MAIN TOPICS, ABSTRACTS & KEY WORDS

Analysis of arc shape and weld forming in triple-wire indirect arc welding LIU Liming, YU Shibao, HU Chenghui (Liaoning provincial key laboratory of material welding and joining technology, Dalian University of Technology, Dalian 116024, China). pp 1-6

Abstract: Gas shielded triple-wire indirect arc welding is a novel welding method. In this paper, a stable triple-wire indirect arc system is established. Aiming at solving the problem of sidewall fusion, the influence of arc shape produced by different welding wire distribution on sidewall fusion is analyzed. Aiming at solving the problem of weld seam interlayer fusion, the method of post-tungsten electrode is put forward. The results show that the stable triple-wire indirect arc system can be established by matching the feeding speed with the melting speed of the main wire and the side wire; the arc of wire distribution IV deviates to both sides of the wall along the welding direction and is concentrated form perpendicular to the welding direction, the arc stability is good, the weld sidewall can be fused evenly and the fusion depth is from 1 to 1.2 mm; the weld seam interlayer fusion can be realized by adding the post- tungsten electrode and the tensile strength of the weld can reach 420 MPa.

Key words: triple-wire; indirect arc; arc shape; side-wall fusion; interlayer fusion

Numerical analysis of the behavior of swing TIG wire-filled weld pool based on tracer particles HUANG Jiankang[1], CHEN Huizi[1], YANG Maohong[2], ZHANG Yuming[3], YANG Fuqian[3] (1. State Key Laboratory of Advanced Processing and Recycling of Non-ferrous Metal, Lanzhou University of Technology, Lanzhou 730050, China; 2. Beihang University, Beijing 100191, China; 3. College of Engineering, University of Kentucky, Lexington, KY 40506, USA). pp 7-13

Abstract: In order to make the liquid metal distribution of TIG welding pool more uniform, the influence of welding torch swing on the behavior of weld pool is studied based on ordinary TIG wire-filled welding. The mathematical model of TIG wire-filled welding for welding torch swing is established, and the tracer particles are utilized. The method compares the temperature field, flow field and droplet mass distribution of ordinary TIG wire-filled and swing TIG wire-filled. The analysis shows that the ordinary TIG wire-filled weld pool profile is basically the same as the swing TIG wire-filled weld pool, but the swing TIG welding changes the flow field behavior in the weld pool by swing arc, which affects the distribution of temperature field and makes the temperature distribution in the weld pool more uniform. The tracer particles distribution shows that in TIG wire-filled welding, the swing TIG wire-filled welding can make the droplet metal more evenly distributed in the weld pool.

Key words: swing TIG welding; numerical analysis; temperature field; flow field; tracer particles

Guidance method of initial welding position based on monocular vision WANG Tianqi, LI Jinzhong, LI Liangyu, HE Junjie (Tianjin Key Laboratory of Modern Mechatronics Equipment Technology, Tianjin Polytechnic University, Tianjin 300387, China). pp 14-18

Abstract: A guidance method of initial welding position based on eye-in-hand single eye vision is proposed, this method could be used to overcome the shortcomings of traditional stereo vision guidance method, such as the complex vision system and tedious guide process. At first, the initial welding position could be obtained through several images respectively from different robot configuration, then the linear equation which is including the point of the initial welding position is established, and this equation is transformed into the base coordinate of robot. Furthermore, the intersection point of two lines is calculated, the coordinate of initial welding position is calculated and used to guide the robot welding at last. The test results show that this method could be used to guide the welding robot in finding the initial welding point with the accuracy.

Key words: initial welding position; monocular vision; visual guidance

High temperature oxidation and thermal shock properties of thermal barrier coating by CoCrAlY surface modification HAN Zhiyong, QIU Zhenzhen, SHI Wenxin, DING Kunying (Tianjin Key Laboratory for Civil Aircraft Airworthiness and Maintenance, Civil Aviation University of China, Tianjin 300300, China). pp 19-22,28

Abstract: CoCrAlY coating was prepared by air plasma spray (APS) on Ni-based superalloy surface, nano-scale Al film was deposited on CoCrAlY surface by electron beam evaporation and then modified by high current pulsed electron beam, finally the ceramic coating was deposited on CoCrAlY surface by APS. The high temperature oxidation test and thermal shock test of the thermal barrier coating in air atmosphere were carried out. The results show that the thermally grown oxide (TGO) formed at the interface of modified CoCrAlY coating and top coating had high continuity and compactness after high temperature oxidation at 1 050 °C,

effectively hinder the further development of oxidation and avoid the formation of corner oxide, and then, the high temperature resistance properties of the thermal barrier coating were improved. The thermal shock test under 1 050 °C high temperature holding and water quenching at 10 °C were conducted, the rate of abscission of thermal barrier coating is only about 2%.

Key words: high current pulsed electron beam; microstucture; high temperature oxidation; thermal shock

Growth kinetics of intermetallic compounds formation between liquid Sn-9Zn-0.1S solders and Cu substrates interface HUANG Huizhen, ZHAO Yanan, PENG Ruyi, DUAN Yuande (Nanchang University, Nanchang 330031, China). pp 23-28

Abstract: The microstructure and growth kinetics of intermetallic compounds formed during the soldering reactions between Sn-9Zn-0.1S solders and Cu substrates at various temperatures ranging from 230 to 260 °C were investigated using scanning electron microscope and optical microscope. The results indicate that a thick planar layer of γ-Cu_5Zn_8 next to Cu substrate and a thin particulate layer of CuZn adjacent to solder can be formed at the Sn-9Zn-0.1S/Cu interface, and the constituent of the interfacial intermetallics do not change with the increase of soldering temperature and the prolonged reaction time, while the thickness of γ-Cu_5Zn_8 layer increases with the soldering temperature and reaction time. The relationship between the thickness of γ-Cu_5Zn_8 layer and the square root of reaction time fits linear, which shows that the growth of the intermetallic layer is diffusion-controlled. Kinetics analysis indicated that the activation energy of the intermetallic growth was 22.09 kJ/mol.

Key words: lead free solder; Sn-Zn; intermetallic compound; soldering temperature; activation energy

Effect of process paths on residual stress of multi-layer and multi-pass laser cladding FU Wei[1,2], FANG Hongyuan[1], BAI Xinbo[2], CHEN Guoxi[2] (1. State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin 150001, China; 2. Shanghai Baosteel Industry Technology Service Co., Ltd., Shanghai 201900, China). pp 29-33

Abstract: Residual stresses of multi-layer laser cladding Co-based coating on Q345 steel surface are measured by blind hole method, and the influence of laser cladding process paths on residual stress of each laser cladding layer is studied. The test results show that the residual stress along the laser cladding scanning direction is much larger than the stress in the vertical direction of the weld bead, and both are tensile stresses. The residual stress of the laser cladding coating increases obviously with the increase of the thickness of the single cladding layer. The residual stress increases by nearly 40% since the thickness of single cladding layer increases from 0.6 mm to 1 mm. Compared with the residual stress in the case where the two cladding layers are in the same scanning direction, the residual stress of coating decreases obviously when the overlaying sequence of two layers of cladding layer is perpendicularly crossed. And the lowest residual stress can be obtained when the surface of the test plate is cladded in zones and the multi-layer cladding layer in each zone are vertically cross-surfacing. A certain pre-deformation of the test plate before cladding has little effect on the final residual stress of the coating, but significantly reduces the residual stress on the back of the test plate.

Key words: residual stress; cladding paths; laser cladding; multi-layer and multi-pass; blind hole method

Defect classification for ultrasonic inspection in weld seam based on LBP-KPCA feature extraction HU Hongwei, ZHANG Jie, PENG Gang, YI Kefu, WANG Lei (Changsha University of Science and Technology, Changsha 410114, China). pp 34-39

Abstract: Weld defects affect the structural safety and the defect classification is important for structural safety evaluation. This paper proposes a method which combines one-dimensional local binary pattern (1-D LBP) algorithm and kernel principal component analysis (KPCA) to extract the characteristics of weld defect echo signal. The 1-D LBP algorithm is used to extract the LBP features of the defect echo signal, and the principal component analysis of the LBP features set is carried out by KPCA. The top N principal components with the contribution rate of more than 90% are selected as the feature vectors for defect classification. The automatic classification of defect types is realized by support vector machine (SVM) based on radial basis function. The experiments of defect features extraction and classification were carried out with the weld defects of slag, porosity and non-penetration. The results show that the accuracy of defect classification is 96.7% when the LBP-KPCA features are used, which is superior to the conventional features. The proposed method provides an important reference for defect classification and nondestructive evaluation of weld defects.

Key words: ultrasonic nondestructive testing; one-dimensional local binary pattern; kernel principal component analysis; support vector machine

Microstructure and properties of GH4169 nickel-based superalloy and FGH96 nickel-based powder metallurgy superalloy inertial friction welding joint ZHANG Chunbo[1], ZHOU Jun[1], ZHANG Lu[2], ZHANG Guodong[2], ZHANG Yongqiang[2] (1. Harbin Welding Institute Limited Company, Harbin 150028, China; 2. AECC Commercial Aircraft Engine Co., Ltd., Shanghai 200241, China). pp 40-45

Abstract: Under the welding parameters that spindle

speed was 650 r/min, moment of inertia was 340 kg·m^2 and welding pressure was 450 MPa, GH4169 and FGH96 was welded by inertial friction welding. Under the action of welding pressure and welding heat cycle, the microstructure of different parts of the welded joint changed, the grains appeared to be refined and deformed to different extents, and the matrix strengthening phase dissolved and deformed to different degrees of dissolution and deformation. Affected by the heat-force coupling effect of the welding, the microhardness of the welded joint was characterized by a " mountain peak" distribution. Mechanical properties of welded joints were tested and analyzed: the average tensile strength of welded joints was 1 366 MPa, and the average tensile strength of high temperature was 1 176.7 MPa. The average long-lasting life was 215 hours at 650 °C and 641 MPa. The welded joint had good comprehensive mechanical properties.

Key words: inertial friction welding; GH4169; FGH96; aircraft engine; aero-engine hot component

Influence of normalizing on microstructure and mechanical properties of Cu/Al explosive welded plate ZHOU Guoan[1], MA Honghao[1,2], SHEN Zhaowu[1], YANG Ming[1], CHEN Peiyuan[3] (1. CAS Key Laboratory of Mechanical Behavior and Design of Materials, University of Science and Technology of China, Hefei 230027, China; 2. State Key Laboratory of Fire Science, University of Science and Technology of China, Heifei 230027, China; 3. Anhui University of Science and Technology, Huainan 232001, China). pp 46-51

Abstract: The copper-T2/aluminum-1060 composite plate is fabricated by explosive welding, using the flying plate of copper-T2 and the base plate of aluminum-1060. After normalizing at 300 °C in intervals, i.e., 12, 24, 36, 48 h for different time, the microstructure, diffusion layers and different mechanical properties of samples were observed and tested. Our results show that the copper-T2/aluminum-1060 alloy composite can be well jointed via explosive welding method, and a typical metal/metal wavy interface, having a period of 200 μm at a relative constant amplitude of about 35 μm, is revealed. In addition, normalizing treatment has a remark contribution to the increase of diffusion layer's thickness. The longer heat treatment time is, the thicker diffusion layers are. With respect to the influence of normalizing on samples' mechanical properties, we find that after a 48-hour heat treatment, the micro-hardness, tensile strength and elongation change from 215 HV, 255.7 MPa, 3.64% to 170 HV, 228.8 MPa, 22.4%, respectively.

Key words: normalizing treatment; explosive welding; Cu/Al composite; microstructure; mechanical properties

Microstructure and mechanical properties of friction stir welded joints of reduced activation ferritic-martensitic steel ZHANG Chao[1,2], CUI Lei[1], LIU Yongchang[1], WANG Dongpo[1], ZHOU Mengbing[2] (1. Tianjin Key Laboratory of Advanced Joining Technology, Tianjin University, Tianjin 300354, China; 2. Nuclear Power Institute of China, Chengdu 610200, China). pp 52-57

Abstract: Microstructure and mechanical properties of friction stir welded joints of 9%Cr reduced activation ferritic-martensitic (RAFM) steel were studied in the present paper. The results indicate that there exists significant microstructural difference at different zones in friction stir welded joints. In stir zone (SZ), dynamic recrystallization of austenite leads to grain refinement, martensitic transformation, dissolution of $M_{23}C_6$ phase and precipitation of M_3C phase. Although microstructure in thermal mechanically affect zone (TMAZ) is similar to SZ, the grain size in TMAZ obviously larger than that in base materials (BM). Both heat affect zone (HAZ) and BM perform tempered microstructural characteristic. The hardness of SZ in joint increases significantly and the distribution is uniform. There is a great variation for hardness in TMAZ. The HAZ is softened and its hardness value is the lowest in the joint. With the increase of the testing temperature, the yield strength decreases monotonically and the ultimate tensile strength first increases and then decreases, while the total elongation decreases first and then increases.

Key words: reduced activation ferritic/martensitic steel; friction stir welding; microstructure; mechanical properties.

Growth mechanism of intermetallic compounds at the solid-state joining interface of aluminum/steel SHEN Zhongbao[1], QIU Ranfeng[1,2], SHI Hongxin[1,2], MA Hengbo[1] (1. Henan University of Science and Technology, Luoyang 471023, China; 2. Collaborative Innovation Center of Nonferrous Metals, Luoyang 471003, China). pp 58-63

Abstract: The explosive welded Al/Q235 joint was annealed under various heating time and temperature keeping the joint stay at solid state condition. The interfacial reaction layer feature was analyzed and the effects of heating temperature and time on the thickness of reaction layer were investigated, the growth of intermetallic compound at the joining interface was studied. The interfacial reaction layer consisting of Fe_2Al_5 adjacent to steel and Fe_4Al_{13} adjacent to aluminum formed in the joining interface. The thickness of intermetallic compound increased with the longer of heating time. The results show that the growth of intermetallic compound satisfies the parabolic rule and that the growth active energy is 33.26 kJ/mol.

Key words: pure aluminum; mild steel; growth mechanism

Analysis of stress strain and shape size optimization of 3D micro-scale CSP solder joints in random vibration HAN Lishuai[1], HUANG Chunyue[1], LIANG Ying[2], KUANG Bing[1], HUANG Genxin[1] (1. Guilin University of Electronic Technology, Guilin 541004, China; 2. Chengdu Aeronautic Vocational and Technical College, Chengdu 610021, China). pp 64-70

Abstract: Three-dimensional finite analysis models of micro-scale chip-scale package were set up in ANSYS. Micro-scale chip-scale package (CSP) solder joints were analyzed in the random vibration of loads, then stress and strain distribution of micro-scale CSP were obtained. And the effects of different solder materials, pad diameter, and solder joint volume to stress and strain of micro-scale CSP solder joints were analyzed. The size of the solder joint, solder joint height, the diameter of pad size as design parameters, the value of stress of the micro-scale CSP solder joints as the target value are applied to design and calculation of 17 sets of experiments using computational simulation. The stresses and shape parameters of micro-scale CSP solder joints are fitted by the response surface method and genetic algorithm for fitting function optimization. The results show: the CSP solder joint parameters with the minimum value of stress in the random vibration is, the maximum size of 0.093 mm solder joint, the height of solder joint is 0.077 mm, the radius of the pad is 0.068 mm. Finally, the optimal combination is verified by simulation experiments: the result of optimal combination is better than 17 sets of experimental results, and the optimization of the micro-scale CSP solder joint structure in the random vibration is realized.

Key words: 3D package; chip scale package; micro-scale solder joints; response surface; genetic algorithm

Electric current characteristic and mechanical properties of Si-glass-Al anodic bonding process XUE Yongzhi[1], HU Lifang[1,2], WANG Hao[1], LI Rong[2], WANG Wenxian[2] (1. Shanxi Key Laboratory of Advanced Magnesium-based Materials, Taiyuan University of Technology, Taiyuan 030024, China; 2. College of Materials Science and Engineering, Taiyuan University of Technology, Taiyuan 030024, China). pp 71-76,86

Abstract: In this paper, a novel current-time model of two-step triple-stack anodic bonding was proposed, and Si-glass-Al was successfully bonded together. The results indicate that the current variation of two bonding process is similar, the currents increase rapidly to the maximum value and then decreases exponentially. The peak current of the second step bonding is always larger than the first step, which indicates resistance produced by incomplete contact between bonding materials has a significant effect on peak current. SEM was conducted to investigate the interfacial structure of the Si-glass-Al samples. At 450 °C/800 V, the thickness of Na+ depletion layer at the glass-Al and glass-Si interfaces is 546 and 820 nm, respectively. The tensile strength of the sample increases with the increase of voltage. Whether Si or Al was bonded first, fracture always occurs near the second step bonding interface or the glass substrate.

Key words: package; anodic bonding; Si-glass-Al; current-time model

Research on fabrication and microstructure between carbon steel double wire and single wire plasma arc additive manufacturing ZHAN Bin, FENG Yuehai, HE Jie, LIU Siyu (Nanjing University of Science and Technology, Nanjing 210094, China). pp 77-81

Abstract: Aiming at the low efficiency and high quality of deposited carbon steel component by using conditional single-wire feed and plasma arc additive manufacturing process, a novel process named double-wire feed and plasma arc additive manufacturing process is proposed. Low carbon steel components were successfully manufactured by this process, then the characterization of deposition size, microstructure and mechanical properties of all samples deposited by two processes were compared. The results show that, under the same process conditions, compared with the single-wire feed and plasma arc additive manufacturing process, the deposition rate of the double-wire feed and plasma arc additive manufacturing process improved by 0.97 times. The average grain size of the samples deposited by double-wire feed and plasma arc additive manufacturing process is fined from 18.75 μm to 13.75 μm on an average. The ultimate tensile strength in vertical direction of the deposited samples is increased by 62.64 MPa, and that in horizontal direction is increased by 67.52 MPa. Moreover, the mean Micro Vickers Hardness of the effective deposited layer raised from 158.95 HV to 175.34 HV.

Key words: double-wire feed; plasma arc; low carbon steel; additive manufacturing

Microstructure formation of the weld by high nickel ductile iron homogeneous welding electrode XU Jinfeng, ZHANG Wenli (Xi′an University of Technology, Xi′an 710048, China). pp 82-86

Abstract: Aimed at the welding difficulties of cast iron that the weld is easy to form the ledeburite and quenched microstructures as well as weld crack during welding. The welding experiment was conducted by using high nickel ductile iron homogeneous welding electrode. The effects of welding technologies on joint microstructure and properties of the homogeneous weld produced by the welding electrode had been researched in detail. The results indicate that the

microstructure of the high nickel ductile iron homogeneous weld is composed of fine columnar austenite dendrite, spheroidal graphite and a little intergranular carbide. With the increase of welding current , the morphology of columnar dentrite in the weld tends to be coarsening, the graphite nodularity increases, and the number of intergranular carbides increases. When the welding current is constant, with the increase of preheat temperature, the graphite morphology becomes worse, the amount of carbides precipitated increases, so the tensile strength of the joint decreases and the hardness increases. By using the high nickel ductile iron homogeneous welding electrod, along with the large welding current technology at room temperature, the microstructure and mechanical properties of the weld could be controlled effectively and the high quantity homogeneous weld with excellent machining property can be obtained.

Key words: high nickel ductile iron homogeneous welding electrode; homogeneous welding; welding current; preheat temperature

Investigation on friction stir welding process of ferritic stainless steel and mechanism of defect formation

TANG Wenshen, YANG Xinqi, LI Shengli, LI Huijun (Tianjin University, Tianjin 300354, China). pp 87-93,111

Abstract: Friction stir welding was performed on joining T4003 ferritic stainless steel by using a tungsten rhenium (W-Re) alloy tool. The weld formation, microstructural characteristics, and mechanism of defect formation in the weld were examined. It was showed that the axial pressure of tool monotonously increased with the increasing of welding speed under different rotational speeds. Defect-free welds were successfully produced at rotational speeds of 150 and 250 r/min. However, wormhole defects were produced near the advancing side of the stir zone in the welded joints at the rotational speed of 350 r/min. This phenomenon tended to decrease with the increasing of the tool axial pressure and welding speed. A phase transformation and significantly harden occurred in the stir zone of the welded joint, and the microstructure in this region changed to very fine grains consisting of duplex structure of equiaxed ferrite and low carbon martensite. An uneven hardness distribution in the weld was observed. Moreover, a balanced-flow model of weld metal was proposed, and employed to analyze the mechanism of defect formation in the weld.

Key words: ferritic stainless steel; friction stir welding; microstructure; welding defects; formation mechanism

Analysis on welding processing properties of plasma-TIG coupling arc hybrid welding

WANG Bo[1,2], SANG Jian[1], ZHANG Hongtao[1,2], TENG Yao[3], WANG Qichen[3] (1. Harbin Institute of Technology at Weihai, Weihai 264209, China; 2. Shandong Institute of Shipbuilding Technology, Weihai 264209, China; 3. Yantai CIMC Raffles Offshore Co., Ltd., Yantai 264000, China). pp 94-99

Abstract: The plasma -TIG coupling arc hybrid welding process was proposed to improve the welding efficiency of mild steel. The stable coupling arc of plasma and TIG is realized under the action of electromagnetic force by designing the intensive torch, and the welding heat source characteristics of the coupling arc have been optimized. The arc shape, weld formation and, mechanical properties are analyzed. The results showed the coupling arc still have good deep penetration welding characteristics. Compared with plasma and TIG welding method, the coupled arc has more reasonable depth-width radio, and has the effect of shock stirring on droplet and welding pool, which promotes grain refinement and reduces the tendency of joint crystallization in fusion zone. One-side welding both sides formation could be achieved by use of the butt welding test with 5 mm thick Q235B steel plates, the weld was smooth without defects and the tensile strength was better than the base metal.

Key words: plasma –TIG; coupling arc; hybrid welding; no spatter

Microstructure based on selective laser melting and mechanical properties prediction through artificial neural net

YANG Tianyu[1], ZHANG Penglin[1], YIN Yan[1], LIU Wenzhao[1], ZHANG Ruihua[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. Hardware Knife Cut Industrial Technology Research Institute Yangjiang, Yangjiang 529533, China). pp 100-106

Abstract: Selective laser melting has been applied to fabricate 18Ni300. SEM is used to observe dendritic growth orientation and solidification structure. Artificial neural network is applied to rank the respective importance of laser power, scanning speed and scanning space for mechanical properties, while BP neural net with improved weight by genetic algorithm is applied to the prediction of tensile property. Results show that the main structure of the specimen is columnar dendritic crystals with significant epitaxial growth. The orientation of the growth is determined by the solidification condition at the bottom of the molten pool. CET can easily take place on the top of the melting pool. Meanwhile, there is transition zone in other places contributed by the thermo capillary convection. The result of the importance prediction by artificial neural network shows: They order from high to low is laser power, scanning speed and scanning space. Since the prediction results agree with the actual ones, BP neural net can effectively predict actual results. The determination coefficient $R^2 = 0.73$.

Key words: selective laser melting; 18Ni300; microstructure; artificial network

A key-hole filling technology for friction stir welding based on the theory of pressure welding DENG Lipeng[1,2], KE Liming[2], LIU Jinhe[1] (1. Northwestern Polytechnical University, Xi′an, 710072, China; 2. Nanchang Hangkong University, Nanchang 330063, China). pp 107-111

Abstract: The key-hole in the end of friction stir welding (FSW) joint is one of the application and promotion barriers. For overcoming the barrier, a new technology based on the theory of pressure welding for filling key-hole is invented and researched on the three phase secondary rectifier resistance spot welder in the paper. The key-hole in the friction stir spot welding lap joint of 3.0 mm + 3.0 mm thickness 2024-T4 aluminum alloy is filled. In the paper, micro hardness and micro structure about the filled joint are all studied, and the bonding mechanism is analyzed according the welding theory and crystallography. The results prove that the filled joint including the fusion welding zone , pressure welding zone, plastic deformation zone and melted stopper zone. The diffusion welding is the major metallurgy bond and fusion welding is the minor form of bond between the stopper and key-hole. The micro hardness and structure around the filled key-hole are not changed by the high-efficiency filling technology.

Key words: friction stir welding; pressure welding; key-hole; aluminum alloy

Microstructure and mechanical properties of electron beam welded joints in different state of TC4 YAN Taiqi[1,2], CHENG Xu[1,2], LI An[1,2], TIAN Xiangjun[1,2], LIU Dong[1,2] (1. National Engineering Laboratory of Additive Manufacturing for Large Metallic Components and Engineering, Beihang University, Beijing 100191, China; 2. School of Materials Science and Engineering, Beihang University, Beijing 100191, China). pp 112-117

Abstract: This paper studied the influence of a specification of electron beam welding on the structure of ‘rolled+ laser deposited’ TC4 welded joints, and analyzed the mechanical properties of the joints. Results show that on the rolled side, the microstructure of heat affected zone changes obviously, the shorter the distance away from welding center, the more amount of transformed β generates, and the columnar grain gradually transforms into equiaxed grain, with the appearance of clustered martensite α'. However, on the laser-deposited side, few changes are observed in the heat affected zone, β grain stays columnar, in which martensite α' generates, no equiaxed grain generates. The change trend of microhardness on both sides is similar, the closer the distance from the center, the higher the microhardness gets, the maximum hardness is around 400 HV found in the fusion zone. The mechanical properties of welded joints are similar to forged TC4, all the fractures locate in the laser-deposited base metal region.

Key words: TC4 titanium alloy; laser additive manufacturing; electron beam welding; microstructure; mechanical properties

Microstructure and mechanical properties of friction plug welding for friction stir welded aluminum alloy LIU Kaixuan[1], SUN Zhuanping[1,2], YANG Xinqi[1], DU Bo[1], SONG Jianling[2] (1. Tianjin Key Laboratory of Advanced Joining Technology, School of Materials Science and Engineering, Tianjin University,, Tianjin 300072, China ; 2. Tianjin Long March Rocket Manufacture Co., Ltd., Tianjin 300462, China). pp 118-125

Abstract: Friction plug welding for AA2219-T87 friction stir welds were performed, the macro/micro structures, hardness distributions and tensile strength were observed and tested, and the tensile fracture was observed by scanning electron microscope. The main findings are as follows: With 7500rpm rotational speed and axial force 40 ~ 55 kN can obtain defect-free plug welded joint; The ultimate tensile strength (UTS) and elongation of FPW joint in perpendicular direction can reach 336 MPa and 8%, respectively, approximately 73. 9% and 66. 7% being equivalent to that of base metal; The weakest bonding regions are always produced at the bottom bonding interface between the BM and PM and how to control the connection quality of the bottom bonding interface should be the key factor affecting the tensile properties of the friction plug welding joint.

Key words: friction plug welding; welding process; microstructure; mechanical property

Microstructure and mechanical properties of linear friction welding joint of TC17 titanium alloy fabricated by laser forming JIN Junlong[1,2], GUO Delun[1,2], LIU Qi[1], ZHANG Tiancang[1,2], JI Yajuan[1,2] (1. AVIC Manufacturing Technology Institute, Beijing 100024, China; 2. Aeronautical Key Laboratory for Welding and Joining Technologies, Beijing 100024, China). pp 126-130

Abstract: Under the background of repairing damaged blades of blisks with linear friction welding, aimed at TC17 titanium alloy which is commonly used for aero-engine blades, one of the welding stub is fabricated by laser forming, microstructure analysis, mechanical properties test and fracture analysis of typical welded joints were carried out, the evolution characteristics of the laser deposition zone before and after linear friction welding and its influence on mechanical properties were emphatically analyzed. Results showed that the size of shortening determines the amount of laser forming structures in the joint, obvious recrystallization occurs in the laser forming deposition zone which participated in the welding

process, the original coarse grains were broken and small α phases were precipitated inside the grains. the tensile properties of the three typical joints are equal to that of the base metal, when the structure of deposition zone is removed in linear friction welding process, the high cycle fatigue strength of the joint can reach more than 90% of that of the base metal.

Key words: laser forming; linear friction welding; microstructure; fatigue property; fracture

Effect of vanadium on microstructure and performance of tungsten carbide hardfacing alloys WEI Wei, HUANG Zhiquan, ZHANG Haiyan, YANG Wei (Zhengzhou Research Institute of Mechanical Engineering Co., Ltd., Zhengzhou 450001, China). pp 131-136

Abstract: In this study, the vanadium content from 0% to 3% were introduced into the tungsten carbide electrodes to prepare hardfacing layer. The products were analyzed by SEM, XRD and EDS, and the effects of vanadium content on the variation of microstructure, abrasive wear resistance and dissolution of the tungsten carbide hardfacing layer was investigated. Result shows that the tungsten carbide dissolution depends on vanadium concentration, as the primarily formed vanadium carbide particles around tungsten carbide retrain the dissolution of tungsten carbide; the amount of vanadium concentration determines the intensity of the dissolution of tungsten carbide, the alloy with 2% vanadium effectively retains the dissolution of tungsten carbides in the alloy. While the vanadium carbide particles increase the matrix hardness to avoid tungsten carbide peel off, hence to improve the abrasive wear resistance of the hardfacing layer.

Key words: tungsten carbides; vanadium; hardfacing; abrasive wear resistance

Study on liquid metal flushing effect during electron beam spot welding FANG Yuchao, YANG Ziyou, He Jingshan (State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin 150001, China). pp 137-142

Abstract: The molten pool behavior of electron beam welding was analysed in order to have a further investigation on the mechanism problems. Based on the theoretical analysis of the the molten pool of electron beam spot welding and boundary layer theory, the flushing effect of liquid metal was mathematically modeled. A three-dimensional transient model was employed to simulate the molten pool in electron beam spot welding based on finite volume method, and the influence of liquid metal flushing effect on temperature field and flow field of molten pool were discussed. The simulation results showed that the liquid metal flushing effect played an important role in temperature field of molten pool, stability of keyhole, flow field of molten pool and position of solid liquid interface. The simulated fusion line of the weld bead follows a good agreement with the experimental result, approving the validation of the mathematical model.

Key words: electron beam spot welding; liquid metal flushing effect; molten pool behavior; numerical simulation

Effect of the degree of rivet opening on the rigidity of the interlock in self-piercing riveting joints ZENG Kai, HE Xiaocong, XING Baoying (Kunming University of Science and Technology, Kunming 650500, China). pp 143-147

Abstract: The effect of the degree of rivet opening on the rigidity of the interlock in 5052 a-alloy self-piercing riveting joints was analyzed by using image processing method. Two type joints with different rivet opening were tested in the proper test machine. The CCD with digital microscope was used to capture the images of the interlock deformation in the loading process. The relative slip between the rivet tip and the bottom sheet was calculated by using correlation analysis method, and the amount of the slip was defined as a measure of stiffness of SPR joints. Finite element models of two type joints with different rivet opening were established to simulate the deformation process of the interlock in tensile test. The results show that a critical value of slip-loading exists in the loading process. When the load value is lower than the critical value, the structural integrity of the interlock is kept and no apparent slip in the interlock can be detected. When the load value is greater than the critical value, the slip in the interlock can be observed and it increases with the increasing of the loading, and the rivet is pulled out, which is named pull-out failure model. The open degree of rivets has a large effect on the strength and rigidity of SPR structure, and high rivet degree can increase the stiffness of SPR joints.

Key words: mechanical interlock in SPR joints; degree of rivet opening; rigidity; image processing; finite element modeling

Device and method for real-time monitoring of electron beam welding process based on space charge collection CHEN Xin, PENG Yong, ZHOU Qi, GUO Shun (Nanjing University of Science and Technology, Nanjing 210094, China). pp 148-152

Abstract: In order to realize the on-line monitoring of the electron beam welding process and ensure the quality of weld formation, a space charge signal acquisition and processing system was developed. The system consists of a sensor acquisition module, a signal processing module and a display analysis module. In this study, multiple sets of 6061 aluminum alloy plate butt welding process tests were carried out, and the electric charge of 8 positions directly above the weld pool was collected in real time. The relationship between the characteristics of the charge signal waveform and the

quality of the weld forming was analyzed, and the criterion for the quality of the weld was established. The results show that the signal waveform collected by the system can effectively evaluate the stability of the welding process and determine the forming defects such as welding misalignment, incomplete fusion and burn-through in real time.

Key words: electron beam welding; monitoring; forming quality

Galvanic corrosion behavior of nuclear steam turbine welded joint in chloride environment OUYANG Yuqing, HUANG Yuhui, WENG Shuo, XUAN Fuzhen
(Key Laboratory of Pressure Systems and Safety, Ministry of Education, East China University of Science and Technology, Shanghai 200030, China). pp 153-160

Abstract: To investigate the effect of geometry of welded joint on the galvanic corrosion behavior, the macroscopic electrochemical experiments, scanning vibrating electrode technique (SVET) and immersion tests were used to study the galvanic corrosion behavior of welded joint of 25Cr2Ni2MoV rotor steel in the chloride solution. The results indicate that the corrosion potential of the WM is the lowest and the corrosion current density is the highest. That is to say, the WM is the anodic region which is prior to be corroded while the BM and the HAZ are the cathodic region which are protected. The infinite focus microscope (IFM) and scanning electron microscope (SEM) were used to further observe the morphology of the specimen surfaces. It is found that the effect of galvanic corrosion is more significant with the increase of welded joint size, but when the joint size increases to a certain extent, the galvanic corrosion effect is weakened.

Key words: nuclear turbine; welded joint; galvanic corrosion; geometry effect