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C18-功能梯度材料

C18-Functionally Graded Materials

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C18. 功能梯度材料（国际）

分会主席：张联盟、陈斐

C18-01

Gradient structured Materials: Processing, Properties and Principles

Yuntian Zhu*

City University of Hong Kong

Gradient structures are naturally occurring phenomena observed in various biological systems, including bones and plant stems, contributing to their remarkable mechanical and functional characteristics. Through thermochemical methods such as nitriding and surface heat treatments, these structures have been deliberately incorporated into mechanical components. Notably, recent advancements have led to the introduction of gradient structures featuring a continuum of grain sizes ranging from the nano to micro scale within metallic materials. This innovative approach has yielded alloys with exceptional strength and ductility properties. In this talk, I will present the intricate processes involved in the fabrication, the unique properties exhibited, and the underlying principles governing gradient structured materials. By exploring these aspects, we can gain a deeper understanding of the potential applications and implications of this emerging field in materials science and engineering

C18-02

Liquid state nanoionics: high-performance computing for novel physics and cross-scale models for engineering

(Jefferson) Zhe Liu*

The University of Melbourne

Dynamic ionic systems are the hidden engines of many electrochemical energy storage and conversion technologies. During dynamic working conditions, the systems are driven far from the equilibrium state. The interplay of multiple transport processes in the heterogeneous electrodes or at the electrolyte/electrode surfaces at their respective time and length scales leads to pronounced ion/electron spatiotemporal heterogeneity, which has enormous implications for functions and performances. Understanding and manipulating the transport and storage behaviour of ions and electrons inside or at the interface of the electrified nanoporous electrodes are essential to developing new systems and optimising existing ones for these energy technologies. However, the spatiotemporal evolution of ions/electrons is not well understood, which is a crucial bottleneck to bridging fundamental science with engineering applications. To address the challenge of lagging knowledge, the community calls for a paradigm shift from intuitive speculation to confirmed scientific knowledge, from trial-and-error serendipity to science-based design, and from qualitative modelling to quantitative prediction. This presentation will overview our computational materials research for ion storage/transport in nanoporous materials in the past decade. This talk will

start with recently discovered ion transport properties/phenomena in our graphene membrane platform with continuously tunable nanoslit size from 10nm down to 0.5nm and MOF/ZIF membranes with designable channel size and surface chemistry. This talk will review our high-performance computing study to reveal the underlying physical mechanisms, such as ion pairing regulated ion transport and dehydration and ion-wall interaction competition-induced ultra-high ion selectivity in MOF/ZIF channels. In the end, this talk will also introduce our efforts to develop methods for device- and system-level device designs, including novel nanoscience-based continuum models, physics-based nano-circuitry models, and machine learning.

C18-03

The potential of topotactic transformation to produce novel nanostructures

Jorge Roberto Vargas-Garcia*,Sarahi Pacheco-Espinoza,Alejandra Verdejo-Palacvios,Cesar Fabian Martinez-Tovar,Maria de los Angeles Hernandez-Perez

National Polytechnic Institute

Topotactic transformation involves a structural change in a crystalline solid such that the orientation of the product crystal is determined by the orientation of the starting material. Topotactic transformation has emerged as a favourable route for the development of new materials with unprecedented properties. In this study, using carbon nanotubes as the starting crystal, we report the synthesis, structural properties and potential applications of novel multi-walled metal oxide nanotubes obtained via topotactic oxidation and dehydration reactions. Due to the significant presence of O vacancies, novel multi-walled CeO2-δ nanotubes used as a support for Pt nanoparticles exhibit excellent catalytic activity in the methanol oxidation reaction. Alternatively, we report on the topotactic intercalation of Mo into the van der Waals gap of multi-walled carbon nanotubes. The Mo intercalant acts as an electron donor dopant, i.e. electrons are transferred from Mo to the host nanotube lattice. This leads to a charge redistribution in the system. The partial charge distribution and the presence of C vacancies generated by Mo intercalation play an essential role in enhancing the activity of the technologically important hydrogen evolution reaction. These findings provide strategic insights into the controlled synthesis of novel nanostructures.

C18-04

Zero-emission thermoelectric power generation and refrigeration for carbon neutrality

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Queensland University of Technology

Climate change caused by the continuous accumulation of greenhouse gases is an imminent threat to mankind and biodiversity. Already a dry land with vulnerable biodiversity, Australia will be hard hit by climate change as

evidenced by the recent natural disasters with much increased frequency and intensity. To stop climate change, we need to significantly reduce carbon dioxide (CO2) to net-zero emissions. In this topic, we timely highlight the latest progress on the up-to-the-date thermoelectric devices with their unique designs and compelling thermoelectric efficiency for harvesting renewable electricity from the environment, which will reduce our dependence on carbon-based energy sources. We carefully summarize the structure-related principles and factors that determine the performance of thermoelectric devices and propose strategies for improving their utilities. Besides, we focus on the timeliest designs for inorganic-based devices, organic-based devices, and hybrid-based devices targeting both power generation for zero-emission. Ultimately, we point out the current challenges, controversies, and prospects of thermoelectric devices.

C18-05

Atomistic modeling of atomic transport at heterogeneous interfaces

Vladyslav Turlo*

Empa - Swiss Federal Laboratories for Materials Science and Technology

In this talk, we will showcase groundbreaking research on the atomistic modeling of reactive Ni/Al and non-reactive Cu/AlN nano-multilayers. Utilizing large-scale atomistic simulations, we delve into the mechanisms of reactive wave propagation, self-propagating high-temperature synthesis, and diffusion-driven dissolution in Ni/Al nano-multilayers. Our team has developed and validated an innovative phenomenological model for diffusion-driven dissolution in these metallic structures, providing unprecedented insights into dissolution-driven reactive wave propagation. This work bridges the gap between atomistic simulations and experimental observations, offering a comprehensive understanding of these phenomena. Expanding our expertise, we have ventured into the atomistic modeling of diffusion and phase transformations in systems with complex chemical bonding. Our findings reveal that the Cu diffusion coefficient in Cu-AlN nano-multilayers can vary by over four orders of magnitude, highlighting the occurrence of fast solid-state diffusion and melt nucleation at non-reactive metal-covalent heterogeneous interfaces. Advanced ab initio methods have uncovered extreme enhancement of solid-state diffusion at N-terminated Cu-AlN interfaces, a phenomenon overlooked by previous models. This discovery challenges the current use of pair interatomic potential models for describing non-reactive interfaces with mixed chemical bonding. This talk will offer valuable insights into the potential of atomistic modeling to revolutionize the development and optimization of functionally graded materials, such as nano-multilayers, for nano-/microjoining applications across various industries. To learn more about our team, activities, and competencies, please visit https://vturlo.science

分会主席：(Jefferson) Zhe Liu、陈志刚

C18-06

Computational Approach for Designing and Optimizing the Co-firing of Functionally Graded Materials.

Tesfaye Molla*

University of Melbourne

Functionally Graded Materials (FGMs) are novel material systems with varying composition and/or properties across their structures to tailor their functional performance to local environments. Discretely graded FGMs are often made from powders, formed by using different functional layers and consolidated using a thermal process called sintering (co-firing). The sintering of non-symmetrical FGMs is often difficult because they are susceptible to processing defects such as shape distortion and even delamination caused by stresses due to differences in sintering rates. Mitigation of these defects, without undermining the functional performance, requires time consuming optimisation of the co-firing process. The traditional trial-and-error based approach is not only costly but also ineffective as the large number of variables makes the problem experimentally intractable. Therefore, there is growing interest in ways to efficiently optimise the manufacture of FGMs because of their importance to the development various advanced technologies including for low carbon energy future. Here, we present summary of studies on developing computational methods to simulate and optimize the co-firing of FGMs. Materials systems ranging from FG ceramics (e.g., solid oxide cells) to FG alloys are included. The studies show the importance of optimizing both process as well as material parameters during co-firing for accelerated development and manufacture of defect free FGMs.

C18-07

Multi-materials components development for power applications by directed energy deposition

Ying Li*,Jan Džugan,Martina KOUKOLIKOVA

COMTES FHT a.s.

In many industrial applications, single-material components struggle to meet all operational demands, necessitating the development of multi-material components. The need to join dissimilar materials, a task preferably managed in controlled factory conditions rather than during on-site assembly, is a significant factor driving this trend. Using components that transition between materials ensures similar-material welds during final installation, simplifying and securing the assembly process. This paper explores key factors influencing the joint quality of multi-material components, focusing on connections between Inconel alloys 718 and 625 with austenitic 316L stainless steel and martensitic 42C stainless steel. All materials are applied using powder-blown laser directed energy deposition methods. The study highlights the importance of deposition sequence for the

material pairs Inconel 718 – SS316 and Inconel 625 – SS42C, and examines how interface orientation and surface quality influences the joint quality in the former pair.

C18-08

Si3N4-Si2N2O 定向骨架结构优化及其在双连续复合陶瓷中应用研究

杨治华*[1]、廖兴祺 [2]、贾德昌 [1]、周玉 [1,2]

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通过冷冻铸造法结合气压烧结工艺制备了具有不同结构波长和开气孔率的 Si3N4-Si2N2O 定向骨架，系统研究了冻铸和烧结工艺对其显微结构与力学性能的影响；提出结合动力学与机器学习建立定向骨架的工艺-结构-性能(PSP)数据模型，厘清了分级微观结构参量对抗压强度的影响权重，实现了在气孔率与强度这组典型竞争性目标下定向骨架的按需设计；进一步研究了基于定向骨架制备的双连续 Si3N4-Si2N2O/SiO2 和 Si3N4-Si2N2O/BAS 复合陶瓷的力-热-电性能与热震损伤行为。

C18-09

Quantifying plasticity contribution in nanolaminates using a strain gradient

Xiaolong Ma*

City University of Hong Kong

Disentangling the intragranular and interfacial plasticity contribution to the overall strain accommodation is crucial to understanding the microstructural evolution and mass transport upon deformation in materials with the nanoscale feature size. In this presentation, we devised an experimental approach to tackle the issue by introducing shear strain gradients into Cu/Nb nanolaminates of different layer thicknesses with the shear perpendicular to the laminate interfaces. Measuring the strain gradient and the resultant lattice disorientation enables a quantitative understanding of the intragranular and interfacial dislocation storage and hence plasticity contribution. We found that intragranular dislocation slip governs the deformation in the 300 nm-layer laminate entirely and, unexpectedly, contributes ~to 80% of the total plasticity in the 30 nm-layer laminate. The experimental method is expected applicable for studying other nanostructured materials.

C18-10

AlN Based Functionally Graded Materials for Long Time High Temperature Sealing and Insulation

Fei Chen*,Mingyong Jia,Yueqi Wu,Qiang Shen

Wuhan University of Technology

Functionally graded materials (FGMs) are composite materials characterized by gradual changes in

composition, structure, and properties, offering substantial design flexibility and the ability to perform under extreme conditions. These gradient interfaces enable effective bonding of materials with significantly different physical properties, facilitating long-term, repeated operation under substantial mechanical loads and extreme temperature variations. High-temperature energy storage systems, such as liquid metal batteries, face significant sealing challenges due to extreme service environments, including high temperatures, corrosive molten salts, and reactive metal vapors like lithium. This necessitates the development of multifunctional gradient sealing materials that combine high-temperature resistance, load-bearing capacity, corrosion resistance, and high insulation.

This study utilizes powder metallurgy co-sintering technology and low-temperature diffusion bonding to prepare symmetrical AlN/Mo/SS304 gradient materials. The research focuses on the strengthening mechanisms of gradient interface and grain boundary, the formation mechanisms of brittle intermetallic compounds, and the enhancement of corrosion resistance by gradient interpenetrating framework in high-temperature environments. Under extreme operating conditions, the AlN/Mo/SS304 sealing component exhibits outstanding performance: resistivity greater than 10^{10} Ω·cm, shear strength exceeding 80 MPa, helium leakage rate lower than 1×10^{-11} Pa·m³/s, and an operating temperature above 300°C. These advancements pave the way for the application of AlN/Mo/SS304 gradient materials in liquid metal batteries.

C18-11

Uncovering the origin of interface stress enhancement and sign inversion in immiscible nanomultilayers

Yang Hu, Giacomo Lorenzin, Jeyun Yeom, Claudia Cancellieri, Lars P.H. Jeurgens, Vladyslav Turlo*

Empa

Nanomultilayers (NMLs) have demonstrated outstanding magnetic, optical, mechanical, and radiation tolerance properties, however, their applications are limited by the intrinsic stresses that develop during their growth. The intrinsic stress caused by the interfaces between two phases, called the interface stress, is much higher in Cu/W NMLs than other reported systems, and shows a sign inversion from tensile to compressive in-plane strains. Using molecular statics simulations with a chemically correct neural network potential, we revealed the significant influence of a few atomic planes of intermixing of Cu and W at the interface on interface stress, well matching the experimentally measured interface stresses. Our findings give the explanation of the ultra-high interface stress for Cu/W NMLs and the origin of the sign inversion, which should be attributed to interfacial metastable phases, being supported by experimental characterization.

C18-12

MICROSTRUCTURAL INFLUENCE ON SUSCEPTIBILITY TO STRESS CORROSION CRACKING IN PIPELINE-GRADE STEELS

Dafne Monserrat González Fong*,DIEGO ISRAEL RIVAS LOPEZ,MANUEL ALEJANDRO BELTRAN ZUÑIGA

Instituto Politecnico Nacional

In this work is evaluated the effect of microstructural characteristics on Stress Corrosion Cracking (SCC) susceptibility in low carbon pipeline-grade steels by using two pipe segments with API 5L specification grades X56 and X60. The results reveal the formation of pits with atypical morphology, where cracks are visualized at the bottom, associated with the initial stage of the SCC mechanism. It was observed that a higher content of pearlite reduces the formation of these pits and enhances microstructural homogeneity due to the distribution of anodic and cathodic sites. Additionally, the results indicated that the occurrence of pits is dependent on the magnitude of the applied stress; higher stress leads to a greater presence of pits. Photographic evidence shows that the generated cracks are associated with non-classical SCC, due to their transgranular characteristics and their location at the bottom of pits with atypical morphology.

C18-13

The effect of ferroelastic domains and ultrahigh-density dislocations on fracture toughness of high entropy niobates

Panpan Wang,Xiaofeng Zhao*

Shanghai Jiao Tong University

This study investigates the fracture toughness and toughening mechanism of (La0.2Nd0.2Sm0.2Eu0.2Y0.2)NbO4, a high entropy material characterized by a high thermal expansion coefficient and low thermal conductivity. Our finding demonstrates a noteworthy 50% increase in fracture toughness for (La0.2Nd0.2Sm0.2Eu0.2Y0.2)NbO4 (~3.09 MPa·m0.5) compared to YNbO4 (~2.11 MPa·m0.5). The superior fracture toughness for (La0.2Nd0.2Sm0.2Eu0.2Y0.2)NbO4 can be attributed to the two key factors: relatively easy ferroelastic domain switching and the presence of ultrahigh-density dislocations (~7×108 mm−2). The enhanced ferroelastic toughening in (La0.2Nd0.2Sm0.2Eu0.2Y0.2)NbO4 is associated with its distinct characteristics, large atomic radius (RA), significant tetragonality (c/a ratio), and low monoclinic β angle. These factors contribute to larger spontaneous strain, smaller coercive strain, and lower transformation strain, respectively. These properties facilitate the formation and switching of the ferroelastic domains. In addition, the interactions between the large strain field surrounding the dislocations and the cracks facilitate crack deflection and bridging. The combined effect of ferroelastic toughening and ultrahigh-density dislocations ultimately leads to the significant improvement in fracture toughness of (La0.2Nd0.2Sm0.2Eu0.2Y0.2)NbO4.

分会主席：叶红玲、陈擎

C18-14

力学形状记忆超材料热机械响应机理研究

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力学超材料通过复杂的人工微结构单元设计和周期性排列获得超常的力学性能，例如轻质高强、负泊松比、负刚度和多稳态等。力学超材料既有研究较多围绕结构设计和力学性能分析展开，结合功能材料构筑力学功能超材料，从材料角度拓展力学超材料的力学性能，实现可调控的力电、力热和力磁等超常响应，是力学超材料的研究热点之一。本报告结合力学超材料 (结构)和形状记忆聚合物 (材料)，提出了可编程和热自适应的力学形状记忆超材料。通过理论分析研究了两类力学形状记忆超材料在温度场下的可编程热机械响应。首先，运用广义分数粘弹性模型研究了具有任意波纹图案的力学形状记忆超材料梁的有效杨氏模量，运用改进耦合应力理论研究了力学形状记忆超材料梁在双侧约束下的自适应后屈曲响应，通过参数分析研究了力学形状记忆超材料梁的有效弯曲刚度和温度敏感性的可调性。然后，运用相演化本构模型研究了基于手性超材料的力学形状记忆超材料板、管的泊松比、杨氏模量和自适应热机械响应，通过数值仿真验证了理论模型的准确性，通过参数分析研究了泊松比、杨氏模量和温度灵敏度的可调性。提出的力学形状记忆超材料有望用于开发热机械传感设备。

C18-15

Exploration and Practice of Northwestern Polytechnical University on Rapid Solidification of High-Temperature Liquid Alloy aboard China Space Station

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Northwestern Polytechnical University

The team from the Laboratory of Space Materials Science and Technology at Northwestern Polytechnical University, led by Academician Wei Bingbo, successfully conducted a study on the rapid solidification of high-temperature alloys in the China Space Station. In this study, a total of 5 batches of high-temperature and refractory alloys, nearly 200 experiments were conducted under microgravity, including heating, melting, cooling, supercooling, solidification, and measurement of thermophysical properties. More than 60 samples were successfully recovered, including refractory Nb alloys, Zr alloys, and Ti alloys. These samples were returned to Earth aboard the Shenzhou manned spacecraft for subsequent research. This study is significant in advancing the understanding of the metastable liquid properties and solidification behavior of high-temperature alloys in the space environment.

C18-16

Functional gradient materials fabricated by laser additive manufacturing

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Huazhong University of Science and Technology

Functionally graded materials (FGMs) are materials that achieve spatially varying properties through gradual changes in composition or microstructure. The compositional gradient can overcome the differences in chemical, metallurgical and thermal properties of heterogeneous materials, to achieve excellent interfacial bonding. Based on phase diagram calculation and lattice structure mechanics prediction models, TiB2/Ti-6Al-4V and Ti-6Al-4V/Cu/Al-Cu-Mg-Ti multi-material gradient lattice structures were fabricated by laser powder bed fusion (L-PBF). The heterogeneous material interface had a good bonding effect, thereby achieving different mechanical properties in different material distribution areas. The research results show that the experimental values of material distribution-lattice structure-mechanical properties in functionally graded materials are consistent with the simulation results. In addition, NAB /SS316L functionally graded materials were fabricated by laser direct energy deposition (L-DED), and the crack-free gradient composition range was calculated based on the phase diagram and crack sensitivity index.

C18-17

增材制造镍钛基形状记忆合金的弹热效应及应变玻璃转变

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通过固体材料内禀序参量在外场下可逆转变的吸/放热效应可实现热力学循环制冷，固态相变制冷技术具有绿色环保、节能高效、低噪稳定等诸多优点，兼具巨大的经济价值和环保价值，并在航空、航天器的温控领域具有重要的应用前景。形状记忆合金作为弹热制冷技术的关键材料体系成为固态制冷剂的重要角色，其力-热转换效率和稳定性成为备受关注的重要技术指标。本次报告重点针对记忆合金的功能疲劳问题，介绍了通过驱动场调控和激光增材制造创制精细微结构方面的工作。首先介绍采用合金共晶点成分和局部快速冷却工艺构筑的纳米复合微结构，然后讨论通过微结构生成小滞后，实现制冷效率和稳定性的大幅提升。之后介绍利用相变滞后损耗占比，建立准确描述弹热材料功能寿命的唯象模型。最后介绍基于深空探测的宽温域超弹性合金与应变玻璃转变的研究进展。

C18-18

Research progress in laser directed energy deposited functionally graded materials

Jinzhong Lu*

Jiangsu University

Functionally graded material (FGM) is a category of engineering materials with tailored chemical composition and microstructure. Laser directed energy deposition (LDED) presents advantages in manufacturing FGM because of high flexibility, rapid prototyping and integrated manufacturing. This report investigates the fusion behavior and microstructure evolution of dissimilar alloys in FGMs under the thermal effect induced by LDED. The synchronous enhancing mechanism of spatially heterogeneous microstructure on strength and toughness of FGMs is unveiled. The crack formation and control mechanisms of LDEDed FGMs are analyzed. The diverse inter-layers are introduced in thin-wall FGMs to eliminate brittle phases and avoid the cracks. Besides, addressing the issue of blade leading edge corrosion susceptibility, a gradual content of alloy with good corrosion resistance is designed. Finally, combining biomimetic structures, system integration and composition design, the future trends of FGMs are listed.

分会主席:侯慧龙、鲁金忠

C18-19

面向增材制造的连续纤维复合材料拓扑优化设计

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纤维增强复合材料由于具有高比强度、高比模量、耐高温、抗疲劳可设计性强等特点，其在高端装备上的用量和应用部位已经成为衡量制造业装备先进性和市场竞争力的标志。高端装备结构的复杂化、大型化为复合材料结构的设计、制造、分析、工艺等带来一系列创新性要求。结构拓扑优化因不依赖于初始构型的选择，实现最佳的传力路径和材料的优化配置，设计出传统理念难以获得的创新构型，已成为航空航天等高端装备领域高性能、轻量化结构设计的重要手段。增材制造技术的发展为复合材料结构拓扑优化设计的复杂构型整体化制备提供了新途径。本研究结合主应力法和连续纤维角度优化（CFAO）的优势，提出一种基于主应力方向的连续纤维角度优化策略（PSO-CFAO）。建立纤维取向和结构拓扑并行优化模型，定义独立连续拓扑变量和纤维角度为设计变量，以柔度最小为目标，结构体积为约束，建立优化模型并求解，在迭代过程中根据主应力方向对纤维角度进行控制，避免主应力法“重复全局最小值”导致的求解困难，同时降低了优化陷入局部最优的风险，实现了结构拓扑和纤维分布的并行优化。结合 3D 打印技术，制备了试件，研究了不同纤维角度铺设对于拓扑优化结构和力学性能的影响规律。结合数据驱动模型，实现连续纤维复合材料结构的多尺度优化，提高了求解效率，实现高效的结构设计和纤维路径规划，促进先进材料设计向自动化和智能化发展。

C18-20

多级孔的纳米多孔金属材料的孔内离子传输速率

陈擎*、王聪诚

香港科技大学

脱合金等手法所制备的纳米多孔金属，兼顾高比表面积、高导电率、高稳定性的优点，在催化、促动、电池等应用中具有极大的潜力。其孔径大小通常在 10 到 100 纳米尺度，因此孔内的传质被认为是其功能性应用的瓶颈，一个常见的改进手段便是制备多级多孔结构，利用微米尺度的大孔来加速传质。此报告中，我们将利用纳米多孔金属结构的高度可控性，来量化孔内离子传输与结构特征（包括孔径和孔隙率）间的关系。以此为基础，我们推得，多级多孔结构的高传质速率并非源于微米孔的尺度，而是因为孔隙率的提高。由此所得到的结构-传质关系，能有效地指导此类功能材料的设计和优化。

C18-21

Effect of morphology on the elastic response of dealloyed porous structure

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中国科学院金属研究所

We report that ligament morphology also governs the mechanical properties of dealloyed porous materials, in addition to the previously reported topology- and size effects. Relative elastic modulus of porous Fe-Cr prepared by liquid metal dealloying decreases dramatically with increasing Cr content. It arises from the enhanced spheroidization of ligaments at higher Cr content, driven by the excess energy of solid/liquid interfaces under dealloying environment. A shape parameter is introduced to quantitatively interpret the ligament-morphology effect on mechanical response of dealloyed porous or nanoporous materials, which might be significant but was often overlooked in previous studies.

C18-22

Study on TaB2-SiC coatings regulated by low-loss film formation

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To achieve high oxygen barrier properties on the surface coatings of carbon structural materials, low-loss film

formation control technology was used to suppress the destructive dynamic evolution of the coatings, thereby enhancing their oxygen barrier capability. This study investigated the effects of boride content and pre-oxidation temperature on the oxygen-hindering properties of TaB_2-SiC coatings and prepared TaB_2-SiC coatings with enhanced oxygen barrier performance. The addition of 40 wt% TaB_2 reduced the oxygen permeability of the coating by 62.16%. However, due to the strong ion complexing ability of Ta^{5+}, excessive TaB_2 weakened the oxygen barrier capability of the coating. A pre-oxidation temperature of 1500℃ resulted in a homogeneous dispersion of Ta-oxide nanocrystal particles within the Ta-B-Si-O composite glass layer. Compared to untreated samples, the active factor and inert factor values of the TaB_2-SiC coating pre-oxidized at 1500℃ decreased by 43.12% and 17.33%, respectively, significantly improving the dynamic stability of the coating during oxidation.

C18-23

Diffusion behavior and growth kinetic of intermetallic compounds in Cu-Ti diffusion couples

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Copper-Titanium (Cu-Ti) diffusion couple is frequently employed to obtain a range of Cu-Ti intermetallic compounds for further study towards pertinent properties, including microhardness, fracture toughness, tensile strength, etc. However, due to the limited diffusion rate in solid-state diffusion couples (less than 10^{-16} m^2/s), the $CuTi_2$ diffusion layer is difficult to observe. Here, Cu-Ti diffusion couples have been designed within a temperature range of 1013 K to 1163 K, which represents the upper temperature limit to ensure solid-state diffusion. The resulting intermetallic compounds, including Cu_4Ti, Cu_4Ti_3, CuTi, and the elusive $CuTi_2$, have been identified in the diffusion zone. Growth kinetics and interdiffusion coefficients of involved Cu-Ti intermetallics have been quantified based on the measured compositional profiles using electro-probe microanalyzer. Moreover, activation energies required for the growth of these intermetallics have been confirmed to be 85.9 kJ mol^{-1} atom (Cu_4Ti), 101.0 kJ mol^{-1} atom (Cu_4Ti_3), 70.0 kJ mol^{-1} atom (CuTi), and 64.9 kJ mol^{-1} atom ($CuTi_2$), respectively. Our current findings could enable a rational design towards fully utilizing encrypted phases which are otherwise difficult to obtain.

C18-24

Additive Manufacturing and Mechanical Properties of TC4/Inconel 625 Functionally Graded Materials by Laser Engineered Net Shaping

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In this short communication, TC4/ Inconel 625 functionally graded materials (FGMs) are fabricated by laser engineered net shaping (LENS) technology. The results in this study show that the TC4/ Inconel 625 FGMs demonstrate a graded composition with a gradient change in the size of eutectic tissues, respectively. The hardness

of the TC4/ Inconel 625 FGMs increase from approximately 440 HV to 660 HV with 10 % gradually decrease of TC4 content. The average value of hardness at 660 HV can be found at 50% TC4/50% Inconel 625 deposited layer. The FGMs exhibit a tensile strength of 701.88 MPa, yield strength of 517.16 MPa, and a uniform elongation of 14.07%.

分会主席:张旭、白洋

C18-25

高熵超高温陶瓷抗氧化组分设计与机制研究

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高熵超高温陶瓷因具有巨大的组分空间，独特的微观结构以及可调控的性能近年来受到国内外研究学者的广泛关注，然而，前期关于高熵超高温陶瓷的研究主要集中在力学和热学性能方面，对于其抗氧化性能的研究较少。为此，我们在国际上率先开展了高熵超高温陶瓷抗氧化性能方面的研究工作，发现其抗氧化性能与其组元成分密切相关；基于材料基因工程理念，借助高通量第一性原理计算和高通量燃烧合成或超快合成实验与机器学习相结合的手段，建立了高熵超高温陶瓷多因素形成能力判据；在此基础上，借助高通量超快合成与氧化实验与第一性原理计算相结合的手段筛选出耐 1500°C 优异抗氧化性能的高熵超高温陶瓷组元成分，揭示了多组元协同抗氧化机制。

C18-26

4D 打印 NiTi 形状记忆合金

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4D 打印技术采用 3D 打印制备智能材料，如 NiTi 形状记忆合金（SMAs），能够实现复杂结构制造和个性化定制。这一进步推动了形状记忆合金在航空航天、医疗等领域的应用。课题组开展了关于 4D 打印的系列研究工作：（1）优化选区激光熔化 4D 打印工艺参数，成型无缺陷和高密度的块状 NiTi 形状记忆合金，并研究其对相变行为的影响，实现良好的双程形状记忆效应。（2）基于 4D 打印结合后热处理策略，调控形状记忆效应和超弹性，促进晶界处的 Ti_2Ni 和 Ni_4Ti_3 纳米沉淀物转变为均匀弥散分布，出色的拉伸性能、形状记忆效应和超弹性。（3）通过<011>织构强化和 Ni_4Ti_3 共格析出强化的协同机制，在拉伸超弹性和驱动效应中兼顾超大回复应变和超高回复率。（4）基于激光原位热处理构建功能基元的策略，调控功能基元内各微区的析出相分布及微观超弹性，在 NiTi 形状记忆合金中实现优异的高载低周疲劳寿命。（5）设计适应人体骨骼不同部位的多孔结构，基于可行功能域设计分析，采用多轨耦合定向凝固技术，编程<001>晶体取向沿任意 3D 方向。相关成果为高性能 NiTi 形状记忆合金的设计提供重要见解，并进一步加速增材制造的工程应用。

C18-27

Gradient Ultra-High Temperature Ceramic Composites with Low-Density and Excellent Ablation Resistance

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Harbin Institute of Technology

The composites with ultra-high temperature non-ablation and lightweight properties have important application prospects in the thermal protection system of hypersonic vehicle. However, the controllable fabrication of composites with heat-resistant and low-density integration have always been the key challenge for thermal protection components operating under ultra-high temperature extreme environments. Here a gradient lightweight ultra-high temperature ceramic composites (UHTCCs) with dense UHTCs layer and porous carbon aerogels (CAs) layer through the combination of continuous carbon fiber fabric were fabricated based on combination process of vibration assisted slurry impregnation (VSI) and polymer infiltration pyrolysis (PIP), which have low-density (0.6~2.0 g×cm−3) and excellent ablation resistance above 2500℃. In addition, the composition and structure of gradient lightweight UHTCCs can be well designed and controllably fabricated, allowing for tailored preparation is expected to meet various service environments, which is made possible by the flexibility and operability of the combination process. Such gradient lightweight UHTCCs possess excellent ablation resistance and low-density are highly desirable for extreme environment applications.

C18-28

Friction of stable gradient nano-grained metals

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The energy dissipated in a metallic frictional contact is largely converted into surface plastic deformation. Surface plastic deformation in turn brings about microstructural discontinuity and localized strain in the surface layer of homogeneous materials upon sliding, inevitably increasing their frictional resistance. In this talk, a novel strategy for lowering the coefficients of friction (COFs) of metals during dry sliding is introduced by producing a gradient nano-grained (GNG) surface layer without changing chemical compositions or phase constitution. Surface morphology variation, subsurface structural evolution and stress field analysis unfold that sliding-induced strain localization and microstructural instabilities are significantly mitigated through dislocation activity and grain boundary activities in the GNG surface layers. In addition, design guidelines for GNG materials with unprecedented low COFs are discussed based on interlinking tribological stress, surface deformation mechanisms and friction behavior.

C18-29

Accelerating High-Performance High-Entropy Alloy Design Using Artificial Intelligence Technology

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High-entropy alloys (HEAs) are composed of five or more elements in equiatomic proportions, typically exhibiting exceptional mechanical properties. However, the complex elemental composition makes designing high-performance HEAs extremely challenging. Traditional methods are time-consuming, labor-intensive, and fraught with issues such as serendipity and trial-and-error approaches. Therefore, employing simulation calculations and integrating artificial intelligence (AI) technology for efficient and accurate HEA design is crucial. The presenter combines first-principles calculations and machine learning AI algorithms to propose new strategies for predicting mechanical performance parameters and phase compositions of HEAs, offering novel insights for accelerating the design of high-performance HEAs. The research achievements include: (1) Based on the largest to-date database of high-entropy alloy films, an interpretable random forest machine learning model was trained and optimized, revealing the significant roles of valence electron concentration, work function, and atomic size difference in the formation mechanisms of the phase structures in magnetron sputtered HEA films. (2) Utilizing high-throughput computing combined with AI active learning, a framework for rapidly predicting HEAs with excellent mechanical properties was designed, avoiding the aimlessness of traditional dataset construction and revealing the enhancing effects of Ni and Au on the strength and plasticity of noble metal HEAs.

分会主席：陈翔、褚衍辉

C18-30

多功能湿敏力学超材料的复杂异常吸湿变形及其可擦写重复编程特性

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作为超材料研究领域的新兴分支，力学超材料基于人工设计的结构单元，在力、热等物理场的激励下，可产生反直觉的异常形变，在电子与光学系统、可展开变形结构、驱动器和传感器等领域具有巨大的应用价值。本论文以双材料弯曲杆手性/反手性结构为单元，设计并制备了具有复杂异常吸湿变形模式的、且可以重复编程的二维及三维湿敏力学超材料。二维湿敏力学超材料具有负泊松比、负吸湿膨胀和多模式吸湿变形特性。通过调节结构单元的材料配置、几何参数和材料参数，实现了超材料等效线性湿膨胀系数从负到正的大范围可调。通过像素化结构设计，使超材料具有梯度、剪切、弯曲和三维卷曲等丰富的各向异性吸湿变形模式。进一步，利用对局部结构单元涂覆可反复擦写的防潮涂层，实现了超材料异常吸湿变形的重复编程。三维湿敏力学超材料具有湿度场下的三维可调（负）膨胀、剪切和扭转等吸湿变形模式，还实现了应力场下超材料的剪切和扭转等受力变形模式。通过结构单元的拼插组合，可以实现异常形变的重复编程。

C18-31

Multiscale Plasticity of Gradient Materials

Xu Zhang*

Southwet Jiaotong University

Overcoming the strength–ductility trade-off is one of the major challenges for metallic materials. Gradient nano-grained (GNG) materials have emerged as a class of hierarchical materials with a gradient distribution of grain size, which can change gradually from nano-scale on the surface to micro-scale in the substrate. As a result of the gradient microstructure, the GNG materials have shown synergetic strength and ductility. In Tthis talk, I will present the study of the deformation mechanism and mechanical behavior of GNG materials through a multiscale modeling approach, including strain gradient plasticity theory, nonlocal crystal plasticity FEM, discrete dislocation dynamics, and molecular dynamics. The multiscale modeling could partially answer the research challenges in the theory and simulation of gradient nanostructured materials.

C18-32

双向均匀化——一种功能梯度的多尺度超材料设计框架

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国防科技大学

“逆均匀化”是一种经典的超材料设计方法，已被成功用于多种类型的超材料结构设计。现有逆均匀化设计工作主要为在胞元设计域内开展的单尺度拓扑优化，为实现清晰连续的结构拓扑，需要较高的离散分辨率，即较高的设计变量规模，还需要消除中间密度单元。因此，基于单尺度逆均匀化方法进行超材料结构设计，存在优化效率不高、设计空间利用率不足等问题，在逐单元式设计中还需要额外处理连通性问题。

本研究提出了一种跨越宏-细-微三个尺度的双向均匀化设计框架，以进行功能梯度多尺度超材料结构的拓扑优化。该框架包括微观到细观的正向均匀化过程和宏观到细观的逆均匀化设计。在微观尺度，由多切割面水平集法生成梯度微结构，并基于扩展多尺度有限元法计算微结构数值基函数。为了加速计算，构建了基于数据驱动的神经网络代理模型预测微结构控制参数和细观等效性能的关系。进一步，基于宏观等效性能设计优化目标，在细观尺度通过拓扑优化获取微结构的最优分布。

本方法在细观拓扑优化中保留了中间密度单元，释放了结构设计空间。与传统单尺度逆均匀化方法相比，本方法显著降低了设计变量规模，可以提升优化效率，降低计算内存需求，并且在逐单元式设计中有天然的结构连通性优势。通过实施多种类型的力学和热学超材料结构设计，数值算例和实验证明了方法的有效性

C18-33

Effect of rare earth element doping on microstructure and electromagnetic wave attenuation properties of SiBCN polymer ceramics

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Wuhan University of Science and Technology

Polymer precursor derived boron-silicon-carbon nitrogen (PDCs-SiBCN) ceramics can be used as ultra-high temperature ceramics and high temperature electromagnetic loss materials due to their excellent high temperature oxidation resistance. However, after cracking at high temperature, SiBCN ceramics are mainly amorphous phase, and its electromagnetic wave loss ability is weak, which can not meet the application needs of electromagnetic wave absorbing materials. By doping rare earth elements, dielectric loss phases such as silicon carbide and graphene can be generated in the original position of SiBCN ceramics, effectively enhancing the electromagnetic wave absorption capacity of the ceramics.

In this study, Y2O3 was added to borosilazane to reveal the effect of Y on the composition and microstructure of BN©/SiC/ crystalline carbon in SiBCN ceramics, and the high temperature oxidation resistance and electromagnetic wave attenuation ability of SiBCN ceramics were analyzed. The results show that a large amount of SiCN and graphite phases are produced after heat treatment, and the degree of crystallization of ceramics increases. SiC, BN©, graphite and other crystals as conductive phase and polarization loss phase and interface polarization work together to make SiBCN ceramics have excellent electromagnetic wave absorption performance: the minimum reflection loss Rlmin reaches -42.22dB, the effective absorption bandwidth EAB reaches 4.72GHz. At 1500 oC air, SiBCN ceramics gained only 0.56 wt% in weight, showing excellent high-temperature oxidation resistance. Therefore, the addition of rare metals is conducive to the growth of dielectric crystals in SiBCN ceramics, and obtain high electromagnetic wave absorption and oxidation resistance.

C18-34

Atomic-Scale Simulations of Hetero-Deformation in Gradient Nanograined Structure

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Wuhan Univeristy of Technology

Gradient nano-grained (GNG) metals and alloys are an emerging class of heterogeneous structured materials with extraordinary mechanistic performances and unnatural plasticity mechanisms, which are unachievable in traditional homogeneous nanocrystalline metals. Experimental and theoretical studies have demonstrated that the improved mechanical performance originated from the hetero-deformation process, where the in-situ observation in the large spatial range through the gradient direction is still challenging, and the major factors that potentially affect this process are still less focused. In the present work, large-scale molecular dynamics simulations are performed on the gradient nanograined structure to investigate the gradient configuration and stacking fault energy

effects on its hetero-deformation process. It is shown that by further tailoring the gradient configuration through the Hall-Petch relationship, the plasticity heterogeneity would be further modified correspondingly, demonstrating enhanced mechanical performances. In addition, the transition of the dislocation mechanism could be observed with the grain size and stacking fault energy variance, which further affects the geometry necessary dislocation pile-up process and the strain gradient near the boundary, and finally the effectiveness of the hetero-deformation. The present work could shed light on the rational structure design methodology for heterostructure metals and alloys.

C18-35

Ultraviolet and thermal dual-curing assisted extrusion-based additive manufacturing of lunar regolith simulant for in-site construction on the Moon

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The establishment of a lunar base is crucial for lunar studies, resource extraction, and advancement in deep space exploration. Considering the limitations of rocket capacity and Earth-Moon transportation costs, the lunar regolith is regarded as the most practical material for lunar base construction. Consequently, the in-situ additive manufacturing technology for simulated lunar regolith has been widely studied in recent years. This paper proposes a novel additive manufacturing approach for lunar regolith simulants. The simulants and several resins were mixed into a paste with a high simulant content of 86 wt.%, which was suitable for the extrusion-based additive manufacturing process. To fully leverage the lunar environment, the feasibility of the ultraviolet (UV) and thermal curing of the resins was first verified, which was followed by the validation of the lunar regolith paste with a solid content of 86 wt.%. After the characterization of the ultraviolet and heat curing properties, the paste was further 3D printed via the extrusion-based device. The extruded paste underwent preliminary curing in a UV environment and was then heated to approximate the daytime lunar conditions, achieving complete curing of the printed component. The cured parts exhibited a compressive strength of 9.83 ± 1.07 Mpa, meeting the requirements for infrastructure construction in the low-gravity lunar environment. This work offers significant implications for future in-situ construction on the Moon using extrusion-based lunar regolith additive manufacturing.

C18-36

Thermally Dynamic Ripening Induced Multi-modal Precipitation Strengthened NiTi Shape Memory Alloys by Laser Metal Deposition

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Wuhan University of Technology

The functional properties of shape memory alloys made by additive manufacturing can be used in numerous applications. Adjusting the precipitation can be one way to tailor the functional properties. In this work, we fabricate NiTi shape memory alloys through laser metal deposition (LMD) technology and facilitate Ni4Ti3 and NiTi2 precipitates by heat treatment. Experimental results show that increasing the heat treatment temperature can switch the precipitates distributed from the grain boundaries to the interior of the grains, accompanied by the increasing size and content of precipitates. We find that the tailored microstructure affects the mechanical performance, manifested by the tensile recovery strain of ~2%, the tensile strength of ~749 MPa, and the strain of ~11 %. Our findings can provide information for designing enhanced shape memory properties and further microstructural studies of NiTi shape memory alloys.

C18-37

Heat Transfer Efficiency Enhancement of Gyroid Heat Exchanger based on Multidimensional Gradient Design

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Wuhan University of Technology

Metamaterials, as artificially designed materials, can be precisely controlled and adjusted in structure to achieve specific performance. However, when subjected to extreme operating conditions like high temperatures and pressures, most periodic homogeneous metamaterials are dependent on the periodic arrangement of their unit structures, exhibiting homogeneous characteristics on a macroscopic scale. This results in a reduction of the overall thermal performance of the metamaterial. Nowadays, a bio-inspired heat exchanger incorporating a triply periodic minimal surface (TPMS) structure has demonstrated great potential in the fields of new energy research and aerospace, which necessitates achieving a balance between low volume and high heat transfer efficiency while maintaining low pressure drop. This study proposes a design strategy for multi-dimensional gradient design of triply periodic minimal surface, breaking through the bottleneck problems of traditional structural mass and low heat transfer efficiency, and greatly improving the overall thermal performance of materials. By employing multidimensional gradient design of TPMS, the designable space for gradient materials' thermal performance is vastly expanded. At the same time, the results show that the convective heat transfer coefficient of the Gyroid with gradient level set values is 26.02–60.10% higher than that of the uniform Gyroid model, and the pressure drop is decreased by 9.66–18.05%.

分会主席：陈刚、付志强

C18-38

Gradient strategy of nano-multilayer hard coatings on cutting tools

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Multilayer hard coatings with gradient structure and nanoscale modulation period are effective to improve the mechanical and tribological properties of cutting tools. However, the effects of gradient structure and modulation period on mechanical performance and thermal stress of hard coatings have not been clarified. In this study, seven groups of prototype multilayer coating models with diverse gradient structure and various modulation period were established using finite element method and fabricated by multi-arc ionic plating. The nanoindentation were simulated to study on the effect of gradient structure on the mechanical performance and thermal stress. Mechanical performances and stress concentration are both weakened with the increase of modulation period, while stress fluctuation becomes more severe. The gradient structure with the thinner layers at the upper and bottom of coatings showed the best mechanical performance in the TiN/TiSiN and CrAlN/TiSiN coatings.

C18-39

高速列车制动盘激光表面增材涂层强韧性调控

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随着高速列车速度的不断提高，传统铸钢制动盘难以满足时速 400 公里高速列车制动的需求，激光表面增材效率高、变形小、稀释率低和与基材的结合强度高等优势，是提升铸钢制动盘表面性能的优选方法。激光表面增材涂层的高强韧性匹配和高耐热疲劳性能是目前面临的难题。本报告提出了一种强度和塑性提升的方法，通过优佳激光表面增材工艺，在铸钢制动盘摩擦面制备了一层 Mn 改性的耐高温的 Stellite 21 涂层，实现了通过固溶强化和 TRIP 效应协同提升 Stellite 21 钴基涂层的强度和塑性。

C18-40

揭示多相多元陶瓷在烧蚀过程中的固相反应现象

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多相复合设计有望进一步提升多元超高温陶瓷的抗烧蚀性能，而充分了解多相多元陶瓷的氧化烧蚀机理是进行多相复合设计的基础。本文通过研究一种三相多元陶瓷（由富 Hf 碳化物、富 Nb 碳化物、富 Zr 硅化物构成）的氧化烧蚀行为，揭示了多相多元陶瓷在烧蚀过程中存在的固相反应过程。研究发现，由于

氧化层的对热流和氧的阻挡，材料内部存在着温度-氧分压双重梯度，因此，基体/氧化层界面区域处在相对较低的温度和氧分压下，这使得该区域多元陶瓷相间发生了固相反应。在固相反应过程中，金属离子在多元陶瓷相之间互扩散，导致了多元陶瓷相的成分演变。这种成分的演变使多元陶瓷相能在更高的氧分压下稳定存在，进而提高了三相多元陶瓷的热力学稳定性。此外，这种固相反应与氧化层中元素优先氧化行为协同作用，增强了三相多元陶瓷的抗烧蚀性能。

C18-41

Particle-based double network hydrogels construct PVDF microfiltration membranes for highly stable and efficient oil/water emulsion separation

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Hubei University of Technology

A new hydrophilic modification method for poly(vinylidene fluoride) (PVDF) membranes is designed via hydrogel blending with high oil-water separation efficiency.[1] We report highly hydrophilic and mechanical strength particle-based double network hydrogel well-immobilized in the membrane by constructing the interpenetrating network. Particle-based double network (PDN) hydrogel of poly(2-acrylamido-2-methylpropanesulfonate)/ polyacrylamide (PAMPS/PAAm) were constructed a stable interpenetrating network with PVDF molecular chains in casting solution via free radical polymerization. And then modified PVDF microfiltration membranes were prepared by spray-modified non-solvent induced phase separation (NIPS).[2] It is worth noting that the construction of this interpenetrating network modulates the surface segregation behavior of the gel during the NIPS, leading to the in situ embedding of the gel network in the PVDF matrix, a remarkable enhancement of hydrophilic modification stability. Dynamic water contact angle (WCA) and water flux measurements confirmed the improved hydrophilicity of PVDF/PDN membrane. The WCA of PVDF/PDN decreased to 0° within 22 s, or a fully wettable surface. The water flux of the PVDF/PDN membrane was finally stabilized at 1969.70 L m-2 h-1), about 1.5-fold of the pristine counterpart, which was attributed to the synergistic effect of the abundant hydrophilic groups and the micro-/nano- structure on the surface of the modified membrane. In a three-cycle oil-in-water emulsion filtration test, PVDF/PDN demonstrated the highest permeate flux and flux recovery, and the oil rejection rates also remained the highest for each cycle. Such results are attributed to a couple of factors, (i) abundant hydrophilic functional groups on PAMPS and PAAm molecular chains endowed strong water binding ability of the membrane surfaces to prevent oil adhesion and (ii) the strong interpenetrating network structure inhibits the loss of hydrophilic modifiers which makes the membrane reusable in the process of circulating oil-water separation.

C18-42

Design and application of a new type of carbon-based structure/function integrated wideband absorbing material

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With the rapid development of modern science and technology and the wide application of electronic equipment, the problem of electromagnetic wave pollution is increasingly complicated and serious. To solve the above problems, strict requirements are put forward for the adaptability, structural characteristics and functionality of the wave absorbing materials. The absorbent material puts forward the wide-band, light weight, flexibility, tensile resistance and extreme environment resistance requirements. In this study, a performance-driven design strategy was proposed, and the composition and structure of periodic long-continuous carbon fiber composites were reverse-designed through the combination of machine learning and finite element simulation to meet the integration requirements of broadband wave absorption and structural properties. Finally, the optimized structure of the composite not only improves the impedance matching and introduces a new loss mechanism, but also results in the effective absorption of 32.7 GHz broadband absorption of the flexible composite with a thickness of only 0.92 mm and a density of only 5.6×10^{-4} Kg/m^2. It also has high temperature resistance, acid and alkali resistance, oxidation resistance advantages. It provides a new method for preparing lightweight, good mechanical properties, extreme use environment resistance, broadband absorption structure/function integrated absorbing composite materials.

分会主席：涂溶、刘艳

C18-43

基于素化设计的高强韧钛

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钛及钛合金具有高比强度、优异耐腐蚀性、良好生物相容性等特点，已广泛应用于航空航天、海洋工程、生物医用等高技术领域。当前，通常需要添加 V、Mo、Nb 等昂贵稀有金属对钛进行合金化，才能获得高强韧性能的钛合金，从而满足高技术领域装备的发展需求。然而，采用稀有金属进行合金化的方法存在成本高、回收难、消耗战略资源等问题，极大限制了高强韧钛合金的广泛应用。本研究基于遍在性氧元素协同提升钛强度和塑性的理念，采用连续梯度成形打印技术，高通量制备得到不同氧含量的 Ti-O 合金，揭示了非平衡相的形成机制，优化工艺和显微组织得到高强韧 Ti-O 合金，力学性能与常用的 TC4 钛合金

相当。本研究开发的高强韧钛不依赖稀有金属强化，实现了高性能钛材料的成分素化，且成本低，易于回收再利用，市场前景广阔。

C18-44

Mo/W 掺杂实现 NiCoCr 异构多主元合金室温与极低温的强度-塑性优异匹配

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本文系统研究了 $Ni_{48}Co_{33}Cr_9Mo_4W_6$ 多主元合金（MPEA）在室温（298K）与低温（77K）环境下的力学行为、变形与强化机制。通过铸造、均质化热处理、冷轧以及退火处理并结合相图预测构筑了具备均质与异质结构的单相 FCC 合金。其中均质结构的合金由等轴晶构成，随着退火温度的逐渐提高，晶粒也逐渐长大（1.4 至 47.8 μm），并在 1173 K 退火 3 min 后实现了强度塑性的匹配，在室温条件下其屈服强度、抗拉强度、断后伸长率分别为 811 MPa、1131 MPa、40.2%，在低温环境下则分别提高至 1085 MPa、1620 MPa、42.7 %。而异质结构的合金则由未完全再结晶区域（~47.1 vol.%）和再结晶区域（~52.9 vol.%）组成，得益于变形过程中上述两种区域不均匀变形所引入的背应力，其在室温与低温环境下表现出更高的强度，屈服强度分别为 1083 MPa 与 1407 MPa，抗拉强度分别为 1247 MPa 与 1699 MPa，并保持着较好的塑性，断后伸长率分别为 24.2%与 30.6%。研究表明合金的强化机制主要包括晶界强化、固溶强化与异质变形诱导强化，其中异质变形诱导强化在异质结构合金的强化中占据主导地位。室温环境变形过程中，位错与层错为合金的主要变形机制，仅有少部分变形孪晶出现在变形后的异质结构合金中，而在低温环境下则由高密度的变形孪晶主导变形过程。本研究不仅对理解多主元合金的组织调控和强化具有重要意义，同时也可为梯度结构构筑调控材料力学性能提供参考。

C18-45

Controllable synthesis of functionally graded mesoporous materials and their applications

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Functionally graded mesoporous materials are popular multifunctional materials, which have great application potentials in various fields. This is mainly because mesoporous nanomaterials not only have the properties of general porous nanomaterials, such as adjustable pore size, large pore volume, high specific surface area, etc, but also possess many advantages of unique morphologies or structures. It has a broad prospect in catalysis, hydrogen storage, separation and electrochemistry. So far, many methods have been developed to regulate the morphology and structure of mesoporous materials, including spraying, drip, Stober method, colloid assisted assembly, confined assembly and solid state reaction. However, the morphology and mesoscopic structure synthesized by the above methods still cannot meet the needs of the development of the times. At the same time, the research on the synthesis

mechanism is not profound enough, and the application research is also very limited. Therefore, it is of great significance to further develop a simple and powerful method to construct bio-inspired porous nanomaterials, to conduct in-depth research on its synthesis mechanism, and to give full play to its application potential.

C18-46

Construction and performance of HfB2-SiC based high oxygen blocking coatings

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To enhance the oxygen blocking properties of HfB_2-SiC based coatings at high temperatures, LaB_6-HfB_2 synergistic reinforcement followed by low-loss film-forming treatment (LFT) was used to prepare HfB_2-SiC-LaB_6 coatings based on the design of functional gradient materials, whose oxidation resistance mechanism as well as the structural evolution at 1700 °C was investigated. After LaB_6 modification, part of La diffused into Hf-Si-O glass, forming a more stable Hf-La-Si-O composite glass layer. The refractory La oxides embedded in the glass layer prevented crack propagation and effectively inhibited the internal diffusion of oxygen. Compared to the HfB_2-SiC coating, the HfB_2-SiC coating with 5 vol% LaB_6 addition exhibited the best oxygen blocking performance, with 85.3% and 74.2% reduction in oxygen permeability and carbon loss rate, respectively. However, the excess La_2O_3 formation from LaB_6 oxidation caused by excess LaB_6 addition consumed local SiO_2 in the glass layer, which disrupted the integrity of the glass layer and increased the diffusion of oxygen. Furthermore, after LFT at 1100 °C, the relatively modest oxidation activity and complete dispersion of metal oxide nanocrystals generated a compact and continuous composite glass layer, which caused a decreased oxidation activity at 1700 °C. The excessive formation temperature might result in oxidized and porous coatings, while lower temperatures could lead to poor fluidity of the glass layer, making it challenging to achieve compact composite glass layers. After LFT at 1100 °C for 360 min, the oxygen permeability and carbon loss rate of the coating were only 0.065% and 0.211×10^{-6} $g\cdot cm^{-2}\cdot s^{-1}$, effectively enhancing the oxidation inhibition ability and dynamic stability of the HfB_2-SiC based coating.

C18-47

氮化硼纤维的微结构演变及力学性能研究

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氮化硼纤维所具有的独特性能，使其可作为新型耐高温透波陶瓷基复合材料的增强相。本文以高纯硼酸为原料，采用熔融纺丝法合成晶体氧化硼前驱体纤维，之后通过两步氮化处理制备出高强度、连续氮化硼纤维。通过对氮化硼微晶粒的形成、结构演变以及纤维微缺陷的分析，阐明了氮化硼纤维微观结构变化

对其力学性能的影响。经 1850℃热牵伸处理得到的连续氮化硼纤维以 h-BN 为主相，且晶粒沿（002）晶面进行取向性生长；纤维抗拉强度达到 890.9MPa，弹性模量达到 40.8GPa。氮化硼纤维力学性能的提升可通过减少气孔数量、降低微孔尺寸、提高晶粒取向度等措施实现。

C18-48

Entropy regulation in spinel oxide with narrowed band gap and lattice distortion toward high-temperature infrared radiation

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Typical infrared (IR) radiation materials, such as spinel structure with transition metal doping, remain challenges on IR radiation performance and thermal stability. Inspired by manipulatable entropy with desired properties, $(Mg_{1/5}Co_{1/5}Ni_{1/5}Cu_{1/5}Zn_{1/5})Al_2O_4$ ($5MAl_2O_4$) with improved infrared radiation property and reduced thermal conductivity has been successfully synthesized. High-entropy strategy significantly narrows the band gap by impurity energy level formation, resulting in an improved 0.91 (0.78-2.5 μm). Simultaneously, $5MAl_2O_4$ emerges site inversion (tetrahedral and octahedral sites) and lattice distortion which benefits the outstanding infrared emissivity of 0.94 (2.5-15 μm, measured at 800 ºC). Furthermore, $5MAl_2O_4$ reaches fairly low thermal conductivity of 2.1 $W\times m^{-1}\times K^{-1}$, 4~5 times decrease compared with MAl_2O_4 end members. The remarkable infrared emissivity and low thermal conductivity offer great potential in energy conservation and heat dissipation.

分会主席：邵刚、文聘

C18-49

Novel Superhard High-Entropy Monoboride: A Promising High-Temperature Wear-Resistant Material

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High-temperature wear failure is a major problem faced by precision components, and developing reliable high-temperature wear-resistant materials is crucial for the development of advanced industries. This study proposes a novel high-entropy monoboride (HEMB)—$(V_{0.2}Cr_{0.2}Ta_{0.2}Mo_{0.2}W_{0.2})B$—with outstanding wear resistance and friction reduction properties at high temperatures (HT). Obtaining the desired properties is challenging owing to the diversity of high-entropy materials and the complex synergistic effects between multiple components. The system is selected partly because of the severe lattice distortion effect and the stable three-dimensional covalent B network of HEMB, which confer it with superhard properties. Additionally, low-melting-point layered oxides generated at

HT reduce wear and provide hydrodynamic lubrication. Significantly, the wear rate of the system reaches 2.35 × 10^{-6} mm^3/(N·m) at 600 ℃, which is lower than those of most materials reported thus far. Nanoindentation tests and aberration-corrected scanning transmission electron microscopy of the surface and cross-section of the wear scar indicate that the high-toughness and dense oxide film generated in situ at 600 ℃ have an excellent protective effect on the material. The findings of this study motivate the development of high-temperature wear-resistant materials using high-entropy methods and provide valuable guidance for future research on wear-resistant materials in extreme environments.

C18-50

Ceramic Materials with Hierarchical Architecture Fabricated by Fast Sintering Techniques

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Novel sintering technology such as spark plasma sintering (SPS), flash sintering, and cold sintering has developed rapidly. The main mechanisms for heat transfer in a sintering process involve heat conduction, heat convection and thermal radiation. According to the famous Stefan-Boltzmann’s law, heat transfer at high temperatures is much more significant. This study aimed at using a modified spark plasma sintering device to generate intense thermal radiation and achieve rapid densification in a short period of time, which is named as "Sintering by Intense Thermal Radiation (SITR)" technology. This approach has been successfully applied in the fields of preparing gradient porous silicon carbide ceramics, silicon nitride foams with a hierarchical pore structure, as well as wave-transparent composites with a sandwich structure. SPS/SITR have shown the advantages of short processing time, adjustable temperature distribution, and near-net formation, which is promising in the area of fast manufacture of ceramics materials with hierarchical architecture.

C18-51

A facile high-efficiency preparation strategy for Al-containing multi-component borides with superior hardness and oxidation resistance

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Multi-component transition group metal borides (MMB2) have become a research hotspot due to their new composition design concepts and superior properties compared with conventional ceramics. Herein, we proposed a new high-efficiency strategy for synthesis of MMB2 using molten aluminum as the medium for the first time. The prepared Al-containing multi-component borides (TiZrHfNbTa)B2 microcrystals had a homogeneous composition with a hexagonal AlB2 structure and ultra-high hardness value of ~35.3 GPa, which was much higher than data reported in the literature and the rule of mixture estimations. Furthermore, combined with the First-principles

calculation results, we found that the Poisson's ratio (v) values exhibit a clearly ascending trend from 0.17 at VEC = 3.5 to 0.18 at VEC = 3.4, then to 0.201 at VEC = 3.2 with the increasing of Al content. This indicates that the intrinsic toughness of multi-component boride microcrystals is obviously enhanced by the trace-doped Al elements. Besides, the fabricated Al-containing multi-component boride microcrystals have superior oxidation activation energy and structural stability. The enhanced oxidation resistance is mainly attributed to the formation of a protective Al2O3 oxide layer and the lattice distortion, both of which lead to sluggish diffusion of O2. These findings propose a new unexplored avenue for the fabrication of MMB2 materials with superior comprehensive performance including ultra-hardness and intrinsically improved thermo-mechanical properties.

C18-52

基于增材制造的梯度合金研究进展

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梯度功能材料是由两种或多种材料复合且成分呈连续梯度变化的一种新型复合材料，在当今飞速发展的工程领域受到了广泛的关注。但传统的梯度功能材料制备技术无法满足航空、医疗、军事等工业领域的需要。而增材制造作为一种新兴技术，提供了一种全新的思路来解决梯度功能材料的制备问题。报告人总结了增材制造制备梯度功能合金的主要方法，讨论了利用激光熔覆与选区激光熔化技术制备钛基、铁基及金属-陶瓷等梯度合金的研究现状及在相应领域的重要应用，并结合现有工作论述利用选区激光熔化制备连续梯度功能合金的原理与研究进展，最后阐述了利用增材制造技术制备梯度功能合金的挑战和机遇，并展望了本领域的未来发展方向。

C18-53

Preparation and performance regulation of ultra-high temperature ceramic boride-silicon based high oxygen barrier coatings

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To achieve a highly oxygen-resistant structure on coatings applied to carbon structural materials, techniques such as low-loss film formation, multiple transition group metal modification, and self-propagating alloying-enhanced micro-zone in-situ repair are utilized to enhance the wide temperature range gradient antioxidation capability of the coatings. Based on the wide-temperature-range film formation law of self-generating glass layers, film formation loss of the coatings is reduced through pre-oxidation film formation treatment. Compared with coatings without film formation adjustment, the oxidation activity of coatings formed at 1200°C for 120 minutes is significantly weakened, with reductions of 33.36% and 82% in structural factor and inert factor values, respectively.

By synergistically enhancing oxygen resistance with dual transition metal silicides, the destructive dynamic evolution of the coating's oxygen-resistant structure is suppressed. The increase in $MoSi_2$ content promotes the homogeneous dispersion of oxide nanocrystals, while the strong complexation film-forming effect of Ta^{5+} increases the viscosity of the glass film. The oxygen permeability of coatings decreases from 0.46% to 0.16%, a reduction of 65.22%, with cumulative protection efficiency increased to 99.70%. Through self-propagating high-temperature synthesis (SHS) technology, non-equilibrium alloyed ultra-high temperature ceramic boride-silicon composite powders are synthesized, strengthening the suppression of boride oxidation loosening by silicon-based components. Compared with commercial powders, coatings prepared from SHS powders exhibit higher density and lower oxidation activity, significantly improving the structural oxygen resistance of the coatings in the active oxidation stage. The lowest oxygen permeability of coatings is 0.3%, with a carbon loss rate of 0.29×10^{-6} $g\cdot cm^{-2}\cdot s^{-1}$.

分会主席：李端、王海龙

C18-54

Sensing Property of Polymer-Derived Ceramics

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Polymer-derived ceramics (PDCs) have attracted extensive attention in many applications due to their excellent high-temperature semiconductor property, distinguished piezoresistive effect, outstanding oxidation and corrosion resistance. Our researches mainly focus on the sensing properties of the polymer-derived ceramics, including the temperature resistance effect in a wide temperature range, and the piezoresistive effect under different pressure and strain. Thus, the diverse sensors with different structures were designed and fabricated. The results show that the prepared sensor devices possess excellent sensitivity, stability, fast response and repeatability, exhibiting great potential to be applied in harsh environments for the detection of temperature, pressure and strain signals.

C18-55

Molecular Orbital Machine Learning for Constructing the Descriptor of OER Activity in Gradient-Component LDH Catalysts

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The theoretical analysis of the oxygen evolution reaction (OER) often relies on the d-band center theory. However, this approach is insufficient for a deep exploration of coordination environments and crystal field effects on the OER performance of active sites. For instance, in layered double hydroxides (LDHs), metal atoms are typically situated within an octahedral coordination environment comprised of six hydroxyl groups, causing further

splitting of the d-orbital into dxy, dyz, dxz, dz2, and dx2-y2. During the optimization and modification of materials, lattice distortions frequently trigger the Jahn-Teller effect, thereby altering the dz2 energy levels of the active site, which is a crucial factor in regulating the OER performance. To address these issues, Ni-X layered double hydroxides (LDHs) where X represents Fe, Co, Cu, or Zn, were chosen as the research subjects in this investigation. This work delves into the crystal field effects (specifically eg and t2g orbitals) and spin polarization of the d-orbital influenced by various doping elements, including electron-deficient (Fe, Co) and electron-rich (Cu, Zn) metals. The filling rate, the energy level center, and the bandwidths of eg and t2g orbitals were systematically analyzed to elucidate the essential orbital characteristics impacting the OER activity. By integrating machine learning with symbolic regression algorithms, a novel descriptor (φ) for quantifying the OER overpotential in binary LDH electrocatalysts was proposed, shedding light on the influence of transitional metal interactions on the overpotential. It reveals that for doping with Fe and Co, the t2g orbitals exert a more pronounced impact on the overpotential, whereas for Cu and Zn doping, the eg orbitals are more pivotal. Therefore, the descriptor can successfully elucidate the patterns of performance variations observed in Ni-X LDHs. This study not only innovatively proposes a descriptor for the OER overpotential but also enriches the d-band center theory, providing a theoretical basis for developing high-performance high-entropy LDH catalysts.

C18-56

基于深度强化学习的多维功能梯度材料多目标优化设计

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功能梯度材料（FGM）是一种物理性能连续变化的先进复合材料，广泛应用于航空航天和生物医学植入物等领域。然而，在实际应用中，热机械载荷往往不是单一方向作用的，这就需要对传统的 FGM 进行多维化设计。多维功能梯度材料（MFGM）拥有在空间多方向上连续变化的性能，具有巨大的潜在应用价值。但其理论研究仍处于初级阶段，面临许多挑战。本研究旨在开发新的体积分数模型，提出有效的采样方法，推导 MFGM 板的静动态力学性能控制方程，并构建高效且准确的优化数值模型，以推动 MFGM 的多目标优化设计和深入发展。首先，通过开发新的体积分数模型，实现任意形状 MFGM 多模式的材料组分梯度分布。其次，提出 Beta 随机采样方法，为性能预测及优化过程提供采样点及随机设计变量。然后，基于新的三阶剪切变形理论和等几何分析，推导 MFGM 板的静动态力学性能控制方程。最后，通过构建、训练和评估卷积神经网络模型（CNN），实现快速而准确的 MFGM 力学性能预测，并采用 CNN 模型代替耗时的等几何分析，结合非支配排序遗传算法-II（NSGA-II），提出一种高效且准确的优化数值模型（CNN-NSGA-II）。研究结果表明，CNN-NSGA-II 能有效地找到多个满足多目标性能需求的最优材料分布。相比传统的 IGA-NSGA-II 方法，采用 CNN-NSGA-II 方法在处理相同的优化问题时，实现了约 21 倍和 49 倍的速度提升。这种速度的提升意味着，在同样的时间内，我们能进行更多的优化迭代，从而更有可能找到满足多目标性能需求的最优材料分布。这对于 MFGM 的优化设计具有重要的意义。本研究提供了一种新的针对 MFGM 的理论研究方法和实际应用策略，为其多目标优化设计和深入发展开辟了新的途径。建议将

这种方法应用于更广泛的应用场景，以实现 MFGM 的全面优化和提升。

C18-57

Preparation of Ti-Pt periodic modulation gradient materials and research on quasi-isentropic loading characteristics

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Quasi-isentropic loading technology based on wave impedance gradient materials is an important technical means to master the dynamic response characteristics of materials, and is crucial to improving the service performance of materials. This article uses electron beam evaporation coating technology to successfully prepare Ti-Pt periodic modulation gradient materials. The gradient change of wave impedance is achieved by modulating the thickness of the two components (Ti and Pt single layer) in the periodic layer. The interfaces between the layers in this gradient material are clear, and the error between the measured thickness and the theoretical thickness is only 1.67%. No metal alloy phase was found in the phase analysis. A first-stage light gas cannon was used to drive the Ti-Pt periodically modulated gradient material to load a 5 μm Al target, which produced a shock-quasi-isentropic loading waveform in the Al target. The quasi-isentropic loading section lasted about 13 ns. The numerical simulation results are in good agreement with the upward trend of the experimental curve. There are large fluctuations in the quasi-isentropic section of the particle velocity, stress and strain rate curves at the 5 μm Al target. The strain rate curve continues to oscillate between positive and negative values, and the amplitude is large. The maximum strain The rate is 7.3×10^7 s^{-1}, the minimum strain rate is -4.5×10^7 s^{-1}, and the average strain rate is 1.3×10^6 s^{-1}. It is observed from the stress cloud diagram that the periodic modulation gradient material loading process will form the pursuit, superposition, and integration process of multiple wave systems. When the target thickness is increased to 60 μm, the wave system completes the integration and transforms into continuous compression wave loading. A first-stage light gas cannon was used to drive the Ti-Pt periodic modulation gradient material to load a 60 μm Al target. The quasi-isentropic section of the particle velocity and stress curve transformed into a smooth loading waveform. The overall strain rate curve was above positive values, and the maximum strain rate was 5.7×10^6 s^{-1}, the minimum strain rate is 4.5×10^5 s^{-1}, and the average strain rate is 1.8×10^6 s^{-1}, achieving a good quasi-isentropic loading effect, indicating that the periodic modulation gradient material and the target thickness need to be matched design. The research results of this article can provide guidance for the application of new periodically modulated gradient structures.

C18-58

基于 Hugoniot 线特征梯度铁基材料的爆炸硬化研究

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梯度纳米结构金属材料的制备方法及其对材料性能的影响已成为当前材料科学领域的一个研究热点。其特殊之处在于其组织结构及尺寸在空间上呈现梯度变化，同时具备高强度和高韧性，不仅打破了强度增加与塑性/韧性降低的规律，而且具有优异的抗疲劳性和耐磨性。本研究利用爆炸压力在铁基材料中的衰减特征，制备梯度铁基材料。首先，通过铁的 Hugoniot 线分析出其相变压力、孪晶与错位激发压力。然后，模拟不同爆速炸药爆炸硬化铁基材加工过程中的最大压力，使得最大输入压力大于铁的相变点，从而获得了具有梯度晶粒、梯度相变、梯度孪晶和梯度位错的铁基材料。最后，采用分子动力学模拟方法解析铁基材料在加载和卸载过程中的组织结构演变，阐述相变、孪晶、位错和梯度晶粒结构的形成机制。研究成果为制备梯度材料提供了新思路。

C18-59

Research on multi-dimensional design, additive manufacturing preparation and controllable loading performance of area array gradient structure

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Controlled loading technology based on wave impedance gradient materials is a mainstream experimental technology for studying the mechanical response behavior of materials under different service load conditions. It is crucial for enhancing the service controllability and safety of materials and establishing a material genetic engineering database. In order to solve the problems of complicated process of stacked component gradient materials and further reduce the initial impact, and obtain a low strain rate load environment at the GPa level, we vigorously develop structural wave impedance gradient materials. This paper designs an area array gradient structure with gradually increasing impedance, and controls the different impedance change forms (P values) and gradient arrangement of the area array gradient structure through mathematical expression. Projection Micro Stereolithography is used to prepare a smooth and defect-free polyacrylate-based area array gradient structure, with a tip size up to 37.9 μm, which is 87.3% higher than the existing area array gradient structure. A first-stage light gas cannon was used to drive area array gradient structures with different P values to hit the Al target at a speed of 500 m/s. A quasi-isentropic loading waveform without initial impact was generated in the Al target, achieving a range of 3.06×10^4~8.88×10^4 /s control of internal loading strain rate. By comparing and analyzing the target hitting experiments and simulation results of different area array structural elements, the wave propagation behavior and integration mechanism of the target hitting process were studied. The results show that: the target first generates point waves, and the point waves spread in a spherical shape to form spherical waves. Waves attenuate during

propagation, and at the intersection of spherical waves, an enlarging spherical wave is formed due to convergence and superposition; multiple enlarging spherical waves form a one-dimensional plane wave due to integration. This paper designed and controlled the area array gradient structure through mathematical expression, realized quasi-isentropic loading of extremely weak initial impact, obtained a load environment of 10^4 /s strain rate under GPa stress, and established the spherical wave formation, propagation and integration mechanism, and studied The results can provide guidance for the application of new area array structural wave impedance gradient materials.

C18-60

Preparation of Ni-Co-S gradient-structured catalysts by electrodeposition and study of their hydrogen precipitation and corrosion resistance properties

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In the ship transportation industry, the bubble drag reduction technology can effectively reduce the ship drag and largely reduce the fuel consumption. Electrolytic water replenishment has many advantages such as energy saving, environmental protection, renewable resources, ship performance optimization, load reduction, etc., which is one of the important directions for the future development of the ship industry. Due to the low ionic concentration and large amount of chloride ions in seawater, the catalytic electrode needs to be prepared with high hydrogen precipitation catalytic activity and certain seawater corrosion resistance to resist chloride ion corrosion and electrochemical corrosion in seawater. Traditional noble metal catalysts (e.g., Pt, Ir) have good corrosion resistance and catalytic performance, but their high cost and scarcity limit their practicality, so one of the difficulties in electrolytic seawater replenishment technology is to develop a highly efficient corrosion-resistant and inexpensive hydrogen precipitation catalysts.Chen et al. prepared Ni-NiCo alloys with different Ni-Co contents, and analyzed the corrosion properties of the different cobalt-Ni-Co alloys. The addition of Co sites can not only synergize with Ni to promote the generation and release of H_2 and improve its hydrogen precipitation performance, but also control the content of NiCo to achieve the modulation of corrosion resistance. In addition, the electronegativity of S atom in metal sulfide is high, which can absorb electrons and make itself negatively charged, and it is easier to adsorb positively charged intermediate products with strong hydrogen precipitation reaction activity. The presence of the bonding agent not only reduces the catalytic activity of the catalyst, but also affects the stability of the catalyst itself to a certain extent.

Thus, we rationally designed the hydrogen precipitation active layer and corrosion-resistant layer by adjusting the Co content, and prepared gradient Ni-Co-S catalysts with different Co contents on nickel foam substrates by electrodeposition to balance their corrosion-resistant properties under the premise of ensuring their hydrogen precipitation performance. Among the available data, when Ni:Co=15 and without elemental S, its corrosion resistance was optimal, with a self-corrosion current of 0.0000915 mA cm^{-2} and an overpotential η_{10} of 251.17 mV at a current density of 10 mA cm^{-2} as the corrosion-resistant layer; when Ni:Co=3.5 and the thiourea doping was

100 g/L, its hydrogen precipitation performance was The best, overpotential η_{10} is 80.13 mV, and the self-corrosion current is 0.000333mA cm^{-2}, as the hydrogen-dissolving active layer; when the corrosion-resistant layer and the hydrogen-dissolving active layer are combined and deposited, we found that, when the corrosion-resistant layer is deposited in the inner layer, and the hydrogen-dissolving active layer is deposited in the outer layer, the samples obtained have a certain performance enhancement compared to the hydrogen-dissolving active and the corrosion-resistant layers alone, with the overpotential η_{10} is 80.07 mV, which is 171.1 mV higher than that of the corrosion-resistant layer, and the self-corrosion current is 0.000147 mA cm^{-2}, which is 0.000186 mA cm^{-2} higher than that of the hydrogen-dissolving active layer.

C18-61

The hot pressing fabrication technology for Cu/PMMA gradient composite materials and controllable loading.

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Leveraging a controlled loading technique predicated on the deployment of gradient impedance materials, this study delves into the complex mechanical response of materials under a spectrum of stress and strain rate conditions. Such an approach is not only paramount for augmenting the operational controllability and safety of materials but is also integral to the construction of a materials genome engineering database, thereby facilitating a deeper understanding of material behavior under extreme conditions. In this research, a Cu/PMMA gradient composite material was meticulously fabricated employing a synergistic methodology combining melt consolidation with integrated hot pressing. This advanced material exhibits a homogeneous phase composition, exceptional interfacial cohesion, superior planarity, and is devoid of any discernible defects. This innovation significantly attenuates the initial impact, thereby expanding the realm of controllable loading applications. The empirical density measurements deviate from theoretical computations by a mere 1.86%, and phase analysis did not detect any metallic alloy phases, underscoring the material's compositional uniformity. Moreover, the actual thickness of the material is found to be within a 5 μm tolerance of the intended design specifications, highlighting the precision of the fabrication process. By employing a single-stage light gas gun to impel the Cu/PMMA gradient composite material against an Al target, a waveform characterized by low-impact quasi-isentropic loading was successfully induced within the Al substrate. Through meticulous tuning of the loading velocity and the structural configuration of the gradient composite (in terms of thickness and layer stratification), a controlled modulation of the strain rate across a continuum from 0.15×105 to 4.52×105 s-1 was realized. The refinement of intermediate layer thickness and the increment of layer count have substantially enhanced the stability of the strain rate variation. Concurrently, an escalation in loading velocity has broadened the stress range and precipitated a threefold amplification in strain rate. The Cu/PMMA gradient composite material has been exemplified as capable of achieving a controlled loading milieu at the GPa magnitude with medium to low strain rates, with an inherent ability to modulate strain rates. The

outcomes of this study provide researchers with a blueprint for the precise manipulation of stress and strain rates in experimental paradigms, enabling the attainment of diverse shock wave loading conditions. This research introduces a novel experimental methodology, enriching the corpus of investigative techniques for the study of materials' mechanical behaviors under a multiplicity of stress and strain rate conditions.