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E05. 材料服役行为与结构安全

分会主席：付安庆、冯春、范志超、张显程、张哲峰

报告

E05-01

油气及新能源工程材料腐蚀与防护研究进展

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随着我国能源开发向深地、非常规、低碳及新能源方向发展，其生产运行过程中面临各种各样的复杂腐蚀难题。本报告重点介绍以下五方面的腐蚀防护研究现状：第一，超深高温高压气井管柱腐蚀，重点介绍超级 13Cr 管柱在气井全生命周期服役环境中局部点蚀（酸化及残酸返排）和应力腐蚀开裂（环空保护液）机理及选材评价方法；第二，非常规页岩气腐蚀，重点介绍页岩气压裂过程中微生物现状，提出了膜下微生物腐蚀评价方法及微生物腐蚀机制，建立了国际上首个微生物腐蚀 ISO 标准；第三，CCUS 超临界 CO_2 腐蚀，我国重点油气田 CO_2 驱油注采过程管柱腐蚀现状，着重介绍腐蚀、应力腐蚀开裂、低温、密封、结垢等五大失效问题；第四，输氢管道氢致损伤，介绍国内外输氢管道建设及技术现状，重点讨论气态氢和离子氢对金属材料的影响机制差异，气态氢环境不同钢级管线钢氢致损伤研究及中国石油气态氢环境装备材料服役评价平台（高温高压气态氢慢拉伸实验系统、高温高压气态氢渗透实验系统、TDS 氢含量测试系统）；第五，压缩空气储能管柱腐蚀，简要介绍我国肥城、应城和金坛等压缩空气储能国家级示范项目建设现状，空气中的氧溶解于盐腔中的卤水导致井筒管柱及其他构件发生严重腐蚀。此外，针对以上部分腐蚀问题，介绍中国石油集团工程材料研究院自主研发的缓蚀剂、双金属复合管、常温固化无溶剂涂层、高性能碳基涂层等防腐技术的研发历程及现场示范应用情况。

E05-02

高通量力学性能测试通法

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自 2016 年西南交通大学力学团队原创提出能量密度等效理论（C 理论），陆续提出了高通量力学和系列力学试验方法：微试样与服役结构材料高通量压入、高通量残余应力压入、高通量小冲杆试验与低周疲劳试验、高通量薄板低周疲劳试验、断裂韧度解析法与高通量性能测试、高通量圆环试验等。报告总结了基于 C 理论提出的微试样力学试验方法通用技术，介绍了高通量、高精度重大仪器装备的进展。

E05-03

激光诱导共晶高熵转变辅助钎焊界面强化及接头氢腐蚀行为

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为了获得高可靠性和长寿命的核反应堆，对燃料组件等堆芯结构材料的性能提出了更高要求。本论文主要围绕 Zr 合金和 CoCrFeMnNi HEA 的钎焊工艺与连接机理展开研究，通过设计 Zr63.2Cu(wt.%)共晶钎料来调控界面冶金反应，并采用激光熔覆 Nb 辅助钎焊来缓解接头残余应力，并对氢环境下接头的服役性能进行研究，从而得到具有优异室温力学性能和氢服役环境下良好性能的接头。在 970 ℃/10 min 钎焊参数下，HEA/Zr63.2Cu/Zr 接头的界面组织为 HEA/HEAP/$Zr(Cr,Mn)_2$ +Zrss/$Zr_2(Cu,Ni,Co,Fe)$ + Zrss + $Zr(Cr,Mn)_2$/Zr，且严重的晶间渗入发生在临近 HEA 一侧。由于晶间渗入引起的应力集中，HEA/Zr63.2Cu/Zr 接头的最大剪切强度仅为 172.1 MPa，且断裂主要发生在钎缝中脆性的 $Zr_2(Cu,Ni,Co,Fe)$相中。

为了有效缓解严重的晶间渗入和母材间 CTE 失配引起的应力集中，开发了一种通过 HEA 表面激光熔覆 Nb 构建过渡层来辅助钎焊 Zr 合金的方法，熔覆层的显微组织主要由球形的 Nbss 和 FCC+HCP Laves 共晶组织组成，在 990 ℃/10 min 钎焊参数下，HEA-Nb/Zr 接头具有最高的剪切强度(255.6 MPa)，且断裂发生在钎缝块状的$(Zr,Nb)(Cr,Mn)_2$。

考虑到核反应堆燃料组件应用背景，对氢环境下接头的服役性能进行了研究。吸氢 24 h 后，HEA/Zr 剪切强度从 172.1 MPa 大幅度降低到 145.9 MPa。这可能归因于 $Zr_2(Cu,Ni,Co,Fe)$相较强的氢解吸性能(85.9 ppm)和氢环境下较低的强度(130.6 MPa)。吸氢 24 h 后的 HEA-Nb/Zr 接头，断裂主要发生在钎缝$(Zr,Nb)_2(Cu,Ni,Co,Fe)$相。HEA-Nb/Zr 接头的剪切强度仅从 255.6 MPa 降低到 225.7 MPa，是 HEA/Zr 接头强度的 1.55 倍，这也表明 HEA-Nb/Zr 接头在氢环境中同样具有良好的力学性能。氢环境下 HEA-Nb/Zr 接头具有较高的强度与两方面有关：(1) $(Zr,Nb)_2(Cu,Ni,Co,Fe)$相在氢环境下仍能保持相对较高的强度(195.3 MPa)以及较弱的 H 解吸性能(15.0 ppm)；(2) 熔覆层中共晶组织具有较强的氢解吸性能(49.2 ppm)且在氢环境仍具有较高的强度(380.5 MPa)，从而削弱氢对接头中其他物相及母材的影响。

E05-04

碳钢储油表面微结构与耐腐蚀性能的关联性研究

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油气输送管道面临腐蚀安全问题，而碳钢储油表面具有稳定油膜、隔离腐蚀性流体等作用，在油水交替等动态管输工况下展现出优异的防护潜力。近年来，围绕储油表面在油水动态润湿条件下开展了系列研究工作，揭示了其多种工况下微液滴致损与自愈合机制，然而材料微结构如何影响油膜耐久性等关键问题尚不明确。本报告以提升碳钢储油表面的长效腐蚀防护性能为目标，通过构建单液滴腐蚀模拟研究方法，系统探究了碳钢表面预处理的微结构对抗腐蚀性能的影响规律，阐明了储油表面液滴腐蚀扩展行为及其微结构依赖性。

本研究选择不同含碳量的碳钢基体（20#、45#和 70#钢），从而调控珠光体组织所占比例分别为 23.82%、57.23%和 90.64%，利用化学侵蚀方法去除铁素体相而保留渗碳体骨架，实现了 3 种碳钢储油微结构的构建。采用原位和非原位结合的方法对液滴在 3 种储油表面上的润湿动力学行为以及腐蚀扩展进行了对比分析，由此评价了储油表面的耐腐蚀性。原位光学显微观察及接触角测量结果均表明，20#碳钢表面因宽浅连通的铁素体凹坑导致油膜 30 分钟以内破裂并引发腐蚀，多级片层状的 45#碳钢表面油膜耐久性则延长至 1-3 小时，而 70#碳钢表面凭借细微深凹结构可维持油膜稳定 5-10 个小时。两种设定的实验情景结果证实 3 种储油表面油膜耐久性和耐腐蚀性的关系为 70#＞45#＞20#。通过扫描电镜和拉曼光谱对腐蚀产物分析，揭示了宽连通沟壑处易形成球状 Fe_3O_4堆积，而均匀深凹结构通过长效滞留油相抑制液相扩散。此外，拉曼光谱证实 70#表面储油能力最优，其腐蚀产物中残留油相峰面积占比最高。本报告将详细论证材料组织结构与表面储油特性及耐蚀性能的构效关系，明确“细微深凹+多级限域”微结构可有效提升油膜长效稳定性，为开发长效高耐蚀储油表面设计提供了理论依据。

E05-05

Effect of Nitriding Treatment on Hydrogen Embrittlement Resistance of S30403 Stainless Steel

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Facing dual challenges of energy security and low-carbon development, hydrogen energy infrastructure

requires significant technological advancements. While austenitic stainless steel demonstrates excellent resistance to hydrogen embrittlement, its insufficient hardness limits applications in moving components of hydrogen equipment. This study investigated gas nitriding of S30403 austenitic stainless steel, successfully producing a 36μm-thick compound layer primarily consisting of CrN and γN phases. Electrochemical hydrogen charging and diffusible hydrogen content analysis established a quantitative relationship between charging duration and hydrogen content, with nitrided specimens exhibiting a remarkable 92% reduction in diffusible hydrogen compared to untreated samples. A comprehensive evaluation through in-situ hydrogen-charged slow strain rate tensile tests and hydrogen gas disc rupture tests revealed that nitrided specimens substantially outperformed their untreated counterparts in tensile properties, demonstrating lower hydrogen embrittlement indices and sensitivity coefficients. Fractographic examination showed ductile dimple morphology under hydrogen-free conditions for both specimen types. However, under hydrogen charging, decreasing strain rate and increasing internal hydrogen progressively transformed the microfracture mechanism from a mixed mode (featuring microvoid coalescence and quasi-cleavage dominated by hydrogen-enhanced localized plasticity - HELP) to quasi-cleavage or intergranular fracture governed by hydrogen-enhanced decohesion (HEDE). The enhanced hydrogen resistance is attributed to dense nitride lattices forming effective hydrogen diffusion barriers at phase/matrix interfaces and nitrogen-supersaturated solid solutions (γN) restricting hydrogen diffusion pathways. This study presents an innovative approach to overcoming the limitations of austenitic stainless steel in hydrogen equipment, thus advancing hydrogen infrastructure development.

E05-06

压水堆二回路碱化剂对核电结构材料的腐蚀演变

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压水堆核电厂的水化学控制对系统设备和关键部件的安全可靠的运行具有重要意义。目前我国第三代核电厂正逐步推广新型碱化剂在二回路中的应用，而新型碱化剂 ETA 等对结构材料的相容性以及作用机制缺乏系统研究和重要的数据支撑。本工作引入并验证了原位循环电化学阻抗谱来研究 304 不锈钢的腐蚀行为的适用性，采用原位 EIS 研究了碱化剂的类型及表面粗糙度两个方面对 304 不锈钢腐蚀演变，尤其是对于其膜层生长动力学的影响。最后，研究了 ETA 分子在 304 SS 腐蚀过程中的影响及作用机制。研究结果表明，利用原位循环 EIS 将不同表面粗糙度的 304 SS 的氧化膜生长的物理化学过程与其电化学响应联系起来，有助于更简明地理解材料在高温电解质中的腐蚀演变。ETA 在高温高压水环境中，除了吸附机制对于不锈钢氧化膜的缓蚀效率贡献，ETA 分子还参与了 304 SS 的外层氧化膜的生长过程。这揭示了新型碱化剂 ETA 在二回路水化学控制中巨大的应用潜力。

E05-07

腐蚀-冲蚀耦合条件下采气树闸阀的综合失效分析

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To address the reason of valve leakage, lab experiments and Fluent simulations were used to study the failure mechanism. Chemical composition analysis, metallographic examination, and mechanical property tests have verified that the material of the gate valve complies with the API 6A standard specifications. The outcomes of Fluent finite-element numerical simulations have disclosed that the airflow velocity in the gate area is positively correlated with the inlet airflow velocity. It increases exponentially as the degree of gate closure diminishes. As the closure degree decreases, the position where the gas impacts shifts towards the gate. The macroscopic appearance of the gate demonstrates that long-term operation in a semi-open state leads to a significant surge in

gas flow velocity, resulting in the erosion of the valve body. This erosion has been identified as the root cause of the leakage incident. Additionally, the electrochemical corrosion induced by CO2 has expedited the failure process. It is advisable to coat the valve surface with a highly wear-resistant and corrosion-resistant material and to regularly monitor the operational status of the valve during daily production. The findings of this research provide substantial guidance for improving the operational reliability and extending the service life of valves.

E05-08

增材制造 HR-2 钢高压氢损伤机理

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在这项研究中，通过高压热充氢处理、拉伸试验、3D-XRD、SEM、EBSD 和 TEM 等方法，探讨了增材制造（AM）HR-2 钢的氢脆（HE）。研究结果表明，尽管 HR-2 钢内部存在孔洞和未熔化颗粒等缺陷，但其机械性能和耐氢脆性能并不逊色于传统方法制造的 HR-2 钢，并保持在较高水平。主要原因是其内部独特的蜂窝结构和在变形过程中形成的 SFs-locks 结构，使得位错只能沿固定方向移动。与无氢样品相比，充氢后样品中的位错沿 SFs-locks 结构进一步移动，形成了具有固定角度的堆垛层错（SFs）和变形孪晶（DTs）。这些结构的存在，使得材料具有良好的耐氢脆性能。

E05-09

304 不锈钢高压氢环境下拉伸性能及氢脆行为研究

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为支持氢经济发展，材料在氢环境下的性能评估至关重要。本研究采用棒状试样在高压釜中进行拉伸试验，系统研究了 304 不锈钢在高压氢气环境下的力学性能变化规律。通过对比分析不同氢气压力、充氢方式（原位充氢与预充氢）、试样几何尺寸及拉伸速率等因素的影响，揭示了各参数对材料氢脆行为的作用机制。实验结果显示：氢脆指数与氢气压力呈正相关关系，当氢气压力从 1MPa 增至 20MPa 时，断面收缩率氢脆指数从 6.5%增至 77.7%；预充氢试样表现出比原位充氢更严重的氢脆现象，在 1MPa 条件下预充氢的断面收缩率氢脆指数(65.6%)显著高于原位充氢(6.5%)，这主要归因于预充氢过程中氢原子有充足时间扩散至材料内部并在晶界、位错等缺陷处富集，而原位充氢时氢扩散与力学加载同步进行，氢渗透不够充分；试样尺寸增大会加剧氢脆倾向，φ10 试样在 10MPa 氢气下的延伸率氢脆指数(70.4%)明显高于 φ6 试样在相同条件下的数值(56.2%)；而拉伸速率变化对氢脆敏感性的影响相对较小。研究建立的管状试样测试方法在保证数据可靠性的同时具有良好的经济性，为氢能源领域相关工程标准的建立和完善提供了科学依据和技术支撑。

E05-10

基于氢环境慢拉伸的高钢级输氢钢管性能研究

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本文针对 L360M、L415M、L450M 等高钢级直缝埋弧焊管母材、焊缝在纯氢环境慢下的拉伸性能开展系列研究，研究表明：不同钢级氢气环境抗拉强度影响不大，母材最高损失 10%以内；不同钢级输氢钢管不同位置的断面收缩率及断后伸长率存在一定程度的减小。总体上，高钢级管材氢脆较为明显，L415M 母材断面收缩率最大损失率 33.3%，断后伸长损失 17.44%、焊接接头断面收缩率最大损失率 43.5%。此次

选用钢材来看，相比 L415MH 钢级管材，L450M 具有更好氢环境慢拉伸性能，说明通过成分组织及制造工艺调控，高钢级管线钢能够获得优异的抗氢脆性能，用于氢气高压管道输送。

E05-11

统一断裂准则

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金属玻璃由于具有不同于金属晶体材料的非晶态结构，其原子排列具有短程有序和长程无序的特点，因而表现出不同的力学性质，如高强度、高弹性极限、高硬度及耐磨性等。研究发现：金属玻璃在拉伸与压缩载荷下表现出明显的强度与剪切断裂角度的不对称性，提出了剪切断裂面上正应力对金属玻璃的断裂具有不同的效应，基于应力状态与断裂机制分析，提出了统一拉伸断裂准则—“椭圆准则”，从理论上定量地解释了各种不同金属玻璃拉伸/压缩强度与断裂角度的差异，通过提出新的参数—断裂方式因子：$\alpha = \tau_0 / \sigma_0$，将材料力学教科书中四个经典断裂准则（最大正应力准则、Tresca 准则、Mohr-Coulomb 准则、von Mises 准则）有机地统一起来；随后通过设计金属玻璃缺口拉伸实验和计算模拟验证了椭圆准则的有效性和唯一性。其次，通过金属玻璃弹性性能与断裂机制的关联，建立了断裂方式因子与泊松比之间的定量关系，通过统一拉伸断裂准则实现对金属玻璃材料拉伸/压缩强度与断裂方式及韧脆转变的预测。

E05-12

金属材料高温疲劳寿命简便快速预测方法

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针对复杂环境与载荷服役构件，经过系统探索与研究，凝炼“化繁为简、以易预难、分门别类、形神尽似”的研究思路，提出系列简便、快速、准确的材料疲劳寿命预测新方法：基于“服役载荷、疲劳机制、预测方法”相似性原则，以“应变能”为核心参数，提出通过室温疲劳性能预测高温疲劳寿命的简便方法，进而提出通过少量低周疲劳性能预测热机械疲劳寿命的简便方法，该方法可以较准确预测高温服役构件材料(铸铁、铸铝、高温合金、钛合金等材料)的疲劳寿命。这些原创系列方法开发成软件，在发电机、内燃机、燃气轮机与航空发动机等重要行业推广应用。

E05-13

A study of surface strengthening on the fretting fatigue crack propagation properties of Ti-6Al-4V dovetail slots

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In aerospace and aviation, fretting fatigue frequently causes the failure of critical components. This study investigates fretting fatigue in the dovetail slots structure of Ti-6Al-4V titanium alloy, using a self-developed surface reinforcement method: Deflected Abrasive Waterjet Process (DAWJP). Experimental research was conducted at both room and high temperatures. FRANC3D and finite element simulations were used to investigate the effects of initial crack angles, crack depths, axial loads, and residual stresses on crack propagation. Crack propagation was analyzed using DIC techniques, and fracture morphology was examined through SEM.

Additionally, a full-life prediction model was proposed, incorporating crack propagation life and temperature effects. The results indicate that the crack propagation in dovetail slots is primarily dominated by mode I cracks, and the initial crack angle has minimal impact on crack initiation life. The crack propagation direction ultimately aligns perpendicularly to the contact surface. DAWJP reinforcement significantly improves the dovetail slots specimen fretting fatigue life, reduces the number of crack sources, and decreases fatigue striation spacing. Additionally, higher loads result in smaller fatigue striation spacing. The error between the model's predicted life and the actual life is controlled within two times of the acceptable error range.

E05-14

Determining Norton creep properties from small punch creep tests by using the representative stress–strain method and inverse approach

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The small punch creep test (SPCT) emerges as an innovative technique for evaluating the creep properties of materials. Although the existing standards, such as CWA 15627 and EN 10371, establishes empirical correlations between SPCT and uniaxial creep tests (UCT), the complexity inherent to SPCT mandates an empirical approach that is both material-specific and labor-intensive for achieving precision. This paper introduces a novel methodology that synthesizes the representative stress–strain method with inverse finite element analysis to extract Norton creep properties of metallic materials directly from small punch test (SPT) and SPCT. The representative stress–strain method to SPT facilitates the determination of elasto-plastic properties at elevated temperatures, enabling a streamlined prediction of Norton creep law parameters by the inverse approach of SPCT. Notably, this methodology circumvents the need for intermediate UCT conversions, thereby providing a more efficient and accurate pathway for directly obtaining Norton creep properties from SPT and SPCT. Experimental validation conducted on P91 and P92NT steels at 600◦C confirms a strong correlation between the predicted Norton creep properties and those obtained from UCT, underscoring the practicality and accuracy of the proposed approach.

E05-15

基于有限元等效仿真的高速精密主轴服役性能研究

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轴承主轴系统的刚度和接触应力是影响其在高速服役条件下加工精度和使用寿命的关键因素，这些特性会受到不同结构参数和服役条件的影响。建立高效准确的计算仿真模型以理解复杂因素对轴承主轴系统非线性动态特性的影响至关重要。本文首先基于经典拟静力学分析模型和等效滚动体材料参数反求法，针对高速服役下轴承刚度与接触应力关系，建立了轴承的二维轴对称有限元模型。并基于该轴承模型进一步构建了 BT30 轴承主轴系统的二维轴对称有限元模型，完成了不同装配参数与服役工况下主轴力学性能的分析。结果表明：在主轴系统中轴承的轴向力会随转速增大而减小，且转速提升会导致 BT30 主轴轴向刚度的降低；同时轴承的最大接触应力随转速增加呈现小幅下降趋势。此外，随着预紧力的增加，主轴的刚度和接触应力均显著增大，但当预紧力达到特定阈值后，这些参数将不再发生明显变化。

E05-16

Optimization analysis of heat exchanger tube and tube sheet joint structure for large diameter heat exchanger

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Taking 10#+Q345R as the heat exchanger tube and tube sheet material, for the failure of tube sheet joints of large-diameter shell and tube heat exchanger, we optimize the structure of heat exchanger tube joints by introducing the TI-level tube bundle of heat exchanger tube. Combined with finite element analysis and tube joint test, the design of reasonable expansion pressure, theoretically verify the feasibility of TI-level tube bundle to improve the strength of the tube joints; pull-off, anatomical and sealing tests on the tube joints, compared to verify the strength of the TI-level tube bundle joints in the new version of the GB/T151 standard. The results show that the same expansion pressure TI grade tube bundle in the sealing is significantly higher than the I grade tube bundle, in the expansion pressure of 100MPa~140MPa interval of at least 25% higher pull-off, and can reduce the manufacturing cost to a certain extent. The results of the study provide a reference for solving the failure problem of large diameter heat exchanger tube and plate joints.

E05-17

高性能钛合金油管专用螺纹连接结构的设计开发与服役安全性能评价

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针对钛合金材料与常规碳钢的力学性能差异，传统油管螺纹连接结构难以直接应用于钛合金油管的问题，本研究设计开发了一种新型高性能钛合金油管专用螺纹连接结构，并对其服役安全性能进行了系统评价。研究采用创新螺纹结构设计，结合特殊表面涂层技术，显著提升了螺纹的上卸扣性能和密封可靠性。通过优化密封结构，增强了连接部位的持久密封能力。同时，开发了一种加速材料松弛释放和疲劳特性的试验方法，以快速验证结构的完整性和密封性能。经 API 5C5—2017 标准四级评价试验验证，该螺纹结构完全满足钛合金油管的使用要求，并表现出优异的抗疲劳性能和长期密封稳定性。研究结果表明，该螺纹连接结构有效提升了钛合金油管柱的服役安全性和结构可靠性，为钛合金油管在苛刻工况下的应用提供了可靠的技术支撑。

E05-18

“三高”气井钻完井条件下井控装置冲蚀及结构优化研究

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随着钻井工艺技术的持续进步，钻井深度不断增加，地层复杂性显著提升，井控风险也随之急剧上升。本研究基于冲蚀损伤理论,确定气相临界速度冲蚀评价标准,采用 CFD 方法研究井控装置在高速气流下的冲蚀损伤情况。在充分掌握冲蚀规律的基础上，通过系统严谨的风险评估流程，精心制定一套关键井控装置抗冲蚀结构优化方案，为井控安全提供坚实的技术支撑。测试研究结果表明：在节流管汇设备应对气体冲蚀方面，孔板阀凭借其独特的结构优势，展现出最为卓越的抗冲蚀性能，冲蚀损伤程度显著低于楔形阀与筒式阀，更加适用于“三高”气井，为复杂油气井的高效、安全开发奠定坚实基础。

E05-19

钻井防喷器失效行为分析及可靠性评价

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川渝地区深层裂缝性气藏高温、高压、高含硫特征突出，开采过程中出现防喷器闸板及壳体等均腐蚀断裂、环形胶芯老化撕裂等情况，严重威胁井控安全。目前防喷器制造标准主要依据 API 16A 和 GB/T 20174 进行制造，但标准测试条件与川渝地区裂缝性气藏契合度不高（腐蚀分压低），且忽略了腐蚀失重（质量减少）、局部腐蚀及油基钻井液渗流侵蚀等因素对防喷器材料的损伤影响，失效过程中的关键行为并不清晰。开展了适用川渝气藏环境的防喷器金属材料抗硫抗腐蚀测试及胶芯侵蚀渗流模拟实验，分析评价防喷器失效行为及可靠性。结果表明，在 H2S 分压 12.25MPa 酸性环境下，防喷器金属材质不会因抗 SSC 及 SCC 失效而产生裂纹失效，但是存在严重腐蚀失重的问题；考虑腐蚀失重影响下，35CrMo 材质性能最佳，4130 材质性能最差；油基钻井液耦合压差作业会侵蚀胶芯原始孔隙通道，在渗流作用下侵蚀面积变大，胶芯强度下降失效。进一步，结合 FMEA 分析方法，构建了适用于酸性气藏的钻井防喷器失效评价数据库，为川渝工区钻井现场防喷器选型和设计提供了依据。

E05-20

压缩空气储能技术及管道用钢管进展

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随着风电、光伏等新型清洁能源的快速发展，其稳定性差，造成发电端与用电端错配问题也逐渐显现。作为应对，国内外大力发展了各种形式的储能技术，包括抽水蓄能、压缩空气储能、电化学储能等。抽水蓄能与压缩空气储能在长时储能领域最为突出，压缩空气储能因其布置灵活等优点得到了快速发展文章通过对压缩空气储能技术及储能管道用钢管的分析，梳理出了空气储能领域用管材服役特点及选材方向。[方法]通过分析和研究压缩空气储能技术、压缩空气储能场景用管材及其服役条件，技术标准获得压缩空气储能用管材的技术要求。[结果]提出盐穴储气是压缩空气储能的主流方向，已有多个项目进入商业运行，人工硐室正处于试验阶段，金属容器类储气装置也已经开始应用，压缩空气储能用管道是非常有前景的技术路线。[结论]碳钢与部分不锈钢不宜用于盐穴注采钢管，碳钢钢管仅适用于无腐蚀性环境的人工洞室的注采。压缩储能采用储气管道方案时，以 X80 钢为代表的高钢级、大口径埋弧焊管可用于压缩储能储气管道。可开展超大规格（管径≥OD2000 mm、壁厚≥25.4 mm）X80 钢级螺旋埋弧焊管的研究，以满足 10 MPa 以上储气装置的需求。

E05-21

钛合金钻杆在油气钻探领域的应用研究

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深层油气、海洋可燃冰等苛刻环境资源逐渐成为我国能源主要采收领域。苛刻的钻采环境对石油钻杆服役性能提出了更高的需求。高性能钛合金钻杆具有低密高强、耐蚀及抗疲劳等特性，可作为苛刻环境能源钻采的入地利器。近十年来，工程材料研究院牵头研制了 105ksi、120ksi、130ksi 三种强度级别，外径 88.9mm、101.6mm、139.7mm 三种规格的全钛合金钻杆产品，完成钛合金钻杆实物性能评价，并在中石化西北局、中石油塔里木油田等成功下井应用。最后探讨了钛合金钻杆技术在能源领域的应用前景和挑战。

E05-22

12mm 壁厚 Q1100E 超高强度钢气保焊工艺试验研究

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工程机械行业 Q960 以上级别高强钢板的使用规模不断扩大，尤其是在起重机吊臂、疏浚耐磨管等结构件的制造上，已基本取代了 Q690 及以下级别的高强钢。随着用户市场对工程机械设备性能要求的提高，对高强钢的使用性能要求也在不断提高，Q960、Q1000 级高强钢板的应用越来越广泛，并有着更高强度级别的需求，研制与使用更高强度级别的钢材是必然的趋势。本文为研究 12mm 壁厚疏浚耐磨管用 Q1100E 板材的焊接工艺，在碳当量分析的基础上，采用混合气体(Ar80%+CO2 20%)保护的气保焊工艺，气体流量 20～25L/min，焊前试板预热温度为 150～180℃。经过试验结果分析，Q1100E 钢板在热输入为 10～14kJ/cm 的条件下焊接，焊接接头的拉伸性能、弯曲性能和冲击性能均符合相关标准和用户技术条件要求。

E05-23

油井管螺纹用耐磨涂料及其工艺研究

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本文研制了一种适用于油井管螺纹涂层的环保型涂料配方，该配方兼具防腐蚀与抗粘扣功能，可完全替代传统螺纹磷化工艺。通过系统研究涂料施工工艺，自主研制了螺纹喷涂专用喷砂装置与自动化涂覆设备，重点优化了表面预处理参数（喷砂粒度＞100 目）、喷涂压力（0.1-0.6 MPa）及梯度固化工艺（130-220℃/30 min）。性能测试表明：涂层厚度 15-25μm，附着力为 A 级，涂层接头紧密距偏差≤0.05 mm；涂层接头经 5 次重复上卸扣试验后，涂层完好，综合性能满足相关标准要求。

E05-24

海洋用 X65MO 钢级直缝埋弧焊管焊接接头强韧性研究

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本文针对近年国外某海洋工程项目对 X65 MO 钢级直缝埋弧焊管的焊缝纵向拉伸和焊接接头冲击韧性提出的特殊要求，试验分析了钢管制造工艺的可行性和合理性，一方面通过研究不同焊丝匹配对 X65 钢级钢管焊缝纵向拉伸性能的影响规律，揭示出焊缝的纵向屈服强度降低至与母材屈服强度水平相当时，可能导致焊接接头在导向弯曲时开裂，对钢管的综合力学性能产生不利影响；另一方面通过母材化学成分设计、焊材杂质元素限定、焊剂碱度控制、以及焊接工艺优化等措施，解决了海洋用 X65MO Φ711×19.1mm 直缝埋弧焊管壁厚中心处的焊缝及焊接热影响区脆化问题，使得该规格钢管 0℃下焊缝的夏比冲击功均值达到 160 J，剪切面积率为 63%，焊接热影响区的夏比冲击功均值为 279 J，剪切面积率为 91%。

E05-25

氧化亚表层对新型镍基高温合金力学性能的影响

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镍基高温合金因其在高温环境下优异的力学性能而被广泛应用于航空发动机和燃气轮机等关键热端部件。然而，在高温服役过程中，氧化是导致材料性能劣化的主要因素之一。本研究聚焦于氧化亚表层的微观结构对一种新型镍基高温合金 K439B 整体力学性能的影响。

研究表明，与相对完整的外氧化层相比，在合金近表面形成的氧化亚表层具有更复杂的微观结构特征，

有大量不连续的内氧化物及严重的元素贫化区。这些微观结构变化显著改变了近表层区域的力学响应。本研究从多个尺度深入表征了氧化亚层的微观结构，多角度解释了氧化亚表层对力学性能衰退的影响和对裂纹萌生机制的改变，对于准确预测镍基高温合金的服役寿命、优化合金成分以及开发更有效的防护涂层技术具有重要的理论和实际意义。

E05-26

低温超临界 CO_2 输送用直缝埋弧焊管开发

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为了满足超临界 CO_2 及含少量杂质条件下输送管材的低温高韧性，采用低 C 中 Mn 微合金化设计、高洁净化炼钢和大吨位压下轧制技术，开发出低温型 L450M 钢级超临界二氧化碳输送焊管用热轧钢板，针对微观组织为多边形铁素体（PF）+超细晶铁素体（F）+珠光体（P）的低温型 L450M 钢级板材，在制管生产线上 JCO 成型时，以 82mm 左右小步长压制 19 次制成高尺寸精度低残余应力的 Φ610×22mm 管型，为了实现埋弧焊管焊缝和热区低温高韧性，采用自主发明冶炼的 Ni-Mo-Ti 型低温焊丝结合高碱度氟碱型烧结焊剂，内焊和外焊均选用三丝埋弧焊，控制内焊和外焊各自焊接热输入 36KJ/cm 左右，试制出超临界二氧化碳输送用 L450M 钢级 Φ610×22mm JCOE 直缝埋弧焊管。经过试验检测，开发出的焊管理化性能完全符合 API Spec 5L(46 版)标准要求。特别是在-45℃下，焊缝和 HAZ 各自平均冲击功都达到 200J，-75℃下母材平均冲击功大于 300J，-75℃下焊缝和 HAZ 各自平均冲击功都达到 120J，也就是焊缝和 HAZ 韧脆转变温度 FATT50%均低于-75℃，而且母材 DWTT 的平均 FATT85%低至-38℃，可见开发的该焊管低温韧性十分优异。对焊缝进行微观组织试验发现，外焊缝中大角晶界占比 68.9%，残余奥氏体组织约占 2.5%，焊缝中存在一定量软而韧的残余奥氏体相提高了焊缝低温下的韧性。该管体和焊接接头的低温高韧性能确保焊管具有高的抗裂纹启裂和抗延性扩展止裂能力，完全满足超临界 CO_2 管安全输送服役要求，也可将该低温型直缝埋弧焊管作为油气站场、严寒极地区域油气输送用管批量推广应用。

E05-27

我国新能源输送用管材研究进展及发展趋势

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管道作为能源输送的重要载体，是“双碳”战略相关新兴产业发展的基础物资保障，是实现能源大规模、长距离输送的重要方式。本研究聚焦于清洁天然气输送用大输量管道用钢管、氢能领域中的氢气输送用管和碳捕获、利用与封存技术领域中的 CO_2 输送用管的发展需求，研究分析了新能源用管材的应用现状、标准规范和研发应用情况，重点介绍了国内研发出的大输量天然气输送用管线钢管、高压长距离纯氢/掺氢管道输送用管线钢管及超临界 CO_2 长距离管道输送用管线钢管产品及主要性能，分别从超大输量天然气管道、输氢管道及超临界 CO_2 输送道输等三个方面分析了发展趋势和需求，提出我国新能源管材产业发展的建议。

E05-28

BBW YOLO: Intelligent Detection Algorithms for Aluminium Profile Material Surface Defects

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Aiming to address the issue of various defects on the surface of aluminum profile materials, which can significantly impact industrial production as well as the reliability and safety of products. In this study, an algorithmic model BBW YOLO (YOLOv8-BiFPN-BiFormer-WIoU v3) based on an enhanced YOLOv8 is proposed for aluminum profile material surface defect detection. First, the model can effectively eliminate redundant feature information and enhance the feature extraction process by incorporating a weighted bidirectional feature pyramid feature fusion network (BiFPN). Second, the model incorporates a dynamic sparse attention mechanism (BiFormer) along with an efficient pyramidal network architecture, which enhances the precision and detection speed of the model. Meanwhile, the model optimizes the loss function using Wise-IoU v3 (WIoU v3), which effectively enhances the localization performance of surface defect detection. The experimental results demonstrate that the precision and recall of the BBW YOLO model have improved by 5% and 2.65%, respectively, compared to the original YOLOv8 model. Notably, the BBW YOLO model achieved a real-time detection speed of 292.3 f/s. In addition, the model size of BBW YOLO is only 6.3 MB. At the same time, the floating-point operations of BBW YOLO are reduced to 8.3G. As a result, the BBW YOLO offers excellent defect detection performance and opens up new opportu-nities for efficient development in the aluminum industry.

E05-29

MXene 辅助硬脂酸改性 ZIF-8 开发具有防冰和除冰性能的光热自修复超疏水防腐涂层

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在防腐涂层的使用过程中，极易受到外界物理损伤和化学腐蚀，从而很快失去防腐性能。为了提高防腐涂层的耐久性和可靠性，自修复性能被广泛应用于防腐涂层中。本研究制备了一种具有光热自修复超疏水防腐性能的双层复合涂层，底层涂层为嵌入形状记忆聚合物（SMP）中的 MXene 所获得的具有光热自修复性能的涂层，顶层涂层为通过 MZSA 接枝硬脂酸改性 ZIF-8 到 MXene 而形成的具有光热效应的超疏水涂层。结果表明，该复合涂层具有良好的超疏水性，水接触角高达 158.7°，滑动角低至 3.7°。此外，该涂层具有出色的耐腐蚀性，在 3.5%（质量分数）NaCl 溶液中浸泡 40 天后，MX1/SMP-MZSA 的防腐效率仍能达到 99.94%，低频阻抗值仍可达 $9.86\times10^8\ \Omega\cdot cm^2$，比纯环氧涂层高出两个数量级。同时，该涂层还具有出色的光热自修复性能以及防冰和除冰性能。本研究为超疏水防腐涂层的自修复提供了新思路。

E05-30

往复柱塞泵十字头-滑道副球铁材料服役磨损行为与失效机理研究

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往复柱塞泵广泛地用于油气开采和煤矿领域中钻井、压裂等场景，然而，其关键动力部件十字头-滑道副球墨铸铁材料频繁发生磨损失效，严重威胁设备运行安全与寿命。本研究对往复泵十字头-滑道副球墨铸铁材料的失效机理进行了分析，通过对材料开展表面与截面微观形貌、元素分布、残余应力、纳米硬度等分析，结合界面固-液耦合润滑油膜动态仿真和结构热变形测试，明确了十字头-滑道副在服役过程中的结构失圆变形模式以及混合润滑状态下的结构薄弱润滑区域，揭示了黏着磨损、氧化磨损为主导的材料磨损形式，阐明了高速重载条件下球墨铸铁层状堆叠式摩擦化学反应膜的形成机制、反应深度与力学性能。最后，基于失效机理提出了局部结构优化、材料改性的防治策略，改进后故障率降低 86%，为往复柱塞泵设备的可靠性与寿命提升提供了理论依据。

墙报

E05-P01

基于 CDM 模型的 GH3535 合金高温蠕变行为研究

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GH3535 高温合金由于具有优异的综合性能，已成为熔盐堆中堆芯容器及回路管道等关键构件的重要结构材料。GH3535 合金长期服役于高温环境下，对其蠕变性能的研究对熔盐堆的设计和安全校核具有重要意义。本研究通过高温蠕变试验获取了 GH3535 合金在 650-750℃温度范围内、不同应力条件下的蠕变曲线，采用连续损伤力学（CDM）模型对 GH3535 合金的蠕变行为进行了分析与模拟，建立了适用于 GH3535 合金的寿命预测模型，该模型能够准确描述材料在不同温度-应力条件下的蠕变变形和断裂行为。结果表明，GH3535 合金在高温下的蠕变行为主要受到温度和应力的影响，不同温度和应力条件下蠕变断裂模式存在差异。在高温和低应力条件下，GH3535 合金的蠕变断口处可观察到大量晶界空洞，主要由晶界滑移和空洞聚集引起，表现为沿晶断裂；而在较低温度和较高应力条件下，以位错运动引起的损伤为主，断裂模式为混合型。CDM 模型的模拟结果与实验数据吻合良好，验证了模型的有效性。研究结论为 GH3535 合金在高温环境下的工程应用提供了理论参考。

仅发表论文

E05-PO01

Analysis of wellbore seal integrity under cyclic loading conditions

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Sealing integrity of wellbore under cyclic load is one of the key issues to ensure production safety during the development of oil and gas fields. In this paper, the sealing integrity of casing and cement ring under cyclic load is studied by means of physical experiment and finite element analysis. The actual working conditions of casing under cyclic load were simulated by self-made test device, and the casing - cement ring - formation 3D model was established with Abaqus finite element software, and the sealing integrity was numerically simulated. The results show that the increase of cyclic load has little effect on the plastic deformation and bearing performance of the casing, but with the increase of the number of load cycles, the cement ring is subjected to circumferential stress, and the displacement of the cement ring with small elastic modulus is larger, which can lead to the poor sealing property of the cementing surface between the casing and the cement ring.

E05-PO02

Effect of different processing routes on microstructure, texture and electrical resistivity of 20μm-thick CuNi alloy foil

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Fabricating micron-scale alloy foil inevitably results in the formation of texture due to the severe plastic deformation, which significantly affects the electrical properties. In the present work, both two-stage rolling route

with severe plastic deformation in final rolling and three-stage rolling route combining lower rolling deformation and intermediate annealing were employed to prepare 20μm-thick CuNi alloy foil. The evolution of microstructure and texture and the resultant electrical resistivity subjected to different processing routes were systematically studied. The results indicate that final foil prepared by two-stage rolling route was dominated by strong Cube, Copper texture and relatively weak Goss, and Brass texture. Increasing the intermediate annealing reduced the grain boundary density and deformation stored energy in finally cold-rolled microstructure. The Brass and Copper texture in final foil was distinctly enhanced. The electrical resistivity of the alloy changed from 0.534 μΩ·m to 0.564 μΩ·m, and it showed an decreasing trend with annealing temperature. The multiple introductions of intermediate annealing reduced crystal defect concentrations (i.e., vacancies, dislocations) induced by severe plastic deformation, thereby suppressing electron scattering effects in cold-rolled alloys and leading to a reduction in electrical resistivity. The decrease in grain size and the enhancement of {110} texture were the main reasons leading to the increase in electrical resistivity of the alloy.

E05-PO03

Cr 含量对低铬钢 CO_2 腐蚀行为的影响研究

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本研究采用高温高压反应釜模拟 CO_2驱油典型工况，系统考察了 Cr 含量（3-7 wt.%）对低铬钢 CO_2 腐蚀行为的影响。通过扫描电子显微镜（SEM）和能谱分析仪（EDS）对腐蚀产物膜形貌及成分进行了表征。结果表明：在实验条件下，低铬钢主要表现为均匀腐蚀，且腐蚀速率随 CO_2分压升高而增大。当 Cr 含量低于 7%时，材料呈现中度腐蚀，表面形成具有较多裂纹、易剥落的腐蚀产物膜；当 Cr 含量≥7%时，腐蚀程度显著降低至轻度腐蚀，这归因于形成了连续致密的腐蚀产物膜，其与基体结合紧密，具有优异的保护性能。本研究揭示了 Cr 含量通过调控腐蚀产物膜特性影响低铬钢耐蚀性的关键机制，为 CO_2驱油环境用钢的选材提供了理论依据。

E05-PO04

Predicting mechanical properties of high-strength titanium alloys through feature engineering-guided machine learning algorithms

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High-strength titanium alloys (HSTAs) demonstrate unique advantages in ultra-deep well drilling and production applications due to their lightweight nature and exceptional flexibility. Accurate prediction of HSTA strength and toughness proves crucial for alloy design and performance assessment. This study proposes a modified greedy algorithm (MGA)-guided machine learning framework for predicting HSTA mechanical properties. The MGA, incorporating a multiple out-of-order addition strategy, demonstrates enhanced feature recognition capabilities in high-dimensional data compared to three conventional feature engineering methods. Furthermore, the MGA exhibits superior feature selection stability relative to the native greedy algorithm. Through optimized algorithm selection, the MGA-guided Gradient Boosting (GB) model achieved the highest prediction accuracy for yield strength and impact toughness. The derived processing-composition window for strength-toughness balance provides valuable insights for designing HSTAs with comprehensive service performance.

E05-PO05

Research Progress in High-Throughput Design of Aluminum Alloys

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Aluminum alloys exhibit low density, high strength, and exceptional characteristics including corrosion resistance, electrical/thermal conductivity, processability, and cost-effectiveness, demonstrating broad application prospects in aerospace, mechanical manufacturing, petroleum/chemical engineering, and related fields. Through alloying design and heat treatment processes, aluminum alloys with tailored properties can be engineered to meet specific application requirements. Traditional alloy development relying on trial-and-error methods faces challenges such as prolonged cycles and high costs. In contrast, high-throughput techniques integrate parallelized experimentation, computational simulation, and database interoperability, significantly enhancing materials research and development efficiency. This review systematically examines the evolution of high-throughput experimental methodologies, spanning from early combinatorial chemistry to the modern Materials Genome Initiative. Key high-throughput fabrication techniques including co-deposited thin-film synthesis, diffusion multiple methods, and laser additive manufacturing are introduced alongside advanced characterization protocols. These approaches enable rapid establishment of composition-structure-property relationships, accelerating the screening and optimization of novel aluminum alloys. Furthermore, the integration of machine learning with high-throughput workflows has advanced process parameter optimization, crack prediction, and performance modulation, offering innovative strategies for aluminum alloy development. Finally, current limitations in high-throughput design frameworks are critically analyzed,with forward-looking perspectives on their applications in oil country tubular goods.

E05-PO06

Research Progress on the Effects of Alloying Elements on the Surface Film Structure and Corrosion Resistance of Titanium Alloys

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Titanium alloys are characterized by high specific strength, excellent thermal resistance, fatigue resistance, and corrosion resistance, along with outstanding biocompatibility, making them widely utilized in aerospace, military defense, petrochemical, marine engineering, and biomedical applications. The excellent corrosion resistance of titanium alloys primarily stems from the formation of a stable passive oxide film on the surface. The incorporation of alloying elements can significantly modify the chemical composition, microstructure, and self-repairing capability of this passive layer, thereby influencing the corrosion behavior of Titanium alloys in aggressive environments such as high-temperature/high-pressure conditions with chloride (Cl^-) and hydrogen sulfide (H_2S)-rich media. In the present work, the effects of typical alloying elements (Al, V, Mo, Nb, Ta, e.g.) on the formation mechanism, stability, and corrosion resistance of the surface oxide film on titanium alloys are systematically summarized. Furthermore, the corrosion behavior of titanium alloy oilfield tubular goods under simulated formation water conditions is discussed. Finally, this paper presents an outlook on the potential applications and future prospects of titanium alloy oil country tubular goods in oil and gas drilling and production.

E05-PO07

Research Progress on Intelligent Recognition Technology of Engineering Material Failure Crack Image

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Due to the manufacturing technique, loading, service environment and other reasons lead to the formation of cracks, which trigger the fracture failure of engineering materials in the manufacturing and service process. Fracture image analysis of engineering materials is an important content in the field of failure analysis. The current crack image intelligent recognition and analysis technology has become a research hotspot for intelligent diagnosis of equipment fracture failure, which is of great significance for equipment failure cause analysis and failure prevention. This paper mainly discusses the research progress of crack image intelligent recognition technology. And the principles of the one-stage and two-stage target detection algorithms as well as the research progress of the crack quantitative analysis technology based on image intelligent recognition are outlined. The advantages and disadvantages of the crack intelligent recognition technology as well as the direction of the future development are analyzed. Finally, we discuss the application of the crack image intelligent analysis technology in the field of failure analysis.

E05-PO08

Study on corrosion behavior of tubing strings during the life cycle service of CO_2 huff and puff well

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The CO_2 huff and puff oil recovery technology involves injecting CO_2 into the reservoir, allowing it to diffuse within the formation and mix with the crude oil, thereby altering the viscosity of the oil. Then opened this well for production, achieving enhanced oil recovery through a process that is both simple and economically efficient. However, the corrosive nature of CO_2 when dissolved in water poses significant safety risks to the integrity of tubing. This paper investigates the corrosion behavior of P110 tubing under the soak conditions, produced fluid environments, and the full life-cycle environment by using high-temperature and high-pressure weight loss methods, scanning electron microscopy, and microstructure analysis. And elucidate the corrosion mechanisms and corrosion characteristics under varying medium conditions and the synergistic effects of multiple environments. The results indicate that, under the soak conditions at 50 ℃, the corrosion rate of P110 gradually increases with the increase of the concentration of CO_2 spilt from the formation and dissolved into the immersion solution, indicating a potential risk of CO_2 corrosion. During the full lifecycle service environment, the tubing continuously encounters CO_2-containing corrosive media in multiple environments, including 50 ℃ soak environment and 80 ℃ produced fluid, inducing an interactive process of corrosion film dissolution-detachment-secondary film formation on the material surface, which synergistically influences the corrosion damage pattern on the tubing surface.

E05-PO09

Research Progress on Prediction of Mechanical Properties of Engineering Materials Based on Materials Genome Engineering

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As the fourth paradigm of materials research and development, materials genome engineering solves the limitations of the engineering materials research and development model based on the “trial and error method”. It improves the efficiency and quality of engineering materials research and development. Engineering Material mechanical properties prediction technology based on the material genome engineering can be through the material composition, microstructure and preparation process to predict the mechanical properties of materials, so as to be able to develop new high-performance materials to meet engineering needs. This paper mainly describes the current state of research on the prediction of mechanical properties of engineering materials from three perspectives: computational simulation methods, machine learning, and deep learning. The computational simulation methods include density functional theory calculations, molecular dynamics simulations, finite element analysis. Machine learning algorithms mainly include Random Forest, Gradient Boosting Decision Tree, K-Nearest Neighbors, Support Vector Regression. Deep learning algorithms mainly include multilayer perceptron machines, deep neural networks, and convolutional neural networks. Then we summarize the current state of the prediction of mechanical properties such as strength, toughness, plasticity, hardness, wear resistance, fatigue life of metallic, ceramic, and composite materials by the above methods. The advantages and disadvantages of material property prediction methods are summarized and the future development direction of engineering material mechanical property prediction is analyzed.

E05-PO10

Failure Analysis of Nickel-Phosphorus coated Oil Tubing in Water Injection Wells of a Certain Oilfield

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To investigate the failure mechanisms of nickel-phosphorus (Ni-P) coated tubing under varying water chemistry and well depths, the surface corrosion products of Ni-P coated tubing from the upper, middle, and lower sections of water injection wells were systematically analyzed using SEM, EDS, and XRD to characterize their morphology, composition, and structure. Additionally, the failure causes of the Ni-P coating and substrate, as well as the corrosion mechanisms, were thoroughly explored. The results indicate that: The corrosion severity of Ni-P coated tubing decreased with increasing well depth. Insufficient coating thickness and substandard pretreatment processes of the tubing led to poor coating adhesion and inadequate corrosion resistance, which were identified as the primary causes of Ni-P coating failure. After coating failure, dissolved oxygen emerged as the dominant controlling factor for substrate corrosion.

E05-PO11

Cr12MoV 轧辊开裂失效分析

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针对某型轧辊热处理后直接开裂的失效事故，运用体视显微镜、扫描电子显微镜、光学显微镜等对失效件进行了分析。结果表明：轧辊的断裂是内应力造成开裂，与轧辊中存在疏松、碳化物偏聚和残余枝晶，以及热处理的加热等因素有关，导致轧辊心部应力较大，致使轧辊开裂。建议严格控制铸造及热处理工艺，保证材料组织均匀性，为准确处理该事故提供了可靠的技术依据。

E05-PO12

金属材料拉伸试验中若干影响因素的分析

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在油气、储运、炼化等工程中，金属管材、板材、棒材、型材等产品有着非常广泛的应用，而这些材料的力学性能是影响工程质量的重要因素。而金属材料的拉伸试验，则是力学性能测试最基础和重要的一个环节，通过对材料进行常温、高温及低温的拉伸试验检测，可以得到屈服强度、抗拉强度及断后伸长率等结果，通过这些参数可判断金属材料发生塑性变形及抵抗断裂的应力，为实际工程中安全评估、结构设计、研发新材料等提供依据。在拉伸试验中，检测结果受到多种因素的影响，包括试验设备、试验方法及人为因素等。文章通过长期的基础实践，总结了若干影响拉伸试验的因素，包括试样制备、试验速率、操作方法、温度因素等方面，分析了拉伸试验检测优化措施，旨在提高拉伸试验检测结果的可靠性和有效性，可为实验室质量监控提供有力支撑。

E05-PO13

Full-scale Burst Test Validation of DWTT Index for Thick-walled Steel Pipes

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In order to reduce the failure risk of large-diameter thick-walled pipelines, optimize pipe production processes, and improve economic efficiency, two full-scale low-temperature burst tests were conducted on OD1422×38.5 mm X80 steel pipes at -5℃. The DWTT shear area values of the test pipes at -5℃ were 71% and 75%, respectively. The test obtained the crack propagation speed and pipe fracture morphology characteristics. The crack propagation speed reached a maximum of 102 m/s before rapidly decaying and arresting, with the fracture shear area exceeding 97%. Comparison with small-scale DWTT results showed that the deformation on the hammer impact side underestimated the true toughness of the specimen, leading to conservative DWTT test results for thick-walled steel pipes; when the average DWTT shear area was not lower than 71%, the steel pipe could achieve self-arrest at 12MPa pressure. The research results provide key technical support for establishing DWTT indexes of thick-walled steel pipes in pipeline engineering standards.

E05-PO14

基于遗传算法的玻璃钢油管复合材料铺层优化

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玻璃钢（FRP）油管因其轻量化、耐腐蚀等优势在国内外油田的应用规模年均增长达 15%。然而，接头螺纹部位因承受交变载荷及热应力耦合效应，成为油管失效的薄弱环节。针对复合材料铺层优化中传统遗传算法存在的早熟收敛、多约束协同优化能力不足等问题，本文提出一种融合动态自适应变异策略的等概率随机遗传算法，该算法创新性地引入三阶段种群进化机制，基于 ABAQUS/CAE 平台搭建参数化有限元模型，实现铺层优化与结构应力场的耦合仿真，采用 Python 脚本实现算法与 CAE 的二次开发集成。计算结果表明：优化后接头最大等效应力降低 21.5%，铺层均匀性指数（SI）由 0.38 提升至 0.72，且满足 API 5CT 标准对铺层连续性的三级要求。该算法同时可满足均衡性、对称性、连续铺层数限制、铺层比例等复杂工程，具有较高的可靠性与工程适用性。

E05-PO15

耐火钢的显微组织及合金设计机理综述: Review of Microstructure and Alloy Design Mechanisms in Fire-resistant Steels

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Fire-resistant steels have been widely used in the field of engineering machinery and architectural structure because of their excellent mechanical properties and satisfactory high temperature strength. With evolving economic demands and infrastructure requirements, progressive enhancement of strength has become imperative for these advanced alloys. Significant microstructural evolution has been achieved through four decades of development, transitioning from ferrite plus pearlite or bainite constituents and complex multiphase systems incorporating bainite, martensite, and retained austenite. This microstructural engineering has enabled remarkable strength progression from initial 235 MPa grades to contemporary 690 MPa high-performance variants. Parallel advancements in alloy design have revolutionized chemical composition strategies. Early formulations relying on costly molybdenum additions (≥0.5 wt.%) have been superseded by economically optimized systems employing multi-component microalloying approaches utilizing Nb, V, and Ti. This review provides a critical analysis of international research progress and industrial implementation of fire-resistant steels, with particular emphasis on: (i) Fundamental mechanisms governing high temperature strengthening phenomena, (ii) Alloy design principles of fire-resistant steels, and (iii) Comparative evaluation of composition-microstructure-property relationships across strength grades. Through systematic comparison of chemical systems, microstructure systems, and fire resistance metrics, we establish performance envelopes for various steel classifications. The analysis concludes by identifying key research frontiers requiring attention to meet next generation engineering demands, including novel thermomechanical processing routes and computational alloy optimization strategies.

E05-PO16

力-电-微生物多场耦合作用下海工装备用钛合金腐蚀机制研究

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在建设海洋强国的战略框架下，高性能海洋工程材料的突破已成为撬动“深蓝战略”的技术支点。与钢材等常用船舶材料相比，以钛合金为代表的先进材料具有优异的耐腐蚀性、高比强度及良好的生物相容性等优点，被广泛应用在海洋工程装备和深海结构中，被誉为“海洋金属”。然而，在长期服役过程中，

海洋环境的严酷性（高盐度、高湿度、微生物附着及动态载荷）对钛合金的耐蚀性能提出了严峻挑战。尤其是在力-电-微生物多场耦合作用下，钛合金表面钝化膜的稳定性易被破坏，诱发局部腐蚀、应力腐蚀开裂及微生物腐蚀等失效行为，严重影响海洋工程装备的可靠性与寿命。本研究针对钛合金在复杂海洋环境中的腐蚀失效问题，系统研究力学载荷、电化学环境与微生物活性耦合作用对其腐蚀行为的影响机制。通过设计模拟海洋环境的力（弹塑性应力）-电（电化学条件）-微生物（典型腐蚀性微生物）三场耦合实验，系统考察了不同应力状态（弹性、塑性）与微生物活动共同作用下钛合金的电化学腐蚀动力学、表/界面反应过程及微观损伤形貌演化规律。结果表明：在单一微生物或单一弹塑性应力作用下，钛合金虽表现出一定的耐蚀性下降，但腐蚀程度相对可控。当塑性应力与微生物共存时，两者产生显著的协同效应，导致钛合金腐蚀速率急剧增加，腐蚀形貌发生本质变化。 塑性变形不仅通过增加位错密度和残余应力提供了更多高活性腐蚀起始点，更破坏了钛合金表面钝化膜的完整性，显著降低了其保护能力。与此同时，微生物代谢活动在塑性应力造成的缺陷区域优先富集并加剧局部电化学侵蚀，形成恶性循环。这种塑性应力与微生物的协同作用最终诱发严重的局部腐蚀，显著加速了材料失效进程。

E05-PO17

Fracture reason analysis of external thread joint of NC50 drill pipe

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This study investigates the complete transverse fracture of an NC50 drill pipe external threaded joint during service. Through systematic methodologies including macroscopic fracture examination, metallographic analysis, chemical composition testing, tensile property evaluation, and Charpy impact tests, the failure mechanism was comprehensively analyzed. Results indicate that the chemical composition, tensile strength, yield strength, and impact toughness of the fractured joint fully comply with the API Spec 5DP-2009 standard requirements, thereby eliminating material defects as the root cause. Furthermore, fracture morphology characteristics and stress state analysis confirm that the failure was primarily induced by excessive torsional overload exceeding the design threshold during operation, leading to shear fracture. The findings provide critical insights for enhancing the operational safety of drill pipe connections and implementing real-time monitoring strategies against abnormal downhole conditions.

E05-PO18

Failure Analysis of Casing Unthreading and Tubing Fracture in a Certain Oilfield

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In July 2023, a leakage incident occurred at an oil and gas well in a certain oilfield, where the wellhead equipment along with a section of casing and tubing were ejected from the well, resulting in a large amount of oil and gas spewing out. To identify the causes of the casing disengagement and tubing fracture, non-destructive testing, macroscopic and microscopic morphology analysis, material physical and chemical property testing and analysis, measurement of casing and coupling thread parameters, and damage morphology analysis were conducted on the failed casing and coupling samples. Combined with the service conditions and well history data of the failed samples, the main causes of the casing slippage were analyzed and inferred, and the failure type and cause of the tubing fracture were analyzed. The analysis found that the material and structure of the failed samples met the standard requirements. No abnormalities were found in the material of the factory end of the failed casing coupling sample, the N80 coupling and P110 casing thread parameters. No factors affecting the connection

strength of the coupling, such as inappropriate factory end tightening torque and incomplete tightening, were found. The main cause of the casing slippage was inferred to be the application of an abnormal load greater than the connection strength of the casing coupling (such as instantaneous high pressure). The fracture of the failed tubing was mainly caused by corrosion fatigue, and the service environment of the failed samples had the characteristics of both CO_2 corrosion and corrosion fatigue (CF). The CO_2 corrosion of the tubing and coupling was slight. The tubing body had a relatively severe corrosion fatigue phenomenon, and there was a certain possibility and potential for corrosion fatigue in the casing and its coupling.

E05-PO19

Research Progress on the Effects of Alloying Elements on the Microstructure and Properties of Al-Cu-Mg Heat-Resistant Aluminum Alloys

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As a typical material for structural lightweighting, aluminum alloys have broad application prospects in the petroleum and petrochemical industry. Among them, heat-resistant aluminum alloys feature high specific strength, high temperature resistance, corrosion resistance, fatigue resistance, and good processing performance, and have been promoted and applied in the field of aluminum alloy drill pipes. However, traditional aluminum alloys are limited to service temperatures below 200'c, which restricts their application in utra-deep oil and gas fields. The performance of heat-resistant aluminum allovs mainly depends on the stability of their microstructure. The present review summarizes the influence rules and strengthening mechanisms of typical alloying elements on the microstructure, mechanical properties, high-temperature resistance and corrosion resistance of Al-Cu-Mg heat-resistant aluminum alloys. The development directions of heat-resistant aluminum alloy drill pipe materials and their application prospects in oil and gas development are also prospected.

E05-PO20

Research Progress on Damage Control and Non-marking Running/Pulling Techniques for Titanium Alloy Oil Well Tubing

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Titanium alloy tubing has become an ideal material for extreme oil and gas environments (high temperature/pressure, H_2S/CO_2/chloride-rich conditions) due to its low density, high strength, excellent corrosion resistance and fatigue performance. Internationally, Grade 28/29 titanium alloys developed by RMI have been successfully applied in sour gas wells, while Weatherford's Ti-6Al-4V drill pipes demonstrate 10 times higher fatigue resistance than steel counterparts. Domestic research started relatively late, but China-made titanium alloy casings achieved their first successful application in natural gas hydrate trial production in 2020, with collapse resistance >42 MPa. The main failure modes include pitting, crevice corrosion and galvanic corrosion, particularly when passive films are damaged in high-temperature (>70 ℃) and reducing acid environments. While corrosion inhibitors (e.g., Na_2MoO_4) can mitigate corrosion rates, novel inhibitors for >160 ℃ conditions remain needed. For wear resistance, surface modifications (e.g., TiN, DLC coatings) and multilayer coating technologies significantly enhance performance. Non-marking running/pulling techniques utilizing optimized jaw designs can control tooth marks to <0.08 mm depth, proving successful in high-sulfur environments. Future breakthroughs should focus on high-temperature acid-resistant inhibitors, hard-soft alternate coatings, and damage-free running

technologies to enable large-scale applications in deep-well and offshore oil/gas development.

E05-PO21

Lightweight Design and Running Friction Comparison of Titanium Alloy Casing in Extended-Reach Horizontal Wells

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To address the challenges of high running friction and limited depth extension caused by the heavy weight of traditional carbon steel casings in extended-reach horizontal wells, this study conducts a comparative analysis of titanium alloy and carbon steel casings using Well Lead drilling software in a deepwater shallow-soft formation well (with a water-to-vertical ratio of 2.36 and maximum dogleg severity of 15°/30 m). The friction sensitivity curve model reveals that the titanium alloy casing reduces static hook load by 13.2% (73 kN), significantly mitigating pipe sagging risks. Notably, at an external friction coefficient of 0.6, the titanium alloy casing exhibits a hook load margin of 142.6 kN, surpassing the carbon steel casing (68.7 kN) by 107% and eliminating critical running risks. Simulation of a 5,000 m lateral section demonstrates that the titanium alloy casing extends the maximum running depth by 12.6% (low friction: 0.2) to 26.1% (high friction: 0.6) compared to carbon steel. Field tests confirm superior running stability of titanium alloy casings in irregular wellbores, though wellbore reconditioning remains necessary for localized obstructions. This study quantifies the relationship between lightweight design and friction sensitivity, providing a reliable basis for casing selection in complex horizontal wells.

E05-PO22

Study on the Electrochemical Corrosion Behavior of Ti-Al-V-Mo-Zr Titanium Alloy Drill Pipe Materials in High-Salt Environments at Different Temperatures

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In this research work, the electrochemical corrosion behavior of Ti-Al-V-Mo-Zr titanium alloy drill pipe materials with different solution treatment temperatures in a 10wt% NaCl high-salt solution was studied. The results show that with the increase of solution temperature, the average grain size of the α phase first decreases and then increases, and the average size of the primary α phase of the material solution-treated at 910 ℃ reaches a minimum value of 27.52 μm^2. With the increase of solution temperature, a dense oxide film rapidly forms on the material surface, gradually reducing its thermodynamic corrosion tendency; however, the temperature increase accelerates the diffusion of chloride ions and charge transfer during the corrosion process, leading to an increase in corrosion rate. The Ti-Al-V-Mo-Zr titanium alloy drill pipe material with the smallest average size of primary α phase exhibits the best corrosion resistance. The corrosion products on the surface of Ti-Al-V-Mo-Zr titanium alloy are mainly TiO_2, TiO, Al_2O_3 and V_2O_5.

E05-PO23

Influence of Solution Temperature on Mechanical Properties of Titanium Alloy Drill Pipe Materials

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Through indoor heat treatment experiments, mechanical property testing, optical microscopy, and scanning electron microscopy, the microstructure and mechanical properties of Ti-Al-V-Mo-Zr titanium alloy drill pipe materials for oil and gas drilling under different heat treatment regimes were investigated, and the strengthening-toughening mechanism of the titanium alloy drill pipe material was analyzed. The experimental results indicate that as the heat treatment temperature increases, the strength initially remains stable and then decreases. The maximum tensile strength is 993 MPa, and the maximum yield strength is 870 MPa. The impact energy shows an increasing trend with temperature, achieving a maximum value of 65 J at 930℃. Under 930℃/2h/AC (air cooling) heat treatment condition, the titanium alloy drill pipe material exhibits a bimodal microstructure, achieving the optimal balance of strength and toughness, with a tensile strength of 958 MPa, yield strength of 829 MPa, and impact energy of 65 J. As the solution temperature increases, the fibrous zone proportion in both tensile and impact fracture surfaces decreases, while the equivalent diameter of dimples increases. The bimodal microstructure combines the advantages of both equiaxed and Widmanstätten structures, effectively improving the comprehensive mechanical properties of the titanium alloy drill pipe material.

E05-PO24

Study on multi-scale strengthening behavior induced by microstructure evolution of cold drawn steel wire

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This study investigates the microstructural evolution and multidimensional strengthening mechanisms of hypo eutectoid pearlitic steel with a carbon content of 0.81% during the cold drawing process. By analyzing the structural transformation of ferrite and cementite phases, the study characterizes the dynamic changes in pearlite colony size, interlamellar spacing, cementite morphology, and dislocation density at multiple scales. Based on the mechanical strengthening characteristics of cold-drawn pearlitic steel wire, the study identifies the main strengthening mechanisms as interface strengthening, dislocation strengthening, and solid solution strengthening, and quantitatively analyzes the effects of various strengthening mechanisms under different strain conditions, finding that the solid solution strengthening effect gradually increases when $\varepsilon > 0.8$. Additionally, the cold-drawn wires exhibit typical structural features such as nanolaminate, metastable, and multi-phase. This study employs in situ tensile testing to investigate the crack propagation behavior of cold-drawn pearlitic steel wire, finding that the multiphase, nanoscale lamellar structure, and metastable phase can effectively achieve stress shielding and crack deflection, significantly enhancing the wire's resistance to crack propagation. This research provides a reference for the design of high-strength, high-ductility materials in advanced engineering applications, revealing potential methods for structural control of pearlitic steel wire and optimization of the drawing process performance.

E05-PO25

Research on Corrosion Behavior of Drill Pipe Materials in Deep and Ultra-Deep Well Acidic Fishing Fluids Environment

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The corrosion behavior and the variation law of the remaining strength after corrosion of S135 and V150 drill pipe materials in acidic fishing fluids (15% hydrochloric acid +4% iron ion stabilizer +4% corrosion inhibitor) at different temperatures used in deep and ultra-deep well were analyzed by means of high-temperature and high-pressure reaction vessels, electron scanning microscopes, X-ray diffraction analysis and mechanical property tests. The results show that with the increase of temperature, the corrosion rate of S135 and V150 drill pipe materials increases exponentially. V150 is more prone to corrosion. Its corrosion rate at 100℃-150℃ is 1.8-2.3 times that of S135, and at 200℃, it is much higher than that of S135. After being soaked at 150℃ for 1 hour, the mechanical properties of V150 material deteriorated. The tensile strength and yield strength decreased by about 2%, the elongation decreased by 10%, and the reduction of area decreased by 7%. After being immersed in a corrosive environment not exceeding 150℃ for 1 hour, the tensile strength, yield strength, elongation and reduction of area of S135 material remain basically unchanged.

E05-PO26

高钢级管线钢 CTOD 试验影响因素研究

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对 X80 管线钢管管体和焊缝进行 CTOD 试验，研究了不同试样厚度、不同跨距和不同试验温度对 CTOD 试验结果的影响规律。结果表明，对高钢级管线钢，不同试样厚度对 CTOD 试验结果基本没有影响；不同跨距对 CTOD 试验结果有影响，跨距越大，CTOD 值越小。试验温度从 20℃开始逐渐降低，CTOD 值也随之降低。

E05-PO27

S135 钻杆外螺纹接头开裂原因分析

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为了分析某井钻杆外螺纹接头开裂原因，通过化学成分分析、力学性能试验、裂纹分析等方法，对 S135 钻杆外螺纹接头开裂原因进行分析。结果表明，失效钻杆外螺纹接头本体摩擦生热，处于高温部位的材质发生塑性拉长形变，接头外径、内径迅速减小。随着阻卡严重，在转动钻柱过程中，钻杆外螺纹接头发生了剧烈的摩擦磨损作用，生成大量的摩擦热，使钻杆接头的温度迅速升高，在泥浆的冷却作用下使得接头处于高温奥氏体状态的材质发生淬火作用，形成大量马氏体组织，硬脆性增加，导致外螺纹接头产生裂纹。

E05-PO28

Effect of cryogenic treatment on the corrosion resistance of iron based alloys: A review

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After deep cryogenic treatment, iron-based alloys exhibit better mechanical properties, but the research progress on the mechanism of their corrosion performance is relatively slow. This article reviews the research progress of deep cryogenic treatment on the corrosion resistance of iron based alloys, focusing on the evolution of carbide precipitation state, lattice structure, grain size, and residual stress at different scales after deep cryogenic treatment. Finally, based on the current research status and shortcomings of deep cryogenic treatment of iron based alloys, the future research directions are prospected. Through the review and analysis, this article aims to provide some guidance for the research and application of improving corrosion resistance of iron based alloys by deep cryogenic treatment.

E05-PO29

Failure analysis of sucker rod in heavy oil thermal recovery

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The failed sucker rod used in heavy oil thermal recovery was analyzed systematically. The results showed that, the main reason of sucker could not be placed down into the barrel after well blockage was the diameter increasing as oxidizing and sulfurizing at the surface of Ni-Cr-Fe anti-corrosive coating. The outer corrosion layer consisted of Ni3S2, Ni7S6, and the inner layer consisted of FeCO3 and NiCr2O4. The volume of corrosion expanded significantly compared with coating. Besides the water steam and oil with high pressure and temperature stuffed in the well, the basic reasons of severe corrosion was the poor ability of the anti-corrosive coating, which was porous, elements segregating and incomplete fusing.

E05-PO30

燃气输送用 Q235B 螺旋缝埋弧焊钢管开裂失效分析

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采用宏观分析、化学成分分析、力学性能检测、金相分析、扫描电镜等分析方法，对燃气输送用 Q235B 螺旋缝埋弧焊钢管开裂原因进行了分析。结果表明，钢管的化学成分、拉伸试验、导向弯曲试验结果符合标准要求。失效钢管断口在宏观上呈脆性断裂特征，开裂源区的金相分析结果显示具有典型的沿晶扩展特征。综合结果表明，失效钢管是在硫化物腐蚀介质中，在运行压力和附加弯曲应力、残余应力等共同作用下，发生应力腐蚀并于表面萌生腐蚀裂纹，裂纹不断沿晶界扩展并最终导致钢管开裂。

E05-PO31

Establishment and Validation of Fracture Toughness Prediction Model for X80 Fittings

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Aiming at the problem that X80 steel tees and elbows of oil and gas transmission pipelines are prone to brittle fracture under complex stress, and the direct testing of fracture toughness is costly and difficult to obtain

samples, this study draws on the Charpy energy-fracture toughness correlation method to carry out a series of research. Samples from key areas of X80 elbows and tees were collected for Charpy V-notch impact tests to obtain energy-temperature curves, and the actual reference temperature (T0) was calibrated through fracture toughness tests of limited samples. TheT0and fracture toughness prediction models were constructed using the direct correlation method, IGC parameter method, and M4P mean method, and the geometric factor was introduced to modify the thickness effect formula of the Master Curve. The research results show that the direct correlation method has a large error, the IGC parameter method significantly improves the accuracy, and the M4P mean method is the best, with an error of only ±10 ℃. The correlation between the predictedT0and the measured value is

R2>0.92, and the modified Master Curve model is consistent with the full-scale bursting test results of the pipe fittings. The established M4P mean method in this study can accurately predict theT0of X80 pipe fittings based only on CVN data, avoiding expensive tests. The modified Master Curve model is applicable to the non-uniform geometry of pipe fittings, providing theoretical support for pipeline integrity assessment.

E05-PO32

The Effect of Heat Treatment on the Corrosion Performance of Martensitic Stainless Steel

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With the increase in extraction depth and due to geographical factors, the pressure in oil layers and the sulfur content in oil and gas rise, posing greater challenges to oil production equipment. Based on the above background and starting from process control, this study investigates the electrochemical properties of martensitic stainless steel after different heat treatments, and conducts microscopic observation and elemental analysis on the samples after hydrogen sulfide stress corrosion. The results show that quenched and re-tempered sample has the best electrochemical corrosion resistance. Which is the result of ferrite produced by sub-temperature quenching reducing the overall corrosion resistance of the material through galvanic corrosion. The specimen did not break after undergoing a 720-hour hydrogen sulfide stress corrosion resistance test. The loose corrosion products on the surface of the hydrogen sulfide stress corrosion resistance specimens are mostly composed of iron oxides, and the corrosion products in the corrosion pits are mainly metal oxides and sulfides.

E05-PO33

人工智能技术在潜油电泵故障诊断中的应用进展与前景

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潜油电泵（ESP）作为当前应用广泛的人工举升方式，具有效率高、排量大、自动化程度高等优点。然而，潜油电泵长期工作于高温、高压及含砂、含气等复杂环境中，故障频发，严重制约采油作业的稳定性与安全性。因此，实现潜油电泵的高效诊断与故障预警，对保障油田安全生产和经济效益具有重要意义。

尽管传统监测方法和现代井下传感技术已具备一定参数采集与分析能力，但现有系统多停留在数据记录和简单判别层面，存在故障判断实时性差、依赖专家经验、精度有限等显著局限性。近年来，人工智能技术在工业故障诊断中的应用为潜油电泵智能监测提供了新思路。本综述系统梳理了深度学习、机器学习和大数据分析等人工智能技术在潜油电泵故障诊断领域的应用进展与发展方向。首先，分析了现有研究中采用传统方法进行故障检测的不足之处及其面临的挑战。其次，针对基于振动、电流、压力等单信号源的智能诊断方法，重点评述了其原理、应用实例及性能表现。并且进一步探讨了基于多源数据的特征融合方法及关键技术，分析了其在提升诊断精度与鲁棒性方面的优势。最后，基于当前研究现状，本文深入剖析

了该领域面临的关键挑战，并从多源信号融合、数据增强以及数字孪生等方面出发，展望了未来发展趋势。

综述表明，人工智能技术，特别是多源数据融合方法，正显著推动潜油电泵故障诊断向智能化、高精度、实时化方向发展，但需进一步解决工程中的实际问题以充分发挥其应用潜力。

E05-PO34

X80 钢级 D1219×18.4mm 螺旋焊管焊接接头反弯试样失效原因分析

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为研究螺旋焊管焊接接头背面导向弯曲失效的原因，对壁厚 18.4mm 的螺旋焊管焊缝反弯试样断口进行了分析。采用宏观分析、金相分析、拉伸试验、冲击试验、扫描电镜检测等手段进行了分析和研究。结果表明，此次反弯试样断裂的主要原因是内焊与外焊焊缝重合区部位存在一处尺寸较大的夹渣，夹渣形成的直接原因在于焊接时焊剂熔渣流动性差，未及时浮出形成夹渣。夹渣在一定程度上破坏了焊缝的韧性，是造成试样断裂的主要原因。

E05-PO35

海上油田复杂环境潜油电泵机组失效分析与可靠性提升对策研究

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海上油田生产井 95%以上采用潜油电泵，产量贡献 98%以上，随着油田开发深入，各种井下复杂环境会直接导致潜油电泵机组失效从而影响油井正常生产，围绕机组失效因素开展可靠性提升有利于保障油田持续增产稳产。本文主要分析了海上油田潜油电泵机组失效情况和失效形式，总结了井液腐蚀、流体冲蚀、举升完整性、设计合理性等主要潜油电泵机组失效因素，提出了潜油电泵机组可靠性提升对策。本文对海上油田复杂环境潜油电泵机组的合理选型与长效可靠运行具有指导意义。

E05-PO36

Research on Accurate Measurement Method of rude Oil Water Content Based on Image Recognition

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In response to the low accuracy and high installation cost of existing portable crude oil water content measurement devices and online water content measurement devices, and the fact that crude oil water content measurement is still mainly based on manual sampling and detection methods in oilfield production, this paper proposes a crude oil water content analysis method based on image recognition technology. By collecting, segmenting, and intelligently identifying the oil-water interface of the oil-water separated sample through image grayscale, the designed pixel ratio algorithm intelligently identifies the water content of the oil product. The effectiveness of the algorithm is verified through sampling analysis. Based on this method, a portable wellhead water content precise measurement device is designed and developed. Referring to the manual water content detection process, a new crude oil water content measurement process is designed for this device. The intermittent sampling mode is adopted to automatically realize functions such as heating, stirring, precipitation, data reading, and data transmission. Through on-site application testing, the reliability of this device's detection has been confirmed, and the application scenarios of this device are also discussed.

E05-PO37

氢损伤及输氢管道用直缝埋弧焊接钢管关键制造技术研究

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在国内外都大力发展氢能的大环境下，特别是我国提出“双碳”目标的时代背景下，输氢管道发展进入快车道，设计、建设方兴未艾。由于高压氢气与管道内壁金属发生杂化效应解离为氢原子，氢原子随之吸附并进入金属内部与金属基体发生交互作用，导致纯氢/掺氢管道运行时会发生氢脆、氢致开裂、氢鼓泡、疲劳断裂等多种形式的氢损伤，所以对于输氢管线钢管控制其与氢环境的相容性至关重要。本文对当前关于氢损伤机理的主流理论和研究进展进行了搜集、整理和介绍，从原材料钢板组织成分设计、生产装备改进提升及制管工艺研究等三个方面介绍了一种 L360 OD610mm×15.9mm 规格输氢直缝埋弧焊管研发过程，对该种钢管的力学性能及氢环境相容性进行测试，并对输氢管道建设及输氢管材研发应关注的内容提出了相关建议。

E05-PO38

油田注汽锅炉冷凝受热面材料选用研究

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油田注汽锅炉冷凝受热面工作环境复杂，面临低温烟气及冷凝液的腐蚀，其材料选择对锅炉高效及安全运行有着重要作用。本文通过对 316L、ND 钢、PTFE 氟塑料等材料的耐腐蚀性、导热系数、机械强度、价格等因素进行综合分析，提出了油田注汽锅炉冷凝受热面使用材料的推荐方案。

E05-PO39

硬质合金中碳含量对钴相的影响

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高性能硬质合金多采用碳化钨-钴-碳按比例混合球磨并高温烧结而成，而碳对钴相及最终合金性能影响较大。本文选取系列碳含量的硬质合金体系，重点分析钴相组成及微结构，结果显示，随着碳含量增加，高温 α 相从 28%增至 81%，而低温 ε 相减少。推断 C 原子以间隙形式固溶于基体中，增加了 a-ε 马氏体切变相变阻力，高温 α 相残留增多。另外随碳含量增加，α 相的点阵常数增大，而 ε 相 a 轴减小，c 轴增加。这表明 C 增多，抑制了 W 原子的固溶，并促进亚稳相析出。

E05-PO40

Numerical analysis of influence of thermal cycle on tubing and casing

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Abstract: There were lots of failures for the thermal wells. FEA analysis was used to conduct thermal cycle simulation on casing and tubing premium connections with metal sealing. The changes of sealing contact pressure and axial stress of the casing and tubing under axial constraint were analyzed for two cases: unconstrained radial expansion of the tubing and constrained casing with cement. The results show that after one high-temperature thermal cycle, the sealing contact pressure of the premium connection decreases. When there is the radial constraint, the decrease is greater and positively correlated with the temperature. After the cycling temperature exceeding 200 ℃, the connection has lost the sealing performance. Thermal cycle increases the axial tensile which causes the risk of tensile fracture of the string. The analysis results provide the data and technical basis for connection selection and string design optimization for high-temperature oil and gas wells.

Key words: premium connection, high temperature, thermal cycle, tubing, casing