

# 表面技术

SURFACE TECHNOLOGY

ISSN 1001-3660  
CN 50-1083/TG

2022年11月  
第51卷 第11期  
Vol.51 No.11

表面技术

第五十一卷

第十一期

二〇二二年十一月



本期封面文章：

耐用铝基超疏水涂层的机械稳定性及抗结冰性能  
李天然，卢晨光，原子超等（大连理工大学等）

## 目 次 CONTENTS

### 专题——面向航空航天部件服役安全的表面处理技术

Special Topic: Surface Treatment Technology for Service Safety of Aerospace Components

1 光冲击铝合金微结构演化及力学行为的分子动力学模拟

Microstructure Evolution and Mechanical Behavior of Laser-shocked Aluminium Alloy by Molecular Dynamics Simulations

朱熠奇, 殷艳, 周留成, 易敏

ZHU Yi-qi, YIN Yan, ZHOU Liu-cheng, YI Min

10 空间环境因素对涂层型自润滑关节轴承磨损寿命影响规律及机理

Spatial Environmental Factors on the Wear Life of Coated Self-lubricating Joint Bearings Influence Law and Mechanism

魏澳博, 马国政, 李国禄, 雍青松, 郭伟玲, 邢志国, 王海斗

WEI Ao-bo, MA Guo-zheng, LI Guo-lu, YONG Qing-song,

GUO Wei-ling, XIN Zhi-guo, WANG Hai-dou

20 基于声发射信号的铝合金 LSP 弹塑性波传播规律探究

Exploring the Law of Elastic-plastic Wave Propagation of Aluminum Alloy LSP based on Acoustic Emission Signal

李耿, 张志芬, 秦锐, 都正尧, 温广瑞, 何卫锋

LI Geng, ZHANG Zhi-fen, QI Rui, DU Zheng-yao,

WEN Guang-rui, HE Wei-feng

35 基于声发射与关键帧选择的 LSP 表面硬度监测

Surface Hardness Monitoring of Laser Shock Peening: Acoustic Emission and Key Frame Selection

都正尧, 张志芬, 秦锐, 李耿, 温广瑞, 何卫锋

DU Zheng-yao, ZHANG Zhi-fen, QIN Rui, LI Geng,

WEN Guang-rui, HE Wei-feng

45 激光冲击强化 MB8 镁合金的工艺分析及摩擦磨损性能研究

Process Analysis and Friction Wear Performance Study of Laser Impact Strengthened MB8 Magnesium Alloy

延黎, 吴昊年, 田乐, 徐培文, 邓涛, 聂祥樊

YAN Li, WU Hao-nian, TIAN Le, XYU Pei-wen,

DENG Tao, NIE Xiang-fan

58 表面机械研磨处理对纯铜棘轮行为的影响: 宏微观试验与本构模拟

Effect of the Surface Mechanical Attrition Treatment on the Ratcheting of Pure Copper: Macro/Micro-tests and Constitutive Modeling

杨康, 赵建锋, 何风, 阚前华, 赵君文, 张旭

YANG Kang, ZHAO Jian-feng, HE Feng,

KAN Qian-hua, ZHAO Jun-wen, ZHANG Xu

70 Cr<sub>3</sub>C<sub>2</sub>-NiCr/TiSiN-CrAlN 复合涂层制备及高温摩擦学行为研究

Preparation and High Temperature Tribological Behavior of Cr<sub>3</sub>C<sub>2</sub>-NiCr/TiSiN-CrAlN duplex coating

尚伦霖, 张广安, 何东青, 李文生

SHANG Lun-lin, ZHANG Guang-an, HE Dong-qing, LI Wen-sheng

### 研究综述 Research Review

80 磨料射流加工技术的发展与研究现状

Recent Advances and Status of Abrasive Jet Machining Technology

胡焰, 陈加东, 戴庆文, 黄巍, 王晓雷

HU Yan, CHEN Jia-dong, DAI Qing-wen,

HUANG Wei, WANG Xiao-lei

99 锂离子电池正极材料改性研究进展

Research Progress on Modification of Cathode Materials for Lithium-ion Batteries

阴启昊, 高波, 尹俊太, 付海洋, 胡亮

YIN Qi-hao, GAO Bo, YIN Jun-tai, FU Hai-yang, HU Liang

113 防/疏冰涂料的机理及其发展趋势

Mechanism and Development Trend of Anti-ice/Deicing Coating

郭乐扬, 李文戈, 吴新锋, 姜涛, 张士陶, 张杨杨  
GUO Le-yang, LI Wen-ge, WU Xin-feng, JIANG Tao,  
ZHANG Shi-tao, ZHANG Yang-yang

126 输氢管线钢防止氢脆研究进展

Research Progress on Protection Against Hydrogen Embrittlement of Hydrogen-transport Pipeline Steels

朱永强, 宋维, 李雨霞, 徐小雪, 曹宇, 冯孟, 李腾蛟, 周奕骐, 齐建涛  
ZHU Yong-qiang, SONG Wei, LI Yu-xia, XU Xiao-xue, CAO Yu,  
FENG Meng, LI Teng-jiao, ZHOU Yi-qi, QI Jian-tao

138 表面残余应力影响因素和调控技术的研究进展

Research Progress of Influencing Factors and Control Technologies on Surface Residual Stress

程勇杰, 王燕霜, 林江海, 黄鹏程, 申玉海  
CHENG Yong-jie, WANG Yan-shuang, LIN Jiang-hai,  
HUANG Peng-cheng, SHEN Yu-hai

153 摩擦表面定域润滑研究进展及发展趋势

Research Progress and Development Trend on the Localized Lubrication of Friction Surface

胡瑞, 陈威, 许春霞, YANG Yue  
HU Rui, CHEN Wei, XU Chun-xia, YANG Yue

164 多巴胺表面修饰在医疗领域的研究进展

Research Progress of the Surface Modification by Dopamine in Medical Field

刘雨晗, 刘德, 王意, 王虎鸣, 曹攀  
LIU Yu-han, LIU De, WANG Yi, WANG Hu-ming, CAO Pan

174 辅助阳极在电弧离子镀和磁控溅射技术中的应用和研究进展

Application and Research Progress of Auxiliary Anode in Arc Ion and Magnetron Sputtering Deposition  
赵栋才, 邱家稳, 肖更竭, 张子扬  
ZHAO Dong-cai, QIU Jia-wen, XIAO Geng-jie, ZHANG Zi-yang

186 表面改性对碳纤维及其复合材料性能影响的研究进展

Progress in Surface Treatment of Carbon Fiber and Composite Material

谢顺利, 雷红红, 张春丽, 张彩丽  
XIE Shun-li, LEI Hong-hong, ZHANG Chun-li, ZHANG Cai-li

## 摩擦磨损与润滑 Friction, Wear and Lubrication

196 织构协同磁流体对 30CrMo3A 合金摩擦性能的影响

Effect of Textures and Magnetofluid Interaction on Tribological Properties of 30CrMo3A Alloy

赵涛, 王优强, 莫君, 朱玉玲, 何彦, 李梦杰  
ZHAO Tao, WANG You-qiang, MO Jun,  
ZHU Yu-ling, HE Yan, LI Meng-jie

205 金属波纹管内表面镀层冲蚀性能

Erosion Performance of Coating on Inner Surface of Corrugated Metal Pipe

陈智华, 全玉栋, 张传杰, 刘延波, 陈荣旗  
CHEN Zhi-hua, TONG Yu-dong, ZHANG Chuan-jie,  
LIU Yan-bo, CHEN Rong-qi

215 表面微坑复合 MoS<sub>2</sub>镍基涂层及摩擦磨损性能研究

Surface Dimples Composite MoS<sub>2</sub> Nickel-based Coating and Its Friction and Wear Properties

李宾, 刘锡尧, 张君安, 刘波, 卢志伟  
LI Bin, LIU Xi-yao, ZHANG Ju-nan, LIU Bo, LU Zhi-wei

226 预沉积 ZnO 薄膜对 ZnO-MoS<sub>2</sub>/ZnO 复合涂层结构与性能影响

Influence of Pre-deposition ZnO Thin Film on Structure and Properties of ZnO-MoS<sub>2</sub>/ZnO Composite Coating

曹明, 赵嵒, 余健, 唐平, 许欢, 钟珮瑶  
CAO Ming, ZHAO Lan, YU Jian, TANG Ping, XU Huan, ZHONG Pei-yao

235 氧化对含氟化物共晶耐磨自润滑涂层机械和摩擦学性能影响

Effect of Oxidation on the Mechanical and Tribological Properties of Eutectic Fluorides Containing Wear Resistant Self-lubricating Coating

邝子奇, 牛少鹏, 宋佳, 李明康, 苏威铭,  
王超, 黄益聪, 曾威, 戴红亮, 黄科

KUANG Zi-qi, NIU Shao-peng, SONG Jia, LI Ming-kang, SU Wei-ming,  
WANG Chao, HUANG Yi-cong, ZENG Wei, DAI Hong-liang, HUANG Ke

244 稠油热采四通管冲蚀特性影响因素数值模拟研究

Numerical Simulation of Influence Factors on Erosion Characteristics of Four-way Pipe in Heavy Oil Thermal Recovery

朱丽云, 王森, 王国涛, 石佳瑞, 王振波, 刘岑凡

ZHU Li-yun, WANG Sen, WANG Guo-tao, SHI Jia-rui, WANG Zhen-bo, LIU Cen-fan

253 法向载荷和速度对  $\beta$ -HMX 晶体纳米划痕性能的影响

Effect of Normal Load and Velocity on Nanoscratch Behavior of  $\beta$ -HMX Crystals

曹之鸿, 何洪途, 李洪涛, 李炳宏, 银颖, 余家欣

CAO Zhi-hong, HE Hong-tu, LI Hong-tao,

LI Bing-hong, YIN Ying, YU Jia-xin

253 离子渗氮对多弧离子镀 CrN 涂层摩擦学性能的影响

Effects of Ion Nitriding on Tribological Performance of CrN Coating by Multi-arc Ion Plating

杨九州, 李立, 张敏, 周少兰, 詹青青, 黄安畏, 杨莉婕, 陈汉宾, 李忠盛

YANG Jiu-zhou, LI Li, ZHANG Min, ZHOU Shao-lan, ZHAN Qing-qing,

HUANG An-wei, YANG Li-jie, CHEN Han-bin, LI Zhong-sheng

## 腐蚀与防护 Corrosion and Protection

271 基于 ISOA-KELM 的风机叶片腐蚀速率预测

Prediction of the Corrosion Rate of Wind Turbine Blade Based on ISOA-KELM

孙栋钦, 汤占军, 李英娜, 陆鹏

SUN Dong-qin, TANG Zhan-jun, LI Ying-na, LU Peng

279 Mo 含量对 FeCoCrNiMo<sub>x</sub> 高熵合金等离子喷焊层组织与性能的影响

Effect of Mo Content on the Microstructure and Properties of High-entropy alloy Coatings

Produced by Plasma Transferred Arc Welding

张乾坤, 唐俊, 肖逸锋, 杜萌萌, 吴靓, 钱锦文, 贺跃辉

ZHANG Qian-kun, TANG Jun, XIAO Yi-feng, DU Meng-meng,

WU Liang, QIAN Jin-wen, HE Yue-hui

287 304 不锈钢和 5083 铝合金在模拟城市地下空间环境中的腐蚀行为对比

Comparative Study on the Corrosion Behavior of 304 Stainless Steel and 5083-aluminum Alloy in Simulated Urban Underground Environment

刘璇, 邵晓峰, 高瑾, 李永红, 胡添奇, 梁帅, 宋嘉良, 肖葵

LIU Xuan, SHAO Xiao-feng, GAO Jin, LI Yong-hong,

HU Tian-qi, LIANG Shuai, SONG Jia-liang, XIAO Kui

295 304 钢表面激光熔覆 Stellite12 钴基涂层组织及腐蚀性能

Microstructure and Corrosion Properties of Laser Cladding Stellite12 Coating on 304 Steel

欧阳昌耀, 李艳玲, 王蕊, 白峭峰, 闫献国, 张建广

OUYANG Chang-yao, LI Yan-ling, WANG Rui,

BAI Qiao-feng, YAN Xian-guo, ZHANG Jian-guang

305 实验室加速环境下水性快干环氧厚浆底漆老化机理及失效过程

Study on Aging Mechanism and Failure Process of Waterborne Epoxy Primer under Accelerated Environment in Laboratory

刘敏, 张海兵, 林冰, 唐鳌磊, 郑宏鹏, 王莹莹, 侯健, 唐聿明, 黎红英, 李平

LIU Min, ZHANG Hai-bing, LIN Bing, TANG Jun-lei, ZHENG Hong-peng,

WANG Ying-ying, HOU Jian, TANG Yun-ming, LI Hong-ying, LI Ping

318 LA43M 镁锂合金表面水热合成 Mg-Al LDH 膜层的耐腐蚀及磨损性能

Corrosion and Wear Resistance of Mg-Al LDH Coatings on LA43M Magnesium Lithium Alloy by Hydrothermal Method

张菊梅, 候安荣, 李嘉诚, 段鑫, 王博, 连朵朵, 张萌春

ZHANG Ju-mei, HOU An-rong, LI Jia-cheng, DUAN Xin,

WANG Bo, LIAN Duo-duo, ZHANG Meng-chun

328 T91/TP347H 焊接接头在含氯溶液中的腐蚀特性

Corrosion Characteristics of T91/TP347H Welded Joints in Chlorine-Containing Solution

缪克基, 尹阳阳, 王婷, 刘川槐, 沈利, 刘建峰, 潘卫国

MIAO Ke-ji, YIN Yang-yang, WANG Ting, LIU Chuan-huai,

SHEN Li, LIU Jian-feng, PAN Wei-guo

## 精密与超精密加工 Precision and Ultra-precision Machining

337 磨粒类型对 K9 玻璃剪切增稠抛光的影响

Effect of Abrasive Type on Shear Thickening Polishing of K9 Glass

段世祥, 吕冰海, 邓乾发

DUAN Shi-xiang, LYU Bing-hai, DENG Qian-fa

347 增减材复合加工 TC4 高精度孔试验对比研究

Comparative Study on High-precision Hole Test of TC4 Titanium Alloy by Additive and Subtractive Materials

石文天, 李季杭, 刘玉德, 闫天明, 林宇翔, 王林

SHI Wen-tian, LI Ji-hang, LIU Yu-de, YAN Tian-ming, LIN Yu-xiang, WANG Lin

360 基于双磁场磁性复合流体的抛光性能

Polishing Performance of Magnetic Compound Fluid Based on Double Magnetic Field

王有良, 史小锋, 陈秀娟, 张文娟, 冯铭

WANG You-liang, SHI Xiao-feng, CHEN Xiu-juan,

ZHANG Wen-juan, FENG Ming

373 基于灰色关联分析的 GH2132 线材高精度切削参数优化

Optimization of High-precision Cutting Parameters of GH2132 Wire Based on Grey Relational Analysis

史丽晨, 刘亚雄, 史炜椿, 卢竹青, 豆卫涛

SHI Li-chen, LIU Ya-xiong, SHI Wei-chun, LU Zhu-qing, DOU Wei-tao

## 表面功能化 Surface Functionalization

385 耐用铝基超疏水涂层的机械稳定性及抗结冰性能

Mechanical Stability and Anti-icing Performance of Robust Aluminum-based Superhydrophobic Coating

李天然, 卢晨光, 原子超, 刘聪, 李云单, 刘亚华

LI Tianran, LU Chen-guang, YUAN Zi-chao,

LIU Cong, LI Yun-dan, LIU Ya-hua

395 纳米液滴撞击润湿梯度表面的分子动力学模拟

Molecular Dynamics Simulation of Nanodroplet Impacting on Wettability Gradient Surface

潘伶, 谢旭清, 郭锦阳

PAN Ling, XIE Xu-qing, GUO Jin-yang

405 复合梯度楔形表面上液滴自输运特性的数值研究

Numerical Study on Droplet Self-transport on Composite Gradient Wedge-shaped Surface

高芳, 郑佳宜, 李准, 余延顺

GAO Fang, ZHENG Jia-yi, LI Zhun, YU Yan-shun

412 In 合金化及固溶处理对 Mg-6Al-1Zn 阳极材料组织和电化学性能的影响

Effect of In and Solid Solution Treatment on Microstructure and Electrochemical Properties of Mg-6Al-1Zn Alloy Anode

谷亚啸, 江静华, 谢秋媛, 马爱斌, 高正

GU Ya-xiao, JIANG Jing-hua, XIE Qiu-yuan, MA Ai-bin, GAO Zheng

423 大气等离子喷涂制备梯度多孔电极及其碱式电解水性能研究

The Preparation and Performance of Gradient Porous Electrodes Obtained via Atmospheric Plasma Spraying Used in Alkaline Water Electrolysis

宋嘉薇, 王先彬, 姜欣格, 刘太楷, 张楠楠, 宋琛, 邓畅光, 邓春明, 刘敏

SONG Jia-wei, WANG Xian-bin, JIANG Xin-ge, LIU Tai-kai, ZHANG Nan-nan,

SONG Chen, DENG Chang-guang, DENG Chun-ming, LIU Min

436 Ti/Co<sub>3</sub>O<sub>4</sub>/RuO<sub>2</sub>-IrO<sub>2</sub> 纳米结构阳极电催化析氧研究

Electrocatalytic Oxygen Evolution Performance of Nanostructured Ti/Co<sub>3</sub>O<sub>4</sub>/RuO<sub>2</sub>-IrO<sub>2</sub> Anode

刘越仁, 辛永磊, 许立坤, 段体岗, 高显泽, 郭明帅

LIU Yue-ren, XIN Yong-lei, XU Li-kun,

DUAN Ti-gang, GAO Xian-ze, GUO Ming-shuai

445 Ta 涂层对 CVD 单晶金刚石焊接强度的影响

Effect of Ta Coating on Welding Strength of CVD Single-crystal Diamond

毛雅梅, 黑鸿君, 高洁, 张孟, 王垚, 郑可, 于盛旺

MAO Ya-mei, HEI Hong-jun, GAO Jie, ZHANG Meng,

WANG Yao, ZHENG Ke, YU Sheng-wang

452 等离子体处理对 AA7075 铝合金表面特性及胶接性能的影响

Effect of Plasma Treatment on Surface Properties and Bonding Performance of AA7075 Aluminum Alloy

刘志浩, 邹田春, 李晔, 巨乐章

LIU Zhi-hao, ZOU Tian-chun, LI Ye, JU Yue-zhang