and evaluation of shock-loaded structures.

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Impact response of Cassini Oval Aperture Auxetic Metamaterials

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Abstract

Recent advances in the protective design of cellular auxetic metamaterials against impact loading have highlighted microstructural configurations capable of reducing stress levels and mitigating subsequent plastic deformation or fracture. In particular, Cassini oval aperture metamaterials have been shown to exhibit superior static performance compared with other conventional auxetic architectures [1,2]. While their static behaviour has been extensively investigated, their response under dynamic impact loading has remained largely unexplored. In this study, we assess the performance of Cassini oval aperture auxetics subjected to dynamic impact conditions. Given that the mechanistic performance of this class of metamaterials under static loading already surpasses that of alternative morphologies, such as lattices with elliptical apertures, we demonstrate that high-negative Poisson's ratio (NPR) microstructures are also capable of sustaining high impact loads, thereby establishing their potential for a wide range of engineering and design applications. Experimental testing and finite element analyses of metallic Cassini oval lattices reveal that internal geometric parameters – including aperture curvature ratio, porosity, and isotropy – play a critical role in governing indentation resistance and impact resilience. Notably, microstructures with high curvature ratios are shown to withstand striker impacts at moderate velocities without exhibiting plastic deformation or fracture. Furthermore, machine learning-based optimisation is employed, using stress deviatoric invariants, principal stresses, maximum shear, and front-face deformation signature as objective criteria to quantify performance and minimise indentation.

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Finite Element Modelling of ceramic-based composite ballistic armour under high-velocity impact: design comparison and sensitivity analysis

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Abstract

Armour-piercing (AP) ammunitions are specifically designed to exploit their large kinetic energy to penetrate through thick and high-toughness armour, posing significant threat to armoured vehicles and, crucially, the safety of their occupants. Passive ballistic armour is thus engineered to absorb and dissipate the energy of an incident projectile to stop it before full penetration is achieved. The armour effectiveness depends strongly on its design, its configuration, and the employed materials, all of which govern its high-velocity impact behaviour. It is therefore clear how accurate and reliable computational models, supported by calibrated material constitutive equations and validated against experimental data, are of paramount importance for the design of such systems, benefitting safety and fostering innovation.

In this work, a case study involving ceramic-based composite ballistic protections impacted by 14.5×114 mm AP-B32 projectiles at velocities of 911 ± 20 m/s is presented. The investigated armour is composed of a ballistic aluminium backing plate and a layer of spaced hexagonal alumina tiles, encapsulated within a filler material. Different backplate-to-tile and tile-to-tile spacing were investigated as well as different impact angles. Sensitivity analyses of the numerical and material parameters were conducted to assess their influence on projectile and armour deformation, failure, and erosion mechanisms, depth of penetration, and overall protective performances. The simulations successfully reproduced the experimentally observed response and key physical phenomena, demonstrating the capability of the modelling approach to provide reliable predictions and support the development of safer and more effective ballistic protection systems.

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Experimental and numerical comparative study on the crashworthiness of pristine and recycled 3D-printed fiber-reinforced lattice structures

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Abstract

In recent years, increasing attention has been given to 3D-printed structures as crash-absorbing components. The variety of materials and structures that can be built with additive manufacturing techniques allows almost endless design possibilities. The energy-absorbing performance of metallic and polymeric lattice structures has been proven to be comparable and even superior to that of conventional engineering solutions [1]. However, significant work needs to be conducted on the crashworthiness evaluation of these structures, with a focus on strain rate dependency and high-strain-rate behavior to assess their real potential. Recycling plastics has become more important in recent years due to the continuous rise in plastic production and the high pollution due to incorrect disposal. Hence, additive manufacturing can be one of the possible solutions to mitigate this global concern, providing ways to process end-of-life plastic products [2], [3]. In this work, 3D-printed lattice structures built from both pristine and recycled short carbon fiber-reinforced PA12 are tested under quasi-static and high-strain-rate conditions, investigating their crash-absorbing performance. Two different printing techniques are employed: FFF 3D printing is used for the pristine material, while FGF 3D printing is used for the recycled material. A cellular structure with a cubic elementary cell, where the diagonal of the cube is vertically oriented, is chosen based on previous evaluation by the authors. Three different densities (200 g/l, 300 g/l, and 400 g/l) are built and tested to observe the effect of different structures on the energy-absorbing behavior in different strain rate conditions. Cylindrical specimens with a diameter of 40 mm and a height of 50 mm are chosen to represent a sufficient number of cells, helping to understand the overall behavior of the structure. A direct impact Hopkinson pressure bar apparatus is employed, with a wave separation technique and high-speed cameras. Such long specimens would require long bars to achieve sufficient compression displacement to analyze the energy-absorbing properties of the structures. The implementation of a wave separation technique helps reduce the length of the experimental apparatus from approximately 15 m to just 3 m (or less if needed) [4]. The effect of the strain rate on the 3D-printed fiber-reinforced structures depends both on the material and the density of the structures [5]. Recycled material proves to suffer from considerable embrittlement due to the increase of strain rate, with a relevant decrease of the specific energy absorbed of up to -25% for the 300 g/l density. Conversely, pristine material shows a positive effect of the increased strain rate, improving energy absorption up to 22% for the highest density. The behavior of the structures is shown to be dependent on microstructural features such as porosity of the printed material, which differs between the pristine and recycled cases. The high level of porosity observed for the pristine material is believed to enhance the deformability of the structure, preventing excessive failure and enhancing energy-absorbing features [6], [7]. Finally, anisotropic finite element models are developed, which are able to simulate the behavior of the structures, reproducing the main aspects of their high-strain-rate behavior with good accuracy. Both the energy absorption behavior and the load evolution during the compression tests are captured by the finite element model, which is completed by an erosion failure criterion that is tuned based on the specimens' density.

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Effect of impact velocity on deformation mechanism of SAC305 lead-free solder

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Abstract

In the automotive and aerospace industries, electronic products are frequently subjected to high-speed impact loads. As solder joints are among the most vulnerable components in electronic packaging, their reliability is critical for the uninterrupted operation of these devices. This study investigates the mechanical behavior and deformation mechanisms of SAC305 lead-free solder under medium-to-high strain rates. Dynamic impact experiments were performed using both extra-long and conventional split Hopkinson pressure bar (SHPB) systems. Scanning electron microscopy (SEM) and electron backscatter diffraction (EBSD) techniques were employed to characterize the microstructural evolution of the material. The macroscopic stress-strain response reveals that the flow stress increases with the strain rate, indicating a positive strain rate sensitivity, with a distinct transition occurring at strain rates exceeding 2300 s^{-1} . Microscopic characterization demonstrates that both twinning and dynamic recrystallization are highly sensitive to the strain rate. During the early stages of deformation (at 5% strain), elevated strain rates significantly promote twin nucleation and induce dislocation annihilation, leading to transient material softening. Subsequently, the proliferation of twin boundaries impedes dislocation slip, resulting in pronounced material hardening. Consequently, at strain rates above 2300 s^{-1} , the strain-hardening rate curve exhibits an initial decrease followed by an increase. Furthermore, the extensive twinning leads to a high-intensity texture at approximately 28° from the center of the (004) pole figure. To accurately describe the material's behavior across a wide range of strain rates, a plasticity model incorporating Johnson-Cook strain rate dependence and a Voce strain-hardening law was developed. The proposed constitutive model demonstrates excellent agreement with the experimental true stress-strain curves. Finally, the optimized model was implemented in ABAQUS via a user-defined material (VUMAT) subroutine, providing a reliable numerical tool for evaluating the reliability of electronic packaging devices under complex dynamic impacts.

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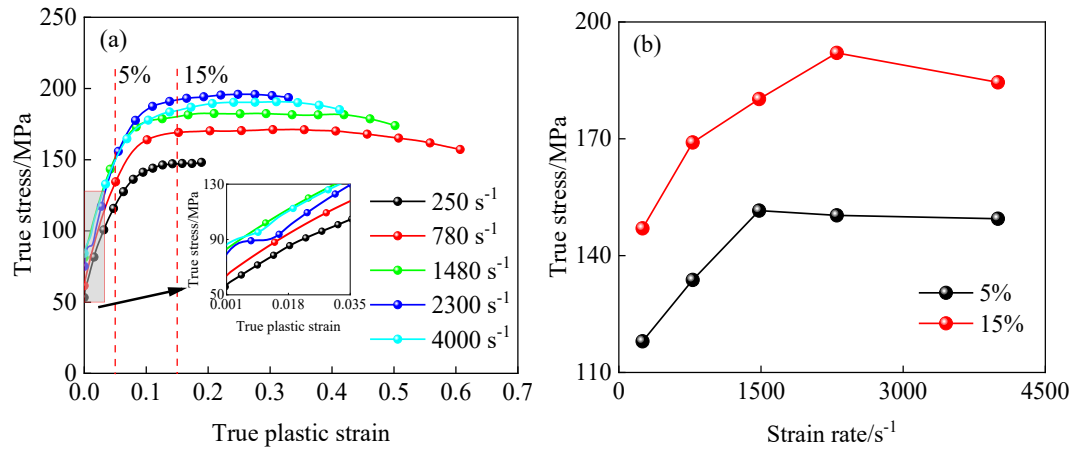


Fig. 1 (a) True stress-true plastic strain curves of Sn-3.0Ag-0.5Cu solders, (b) The relationship between strain rate and true stress under 5 % and 15 % strain

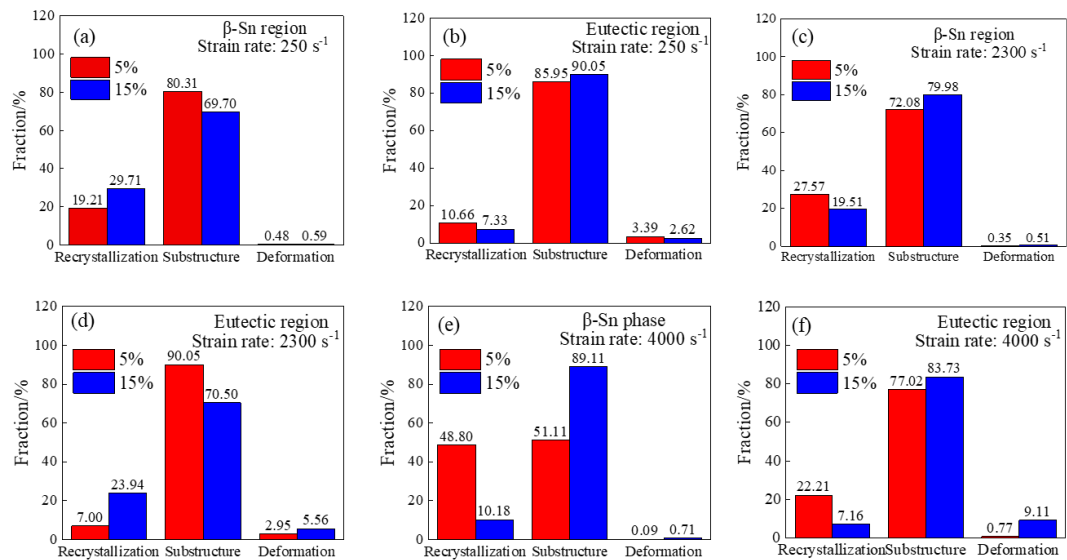


Fig. 2 Histogram of recrystallization, substructure and deformation: (a) 250 s⁻¹, β -Sn region; (b) 250 s⁻¹, Eutectic region; (c) 2300 s⁻¹, β -Sn region; (d) 2300 s⁻¹, Eutectic region; (e) 4000 s⁻¹, β -Sn phase; (f) 4000 s⁻¹, Eutectic region

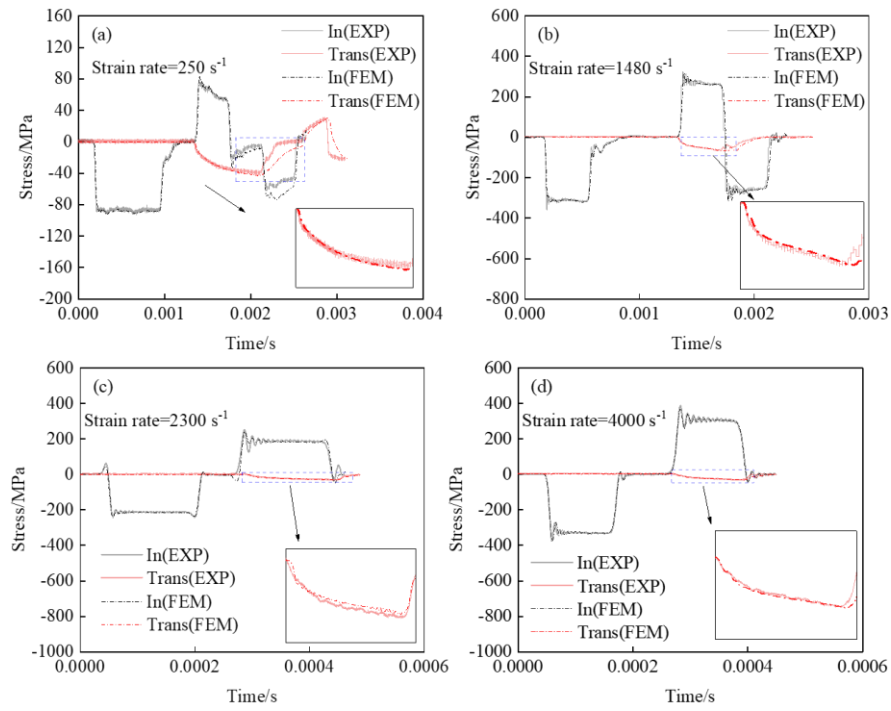


Fig.5 Comparison of stress signals between experiments and simulations

Topologically Integrated Helical Sponge Bio-Hybrid Lattice with Enhanced Dynamic Strength and Energy Absorption

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Abstract

Lattice structures are widely explored for impact protection and energy absorption, yet achieving stable deformation and efficient energy dissipation under dynamic loading remains challenging [1-3]. In this study, a helical sponge bio-hybrid lattice structure (HSBLS) is proposed by topologically integrating the skeletal architecture of the deep-sea glass sponge (*Euplectella aspergillum*) [4,5] with the Bouligand-type helicoidal structural features of mantis shrimp dactyl club [6,7]. The structure was fabricated by selective laser melting (SLM), and its quasi-static and dynamic compressive responses were systematically investigated using a universal testing machine and a direct-impact Hopkinson pressure bar (DHPB), covering low (0.01 s^{-1}), intermediate (100 s^{-1}), and high (1200 s^{-1}) strain-rate conditions. Full-field deformation was monitored by digital image correlation (DIC) to validate the applicability of the DHPB method and the single-wave data reduction procedure for this class of structures. The results show that, when the impact velocity is below 51 m/s , stress equilibrium is largely maintained after the initial transient stage and inertial effects remain limited, indicating that the measured stress-strain curves can still reliably characterize the effective mechanical response of the structure. Compared with the conventional sponge-based lattice structure (SBLS), the proposed HSBLS exhibits improved high-rate performance, with increases of 18.4% in initial strength and 23.2% in energy absorption efficiency while maintaining stable mechanical behavior. Furthermore, finite element simulations were performed in Abaqus/Explicit to elucidate the deformation modes and failure mechanisms in conjunction with the experimental observations. The simulations and experiments consistently show that HSBLS suppresses stress drops caused by nodal failure, promotes a more stable progressive collapse mode, and thereby significantly enhances energy dissipation capability. These findings reveal the deformation and energy absorption mechanisms of bio-inspired sponge-like lattice structures under dynamic loading and provide a pathway for the design of high-performance energy-absorbing metamaterials.

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Impact Mechanical Behavior and Energy Dissipation Analysis of Rock-Concrete Composites with Different Interface Roughness

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Abstract

Rock-concrete composites, as key structural elements in underground engineering and protective systems, exhibit impact resistance governed by the coupled effects of interface roughness and impact loading. This study aims to clarify the multiscale mechanisms by which interface roughness regulates the dynamic response and energy conversion of rock-concrete composites. Four rock-concrete composites with different interface roughness levels (equivalent JRC ($eJRC$)=0, 2, 4, and 6) were prepared, and Split Hopkinson Pressure Bar (SHPB) tests were conducted at impact air pressures of 0.10, 0.15, and 0.25 MPa. Based on the dynamic stress-strain curves, the dynamic compressive strength, peak strain, deformation modulus, and energy partitioning were systematically evaluated. In addition, the impact-induced fragmentation characteristics and pore-structure features were investigated through fractal-dimension analysis and nuclear magnetic resonance (NMR) testing. The results show that both the dynamic compressive strength and deformation modulus increase approximately linearly with interface roughness, with the most pronounced enhancement occurring at high strain rates. The unit volume energy density first increases and then decreases with roughness, reaching a maximum at $eJRC=4$. Meanwhile, the energy reflection coefficient is minimized at $eJRC=4$, indicating the most effective energy dissipation and wave-energy transmission into the specimen. As the impact air pressure increases, the failure mode evolves from localized failure to overall failure and ultimately to pulverization; higher roughness can delay failure development and improve structural integrity. Fractal-dimension and NMR results further reveal that moderate roughness promotes crack propagation while suppressing the formation of large pores, thereby enhancing mechanical performance at the mesoscale. Overall, this study elucidates the multiscale mechanisms by which interface roughness controls the dynamic response and energy conversion of rock-concrete composites, providing theoretical support for the design of impact-resistant structures.

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Dynamic behavior and damage mechanism of white sandstone under cyclic impact and acid-base erosion

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Abstract

To investigate the degradation behavior and damage mechanism of sandstone under acid-base erosion and cyclic impact, a series of constant-amplitude impact tests were conducted on acid-base-eroded white sandstone using a Split Hopkinson Pressure Bar (SHPB) test device at four impact pressures, including 0.12 MPa, 0.125 MPa, 0.13 MPa, and 0.135 MPa. The effects of impact number, stress-strain response, deformation modulus, and energy evolution were analyzed, and a cumulative damage factor was defined based on the Lemaitre strain equivalence principle. Results indicate that both erosion and impact pressure significantly affect the impact resistance of sandstone. The intact specimens endured up to ten impacts at 0.12 MPa, whereas eroded specimens failed after fewer than two impacts at 0.135 MPa. All stress-strain curves exhibited rebound behavior after the peak. With increasing impact cycles, peak stress and deformation modulus decreased by up to 57.1% and 86.1%, while peak strain, average strain rate, and cumulative specific energy absorption value increased to 0.136, 75.95 s⁻¹, and 1.98 J·cm⁻³, respectively. The cumulative damage factor showed a strong negative correlation with dynamic peak stress ($R^2 > 0.93$), confirming that acid-base erosion and higher impact intensity accelerate crack propagation and exacerbate dynamic failure.

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Projectile–Target Coupled Fragmentation and Energy-Partition Mechanisms of Ceramic/Metal Composite Armor under High-Velocity Penetration

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Abstract

Addressing the critical bottlenecks of unclear energy dissipation mechanisms and the underestimated contribution of dynamic projectile core fragmentation in ceramic/metal composite armor under high-velocity penetration, this study investigates the vertical penetration of 12.7 mm armor-piercing incendiary projectiles into 15 mm SiC/6 mm Q235 composite targets. By combining ballistic tests (across a 400–800 m/s velocity gradient) with high-fidelity 3 D explicit dynamic modeling in ANSYS/LS-DYNA, the research employs the JH-2 ceramic constitutive model and the Johnson–Cook metal constitutive/failure model. Model reliability is validated through mesh convergence analysis and comparisons of typical ballistic parameters, including ceramic cone dimensions, back face signature (bulge) height, and residual core mass. Building on this, an energy decomposition framework for the projectile-target system is proposed. Impact energy is quantitatively partitioned into components such as core melting internal energy, core crack propagation internal energy, core plastic internal energy, fragment kinetic energy, ceramic fracture internal energy, ceramic plastic internal energy, and backing plate deformation internal energy. This reveals the spatiotemporal evolution of coupled projectile-target fragmentation and rate-dependent energy allocation laws. Results indicate that the penetration process comprises four stages: melting dwell, formation of the Mescall comminution zone, ceramic cone-backing plate synergy, and projectile core deflection-secondary fracture. Under the 700 m/s condition, core crack propagation absorbs approximately 2079 J (28.33% of initial kinetic energy), and fragment kinetic energy accounts for 1465 J (19.96%). Meanwhile, ceramic fracture absorbs roughly 1956 J (26.65%), and backing plate plastic absorption is about 936 J (12.77%). Energy consumption related to dynamic projectile fragmentation totals approximately 57.81% of the total energy, significantly higher than the ceramic side's share (~28.83%), indicating that core fragmentation is the dominant energy dissipation channel determining system protection efficiency. As velocity increases from 400 m/s to 800 m/s, the proportion of ceramic fracture internal energy rises from ~20.47% to 27.64%, and core crack propagation internal energy increases from ~24.59% to 28.81%, while the proportion of plastic energy dissipation decreases. This indicates a shift in energy absorption modes from plastic flow to fracture-dominated fragmentation. Concurrently, the peak acceleration shifts from the backing plate-dominated stage at low speeds to the strong ceramic-core coupling stage at high speeds, reflecting a forward shift in energy dissipation characteristics. This paper elucidates the mechanisms of coupled projectile-target fragmentation and energy redistribution under high-velocity penetration from a system energy perspective, providing verifiable theoretical bases and quantitative metrics for the energy path optimization design of composite armor under areal density constraints.

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Microstructural and mechanical properties of CF/PEEK gyroid structures

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Abstract

The CF/PEEK gyroid structure uniformly distributes external loads (e.g., hydrostatic pressure and wave impact), which is essential for long-term marine components such as propellers, offshore platforms, and floating structures. To elucidate aging evolution, CF/PEEK gyroid structures were exposed to a saline solution, alternating temperature, examining microstructural and macroscopic changes. Alternating temperature are the primary factors elevating the glass transition temperature and influencing decomposition temperatures. Conversely, alternating temperature attenuates surface damage by reducing hydroxyl generation and promoting aliphatic hydrocarbon fragments. The impact failure mode shifts to progressive crushing. This study clarifies aging mechanisms under saline solution and alternating temperature, providing fundamental insights for critical engineering applications.

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Numerical Simulation and Experimental Study on the Momentum Transfer Characteristics and Impact Effects of Kinetic Impact on Quartz Sand

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Abstract

Kinetic impactor technology is one of the most mature and promising techniques for planetary defense. In this study, quartz sand is selected as a simulant for rubble-pile asteroids characterized by extremely low cohesion. A vertical-impact experimental system with gravity-direction loading is established, incorporating high-speed photography and laser vibrometry to investigate the momentum transfer characteristics and impact effects resulting from kinetic impact on quartz sand. Complemented by numerical simulations, a computational model for kinetic impact on quartz sand is developed using the Smoothed Particle Hydrodynamics (SPH) method, and its validity is verified through experimental data. The results provide critical support for the engineering design and deflection efficiency assessment of future planetary defense kinetic impactor missions.

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Understanding 3D Printed Concrete (3DPC) against Projectile Impacts

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Abstract

Since the early 2000s, 3D Concrete Printing has been rapidly developed as a promising technique to conquer conventional construction limitations, such as shortage of skilled manpower, low profit margins with the overrun project budget and timeline. The rapid growth of 3D-printed concrete (3DPC) in the construction industry has also spurred interest in its application for military-deployed operations due to its faster, safer, and less labor-intensive construction process. In both civilian and military contexts, 3DPC structures may need to withstand high-velocity impact loads, such as vehicle collisions or projectile impacts. Despite advancements in 3DPC technology, limited research has been conducted on its performance under impact and blast loads. Given the distinct characteristics of 3DPC compared to conventional cast concrete, this study investigates how 3D printing influences impact resistance by analyzing the equivalent crater diameter (Deq) and depth of penetration (D.O.P). The findings indicate that 3DPC can achieve similar impact resistance as cast specimens. By enhancing the understanding of impact resistance in 3DPC, this research provides a foundation for optimizing its design for high-impact applications.

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Dynamic Mechanical Behavior and Wave Propagation Analysis of Lattice Structures under High-Velocity Impact

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Abstract

Lattice structures, owing to their lightweight nature, high specific strength, and excellent energy absorption capacity, have been widely applied in impact protection, aerospace, and advanced manufacturing [1]. Although their quasi-static mechanical behavior has been systematically investigated, the failure modes and underlying mechanical mechanisms under high-velocity impact loading remain insufficiently understood. To address this issue, this study systematically investigates the dynamic mechanical responses of several representative lattice topologies, including strut-based, plate-based, and surface-based architectures, under high strain-rate loading. First, a typical TPMS-Gyroid lattice structure was fabricated using selective laser melting (SLM), and its mechanical response was examined through a combination of experiments and finite element simulations under different strain-rate conditions. The results show that the numerical simulations can successfully reproduce the experimental stress-strain responses and characteristic deformation modes, thereby validating the effectiveness of the model. On this basis, Taylor impact simulations were further conducted for multiple lattice topologies. The results reveal that all lattice structures exhibit pronounced layer-by-layer crushing under high-velocity impact, whereas the propagation speed of damage shows a strong dependence on lattice topology, leading to significant differences in wavefront velocity. Based on shock wave theory [2, 3], the dynamic stress-strain curves of different lattice structures under high-velocity impact were extracted. Compared with the quasi-static results, lattice structures under high-velocity impact exhibit higher initial peak stress and larger densification strain, indicating that the coupling of strain-rate effects and stress-wave propagation significantly alters their macroscopic compressive response. This study reveals the deformation and failure mechanisms of lattice structures under high strain-rate impact conditions and provides a theoretical basis for their structural optimization and design in impact protection applications.

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A rapid method for measuring the rock brittleness index: Rapid characterization of rock brittleness based on LIBS technology

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Abstract

The brittle index is a crucial indicator in the assessment of rockbursts. The mineral brittle index (MBI) is widely utilized due to its simplicity and accessibility. However, the lengthy and inefficient mineral composition testing cycle presents a significant challenge. A novel approach using laser-induced breakdown spectroscopy (LIBS) to rapidly convert spectral elements into minerals and measure the rock brittleness index was introduced in this paper. The laser spectra of metamorphic sandstone and granite were measured by LIBS, and some rock elements were tested by X-ray fluorescence (XRF) to construct a spectral elemental model. Furthermore, the mineral composition of the rocks was determined by X-ray diffraction (XRD). Eight major elements, Si, Al, K, Ca, Na, Fe, Mg, and Ti, were selected as independent variables. Element-mineral correlation analysis was performed using centered log-ratio transformation (CLR) processing. A random forest regression (RF-R) element-mineral transformation model was established for rapid conversion of spectral-element-mineral brittle index. Finally, mechanical testing of rock embrittlement in the DJ Tunnel was conducted to verify the efficacy of MBI in characterizing rock embrittlement in the DJ Tunnel. The results demonstrate that predicted values of mineral compositions are in good agreement with experimental values and that predicted values of brittleness indices are also in good agreement with experimental values. The rapid and effective application of LIBS in determining rock mineral composition and rock brittleness index has been realized, which is of great significance for further realizing the rapid assessment of rock brittleness and rockburst prediction at engineering sites.

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Integrated Design of Origami-Based Structural Metamaterials for Tailored Dynamic Mechanical Properties and Electromagnetic Stealth

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Abstract

This study targets the synergistic service requirements for impact resistance and electromagnetic stealth, and conducts the integrated design of dynamic mechanical and electromagnetic properties for 3D-printed origami-based compression-torsion metamaterials. Composite functional units are constructed using origami skeletons and wave-absorbing materials. The regulatory mechanism of structural parameters on the dynamic mechanical behavior is systematically revealed via finite element simulation. Metamaterial specimens with different rotational angles of origami skeletons and ratios of wave-absorbing materials are fabricated, and the inherent interfield coupling mechanism between dynamic mechanical response and electromagnetic wave attenuation/absorption characteristics is clarified. The results demonstrate that synergistic and precise modulation of mechanical deformation and electromagnetic wave absorption performance can be achieved through parametric design of origami structures, endowing the material with excellent impact resistance and high-efficiency electromagnetic wave attenuation simultaneously. This work innovatively proposes a multifunctional coupling design strategy across mechanical-electromagnetic fields, overcoming the design bottleneck of incompatible performance in traditional single-functional materials. It provides new insights and guidance for the development of new-generation integrated impact-resistant and electromagnetic stealth metamaterials.

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Intelligent identification and quantification method of rockburst behavior characteristics based on vision and 3D laser point cloud technology

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Abstract

Aiming at the problem of recording rockburst events, a safe and intelligent identification technology and instrument are developed. The instrument mainly consists of a network spherical camera and LiDAR. Corresponding processing algorithms have been developed to automatically measure the occurrence time, location, velocity, and size of rockfalls during rockburst. The instrument was applied to a tunnel construction site in Southwest China, where 96 rockburst events were collected and identified. The results show that: rockburst in this tunnel mostly occur at the vault and right arch shoulder, mainly within 150 min after the tunnel face blasting, the velocity of the falling rocks can reach 12.297 m/s, the falling process is only about 1 s, and the size of the falling rocks is mainly stones smaller than 0.2 m. The results indicate that this method has good detection performance and can provide beneficial technology and equipment for further statistical analysis of the occurrence patterns of rockburst.

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A Scaling Prediction Method for Structural Dynamic Response under Blast Loading Based on Equivalent Static Loads

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Abstract

In real physical systems, several factors—such as strain-rate effects, gravity, and material damage and fracture—cannot be rigorously scaled, leading to pronounced scaling effects in the dynamic response of structures subjected to blast loading. Consequently, traditional scaling methods based on linear elasticity are inadequate for accurately predicting the response characteristics of prototype structures. To address this limitation, an equivalent static load-based scaling prediction method is proposed. Distinct from conventional approaches that attempt to achieve similarity by modifying the initial conditions of scaled model tests, the proposed method introduces dimensionless correction factors to adjust model test results, thereby enabling more accurate prediction of the dynamic response of prototypes. Moreover, the proposed dimensionless correction factors provide an effective means to quantify scaling effects in structural dynamic responses. The accuracy of the proposed method is validated through numerical simulations and blast tests, demonstrating a maximum prediction error of less than 7.7%. Further analysis of the similarity in maximum deformation of fundamental structural components indicates that, under a geometric scaling factor of 1/10, different components exhibit varying degrees of deviation from geometric similarity. The maximum deviations reach 61.6% for steel beams, 15.5% for reinforced concrete beams, 51.0% for steel columns, 42.3% for reinforced concrete columns, and 11.7% for reinforced concrete two-way slabs. Overall, the proposed analytical framework provides a robust theoretical basis and practical guidance for the design of scaled blast tests and the prediction of prototype structural responses under severe dynamic loads.

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Additively Manufactured SS316L–W Impedance-Gradient Flyers for Controlled Ramp-Wave Loading

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Abstract

Ramp-wave loading provides a continuous compression path with reduced thermal effects, making it highly valuable for investigating the dynamic response of materials under extreme conditions. A key requirement for gas-gun-based ramp loading is the fabrication of gradient flyers with controllable wave-impedance distributions. However, conventional fabrication methods for gradient impactors are often labor-intensive and limited in compositional precision. In this work, laser powder bed fusion was used to design and fabricate SS316L–W gradient flyers with tailored impedance profiles for efficient ramp-wave generation. The SS316L–W system was selected because the large density contrast between SS316L and W enables a wide impedance adjustment range. Single-composition SS316L–xW samples were first fabricated to evaluate densification behavior, showing that high relative density could be maintained up to 70 wt.% W, while higher W contents caused obvious porosity. Based on this result, an SS316L–W gradient flyer with W content increasing from 0 to 70 wt.% was prepared. Microstructural characterization confirmed a continuous compositional transition, uniform W-particle distribution, and well-bonded interfaces without delamination. Plate impact experiments using a single-stage light gas gun demonstrated that the designed gradient flyer generated a distinct ramp-wave stage in the free-surface velocity profile, unlike a conventional SS316L flyer. The different loading path also led to a modified spall response of the SS316L target. These results demonstrate that LPBF-fabricated SS316L–W impedance-gradient flyers provide an effective route for controlled ramp-wave loading and dynamic material response regulation.

A thermodynamically consistent initialization approach for driver gas in a large-diameter shock tube: Experimental and numerical study on shock wave dynamics

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Abstract

Shock tubes serve as essential facilities for replicating blast environments in laboratory-scale dynamic tests of structures and materials. The accurate prediction of shock wave characteristics depends heavily on the proper definition of the driver gas's initial thermodynamic state. Commonly, the driver gas is prescribed solely by its filling pressure, ignoring the temperature elevation caused by rapid pressurization. This simplification leads to a thermodynamically inconsistent starting condition and diminished predictive fidelity. This work focuses on a 640 mm inner-diameter gas-driven shock tube, combining physical experiments with numerical simulations. Pressure histories are recorded under various driver pressures and tube configurations. A thermodynamic correction procedure is proposed that explicitly accounts for the temperature increase during pressurization, allowing a consistent assignment of density, pressure, and internal energy in the computational model. Validated against measured data, the corrected approach eliminates the systematic underestimation of peak overpressure and shock speed observed in the uncorrected case. The underlying theory and limitations of the correction are examined, and empirical correlations for key shock parameters are derived, offering an improved, physically sound framework for shock tube design and performance prediction.

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Damage Mechanism And Mechanical Response Of Composite Subjected To High-Velocity Sand Erosion

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Abstract

Carbon fiber reinforced polymer (CFRP) composites possess high specific strength, high specific stiffness and low density, rendering them widely used in aero-engine structures[1]. However, aircraft operating in desert environments frequently ingest sand particles, causing erosive damage to composite blades that can lead to catastrophic failure[2]. Traditional air-jet sand erosion tests cannot realistically replicate the engine sand-ingestion process and lack precise control of impact velocity[3-5].

To overcome these limitations, this study proposes a novel rotating-arm sand erosion test method that accurately simulates real engine conditions and enables precise regulation of particle impact velocity. Using this apparatus, the erosion behavior of CFRP laminates was systematically investigated at impact velocities of 100 – 200 m/s and erosion durations of 20 – 60 mins. The damage evolution was quantitatively characterized, revealing a progressive transition from surface abrasion to deep internal damage with increasing velocity and exposure time, accompanied by significant degradation of surface and internal structural integrity.

Post-erosion quasi-static tensile tests were performed, and a theoretical model relating residual tensile strength to erosion parameters was established. The model shows excellent predictive accuracy (average error < 7 %) when validated against experimental data. In addition, infrared thermography fatigue tests were conducted on the eroded laminates; the residual fatigue limit and fatigue life were predicted from temperature-rise data, and a corresponding theoretical model was developed. Results demonstrate that both erosion velocity and duration exert substantial influence on the residual tensile strength and fatigue properties of CFRP.

This work provides an effective experimental platform and predictive tools for evaluating and enhancing the sand-erosion resistance of aerospace composite components.

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Dynamic behavior and a phenomenological elastoplastic model of metal fiber sintered sheets

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ABSTRACT

Metal fiber sintered sheets are metal cellular materials with good balance between density and strength, promising for structural and functional applications. However, very limited investigation on their dynamic constitutive model has been reported. In this paper, a comprehensive experimental study of MFSSs with six different relative densities was performed. The stress-strain responses to uniaxial compression, uniaxial tension, and simple shear under quasi-static loading, and uniaxial compression under dynamic loading were measured. Loading in both in-plane and out-of-plane directions were considered to investigate the transversely isotropic behavior of MFSSs. The loading process was captured using high-speed camera combined with Digital Image Correlation (DIC), according to which the macroscopic deformation mode was analyzed. MFSSs with higher relative density exhibit enhanced compression stiffness and strength but lower energy absorption efficiency. And the in-plane stiffness and strength are much larger than those in the out-of-plane direction. As the strain rate increases, the strain rate hardening effect is more obvious in low-relative density MFSSs, owing to their micro-inertia effect. A modified macroscopic phenomenological constitutive model incorporating strain rate hardening term was developed. In the modified model, anisotropy of the post-yield response is characterized by a hardening matrix containing six hardening functions, and these are also determined by the six basic experimental tests rather than complex multiaxial ones, which can greatly facilitate practical applications of the model. Combined shear-compression dynamic loading test of MFSSs was conducted to verify the validity of the developed model.

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Errors and influencing factors caused by area mismatch in SHPB devices: Decoupling analysis of generalized wave impedance

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Abstract

The split Hopkinson pressure bar (SHPB) apparatus is commonly used to study the dynamic behavior of materials at high strain rates[1-2]. However, its accuracy depends on experimental methods and data processing, and the measured Young's modulus is often lower than the true value. This discrepancy is usually attributed to stress non-uniformity at the specimen ends. However, theoretical analysis indicates that when stress is non-uniform at the ends, the measured Young's modulus should be overestimated rather than underestimated, suggesting that there may be other contributing factors. In this study, theoretical analysis and numerical simulations were used to investigate the applicability of the generalized wave impedance assumption in SHPB experiments and its impact on measurement errors[3]. When there is a mismatch between the cross-sectional areas of the specimen and the bars, the continuity conditions for the reflected and transmitted waves at the free surface are difficult to satisfy, resulting in higher-than-theoretical reflected waves and lower transmitted waves, leading to an underestimation of the stress-strain curve. At the left and right ends of the specimen, as the impedance ratio between the specimen and the bar decreases, the continuity conditions for the transmitted and reflected waves become closer to being satisfied, but the continuity condition at the right end becomes harder to meet. This leads to an average error of less than 1.2% between the simulated and theoretically calculated reflected waves when the impedance ratio is less than 1:5, while the average error for transmitted waves is approximately 10.1%. When the impedance ratio decreases to 1:100, the accuracy of the reflected wave is extremely high, with an error of less than 1.5% for the transmitted wave compared to the theoretical value. Additionally, as stress waves propagate back and forth within the specimen at both ends, the non-fulfillment of the interface continuity conditions intensifies the error in transmission and reflection, causing cumulative errors in the stress waves within the specimen. Thus, specimens with lower acoustic velocities generate smaller errors, reducing the back-and-forth reflections of stress waves within the specimen, which minimizes the additional error caused by the generalized wave impedance assumption.

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Study on the Anti-Penetration Performance of SiC Ceramic-Fiber Composite Armor

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Abstract

In this paper, 12.7 mm armor-piercing incendiary projectiles were used to normally penetrate SiC ceramic-fiber composite targets[1]. By observing the recovered projectile cores and the overall failure morphologies of the ceramic-fiber composite plates, the main damage modes of the projectile cores and fiber laminates were analyzed. Meanwhile, multi-stage sieving and weighing of the recovered projectile cores and ceramic fragments were carried out. The results show that the mass distributions of the projectile core and ceramic fragments under different backplate configurations follow a power-law distribution. The experimental results indicate that for a single laminate as the backplate, when the backplate material is T300, the degree of fragmentation of both the projectile core and the ceramic is the highest[2]. Adding a T300 transition layer between the SiC ceramic and Kevlar or UHMWPE increases the fragmentation degree of the projectile core and ceramic, leading to enhanced energy dissipation. The projectile core head mainly exhibits comminuted abrasive wear; larger core fragments are primarily caused by tensile-shear failure under the combined action of shear stress and tensile stress. The main failure modes of the ceramic under high-velocity impact are the formation of a ceramic cone and the propagation of radial cracks. The main failure modes of the UHMWPE laminate are delamination caused by tensile waves, permanent plastic deformation on the back face, and perforation failure mainly induced by shear waves. The failure modes of the Kevlar laminate are generally similar to those of the UHMWPE laminate, except that the perforation failure of the Kevlar laminate is mainly caused by tensile waves. The damage mode of the carbon fiber T300 laminate is predominantly cruciform brittle fracture induced by shear waves. By constructing a stiffness-gradient fiber structure—i.e., inserting a high-stiffness carbon fiber material between the ceramic and the high-tensile-strength fiber—the stiffness support effect of the fiber backplate structure on the ceramic material can be altered. This study provides research insights for enhancing the protective performance and lightweight design of ceramic-fiber composite armor. By adjusting the stiffness gradient of the fiber structure, the superior properties of each component of the composite armor can be fully utilized, thereby maximizing the defensive capability of the composite structure.

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Modeling and Validation of 95W Tungsten Heavy Alloy Considering Stress State, Strain Rate, and Temperature Effects

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Abstract

Tungsten heavy alloys (WHA) serve as critical materials in defense applications such as armor-piercing projectiles[1-3], where service conditions involve wide strain rates, extensive temperature ranges, and complex stress states. Accurate characterization of their plastic response is essential for engineering simulations. This study focuses on 95W tungsten heavy alloy, conducting mechanical experiments under broad strain rate ranges, wide temperature variations, and diverse stress conditions. Using the inverse iteration method, precise equivalent stress-equivalent plastic strain curves were derived, with weighted SVD and CP decomposition employed to quantitatively evaluate the decoupling validity among reinforcement mechanisms[4]. Results demonstrate that strain hardening, strain rate hardening, thermal softening, and stress state effects in 95W alloy exhibit approximate decoupling within experimental parameters. Based on these findings, a novel constitutive model incorporating strain hardening, strain rate hardening, thermal softening, and stress state effects was developed. Experimental validation using Shear-1 specimens and Taylor rod impact tests confirmed that the model achieves significantly lower prediction errors (RMSE=0.90, energy error 5.20%) compared to Johnson-Cook and Du models, while accurately reproducing deformation morphologies during both normal and oblique impacts on Taylor rods[5-6]. This study provides a reliable constitutive model for numerical simulations of tungsten heavy alloys under complex conditions, with its asymmetric yield function formulation offering valuable reference for modeling other metallic materials exhibiting tensile-compression-shear asymmetry.

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Penetration Behavior and Configuration Design of Long-Rod Projectiles under Damage Regulation

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Abstract

The mushrooming effect represents a critical bottleneck limiting the high-velocity penetration performance of long-rod projectiles. This phenomenon fundamentally stems from the complex coupling between material dynamic failure characteristics and the evolution of projectile nose morphology during penetration. However, existing studies have predominantly focused on static material properties such as density and strength, while the mechanism by which damage regulation governs nose evolution and consequently affects penetration efficiency remains poorly understood. In this study, a numerical model of 95W tungsten alloy long-rod projectiles vertically penetrating semi-infinite 603 steel targets was established using LS-DYNA and validated against experimental data. The influence of failure strain ranging from 0.1 to 3 on penetration behavior was systematically investigated. Results reveal that failure strain exerts a dual regulatory effect on penetration performance. Appropriately reducing failure strain can suppress plastic flow at the projectile nose and eliminate the "mushrooming" morphology. However, excessively low failure strain (<0.5) causes premature material failure, leading to a sharp increase in mass erosion rate. When these two competing mechanisms reach an optimal balance, the dimensionless penetration depth increases by 7.40%. Energy analysis further demonstrates that failure strain fundamentally reshapes the system's energy distribution pattern. At moderate failure strain, the target internal energy accounts for the highest proportion of total energy, the crater diameter remains relatively small, and axial penetration efficiency is maximized. Based on these mechanistic insights, a layered gradient damage configuration was proposed. Simulation results show that the optimal two-layer and three-layer configurations enhance penetration depth by 11.6% and 9.23%, respectively. The above results validate the feasibility of improving long-rod projectile penetration performance through layered gradient damage design.

Data-driven Lightweighting and Terminal Lethality Enhancement of PELE Projectiles: A Comparative Machine Learning and Multi-objective Optimization Framework

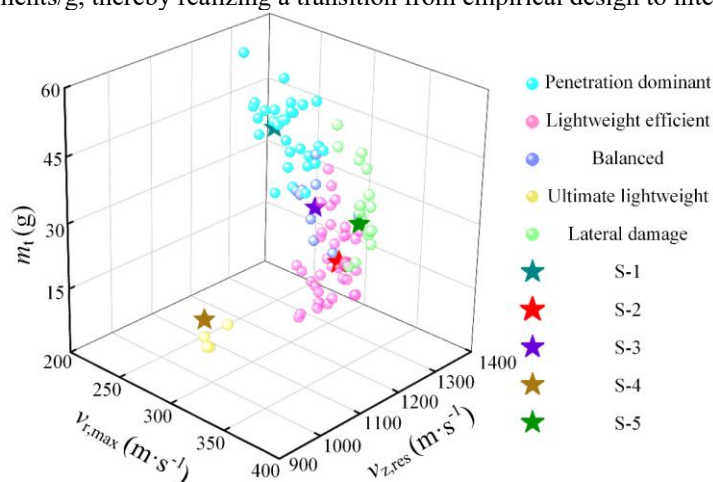
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Abstract

Traditional PELE design faces a persistent conflict between structural lightweighting and extensive damage area[1]. This study proposes an integrated data-driven optimization framework combining ballistic experiments, high-fidelity simulations, and machine learning. Ballistic experiments reveal a terminal lethality saturation beyond 1000 m/s and a jacket failure mode transition from macroscopic spalling to comminuted fracture. Validated by experiments (the average relative error < 5%), The Back Propagation Neural Network (BPNN)-based surrogate model was developed[2], demonstrating superior generalization ($R^2 > 0.96$) over Extreme Gradient Boosting (XGBoost) and Radial Basis Function (RBF) in mapping non-linear impact responses. Using the Non-dominated Sorting Genetic Algorithm II (NSGA-II) to navigate the Pareto optimal front, a best-compromise configuration was identified. The optimized design significantly alleviates the conflict between mass and effectiveness: compared to the experimental baseline, it achieves a 58.51% weight reduction while enhancing maximum radial velocity by 30.45% and axial residual velocity by 11.65%. Crucially, the specific fragment yield rate increased from 0.45 to 0.87 fragments/g, thereby realizing a transition from empirical design to intelligent fragmentation.



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Dynamic In-Plane Torsion for Large-Strain Thermo-Mechanical Characterization of Sheet Metal and Taylor–Quinney Coefficient Identification

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Abstract

Accurate characterization of metallic materials under large plastic strains and high strain rates remains essential for predictive simulations of dynamic forming, crash, and impact processes. This talk presents the development and application of a novel high-strain-rate in-plane torsion experiment for shear-dominated loading at strain rates up to approximately 1000 s^{-1} and equivalent plastic strains approaching 2. The experimental setup is based on split Hopkinson torsion bar principles and uses a 5 m long, 40 mm diameter steel bar that is elastically preloaded by a hydraulic actuator. Rapid release through a custom clamp system generates torsional loading waves, which are measured by strain gages and separated using a deconvolution algorithm to identify incident and reflected waves throughout the experiment. A key feature of the design is full optical access to the specimen surface for synchronized high-speed optical imaging for Digital Image Correlation and infrared thermography for simultaneous measurement of strain and temperature fields [1].

The method is validated on steels and aluminum alloys and subsequently exploited to identify the Taylor–Quinney coefficient at very large strains, including high-rate torsion tests with terminal temperatures up to 350 °C [2]. The resulting experimental database, complemented by uniaxial tension, notched tension, and shear tests over strain rates from 0.001 s^{-1} to 900 s^{-1} , is used to calibrate thermo-mechanical simulations with a non-associated Hill’48 plasticity model and a temperature- and rate-dependent hardening law.

References

- [1] V Grolleau, X Colon, B Galpin, CC Roth, D Mohr, “Design of a High Strain Rate In-plane Torsion Experiment”, International Journal of Impact Engineering, 2026. <https://doi.org/10.1016/j.ijimpeng.2026.105782>
- [2] X Li, CC Roth, V Grolleau, D Mohr, “Dynamic In-Plane Torsion–Based Identification of the Taylor–Quinney Coefficient for Improved Thermo-Mechanical Simulations under Shear and Tension”, International Journal of Impact Engineering, 2026. <https://doi.org/10.1016/j.ijimpeng.2026.105707>
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