MAIN TOPICS, ABSTRACTS & KEY WORDS

Effect of high frequency longitudinal alternating magnetic field on droplet transfer and spatter rate in high current GMAW welding   FAN Ding[1,2], YANG Wenyan[1], XIAO Lei[1], HUANG Jiankang[1,2] (1. School of Materials Science and Engineering, Lanzhou University of Technology, Lanzhou 730050, China; 2. State Key Laboratory of Advanced Processing and Reuse of Nonferrous Metals, Lanzhou University of Technology, Lanzhou 730050, China). pp 1-5

Abstract: In the process of gas shielded arc welding (GMAW), it is a direct way to increase the welding deposit rate by adopting high wire feeding speed, increasing welding current and dry elongation. However, when the droplet transfer is changed into rotating jet transfer, the arc is unstable, the spatter increases and the weld formation becomes worse. A longitudinal alternating magnetic field with different frequencies is applied to control the weld formation. The arc shape and droplet transfer during welding were photographed by high-speed video camera. The effects of magnetic field with different frequencies on droplet transfer and welding spatter rate were studied. The results show that the mechanism of spatter is different with different droplet transfer modes; when the applied frequency is 1 000 Hz longitudinal alternating magnetic field, the rotating radius of arc decreases, the stiffness of arc increases, the arc is more stable, the welding spatter rate decreases, and the weld shape is improved.

Key words: swirling jet transition; high frequency magnetic field; high speed photography; spatter rate; evaporation rate

Brief analyses of thermo-mechanical coupling issue on welding structures   WANG Ping[1,3], LIU Yong[1], CHANG Hexi[2], DONG Pingsha[3] (1. State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin 150001, China; 2. Hebei University of Science and Technology, Shijiazhuang 050000, China; 3. Department of Naval Architecture and Marine Structure, University of Michigan, Ann Arbor 48105, USA). pp 6-11

Abstract: To understand the basic mechanism in the design and manufacture of welded structures, the evolution of stress and strain in the thermal-mechanical coupling process was studied by using one-dimensional bar model with rigid constraints on both ends. The necessary condition for the compressive plastic zones was proposed, namely, the temperature differences should no less than $2\Delta T$. Under force and moment equilibrium condition, the 1-Bar theory was applied into two-dimensional plates. The 3-Bar model was then developed to study the effects of welding heating and cooling processes on the distribution of two-dimensional longitudinal residual stress. It was found that the width of the local heated strip in 3-Bar model equals to the width of the welding plastic zone. The longitudinal residual stress of the welding plastic zone is close to the material yield strength. The dimension, profile and location of the plastic zone are the key parameters in the design of the weld joint. The asymmetric distribution of the neutral axis should be limited to avoid additional deformations. Flame straightening process was studied using 1-Bar model. It was found that the residual stress and the plastic strain could not be changed from the second thermal cycle. The repeated heating in the repair zone is useless. The effects of flame straightening could be predicted simply by inputting the heating peak temperature and heating width into 3-Bar model.

Key words: weld residual stress; local plastic zone; 3-Bar model; flame straightening

Calculation of radiative properties for argon plasma in ultraviolet A and B   WANG Fei[1,2], LI Huan[1], Cressault Yann[2], Teulet Philippe[2], YANG Ke[1] (1. Tianjin Key Laboratory of Advanced Joining Technology, Tianjin University, Tianjin 300072, China; 2. Laboratoire Plasma et Conversion d'Energie (LAPLACE), UPS, INPT, Université de Toulouse, Toulouse 31062, France). pp 12-15

Abstract: Exposure to ultraviolet A (315 ~ 400 nm) and B (280 ~ 315 nm) from welding arcs is an important risk factor for the development of skin cancer. Based on the concept of net emission coefficient, the radiative properties within the ultraviolet A and B ranges are calculated for argon plasma with a radius of R_p in the temperatures 5 000 ~ 25 000 K at atmospheric pressure. The various radiative mechanisms, including continuum (recombination and bremsstrahlung) and line radiation, are considered. It is concluded that although the self-absorption effect is prominent for the entire spectrum, it is very weak for the ultraviolet A and B. When R_p = 1 mm, the ultraviolet A and B radiations account for at most of 6.0% and 1.9%, respectively. To the entire spectrum (35 ~ 4 500 nm) radiation, and account for at most of 36.5% and 5.0% to non-vacuum-ultraviolet (200 ~ 4 500 nm) radiation. This study establishes a theoretical basis for the study of the ultraviolet radiation posed by TIG arcs.

Key words: ultraviolet; radiation; welding arcs; skin cancer; net emission coefficient

Microstructure and mechanical property of Al₂O₃/Ti joint with biocompatibility   LIN Panpan[1], LIN Tiesong[1], HE Peng[1], WANG Maochang[1], YANG Hangao[2] (1. State Key

Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin 150001, China; 2. Shenzhen Institute of Advanced Technology, Chinese Academy of Sciences, Shenzhen 518055, China). pp 16-23

Abstract: In this paper, the experimental materials of Al_2O_3 ceramic and pure Ti metal were modified by metals Mo and Ti by magnetron sputtering and brazed using Au filling metal. The effect of joining process and Ti metallizing layer thickness on the microstructure and mechanical property of the joints was investigated. The results show that the microstructure of the Al_2O_3/Ti joint mainly consisted of Au braze and (Au, Mo)ss. There were a few (Ti, Mo)ss and Ti_xAu_y intermetallic compounds (IMCs) among the (Au, Mo)ss. A few TiO_2 and Ti_xAu_y IMCs were also observed at the Al_2O_3/braze interface and in the weld. The kind of phases in the weld was free from influence of bonding temperature, holding time and Ti metallizing layer thickness. However, both the number and distribution of phases in the weld change with bonding temperature, holding time and Ti metallizing layer thickness. The shear strength of joints was changed by the bonding temperature, holding time and Ti metallizing layer thickness because these factors influenced the distribution uniformity of solid solution and the number of IMCs in the weld. When the thickness of Ti metallized layer was 0.2 μm, maximum shear strength of 138 MPa was achieved at 1 080 °C for 5 min.

Key words: Al_2O_3 ceramic; pure Ti; Au braze; microstructure; mechanical property

Heat transfer modeling and cooling method for aeroengine blade MPAW repair

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Abstract: Heat source parameters and cooling rate are the key factors affecting the repairing welding quality of titanium alloy blade. In the present work, the mathematical model of welding heat source is established based on the principle of pulse heat source superposition and Gaussian distribution. The finite element model of welding repair is established according to the solid structure of the fixture. The heat transfer process is modelled by COMSOL and the heat source model is verified by experiments. According to the heat transfer simulation results, the heat transfer characteristics, cooling structure and fluid parameters of the fixture are analysed. The maximum temperature variation after adopting the cooling method is analysed and the welding experiment is carried out by establishing the parameterized surface of typical positions. The results show that the heat source model is in good agreement with experimental measurements. The heat exchange method can effectively improve the repairing welding quality.

Key words: blade repair; heat transfer modeling; cooling method; MPAW; heat flow coupling

Droplet transfer and weld forming of Tri-arc DE welding

ZHENG Jia, LI Liangyu, ZHONG Pu, WANG Tianqi (Advanced Mechatronics Equipment Technology Tianjin Area Laboratory, Tianjin Polytechnic University, Tianjin 300387, China). pp 31-36

Abstract: The influence of different current and pulse frequency of M-arc on the droplet transfer behavior was verified using a welding system with Tri-arc DE welding and a high speed camera and waveform synchronization acquisition system. The results show that the main reason for the change of the droplet transfer behavior is the force produced by M arc. Then, there is a corresponding relationship between the droplet transfer behavior and the change of the M-arc current. With the increase of the M-arc current, the droplet transfer behavior changed from short circuit transition + jet transition to large drop transitions, jet drop transitions and jet transitions. With the increase of M-arc pulse frequency, the droplet transfer changed several drops per pulse, one drop per pulse, one drop within several pulses. The ideal weld forming pattern is the one-drop one transition phase.

Key words: Tri-arc DE; droplet transfer behavior; weld formation; welding current; pulse frequency

Influence of rivet on process and failure behavior of self-piercing riveting in dissimilar sheets of TA1 and 1420 Al-Li alloys

ZHANG Xianlian, HE Xiaocong, ZENG Kai (Kunming University of Science and Technology, Kunming 650500, China). pp 37-43

Abstract: Using self-piercing riveting (SPR), riveting processes of dissimilar sheet combinations in TA1 titanium and 1420 aluminum lithium alloy sheets were analyzed with different rivets in detail. And SPR joints of TA1-1420 (TAF), 1420-TA1 (ATF) and TA1-1420 (TAS) were fabricated from different rivets with length of 6 mm and hardness of 44 HRC ± 2 HRC and 48 HRC ± 2 HRC, correspondingly. Through tensile-shear tests and fatigue tests, failure modes of three groups of joints were obtained. Furthermore, influences of rivet on failure behaviors of self-piercing riveting dissimilar sheets in TA1 and 1420 aluminum lithium alloys were analyzed using electron scanning microscope (SEM). Results show that: rivets have a significant influence on riveting processes of dissimilar sheet combinations. And they can be effectively connected with the rivets of proper length. The upsetting degree can be reduced with the hardness of rivets increased. As the hardness of rivets increased, the failure parts are changed from the huge deformation area to the bottom of

the joint and the hardness of rivets also have a significant influence on the failure behaviors of these joints.

Key words: self-piercing riveting; titanium alloy; aluminum lithium alloy; riveting process; failure behavior

Effect of temperature on fracture toughness of SA508-III weld metal   LI Xiangqing, DING Zhenyu, BAO Shiyi, GAO Zengliang (Engineering Research Center of Process Equipment and Remanufacturing, Zhejiang University of Technology, Hangzhou 310014, China). pp 44-47

Abstract: In order to obtain the effect of temperature on fracture toughness of the SA508-III weld metal, the constitutive curve method (CCM), ASTM and ISO standard were applied to determine the fracture toughness of weld metal in typical temperature points. The fracture toughness value obtained from CCM showed a reduction trend with the increase of temperature. When the temperature increased from 20 °C to 100 °C and from 100 °C to 320 °C, the fracture toughness value were reduced to 11.1% and 5.4%, respectively. SEM fracture photographs of Compact Tension specimens revealed that the tested SA508-III weld metal presented ductile fracture at test temperature points. However, when the temperature reached 100 °C to 320 °C, dimples became shallow and small, which led to the decrease of fracture toughness. Moreover, this study also found that the fracture toughness obtained from CCM was the same as that of ASTM standard at 20 °C and 100 °C, and intermediate between that of ASTM and ISO at 320 °C.

Key words: blunting line equation; SA508-III steel; welded joint; fracture toughness

Analysis of microstructure and mechanical properties of the aluminum alloy T-joint welded by stationary shoulder friction stir welding   HAO Yunfei[1], MA Jianbo[1], BI Huangsheng[1], LI Chao[1], WANG Guoqing[2] (1. Capital Aerospace Machinery Company, Beijing 100076, China; 2. China Academy of Launch Vehicle Technology, Beijing 100076, China). pp 48-54

Abstract: 2219C10S aluminum alloy T-joint was successfully performed by stationary shoulder friction stir welding. The weld surface is smooth and has no obvious thickness-reduction. The PAUT testing on the back of the substrate plate shows that all the surfaces between the substrate and rib plates were welded thoroughly. The macro-structure revealed two weld contours symmetrically distributed in the center of the rib plate. The unilateral weld contours also exceeded the center line of the rib plate. The microhardness distribution of the joints shows a unique U-shaped distribution, and the microhardness of the weld nugget zone was the lowest. The crack of tensile specimens with the two directions of T-joint initiated at the tangent of the tension plate and the corner of the joint R1. However, the transverse areas of the fracture surface for the two types of tensile specimens are quite different. This is the main reason why the tensile strength along the direction of rib plate was 20 MPa lower than that along the direction of the substrate plate.

Key words: T joint; stationary shoulder friction stir welding; microhardness; tensile property; fracture location

Investigation on high speed laser-MIG hybrid welding process of 6N01S-T5 aluminum alloy   WANG Wei, WANG Hao, CHEN Hui, ZHU Zongtao (Southwest Jiaotong University, Chengdu 610036, China). pp 55-60,66

Abstract: To reduce the welding distortion and joint softening defects of 6N01S-T5 aluminum alloy, high-speed (4.8 m/min) laser-MIG hybrid welding process is performed. The mechanical properties and microstructure of welded joints are analyzed by microhardness test, tensile test, metallographic and SEM with EDS. The welding distortion of the butt joint is tested by coordinate measuring apparatus. The residual stress is measured by X-ray residual stress measurement instrument. The results show that the good appearance of weld is attained at the welding speed of 4.8 m/min. The average tensile strength of the high speed welding joint is 207 MPa, which is 71% of the base metal. Compared with the low speed welding process, the welding wire consumption is reduced by 68% and the welding efficiency is greatly improved at high speed welding process. Meanwhile, the width of the joint softening zone is reduced by 60%. The welding distortion is smaller and the range of residual tensile stress is narrower.

Key words: laser-MIG hybrid welding; 6N01S-T5 aluminum alloy; high speed welding; welding distortion; residual stress

Testing of hot crack using laser-MAG combined welding for 42CrMo steel   CHEN Genyu[1], ZHANG Yan[2], LEI Ran[1] (1. State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha 410082, China; 2. Hunan Institute of Science and Technology, Yueyang 414006, China). pp 61-66

Abstract: The welding processes of transient flow and solidification behaviors were observed using high speed camera. The moving velocity of the interface between solids and liquids was calculated. The temperature variation of welding process was obtained by infrared thermal imager and the temperature gradient was calculated. The hot crack tendency of welded joint was investigated under three welding process of autogenous laser welding, laser-MAG hybrid welding guided by laser and laser-arc hybrid welding guided by arc. The results show laser-MAG hybrid welding guided by laser produced the lower moving velocity of solids and liquids, the lower temperature gradient, and smaller strain rate and sensitivity of hot crack. The microstructure and hardness were

also tested in laser-MAG hybrid welding guided by laser.

Numerical simulation of arc characteristics under mixtures of argon and hydrogen in gas tungsten arc welding   LIU Zhengjun, LI Yuhang, SU Yunhai (Shenyang University of Technology, Shenyang 110870, China). pp 67-71

Abstract: An axisymmetric model based on the magnetohydrodynamic (MHD) is established to investigate the effect of hydrogen on heat transfer and fluid flow characteristics of argon plasma in GTAW. The profiles of temperature and voltage drop, distributions of arc pressure and current density are simulated by utilizing the fluid dynamic theory coupled with Maxwell equations. The quantitative analysis and comparison of anodic heat fluxes under pure argon and mixtures of argon and hydrogen are also obtained. The results show that the addition of 10% hydrogen to argon makes the arc slightly constricted and increases electromagnetic forces up to 2 times of the conventional arc. Meanwhile, it also increases the temperature, plasma flow velocity, arc voltage, current density. This leads to more energy transferred to the anode, which can partly improve the thermal efficiency. The present study may provide theoretical reference for the further applications of high efficiency GTAW process.

Detection of horizontal weld seam collapse based on grid laser lines   WANG Qisheng, GAO Yanfeng (Nanchang Hangkong University, Nanchang 330063, China). pp 72-76

Abstract: A method for the online detection of horizontal weld seam collapse was proposed, in which the weld seam collapse was detected according to the deformation of the 5×5 grid laser lines projected on the surface of the weld seam. Firstly, the images of the grid lines were processed and the vertical and horizontal pixel points were obtained. Then the vertical pixel points were fitted into five spline curves based on Gaussian function. Each of these spline curves was fitted into four segments, and the intersection points of the curve segment with the straight segment was obtained. The intersection points and the highest points on the five vertical spline curves were fitted into three straight horizontal lines based on a least square method. Finally, the collapse of weld seam was obtained by calculating the distances between the three straight horizontal lines. The experimental results show that this method realizes the online detection of horizontal weld seam collapse. This work is expected to provide the foundation for closed-loop control of horizontal weld seam formation.

Research on IIW multiaxial fatigue criterion based on notch stress approach   HU Xin[1,2], YAN Renjun[1,2], SHEN Wei[1,2], HU Yaoyu[1,2], HE Feng[3] (1. Key Laboratory of High Performance Ship Technology of Ministry of Education, Wuhan University of Technology, Wuhan 430063, China；2. School of Transportation, Wuhan University of Technology, Wuhan 430063, China；3. Hubei Hang Da Technology Co., Ltd., Wuhan 430040, China). pp 77-81

Abstract: Multiaxial fatigue strength evaluation of welded joints is a complex subject for engineering. Based on IIW multiaxial criterion, experimental data from published literatures were re-evaluated using notch stress approach. The results reveal that the uniaxial fatigue assessment S-N curve recommended by IIW is unfit for multiaxial fatigue. Whereas, the data points of proportional loading and non-proportional loading have good coincidence under notched stress system. The assessment result is dangerous when the number of cycles is in the range of $1 \times 10^4 \sim 1 \times 10^5$, and it is too conservative over 1×10^5 times. Based on this, the S-N curve ($FAT = 430$ MPa, $m = 5.8$) with the probability of survival $P_s = 97.7\%$ is proposed for both proportional and non-proportional loading. This work can provide useful references for fatigue life prediction of engineering welded structures.

Intelligent recognition algorithm of welding point based on structured light   ZHU Qidan, WANG Yanke, ZHU Wei, LIU Yue (Institute of Intelligent Control, College of Automation, Harbin Engineering University, Harbin 150001, China). pp 82-87,99

Abstract: In the process of automatic welding, welding point needs to be recognized with the help of laser. However, it suffers from the arc light and reflect light on the surface of some materials and the resulting accuracy of recognition cannot be guaranteed. In terms of this issue, the recognition network based on heatmap is proposed with combination of deconvolution and feature pyramid network. It extracts pyramid feature using residual convolutional neural network and generates key-point heatmap for each scale, which can tell the exact position of welding point. Compared with template matching and original feature pyramid network, such network performs better in the recognition of welding point with strong robustness and can work well in the context of various noise and complex interference.

tion of welding point

Numerical simulation analysis of crack propagation in weld toe considering multiple cracks

YU Xi[1], WEI Guoqian[1,2], LI Shanshan[1], YE Fan[1], CHEN Siwen[1] (1. Key Laboratory of Metallurgical Equipment and Control Technology, Wuhan University of Science and Technology, Wuhan 430081, China; 2. Hubei Key Laboratory of Mechanical Transmission and Manufacturing Engineering, Wuhan University of Science and Technology, Wuhan 430081, China). pp 88-93

Abstract: Aiming at the existence of multiple cracks at the weld toe, the numerical simulation of the multi-crack propagation process was carried out. Consider the short crack growth stage. The M-integral is used to calculate the stress intensity factor of the entire crack front. The specific influence of this factor on the propagation behavior before and after the fusion of the crack front is simulated and analyzed. The results show that the difference in crack spacing will directly lead to the difference. The influence of the stress intensity factor before and after the fusion of the crack front is different. The shape of the crack front has different shapes due to the initial crack spacing. The relative crack spacing L/a=1 boundary inflection point can be used as an effective reference for subsequent engineering research. The fatigue test of the cross-welded joint was carried out, and the simulation results were verified.

Key words: multiple cracks; the propagation of crack front; stress intensity factor; NASGRO; numerical simulation

Research of a novel double-pulsed MIG welding power supply

ZHONG Qiming, XIE Fangxiang, WANG Zhenmin (South China University of Technology, Guangzhou 510640, China). pp 94-99

Abstract: In order to improve the overall performance of double-pulsed MIG welding equipment, a novel welding power is developed based on silicon carbide power devices. The inverting frequency is up to 100 kHz, which is beneficial to precisely control welding arc. Control circuit of the proposed welding power is composed of the main control circuit, a digital panel, wire feeder control circuit, in which STM32F405RGT6 is the control core. A corresponding control software is designed according to double-pulsed MIG welding task requirements. The incremental PID algorithm is used to control the output and double-pulsed welding is realized by single pulse output with pulsating wire feeding. Test result shows that the proposed welding power supply has a fast-dynamic response, which can effectively cooperate with the pulsating wire feeding to weld. The fish scales of the weld are clear without obvious defects.

Key words: silicon carbide power devices; double-

pulsed MIG welding; digital welding power supply

Finite element simulation of melting heat accumulation in laser additive manufacturing

TANG Qi[1], CHEN Jingqing[1], CHEN Peng[1], CHEN Yong[1], ZHAO Ying[2] (1. Southwest Jiaotong University, Chengdu 610031, China; 2. Tianjin Polytechnic University, Tianjin 300387, China). pp 100-104

Abstract: In this paper, the temperature field of single-layer and multi-beads Selective Laser Melting (SLM) of H13 die steel was simulated by using Gauss body heat source. The heat accumulation of different scanning lengths and its effect on the morphology of molten pool during S-type scanning were studied. The correctness of the simulation was verified by experiments and an improved measure was proposed to reduce the heat accumulation. The results show that the shorter the scanning length, the more serious of the heat accumulation, and accordingly the higher the maximum temperature of the molten pool in the fifth bead. By taking the average growth rates of melting length, melting depth and melting width under different scanning lengths as the standard, the average growth rates of them were 32.1%, 27.1% and 13.5%, respectively. The maximum temperature of the fifth bead was reduced from 3 115.6 °C to 2 881.51 °C when employed a unidirectional scanning at 6 mm. However, the time of completing the same pass is twice as much as that of the S-type scanning.

Key words: H13 die steel; selective laser melting; temperature field; heat accumulation

Investigation on the solidification segregation behavior of GTAW nickel alloy deposited metal

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Abstract: The solidification segregation behavior of deposited metal with nickel alloy wires by GTAW was investigated by Optical Microscope (OM), Scanning Electron Microscope (SEM), Energy Dispersive Spectroscopy (EDS) and Electron probe X-ray microanalyser (EPMA), etc. Results indicated that microstructure was composed of γ phase, MC carbides, Laves phases in the deposited metal. The metallurgical structure was columnar crystals with segregation zone of 5 ~ 10 μm in width. The segregation coefficients of primary elements were calculated with EPMA results according to Scheil formula, $k_{Nb} = 0.23$, $k_{Mo} = 0.68$, $k_{Ni} = 1.07$, $k_{Cr} = 1.05$, $k_{Fe} = 1.23$. During solidification, Nb and Mo tended to segregate in the liquid phase, while Fe prefers to distribute into solid phase, Ni and Cr did not show significant distributions differences between liquids and solids. The reaction sequence of deposited metal with experimental nickel

alloy wires during solidification was L→L+γ→L+γ+MC→L+γ+MC+Laves→γ+MC+Laves.

Research on microstructure and mechanical properties of high strength Al-Mg alloy fabricated by double-wire and gas tungsten arc additive manufacturing process   HE Jie, FENG Yuehai, ZHANG Lin, ZHAN Bin (Nanjing University of Science and Technology, Nanjing 210094, China). pp 109-113

Abstract: A new gas tungsten arc additive manufacturing process, with two homogeneous aluminum magnesium alloy wires synchronously feeding into same molten pool, was performed to manufacture high strength aluminum magnesium alloy component. Straight wall specimens were deposited by traditional single wire feeding and double-wire feeding gas tungsten arc additive manufacturing process, respectively. The difference in appearance size measurements, optical microscope, mechanical properties of the specimens were comparative studied in details. The results show the deposition rate of the double wire feeding mode is 2.08 times of the single wire feeding. The double wire feeding mode achieves finer grain. Moreover, the ultimate tensile strength of the double wire feeding mode reaches 71% of the 7A52 aluminum magnesium alloy. Compared with the single-wire feeding. the longitudinal ultimate tensile strength improved by 7% and the longitudinal elongation improved by 5% as well.

Key words: double-wire feeding; gas tungsten arc; high strength aluminum magnesium alloy; additive manufacturing

Formation mechanism of microstructure of laser cladding high chromium Fe-based alloy and its effect on microhardness   YIN Yan[1], PAN Cunliang[1], ZHAO Chao[1], ZHANG Ruihua[2,3], QU Yuebo[2,3] (1. State Key Laboratory of Advanced Processing and Recycling of Nonferrous Metals, Lanzhou University of Technology, Lanzhou 730050, China; 2. China Iron & Steel Research Institute Group, Beijing 100081, China; 3. Yangjiang Knif-Seissor Hardware Research Institution of Industry Technology, Yangjiang 529533, China). pp 114-120

Abstract: A high chromium iron-base alloy with the coaxial powder laser coating is implemented on the surface of the 3Cr13 stainless steel blade by using 2 kW fibre-optical disc laser to improve the hardness of the blade. SEM, EDS, EPMA and XRD are used to analyze the microstructure of the cladding layer and the microhardness is tested. The results show that the cladding layer is well-formed and metallurgically bonded with the substrate without defects such as cracks, porosity and so on. With the change of the heat dissipation and the constitutional supercooling, microstructure can be roughly divided into three regions: dendritic region, eutectic fine grain

region and coarse grain region. The carbides of $(Fe,Cr)_7C_3$ is distributed in each region to increase the hardness and abrasion resistance of the cladding layer. As the size of the grain in each region is different, the hardness of the cladding layer is differently distributed. While, the addition of Ni element promotes the austenization of the matrix in the cladding layer. It can play a role in the toughness of the carbides with high hardness during the use of the knife. Thus, the comprehensive mechanical properties of the cladding layer are obtained.

Key words: laser cladding; Fe-based alloy; microstructure; microhardness

All-position plasma arc welding process for thick TC4 tube and mechanical properties of welded joints   GUO Chunfu[1], LIU Boyan[1,2], DONG Chunlin[1], YI Jianglong[1] (1. Guangdong Provincial Key Laboratory of Advanced Welding Technology, Guangdong Welding Institute (China-Ukraine E.O. Paton Institute of Welding), Guangzhou 510650, China; 2. Shenyang University of Technology, Shenyang 110870, China). pp 121-126

Abstract: A new plasma arc welding process for thick-walled TC4 titanium alloy tube was investigated. All-position high-quality welding joints of titanium alloy were achieved through parameters optimization. The microstructure, fracture morphology and microhardness of the welded joints at ordered locations were characterized by optical microscopy, scanning electron microscopy and micro Vickers hardness tester. The results reflected that the microstructure of the weld metal and the heat-affected zone of the characteristic joint were mainly composed of basket-shaped α' phase, needle-like α phase and coarse β phase. The tensile fractures of specimens was occurred at base metal, revealing well tensile properties. The fracture morphology of the impact specimens was ductile fracture. The hardness of weld metal and heat affected zones was higher than that of base metal, respectively.

Key words: titanium alloy tube; plasma arc welding; all position welding; microstructure; mechanical propertie

Effects of WC and Al_2O_3 on the microstructure and erosion wear resistance of $FeAlCoCrCuTi_{0.4}$ high-entropy alloy coating by argon arc cladding   DONG Shizhi[1], MENG Xu[1], MA Zhuang[1,2], ZHAO Yuechao[3] (1. Liaoning Technical University, Fuxin 123000, China; 2. Liaoning Institute of Science and Technology, Benxi 117300, China; 3. Yantai Nanshan University, Longkou 265713, China). pp 127-132

Abstract: $FeAlCoCrCuTi_{0.4}$, WC/Al_2O_3-$FeAlCoCrCuTi_{0.4}$ high-entropy alloy (HEA) coating had been cladded by means of argon arc cladding. The effects of WC and Al_2O_3 on microstructure and properties of $FeAlCoCrCuTi_{0.4}$ high entropy alloy coatings were investigated by means of XRD, SEM, EDS, hardness testing and erosion wear testing. The results show that the alloy coating prepared by argon arc

cladding has good formability, no holes, cracks and other defects, and high strength metallurgical bonding with the matrix. The addition of WC and Al_2O_3 has a significant effect on reducing the dilution rate of the coating. The three kinds of coatings are mainly composed of BCC phase (Fe-Cr solid solution), and the grains exist in the form of cellular dendrites. After adding WC, the grain size is obviously refined, and the hardness of the coating is 685.8 HV under various strengthening effects. The addition of WC and Al_2O_3 significantly improved the erosion wear resistance of the coating, and the wear resistance could almost reach 2 times of that of FeAlCoCrCuTi$_{0.4}$ high entropy alloy coating.

Key words: high entropy alloy; composite coating; hardness; erosion wear resistance

Relationship between stress calculation function of indentation strain-gage and mechanical properties of low-alloy steel CHEN Jing, KAN Ying, JIANG Yunlu, CHEN Huaining (Key Laboratory of Nuclear Materials and Safety Assessment, Institute of Metal Research, CAS, Shenyang 110016, China). pp 133-138

Abstract: Indentation strain-gage method is one of basically non-destructive stress determination methods. It has some advantages, like quickness, convenience, accuracy and so on. One of the factors influencing the accuracy of stress measurement is determination of stress calculation function (the relationship between strain increment $\Delta\varepsilon$ and the elastic strain ε). Based on existing research, the relationship between stress calculation function and mechanical properties for 12 kinds of low-alloy steels was discussed in this paper. The numerical simulation method combined with experimental calibration results was adopted. The study shows that stress calculation function for a certain steel could be extracted if its mechanical properties and $\Delta\varepsilon_0$ were obtained. By this way, the complex experimental calibration tests or numerical simulation works could be eliminated.

Key words: indentation strain-gage method; stress calculation function; numerical simulation; low-alloy steel; mechanical property

A novel method for evaluation of welding residual stress redistribution during fatigue crack growth WANG Qiang, YAN Zhongjie, LIU Xuesong, FANG hongyuan (State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin 150001, China). pp 139-142,148

Abstract: A novel methodology for evaluation of welding residual stress (WRS) redistribution during fatigue crack growth (FCG) was proposed in this paper and some necessary equations were derived. By using strain gauge rosettes (with three strain gauges of different directions manufactured on one substrate) attached to the surface of the sample along the potential crack propagation path, the amounts of strain change were collected by a dynamic strain testing system and the corresponding amounts of WRS redistribution were calculated following our equations, which were used to characterize the WRS redistribution thereafter. Experimental tests were carried out to determine the redistribution of WRS during FCG of a high strength steel welded joint employing our proposed methodology. It turned out that this straightforward methodology was capable of accurately capturing the WRS redistribution during FCG relative to an analytical method proposed previously in the literature.

Key words: welding residual stress; residual stress redistribution; high strength steel; experimental testing

Research on microstructure and corrosion behavior of multi-pass welded joints of hyper duplex stainless steel GAO Zhanqi[1,2], JING Hongyang[1,2], XU Lianyong[1,2], HAN Yongdian[1,2] (1. School of Materials Science and Engineering, Tianjin University, Tianjin 300072, China; 2. Tianjin Key Laboratory of Advanced Joining Technology, Tianjin 300072, China). pp 143-148

Abstract: Microstructure and corrosion properties of multi-pass welded joints of 2507 hyper duplex stainless steel by multi-pass gas tungsten arc welding were studied. Two different shielding gases were used in the tungsten argon arc welding. The effect of welding pass and nitrogen addition on the microstructure and corrosion performance was discussed. The results showed that the weld center had higher austenite content. Its corrosion rate was about 0.68 times of the weld root. The weld cap showed better corrosive properties due to its obvious intragranular austenite though its austenite content was close to weld root. The weld root was the weakest region in the weld metal. The mixing zone showed the highest corrosion rate due to the existence of heat affected zone. The addition of nitrogen promoted the formation of austenite and reduced the corrosion current density by one magnitude and improved the overall corrosion performance.

Key words: duplex stainless steel; multi-layer and multi-pass welding; microstructure; polarization

Research on underwater wet manual SHS welding HAN Fengqi[1], LI Zhizun[2], SUN Liming[2], MA Yunhe[2], SHEN Chao[2] (1. Shijiazhuang Tiedao University, Shijiazhuang 050043, China; 2. Army Engineering University, Shijiazhuang 050003, China). pp 149-155

Abstract: Based on self-propagation high-temperature synthesis technology (SHS technology) and principle of underwater wet electric-arc welding, a new wet manual SHS welding is proposed and investigated. It could be used in rapid repairing underwater metal structures. The rod and coating of electrode was developed for underwater welding. The welding was performed and microstructure and properties of the

welding joint were tested. The results show that underwater metal structures could be welded successfully with this welding method on the condition of no electric, no gas and no other equipment. Welded joints, which were one-side welded with back formation, were obtained and the tension strength reached 267 MPa, the impact energy was 13.8 J. SEM and EDS revealed that the weld metal was composed of matrix of α-Cu solid solution and massive second phase enriched with Fe precipitates. The epitaxial nucleation was found between base metal and weld metal, which formed gradient fusion welding. The tensile fracture occurred at weld metal or fusion zone. There were a great number of dimples in the fracture, which confirmed that the fracture is the mode of ductile fracture.

Key words: manual SHS welding; underwater wet welding; emergency maintenance; combustion welding rod; microstructure and properties

Design of a Ti-6Al-4V functionally graded network structure and its compression properties SHAO Shiyou, LI Dong, ZENG Chunjie, ZHANG Tao (Shanghai University of Engineering Science, Shanghai 201620, China). pp 156-160

Abstract: The porous Ti-6Al-4V structure with high porosity is produced by electron beam selective melting, which is intended to replace human cancellous bone. The open mesh structure can provide space for the in-growth of bone tissue that it can play a better role in fixing. A computer aided design (CAD) was used to prepare a functionally graded network with low density (0.78 g/cm^3), high porosity (82%) and elastic modulus of 2.7 GPa. The results show that this structure has a modulus of elasticity which is similar to the cancellous bone compared with the dense part. It can effectively avoid the stress shielding effect. In addition, by increasing the thickness between the layers, it is possible to effectively prevent cracks from rapidly expanding in the mesh structure and improve safety. The yield strength of this structure is 62 MPa. The fine α' phase in the microstructure of the sample is beneficial to improve the life of the implant.

Key words: electron beam selective melting; network structure; porosity; implant