MAIN TOPICS, ABSTRACTS & KEY WORDS

Numerical simulation on residual stress and deformation for WAAM parts of aluminum alloy based on temperature function method JIA Jinlong[1], ZHAO Yue[1], DONG Mingye[1], WU Aiping[1], LI Quan[2] (1. Tsinghua University, Beijing 100084, China; 2. Capital Aerospace Machinery Corporation Limited, Beijing 100076, China). pp 1-6

Abstract: Wire arc additive manufacture (WAAM) is a new way to fabricate large-scale complex aluminum alloy components, but the performance of the parts is critically influenced by residual stresses and deformation. A sequentially thermal-mechanical coupled model of residual stress and deformation for aluminum alloy WAAM parts was established based on commercial FE software ABAQUS. The temperature field was calculated by the moving heat source (MHS) method. The temperature function was obtained according to the distribution of the peak temperature. Furthermore, the MHS method and segmented temperature function (STF) method were used to calculate the residual stress and deformation. The results show that the STF method satisfies both the efficiency and accuracy requirements. 1-segment, 3-segment, and 5-segment STF methods can shorten the time for mechanical analysis by 91%, 79%, 63%, respectively. The error of the residual stress and deformation are all less than 20%. STF method provides an effective way to predict the residual stress and deformation of large-scale WAAM parts.

Key words: wire arc additive manufacture; numerical simulation; residual stress and deformation; temperature function method

Microstructure evolution and joining mechanism of brazing (C_f-SiC_f)/SiBCN to Nb with TiZrNiCu LIN Panpan[1], YANG Jia[1], BU Lanbin[1], Lin Tiesong[1], LONG Weiming[2] (1. State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin 150001, China; 2. State Key Laboratory of Advanced Brazing Filler Metals and Technology, Zhengzhou Research Institute of Mechanical Engineering, Zhengzhou 450001, China). pp 7-13

Abstract: In this work, TiZrNiCu was proposed to realize the joining of the improved high temperature ceramic (C_f-SiC_f)/SiBCN and Nb. The effects of brazing temperature and holding time on interface microstructure and mechanical properties were investigated, and the joining mechanism was detailed described. The joint shear strength reached maximum of 36 MPa at 900 °C/20 min, in which typical interface structure was SiBCN/TiC+ZrC/Ti_5Si_3 +Zr_5Si_3 /$(Ti,Zr)_2$(Cu,Ni)/(Ti-Nb)ss/Nb. During the brazing process, Cu-Si brittle compounds were formed in the ceramic by infiltration of Cu into the (C_f-SiC_f)/SiBCN, responsible for the fracture path extended from the solder layer to the ceramic side in most cases. When the holding time was 30 min, the joint was directly broken on the ceramic base material due to the excessive penetration effect of Cu; at excessive temperature, the fracture occured in the filler, since the large difference between the (Ti-Nb)ss and the solder materials.

Key words: ultra-high temperature ceramic; amorphous solder; interface structure; joint mechanism

Pure titanium TA2 thin plate double tungsten electrode argon arc welding process HUANG Jiuling[1], KONG Liang[1], WANG Min[1], WU Dongsheng[1], LI Fang[2] (1. Shanghai Key Laboratory of Materials Laser Processing and Modification, Shanghai Jiaotong University, Shanghai 200240, China; 2. Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration, Shanghai 200240, China). pp 14-18

Abstract: In order to research the effect of welding gun tilt angle and the electrode inter-distance on coupling arc and weld formation for the tandem TIG welding of 1.24 mm thick titanium, this paper illustrated the mechanism of weld defect formation and inhibition, analysing the arc shape, current and voltage waveform by high-speed photography and electrical signal acquisition system. Experimental results showed that small arc interference and satisfactory bead formation were gained when the electrode inter-distance was between 11 ~ 15 mm. Beause of the back flow liquid metal suppressed, undercut was not found when the two guns distributed symmetrically. By using reasonable process parameters for the butt welding, the welding speed reached 3 m/min and the joint tensile sample fractured in the base metal with 434 MPa tensile strength and 31.4% elongation.

Key words: tandem TIG welding; welding gun tilt angle; the electrode inter-distance; arc shape; bead formation

Influence of repair length on residual stress in the repair weld of P92 steel BU Fanhui[1], XU Lianyong[1,2], HAN Yongdian[1,2], ZHAO Lei[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 19-24

Abstract: Based on SYSWELD software, a 3-D finite element simulation is performed to investigate the temperature field and residual stress in the repair weld process of P92 plate.

The results show that large tensile residual stresses are genetated in the repair weld and heat affected zone, and decrease in the base metal gradually. With the increase of repair length, the transverse residual stress decreased in the middle of plate surface, HAZ and weld metal. The longitudinal stess shows a declining trend in weld matal with the increase of repair length, while in the middle of plate surface and HAZ, it is affected a little by the repair length.

Key words: P92 steel; residual stress; numerical simulation; weld repair

Influence of welding residual stress in fatigue crack growth of 7N01 aluminum alloy MENG Jinkui, WANG Ping, MA Jianxiao, FANG Hongyuan (State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin 150001, China). pp 25-29

Abstract: Welding residual stress affects crack propagation as an average stress. Residual stress was separated from the average load stress. By constructing a typical welding residual stress field, the stress intensity factor of the welding residual stress field was calculated with the extended finite element method. The fatigue expansion test of the compact tensile (CT) specimen was carried out. Based on the Walker formula, the average stress intensity factor K_m (static amount) at the crack tip and the magnitudeΔK (dynamic amount) of the stress intensity factor were separated to obtain the nonlinear relationship between da/dN versus K_m andΔK. The results showed that the stress ratio was nonlinear with the crack length under different external loads and the residual stress had a scale effect on crack propagation. When the crack length of CT specimen was less than 2 mm, the residual stress field obviously affected the fatigue crack growth rate while the external load was the dominant factor, when the crack length of CT specimen was more than 2 mm.

Key words: welding residual stress; fatigue crack propagation behavior; 7N01 aluminum alloy; length scale

Properties of 316L stainless steel joints brazed with corrosion resistant nickel-based filler metal LI Yunyue[1], LI Zhuoxin[1], LI Hong[1], Jacek Senkara[2], ZHUANG Hongshou[3] (1. Beijing University of Technology, Beijing 100124, China; 2. Warsaw University of Technology, Warsaw 999038, Poland; 3. Beihang University, Beijing 100191, China). pp 30-38

Abstract: The brazing of 316L stainless steel was carried out by using Nickel based filler metal BNi685 foil. The effect of brazing clearance on the microstructure and mechanical properties of brazed joint was studied. The corrosion resistance of joints brazed with the new BNi685 foil, commercial BNi2 and BNi685 paste filler metals were also compared. The results show that with the increase of gap clearance, the tensile strength of the brazed joint decreases gradually, and the microhardness at the center of the joint increases. When the brazing clearance is 50 μm, the joint achieved a maximum tensile strength of 244 MPa. The microstructure of the brazing seam is mainly composed of $Ni_{2.9}Cr_{0.7}Fe_{0.36}$ ductile phase and a small amount of FeNiCr(P) brittle phase. With the increase of gap clearance, the FeNiCr(P) brittle phase at the center of the brazing seam increases, and the $Ni_{2.9}Cr_{0.7}Fe_{0.36}$ ductile phase decreases. The corrosion resistance of the BNi685 brazed joint is superior to that of the BNi2 and BNi685 paste brazed joint. BNi685 filler metal has a strong application potential for EGR coolers fabrication.

Key words: vacuum brazing; nickel-based filler; gap clearance; corrosion resistance

Reliability analysis of thermal shock for SnAgCu solder joints of FCBGA devices JIANG Nan[1], ZHANG Liang[1,2], LIU Zhiquan[2], XIONG Mingyue[1], LONG Weimin[3] (1. Jiangsu Normal University, Xuzhou 221116, China; 2. Institute of Metal Research, Chinese Academy of Sciences, Shenyang 110016, China; 3. State Key Laboratory of Advanced Brazing Filler Metals & Technology, Zhengzhou Research Institute of Mechanical Engineering, Zhengzhou 450001, China). pp 39-42

Abstract: The reliability of SnAgCu solder joint of flip chip ball grid array packaging (FCBGA) device was analyzed by finite element method and Garofalo-Arrheninus steady-state constitutive equation under thermal shock. The results showed that the reliability of Sn3.9Ag0.6Cu solder joints was relatively high. By analyzing the mechanical constitutive behavior of SnAgCu solder joint, the maximum value of solder joint stress was found at the corner of the contact spot between the solder joint and the chip. The stress of SnAgCu solder joint changed periodically over time. The solder joint stress and creep of the solder joint Sn3.9Ag0.6Cu was the smallest, the Sn3.8Ag0.7Cu solder joint second, and the solder joint stress and creep of the Sn3.0Ag0.5Cu solder joint was the largest, which agreed with the actual test results of the FCBGA device. The fatigue life of solder joints was calculated by creep strain fatigue life prediction model. It was found that the fatigue life of Sn3.9Ag0.6Cu solder joint was higher than that of Sn3.0Ag0.5Cu and Sn3.8Ag0.7Cu solder joint.

Key words: finite element method; thermal shock; solder joint; reliability; fatigue life

Microstructure and properties of 304L stainless steel submerged arc welding joint under different annealing conditions ZHANG Jianxiao[1,2], CHEN Huizi[1], FENG Wei[3], HUANG Jiangkang[1], FAN Ding[1] (1. State Key

Laboratory of Advanced Processing and Recycling of Non-ferrous Metals, Lanzhou University of Technology, Lanzhou 730050, China; 2. Lanzhou LS Heavy Equipment Co., Ltd., Lanzhou 730314, China; 3. Harbin Well Welding Co., Ltd., Harbin 150028, China). pp 43-48

Abstract: The butt joint experiment of 304L stainless steel thick plate was carried out by submerged arc welding method. The microstructure and properties of 304L stainless steel welded joint were analyzed by observing the microstructure of welded joint, combining with the impact toughness of welded joint at –196 °C and the residual stress test under different annealing conditions. The results show that the microstructure of heat affected zone is austenite, and the weld zone is austenite + a small amount of austenite. The results show that the residual stresses in weld seam and heat affected zone change greatly after annealing, and the residual stresses are further released with the increase of annealing temperature. In impact test, the impact energy of heat-affected zone at –196 °C decreases sharply with the increase of annealing temperature, and the impact work in weld zone at –196 °C decreases sharply with the increase of annealing temperature. The impact work showed a steady downward trend.

Key words: submerged arc welding; 304L stainless steel; annealing; residual stress; toughness

Effects of microstructure inhomogeneity on strain concentration of heat affected zone of TA15 titanium alloy electron beam weld joint LIU Chang[1], DENG Caiyan[1,2], GONG Baoming[1,2], ZHANG Chengze[1] (1. School of Materials Science and Engineering, Tianjin University, Tianjin 300072, China; 2. Tianjin Key Laboratory of Advanced Joining Technology, Tianjin 300072, China). pp 49-52,81

Abstract: The effects of inhomogeneity of α phase and α' phase on strain concentration of heat affected zone of TA15 titanium alloy electron beam weld joint were investigated through instrumented nano-indentation test and tensile test of small specimens combined with the microstructure-based finite element method. The results showed that the yield strength and the hardening exponent of α' phase were higher than α phase. The α' phase was the "harder" microstructure, while the phase is the "softer" microstructure. Two phases had different mechanical properties, so the microstructures of heat affected zone were inhomogeneous. The inhomogeneity of microstructure resulted in the inhomogeneity of stress and strain. The α' phase had higher stress while the α phase had higher strain, which caused the incongruity of plastic deformation and eventually led to the plastic strain concentration bands along α phase.

Key words: titanium alloy; electron beam welding; heat affected zone; inhomogeneity of microstructure

Study on non-uniform properties of 316L thick plate joint using electron beam welding in port stub of vacuum vessel XIA Xiaowei[1,2], WU Jiefeng[1,3], LIU Zhihong[1], SHEN Xu[1] (1. Institute of Plasma Physics Chinese Academy of Sciences, Hefei 230031, China; 2. University of Science and Technology of China, Hefei 230022, China; 3. Baosheng Group of China, Yangzhou 225800, China). pp 53-58

Abstract: The vacuum vessel is the core component of the China future fusion engineering test reactor. Port stub is a part of vacuum vessel and it is welded by electron beam welding (EBW), which has capability to weld more than 50 mm thickness stainless steel by a single pass. In order to explore non-uniform properties of EB welded joint, beam oscillation was applied during the welding process and the microstructure and microhardness of 50 mm 316L austenitic stainless steel welded joint were analyzed. The results showed that the weld microstructure was composed of austenite and ferrite. From the upper layer near the center line of the weld to the lower layer, the microstructure changed from coarse lathy/skeletal ferrite to more close-packed skeletal ferrite and equiaxed gain. Welded joints with beam oscillation appeared equiaxed gain earlier in the weld thickness direction. Beam oscillation can improve the quality of the welds surface forming. The microhardness of the welds gradually increased from the upper layer to the lower layer.

Key words: electron beam welding; beam oscillation; solidification mode

Study on plasma wire and arc additive manufacturing process of titanium alloys with twin-wire feeding XU Junqiang[1], PENG Yong[1], ZHOU Qi[1], WANG Kehong[1], ZHU Jun[2] (1. Nanjing University of Science and Technology, Nanjing 210094, China; 2. Nanjing Institute of Technology, Nanjing 211167, China). pp 59-64

Abstract: TC4-TA2 titanium alloy component was deposited by plasma wire arc additive manufacturing with twin-wire feeding and its good depositional morphology and excellent mechanical properties were expected. OM, SEM, EDS, XRD, tensile and hardness test were carried out to study the macro and microstructure of the component, as well as mechanical properties. The results showed that there were two kinds of microstructures in the component. They were the colonies of α phase which was distribute in the junction of the deposited layer and the lamellar of α + β phase which was distribute in the center of the deposited layer. The tensile strength of specimens in the vertical and horizontal directions were 998 MPa and 1 037 MPa, respectively. Meanwhile, their elongation at break were 9.2% and 5.7% and the fracture appeared as brittle cleavage fracture. The experimental results

showed that the plasma arc additive manufacturing with twin-wire feeding can realize the preparation of dissimilar titanium alloy components.

Key words: twin-wire feeding; titanium alloy; additive manufacturing; microstructures; tensile strength

Force analysis of droplet in MAG arc surfacing with stainless steel self-shielded cored wire as laser intervened

LIU Xiyang[1,2], YANG Miaosen[2], XU Kai[1], HUO Shubin[1,3], LIU Manyu[1,3] (1. Harbin Welding Institute Limited Company, Harbin 150028, China; 2. Shanghai Dianji University, Shanghai 201306, China; 3. Harbin Well Welding Co., Ltd., Harbin 150028, China). pp 65-70

Abstract: Selecting the stainless steel self-shielded flux cored wire as research subject, the pictures of droplet and electric arc were taken using high-speed photography and force on the droplet was analyzed during MAG surfacing intervened by laser. The results showed that laser intervening changed melted state of end of the wire. The melted states were partial melting, half melting and dead melting. Laser intervening made electromagnetic pinch force and the components of plasma flow force in axial line of wire increase, which were beneficial to droplet transfer. Laser intervening made surface tension force reduce, which was beneficial to tessellate droplet. Laser intervening increased atmosphere dynamics and promoted droplet transfer in appropriate laser parameter. The track of droplet transfer had three patterns which were right shaft transfer, left shaft transfer and along the shaft transfer.

Key words: laser technique; droplet force; self-shielded flux cored wire

Relationship between welding torch shift and penetration shape in asymmetrical root welding

YUE Jianfeng, XU Kai, LIU Wenji, SHEN Zhenqian (Key Laboratory of Modern Electromechanical Equipment Technology, Tianjin University of Technology, Tianjin 300087, China). pp 71-76

Abstract: Due to asymmetric structure on both sides of single side V-groove fillet weld of medium and thick plate, there is a great difference in heat dissipation during root welding, which is easy to produce incomplete fusion. In order to ensure a good penetration shape of root welding, the strategy of adjusting the welding torch angle in real time according to the changes of the front weld pool was proposed. The experimental results showed that the position of the torch shifted regularly relative to the welding pool with the change of welding angle. After median filtering and other processing on the acquired images of the front weld pool, the position coordinates of the welding torch center were obtained, and the internal penetration shape with different angles were studied. The quantitative relationship between the position offsets of the welding torch relative to the weld pool and the internal penetration shape were established. This provided a new method for predicting and controlling the internal penetration shape by using the feature information of the front weld pool.

Key words: asymmetrical root welding; welding torch angle; penetration shape; picture processing

Magnetic field characteristic simulation and magneto-optical imaging detection of weld cracks

MA Nüjie, GAO Xiangdong, DAI Xinxin, ZHANG Nanfeng (School of Electromechanical Engineering, Guangdong University of Technology, Guangzhou 510006, China). pp 77-81

Abstract: Simulation and experiment of magneto-optical imaging non-destructive testing of weld under alternating electromagnetic field were carried out. The weld crack magnetization under the alternating magnetic field of carbon steel (Q235) was studied. Based on a simulation model of alternating magnetic field excitation, the magnetic field density (magnetic flux density) curve distribution of the weld crack with 0.03, 0.05, 0.07 and 0.1 mm gaps were analyzed. Simulation results were verified by the magneto-optical imaging nondestructive testing system. Experimental results show that the weld cracks of different gaps have the same shape of the flux density mode curve, and there is significant difference between N pole and S pole. The amplitude of the flux density curve and the transition area will decrease as the crack gap decreases.

Key words: weld crack; alternating magnetic field; magneto-optical imaging; simulation

Metal transfer characteristics in the GMAW horizontal welding process under local dry environment

GAO Yanfeng, WU Dong, HUANG Linran (Nanchang Hangkong University, Nanchang 330063, China). pp 82-86

Abstract: A local dry underwater weld method was proposed in this paper for the underwater structures horizontal welding. Through designing the structure of waterproof chamber, a flowing up wind field was formed, and this wind field was used to reduce the molten pool dropping during horizontal welding process. A high speed camera was used to record the metal transfer process, then the characteristic of metal transfer of GMAW in the local dry environment was researched. The results show that B type short circuiting transfer more easily happened in the local dry welding environment. In the globular transfer status, due to the mass of droplet was relatively large, the lateral wind had less influence on the droplet. The droplet transfers into molten pool along downwards direction. In the spray transfer status, the lateral wind had less influence to the welding arc but make the droplet transfer into the molten pool slightly along a upward direction. It was beneficial to depress the molten pool dropping during horizontal welding process and improved the welding bead forming quality. The results had certain reference value to

improve the horizontal welding quality.

Key words: local dry welding; horizontal welding; metal transfer; GMAW

Explosive welding experiment and property test of TA2-1060-TA2 cladding plate FANG Zhonghang[1], SHI Changgen[1], FENG Ke[1], GE Yuheng[2], YOU Jun[1] (1. Army Engineering University of PLA, College of Field Engineering, Nanjing 210007, China; 2. High Speed Institute of China Aerodynamics Research & Development Center, Mianyang 621000, China). pp 87-92

Abstract: To solve technical problems of low weldability and easy generation of brittle intermetallic compounds during titanium-aluminum explosive welding, the low-detonation-velocity powdery emulsion explosive, lower limit of charge thickness and upper limit of distance between the flyer and base plates were determined, thereby successfully manufacturing "1 + 14 + 1" TA2-1060-TA2 double-sided metal cladding plate with 100 % welding rate. The results of OM, SEM, EDS tests showed that the interfaces of the cladding plate presented the high quality small wavy bonding; under the action of peak blocking and flyer plate extrusion, the flowing of the base and flyer plates generated the vortex structure where the ingot structure wrapping molten metals were observed; different levels of elemental diffusion took place near the bonding interfaces. The mechanical test results showed that the bending strength, tensile strength and microhardness peak value of the cladding plate were 288 MPa, 165.5 MPa and 227 HV, respectively, which met the requirements of industrial production.

Key words: explosive welding; bonding strength; small wave bonding

Effect of energy director on microstructure and mechanical properties of CF/PEEK joints obtained by ultrasonic welding ZHANG Zenghuan[1], SU Xuan[2], LI Hao[1], TAO Wang[2], WANG Yuhua[1] (1. Shanghai Aircraft Manufacturing Co., Ltd., Shanghai 200436, China; 2. State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin 150001, China). pp 93-98

Abstract: The ultrasonic welding was employed to connect carbon-fiber-reinforced polyetherether-ketone (CF/PEEK) composites. The effects of the shapes of energy directors (ED) on the microstructure and mechanical property of joints were mainly investigated. The results showed that the heat affected zone (HAZ) of the joints was larger when the rectangular or triangular ED were used, which was caused by the high viscoelastic deformation of EDs, rapid heating rate at the interface and high interface temperature. Thermal stress was larger at the interface between carbon fiber and resin in the HAZ, which easily resulted in cracks and other defects. In addition, the flow pattern of ED made void defects easily occurred. Therefore, the joints had poor mechanical property. When flat ED was used, the interface formed a good connection with ultrasonic action time of 0.9 s. The flow pattern of flat ED was better than that of the rectangular and triangular ED, so no void defects occurred in joints whose tensile-shear strength could reach 28 MPa.

Key words: ultrasonic welding; CF/PEEK; energy directors; interface temperature; mechanical property

Characteristic of titanium/steel dissimilar metals joint brazed by bypass-current arc welding MIAO Yugang[1], LIN Zhicheng[1], ZOU Junpan[2], GUO Junliang[2], HAN Duanfeng[2] (1. National Key Laboratory of Science and Technology on Underwater Vehicle, Harbin Engineering University, Harbin 150001, China; 2. College of Shipbuilding Engineering, Harbin Engineering University, Harbin 150001, China). pp 99-103

Abstract: The titanium and steel dissimilar metals were brazed by bypass-current arc welding with S211 copper alloy as filler metal. The macro and microstructure, element distribution, and tensile strength of the brazed joints were analyzed by using optical microscopy, scanning electron microscopy, universal tensile testing machine and other technologies, and the hardness distribution of joint was analyzed by using a micro-hardness tester. A well brazed joint of titanium/steel was obtained, and no obvious welding defects were found. Hardness test found that the hardness in the titanium/copper area was significantly increased, and this was related to the easy formation of Ti-Cu intermetallic compound in the titanium/copper area. The fracture of the titanium/steel brazed joint occured on the copper/titanium side, the fracture mode was ductile-brittle mixed fracture, and the tensile strength reached 291.55 MPa, which was about 88% of the strength of the copper solder.

Key words: Ti/steel dissimilar metal; bypass-current arc brazing; element analysis; tensile strength; hardness

Design modeling and experimental verifications of the laminated busbar for high frequency arc welding inverter HE Yaning, XIONG Gang (Chengdu Xionggu Jiashi Electrical Co., Ltd., Chengdu 611731, China). pp 104-110

Abstract: With the increase of switching frequency, reducing stray inductance becomes one of the key factors in designing high frequency arc welding inverter. In order to meet the demand of DPS-500 of 50 kHz/20 kW, a laminated busbar was designed, which integrated DC link capacitor, soft start circuit, IGBT module and three-phase rectifier module. The numerical calculation of quasi-static electromagnetic field was carried out using ANSYS Q3D. Parasitic parameter matrices were extracted. The multi-port circuit model of the

laminated busbar was built. The impedance vs frequency characteristic and the switching behavior of the laminated busbar was simulated and measured individually based on impedance resonance method and double pulse test method. Stray inductance of the laminated busbar was extracted by two different ways aforementioned. The results showed that the design was valid. The modeling accuracy of the laminated busbar was verified in frequency and temporal-domain by comparing results of simulation and experiment. Finally, the causes of errors was discussed.

Key words: stray inductance; laminated busbar; impedance resonance method; double pulse test; multi-port circuit model

Effect of Mo content on microstructure and properties of $FeAlCuCrNiMo_x$ alloy SU Yunhai, DENG Yue, DOU Lijie, LIANG Xuewei (Shenyang University of Technology, Shenyang 110023, China). pp 111-115,160

Abstract: In order to study the effect of Mo element on the microstructure and other properties of $FeAlCuCrNiMo_x$ high entropy alloys, $FeAlCuCrNiMo_x$ high entropy alloy powder was used as core flux wire and then surfaced on 45 steel plate with gas protection. The hardness, microstructure and corrosion resistance of the weld were analyzed The results showed that $FeCuCrAlNiMo_x$ series high entropy alloy consist of single body centered cubic AlFe phase. When $x = 0.8$, the structure of alloy surfacing layer was minimal, the grain boundary was obviously strengthened, the hardness of the alloy surfacing layer was the highest, the average hardness was 47.8 HRC, and the minimum wear amount was 0.08 g. The corrosion potential reduced after a certain amount of Mo element was added, this meant that the corrosion resistance was worse.

Key words: high entropy alloy; grain size strengthening; microstructure; mechanical property; electrochemical corrosion

Capacitor discharge welding of Ta1 and 0Cr18Ni9 thin plates YANG Quanhu[1], ZHAI Qiuya[1], XU Jingfeng[1], JI Tengfei[2], YE Jianlin[2] (1. Xi′an University of Technology, Xi′an 710048, China; 2. Xi′an United Pressure Vessel Co., Ltd., Xi′an 710201, China). pp 116-121

Abstract: Capacitor discharge spot welding with rapid solidification characteristics of Ta1 and 0Cr18Ni9 thin plates were carried in present paper. The microstructure and properties of the welding joints between by direct CDW and adding $Fe_5Co_{24}Ni_{27}Cu_{25}Cr_{19}$ interlayer alloy were analysed and discussed. The results show that the solute trapping can effectively inhibit brittle intermetallic compounds to realize welding tantalum and steel welding. The welding joints of the direct CDW possess hyperbolical and gyro shaped and the melting zone is located in one side of the 0Cr18Ni9 plate. Nuggets appear about 0.2 mm subcircular porosity in diameter, and Fe_5Ta_3 and Cr_2Ta intermetallic compounds are produced at the interface between tantalum and steel. The welding joint added high entropy interlayer alloy is composed of cap-shaped nugget and fusion area of the transition base metal. Furthermore, the nugget have simple solid solution structure and fine microstructure which consisted of columnar crystals. Under the same condition, shear strength of the joint is 239 MPa by direct spot welding of Ta1 and 0Cr18Ni9 and the higher shear strength of Ta1/0Cr18Ni9 spot welding joint by CDW reached 374 MPa.

Key words: tantalum; capacitor discharge welding; brittle intermetallic compounds; high entropy alloy

Effect of ceramic phase on microstructure and mechanical properties of ferrous matrix composite JIA Hua[1,2], LIU Zhengjun[2], LI Meng[1], ZHANG Kun[2] (1. Dalian Ocean University, Dalian 116300, China; 2. Shenyang University of Technology, Shenyang 110870, China). pp 122-127

Abstract: In order to improve the wear resistance of the material surface, the Fe-Cr-C-B-N-Ti - based iron matrix composite was prepared on the Q235 matrix metal surface by using the bright arc surfacing technology. Metallographic microscope, scanning electron microscope, X ray diffractometer, Rockwell hardness tester and abrasive wear tester were used to analyze and test the microstructure and properties of iron-based composites. The results show that the matrix structure of iron-based composites is composed of martensite (M) and a small amount of retained austenite (A), and the hard phase is composed of TiB_2, TiN, TiC, $M_{23}(C, B)_6$, $M_3(C, B)$ and M_2B. With the increase of titanium addition, the hardness phase particles (TiB_2, TiN and TiC) and eutectic hard phase ($M_{23}(C, B)_6$, $M_3(C, B)$ and M_2B) increase, and the matrix structure decreases and refine. When the amount of titanium is 4%, the wear resistance of the iron matrix composite is the best, at this time the hardness is 66HRC and the wear amount is 0.042 9 g.

Key words: in situ synthesis; open arc surfacing; ceramic particles; iron matrix composites; microstructure and properties

Microstructure and strength of the C_f/SiC composite joint brazed with Co-Nb-Pd-Ni-V filler alloy LI Wenwen, XIONG Huaping, WU Xin, CHEN Bo (Welding and Plastic Forming Division, Beijing Institute of Aeronautical Materials, Beijing 100095, China). pp 128-132

Abstract: The C_f/SiC composite joint was brazed with newly-designed Co-Nb-Pd-Ni-V filler alloy at the brazing temperature from 1 200 °C to 1 320 °C, and the brazing time was fixed at 10 min. The results showed that elements V and Nb in filler alloy played active roles in the interfacial reactions during the brazing procedure, and two interfacial reaction layers VC and NbC were formed at the C_f/SiC surface. Under the brazing condition of 1 280 °C/–10 min, the joint micr-

ostructure can be characterized as (VC/NbC) double layers/ (Co, Ni)$_2$Si + CoSi + NbC + Pd$_2$Si/ (NbC/VC) double layers. The optimum joint strength can be achieved brazed at 1 280 °C for 10 min, and the room-temperature bend strength was 61.0 MPa. Furthermore, the joint strength tested at 900 and 1 000 °C was even elevated to 83.2 and 87.7 MPa, respectively. The good high-temperature joint strength can be attributed to the formation of high- melting- point compounds, such as NbC and Pd$_2$Si.

Key words: C$_f$/SiC composite; brazing; microstructure; joint strength; interfacial reaction

Analysis of growth behavior of intermetallic compound in diffusion bonding of Ti alloy/Cu/stainless steel LIU Shuying[1,2], ZHANG Dongdong[3], LIU Yazhou[1], SUN Yanyan[1] (1. Henan University of Science and Technology, Luoyang 471023, China; 2. Collaborative Innovation Center of Nonferrous Metals, Luoyang 471023, China; 3. Dongfeng Precision Casting, Shiyan 442000, China). pp 133-138

Abstract: The mechanical properties, the generation types, the formation order and the growth thickness of the Ti-6Al-4V/Cu/304 vacuum diffusion welded joint were investigated and studied by means of tensile, SEM scanning, energy spectrum analysis, XRD test and thermo kinetic analysis. The results show that under the bonding pressure of 5 MPa, the tensile strength of the joint increases first and then decreases with the increase of the bonding temperature and time, and the maximum joint is 163 MPa at the bonding temperature of 1 223 K and the time of 3.6 ks, and the excessive temperature and time are unfavorable to the joint performance. With copper foil as the intermediate layer, intermetallic compounds are not formed at the Cu/304 interface. However, a multilevel transitional tissue consisting of solid solution, intermetallic compound Ti$_x$Cu$_y$, Ti$_x$Cu$_y$, ect. is formed between the titanium alloy /Cu interface. The evolution of the structure from titanium to stainless steel side is as follows Ti$_2$Cu, TiCu, TiCu$_2$, TiCu$_3$, TiCu$_4$, Ti$_2$Fe, FeTi, and TiFe$_2$ intermetallic compounds. The order of the generation of the reactant is the lowest priority of the value of theΔG; The effect of Ti$_x$Cu$_y$ on the joints strength of the intermetallic compound is slightly stronger than that of Ti$_x$Cu$_y$ compound. The fracture is caused by the fracture of the Ti$_2$Cu intermetallic compound in the zone II of the titanium alloy side, which extends into the diffusion layer of intermetallic compounds at the boundary of the zone II –III and is brittle fracture. Therefore, improving the interface structure from the titanium alloy/Cu side is the main way to improve the joints strength. According to the empirical formula, the layer thickness of the intermetallic compound can be controlled by adjusting the temperature and time.

Key words: diffusion bonding; interlayer; intermetallic compounds; interface structure; fracture mechanism

Influence of the filler metals′ forms on semi-solid pressure reaction brazing joints LI Juan[1,2], QIN Qingdong[1,2], LONG Qiong[1,2], ZHANG Yingzhe[1,2] (1. 2011 Special Function Materials Collaborative Innovation Center of Guizhou Province, Guiyang, 550003, China; 2. Key Laboratory of Light Metal Materials Processing Technology of Guizhou Province, Guiyang 550003, China). pp 139-144

Abstract: 70% SiC$_p$/Al composites were semi-solid pressure reaction brazed with the Al-Si-Mg-Cu-Ti filler metal in different forms, the connotation of the welding method was expounded, and the microstructures and properties of the joints were analyzed. The results indicated that the joints mainly contain Al matrix, dark gray ringed and massive Ti$_7$Al$_5$Si$_{12}$ compound, and massive Ti phase when they were filled with pulverous filler metal; the joints mainly contained Al matrix and short clubbed Ti$_7$Al$_5$Si$_{12}$ compound when they were filled with schistose filler metal. The bonding of interface was the main factor affecting the performance of the joint. The filler metal and the base material were fully combined during brazing when they were filled with powder filler metal, which provided many atomic diffusion channel at the interface of the joint, so that they were well combined without clear dividing line, the shear strength of the joint reached 92.1 MPa, and the fracture was ductile and brittle mixed fracture; There was clear dividing line at the interface when the filler metal was schistose, so that the shear strength of the joint was low, 43.9 MPa, and the fracture was brittle fracture.

Key words: filler metal form; semi-solid pressure reaction brazing; interface; properties

Study of technology and structure property on friction plug welding of dissimilar aluminum alloy SUN Zhuanping[1,2], YANG Xinqi[1], LIU Kaixuan[1], DU Bo[1] (1. Tianjin University, Tianjin 300072, China; 2. Tianjin Changzheng Rocket Manufacturing Co., Ltd., Tianjin 300451, China). pp 145-150

Abstract: Based on the friction push plug welding method, the investigations of friction plug welding experiments for AA2024-T3 and 7075-T6 friction stir welds with 8 mm thickness by using the AA2219-T6 plugs were performed, the varying features of microstructures, micro-hardness profiles, mechanical properties and fracture modes of various welding pressure have been analyzed in detail. The results showed that tight joints were obtained between plug and base metal or FSW welds. The transition zone from plug to base metal or FSW welds consisted of equiaxed grains. Grain growth occurred in the thermo-mechanically affected zone and heat affected zone. Micro-hardness of plug zone was 85 ~ 95 HV, which is the weakest areas of whole FPW joints. The tensile strength and

elongation of AA2024 FPW joints can reach above 70% and 65% of the base metal respectively. The tensile strength and elongation of AA7075 FPW joints can reach above 62% and 48% of the base metal respectively. The fracture modes of FPW joints were ductile.

Key words: aluminum alloy; friction push plug welding; microstructures; micro-hardness profiles; mechanical properties

Study on welding process and mechanical properties of resistance spot brazed pure aluminum 1060 to galvanized steel ZHANG Changqing[1], JIN Xin[2], WANG Weijie[2], QIN Zhuo[2], RONG Chen[2] (1. State Key Laboratory of Gansu Advanced Non-ferrous Metal Materials, Lanzhou University of Technology, Lanzhou 730050, China; 2. College of Materials Science and Engineering, Lanzhou University of Technology, Lanzhou 730050, China). pp 151-155

Abstract: Resistance spot brazing of pure aluminum 1060 to SGCC hot-dip galvanized steel was investigated. The microstructure of the intermetallic compound (IMC) in the interfacial layer was analyzed, and the mechanical properties of the joint was tested. The results showed that the aluminum-silicon brazing filler metal had a well wettability, and the intermetallic compound with double-layer structure and uneven thickness less than 10 μm generated at the interface of the welded joint. When the welding current was 7.8 kA, the maximum tensile shear load of the joint was 4.72 kN, which was significantly higher than that of the resistance spot welding joint under the same process parameters. The fracture of the joint mostly occured on the side of aluminum plate, and it was mainly in the heat affected zone (HAZ) rather than the welding spot, indicating that the resistance point brazing joint was of good quality. However, the local incomplete brazing was found in the weld interface at the aluminum side, where the tensile stress was generated, and the weld interface tended to crack under the stress of the intermetallic compound.

Key words: pure aluminum; galvanized steel; resistance spot brazing; microstructure; mechanical properties

Structure and mechanical property of TC17 linear friction welding joint JI Yajuan, ZHANG Tiancang, ZHANG Lianfeng, GUO Delun (AVIC Manufacturing Technology Institute, Aeronautical Key Laboratory for Welding and Joining Technologies, Beijing 100024, China). pp 156-160

Abstract: TC17 titanium alloy which usually used on the fan and compressor disk were selected. Microstructure and mechanical property of joint were investigated. Microstructure character of different part of joint was analyzed also. Results showed that the joints included three zones, base metal (BM), thermal mechanical affected zone (TMAZ) and weld zone(WZ). The microstructure of joint middle part was equiaxial grains, but the bottom part was the elongated grains. Dynamic recrystallation happened at the weld zone. Tensile test result showed that joint tensile strength equal to the TC17 base metal. The average hardness value of the HAZ was 486 HV which was higher than that in the BM and WZ.

Key words: titanium alloy; linear friction welding; microstructure; tensile strength; hardness