MAIN TOPICS, ABSTRACTS & KEY WORDS

Three-dimensional flow characteristics of the T-joint by corner stationary shoulder friction stir welding ZENG Shenbo, CHEN Gaoqiang, ZHANG Gong, SHI Qingyu (Key Laboratory of Advanced Material Processing Technology, Department of Mechanical Engineering, Tsinghua University, Beijing 100084, China). pp 1-5

Abstract: A 0.1mm copper foil was embeded in the transverse direction of T-joint as marker material by corner stationary shoulder friction stir welding. After welding, X-ray 2D transmission and X-ray 3D scanning were carried out on the corner weld of T-joint. 2D and 3D flow fields of the marker material of corner weld were obtained. Friction shear was dominant effect in the thermoplastic material of the advancing side. Material flow was mainly along the direction of welding, and flows through the retreating side to the advancing side. Material of the retreating side was mainly extruded. Due to the T-joint pin threads, the material flowed backward and downward as a whole. At the same time, it was found that there was an "accumulation area" of marker material at the adjacent rear of the stationary shoulder. According to the observed results, the main three-dimensional flow characteristic model of T-joint corner weld was established.

Key words: T-joint; corner stationary shoulder friction stir welding; flow; X-ray 2D/3D

Influence of pulse current waveform on mechanical properties of Tandem double wire MIG welding XUE Jiaxiang[1], LIN Fanglue[1], JIN Li[2], HU Yu[1] (1. South China University of Technology, Guangzhou 510641, China; 2. Guizhou Minzu University, Guiyang 550025, China). pp 6-10

Abstract: As an efficient welding method for stainless steel, double wire pulse MIG welding is one of the hot spots in welding industry. However, how to select and adjust the current waveform parameters of double wire MIG welding is still a difficulty. In order to optimize the welding method of stainless steel and improve the welding efficiency, duplex stainless steel was used as the welding workpiece. The welding quality of duplex stainless steel was studied by comparing the parameters of current waveform through the research on the double wire trapezoidal wave double pulse welding, double wire rectangular wave double pulse welding and double wire single pulse welding. The results showed that under the condition of the same line energy, the double-wire trapezoidal wave double pulse welding had better stability than the double-wire rectangular wave double-pulse welding and the double-wire single-pulse welding, and the welding quality of the former was higher, and it could be seen more fish scales, while significantly increasing the tensile strength, hardness and toughness of stainless steel joints.

Key words: pulsed MIG welding; grain refinement; tensile strength; pulse current waveform modulation

Effect of the SiC content in the Ag-Cu+SiC composite brazing filler on the microstructure and mechanical properties of the Al_2O_3/TC4 brazing joint LI Chun[1], ZHENG Zujin[1], QI Junlei[2], FENG Jicai[1], CAO Jian[1] (1. State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin 150001, China; 2. School of Materials Science and Engineering, Harbin Institute of Technology, Harbin 150001, China). pp 11-16

Abstract: The joining between Al_2O_3 and TC4 titanium alloy was realised using Ag-Cu+SiC composite filler metal. The effects of the mass fraction of SiC and the brazing temperature on microstructure and mechanical properties of the joint were investigated. It was found that the typical microstructure of the joint is Al_2O_3/Ti_3Cu_3O/Ag solid solution + Cu solid solution + TiC + Ti_5Si_3/$TiCu_2$/TiCu/TC4. The thickness of the reaction layer adjacent to the ceramic is increasing with the rising of the temperature and is decreasing with the growing mass fraction of the SiC. For the joint with a small amount of SiC, the reaction products distribute uniformly, while for the joint with a large amount of SiC, the reaction products tends to agglomerate. Reaction products of brazing change from agglomerated distribution to uniform distribution with the increase of brazing temperature. The shear strength of the joint first increases and then decreases with the increase of the brazing temperature and the SiC mass fraction. The highest shear strength of the joint reaches 98 MPa when the mass fraction of the strengthening phase is 3% and the brazing temperature is 870 °C.

Key words: alumina ceramics; titanium alloy; brazing; microstructure; strength of the joint

Effect of pulse laser-arc arrangement on metal transfer and bead formation characteristics of aluminum alloy welding JIA Yazhou, CHEN Shujun, XIAO Jun, BAI Lilai (College of Mechanical Engineering & Applied Electronics Technology, Beijing University of Technology, Beijing 100124, China). pp 17-24

Abstract: 2219 aluminium alloy with 5 mm thickness was used as the experimental material, the metal transfer and bead formation characteristics of aluminum alloy welding under different pulse laser-arc arrangement (i.e. different laser

incident points) were studied, and the mechanism for the increase of weld penetration was analyzed. The results show that when the pulse laser irradiates the base material, it mainly provides heat input to the base metal, and the temperature increase of the base material helps to promote the droplet spread and stabilize the metal transfer process; when the pulse laser illuminates the solid-liquid interface of the droplet, it primarily provides a recoil force to the droplet. A stable "one pulse per droplet" transfer is obtained, which significantly increases metal transfer frequency and the droplet flight speed. The welding penetration is enhanced by the increase of droplet impact force on the molten pool. When the pulsed laser alternately illuminated the molten pool and the droplet, on the one hand, the base material can be heated to facilitate the spreading of the droplet, and on the other hand, the metal transfer frequency and the uniformity of the bead formation can be improved.

Key words: pulse laser-MIG hybrid; aluminum alloy welding; metal transfer; bead formation

Research on plasma-MIG hybrid welding process of TATM700 steel ZHANG Hongtao[1], SANG Jian[1], WANG Qichen[2], TENG Yao[2], ZHANG Wenjie[3] (1. Harbin Institute of Technology at Weihai, Weihai 264209, China; 2. CIMC Marine Engineering Research Institute Co., Ltd.,Yantai 264000, China; 3. Weihai Donghai Shipyard Co., Ltd, Weihai 264209, China). pp 25-30

Abstract: Process research on 12.5 mm thick low alloy high strength TATM700 girder steel for automobile structural parts was studied by plasma-MIG hybrid welding equipment. The weld formation, weld microstructure and mechanical properties under different groove forms were analyzed. Furthermore, it compared with the multi-layer manual TIG method of flux cored wire. The results showed that the groove form has less influence on the plasma-MIG composite welding seam. The sample welded by the composite welding method is well formed and the cross-sectional shape is reasonable. The weld structure consists of a small amount of side slab ferrite and a large number of acicular ferrite. The joint strength and bending performance are better than manual TIG welding, the tensile strength reaches 95% of the base metal, and the hardness is slightly lower than the multi-layer multi-channel hand-welded TIG welding sample.

Key words: plasma – MIG; composite welding; weld microstructure; mechanical properties

Effects of CMT+P process and post heat treatment on microstructure and properties of TC4 component by additive manufacturing GOU Jian[1,2], WANG Zhijiang[1,2], HU Shengsun[1,2], TIAN Yinbao[1,2] (1. Tianjin University, Tianjin 300072, China; 2. Tianjin Key Laboratory of Advanced Joining Technology, Tianjin University, Tianjin 300072, China). pp 31-35,46

Abstract: CMT + P procedure was used in wire and arc additive manufacturing of TC4 titanium alloy. Aiming at inhomogeneity in microstructure and properties by heat accumulation in addictive manufacturing process, two heat treatment processes were used to improve the inhomogeneity and promote the performance of component by addictive manufacturing. The results showed that the as-built wall in a good appearance can be obtained with CMT+P procedure. When the wire feeding speed is 6 m/min and the welding torch speed is 0.3 m/min, the heat input is 313 J/mm, and the microstructure of as-built wall is continuously growing from bottom to top. The grain size for different positions of sample becomes uniform and the resistance to plastic deformation for the sample is enhanced after heat treatment. Tensile testing shows that the component has the highest tensile strength of 1 124 MPa under 600 °C and 4 h condition. The fracture analysis shows that all the fracture modes are ductile fracture.

Key words: microstructure; heat treatment; additive manufacturing; titanium alloy

Use total focusing method to image the near-surface planar defect in welded joint Yu Peng, Gang Tie (State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin 150001, China). pp 36-40

Abstract: Total focusing method (TFM) is used to synthetically focus at every image point in a target region. Half-Skip TFM (HSTFM), as a post-processing imaging algorithm of ultrasonic array data, is developed based on TFM. TFM and HSTFM are to image and characterize near-surface planar defects (vertical to the surface of welded joint) in the welded joint, respectively. The result showed that only the indication of the defect tip without root can be seen in the TFM image; in the image formed using HSTFM, the indication of the whole face of the planar defect can be clear observed. Meanwhile, using the HSTFM image of the defect, the near-surface defect with great reliability is sized.

Key words: non-destructive testing; ultrasonic array; total focusing method; welded joint; defect

Investigation on cold cracking susceptibility of X100 pipeline steel YAN Chunyan[1], YUAN Yuan[1,2], ZHANG Kezhao[1], WU Lichao[1], WANG Baosen[3] (1. Hohai University, Changzhou 213022, China; 2. CRRC Zhuzhou Locomotive Co., Ltd., Zhuzhou 412001, China; 3. Baosteel Central Research Institute, Shanghai 200431, China). pp 41-46

Abstract: The Tekken test using E10018 electrode and finite element (FE) simulation to evaluate the cold cracking susceptibility of X100 pipeline steel has been performed. The impact of preheating condition on the HAZ microstructures, distribution of hardness, and the stress-strain state in the welded joint was analyzed. The experimental results showed

that X100 pipeline steel reveals certain susceptibility to cold cracking without preheating. It was found that preheating temperature below 100 ℃ resulted in a lower cold cracking susceptibility. Preheating temperature of 100 ℃ is most effective with zero cracking ratios due to a relative fine CGHAZ microstructure and low M-A constituent amount, a low hardenability, low level stress and strain level. However, excessive preheating temperature of 150 ℃ and 200 ℃ can lead to higher cold cracking susceptibility due to an increase in CGHAZ grain size, M-A constituent amount, equivalent stress level and strain level in the Tekken specimens. Preheating temperature of 100 ℃ is recommended to reduce cold cracking.

Key words: X100 pipeline steel; cold cracking susceptibility; stress; strain

Thermal-stress analysis of wire-arc additive manufacturing 2Cr13 parts with different interlayer idle time HAN Wentao, LIN Jian, LEI Yongping, GE Jinguo (Beijing University of Technology, Beijing 100124, China). pp 47-52

Abstract: During the wire-arc additive manufacturing, the thermal and stress evolution inside the as-deposited parts has an important influence on the quality of the parts. Temperature and stress characteristics of 2Cr13 thin-wall parts, with interlayer idle time of 30, 120, 210 and 300 s was simulated using the three-dimensional finite element model. The simulation results have a good agreement with the corresponding experimental results. The results indicated that longitudinal residual stress distribution of the buildup with 30 s interlayer idle time are significantly different from those of deposits with other interlayer idle time. When the interlayer idle time is longer than 210 s, the further increase of the interlayer idle time can hardly reduce the stress. Consequently the interlayer idle time of the wire-arc additive manufacture 25-layer thin-walled 2Cr13 parts is suitable between 120 ~ 210 s.

Key words: wire-arc additive manufacturing; interlayer idle time; finite element simulation

Effect of nickel on conductivity and corrosion of copper/stainless steel GTAW joints WANG Rui[1], SHI Yu[1], LI Guang[1], LI Chunkai[1], HOU Guoqing[2] (1. State Key Laboratory of Advanced Processing and Recycling of Nonferrous Metal, Lanzhou University of Technology, Lanzhou 730050, China; 2. Guangxi Liugong Machinery Co. ,Ltd. , Liuzhou 545007, China). pp 53-58

Abstract: According to the requirements of the new type copper/stainless steel electrolytic copper permanent cathode plate welding joint, T2 copper and 316L stainless steel were jointed with GTAW welding method. Three different Ni content welding wires S201, S231 and CuNi-7 were applied as filler materials. The microstructure, composition, electrical conductivity and corrosion resistance of joints were studied by optical microscope, scanning electron microscope, energy spectrometer, metal conductivity meter and electrochemical workstation. The results showed that no obvious defects are occurred in the interface of joint with three different wires. When the content of Ni is low, a small amount of microcracks generate in the steel side weld. The strip, block-like Ni-Cr-Fe phases increase with the increasing of Ni content. There exists an inverse relationship between the conductivity of joint and the amount of Ni-Cr-Fe phase. The corrosion resistance of joint under acidic condition can be greatly improved by the increasing content of Ni in the joint.

Key words: copper/stainless steel dissimilar metal; gas tungsten arc welding; conductivity; corrosion

Analysis of arc physical property in argon-nitrogen TIG welding based on spectral diagnosis XIAO Xiao[1,2], ZHANG Keke[1], LI Fang[2], HUA Xueming[2] (1. Henan University of Science and Technology, Luoyang 471023, China; 2. Shanghai Key Laboratory of Materials Laser Processing and Modification, Shanghai 200240, China). pp 59-62

Abstract: Hybrid shielding gas was often used in arc welding to improve its quality and speed. The research of its physical property is difficult, since the composition in hybrid shielding gas welding is complicated and variable. Arc plasma in argon-nitrogen tungsten inert gas (TIG) welding was chose as the research object, the double charge coupled device (CCD) experimental system was setup to obtain spectrum image of Ar I and N I, Fowler-Milne method was used to calculated the temperature and mole fraction distribution in 50%Ar + 50%N_2, 80%Ar + 20%N_2 and 100%Ar arc plasma. The results showed that the radius shrinkage can reach 50%, and the temperature raise ccan reach 12% in 50%Ar + 50%N_2 arc plasma. It provides the theory basis for the research of weld seam forming essence through the analysis of the physical property of argon-nitrogen arc plasma.

Key words: argon-nitrogen mixed gas tungsten inert gas shield welding; spectral measurement; standard temperature method

Research on forming control for single-pass multi-layer of WAAM ZHANG Jintian, WANG Xinghua, WANG Tao (Luoyang Ship Material Research Institute, Luoyang 471023, China). pp 63-67

Abstract: The wire & arc additive manufacturing (WAAM) of cold metal transfer (CMT) for high-strength marine steel was studied. By analyzing the influence of different proportion of shielding gas on the morphology of single-pass single-layer, the results showed that the wetting capacity of single-pass single-layer increases with the increase

of CO_2 in the shielding gas. And a full-period cosine function prediction model was established, which could accurately predict the section profile of single-pass single-layer under 80% Ar + 20% CO_2 shielding gas. According to the forming characteristics of single-pass multi-layer, a prediction model for single-pass multi-layer uplift distance h was established based on the area relationship and geometric morphology. The relative error of the predicted value of uplift distance h was less than 3.50%. By establishing the uplift distance model, it provided theoretical support for single-pass multi-layer of wire & arc additive manufacturing.

Key words: cold metal transfer; wire & arc additive manufacturing; single-pass single-layer; single-pass multi-layer

Influence of extraction fume by environmental welding torch on low current CO_2 gas shielded arc welding

HUANG Yong[1,2], ZHANG Jiajie[1,2], RAN Xiaolong[1,2], MAO Yu[3] (1. State Key Laboratory of advanced Processing and Recycling of Non-ferrous Metals, Lanzhou University of Technology, Lanzhou 730050, China; 2. Key Laboratory of Non-ferrous Metal Alloys and Processing. Ministry of Education, Lanzhou university of Technology, Lanzhou 730050, China; 3. Jinan North Welding Tools Co., Ltd., Jinan 250000, China). pp 68-72

Abstract: Using environmental welding torch, low current CO_2 gas shielded arc welding at flat position was carried out to analyze the change of arc shape, current and voltage, the droplet transfer and weld formation, weld metal tensile mechanics and X-ray radiographic inspection. Fume extraction effect and its influence on welding process and weld quality were evaluated. The results showed that using environmental welding torch is able to dramatically low down the welding fume diffusion to the environment during the low current CO_2 gas shielding welding. It will not impact the shape of weld or cause welding defects, although the frequency of droplet transfer of short circuit transition is slightly quickened, the stabilities of suspend droplet and arc get a little worse. The yield strength of weld is slightly decreased, while the tensile strength is slightly increases.

Key words: environmental welding torch; carbon dioxide gas shielded welding; short circuit transition; welding process; weld quality

Analysis of welding characteristics of ultra-high power laser-arc hybrid welding

HUANG Ruisheng[1], YANG Yicheng[1, 2], JIANG Bao[1], NIE Xin[1], WANG Ziran[1] (1. Harbin Welding Institute Limited Company, Harbin 150028, China; 2. China Academy of Machinery Science and Technology Group Co., Ltd., Beijing 100044, China). pp 73-77,96

Abstract: Using ultra high-power laser-arc hybrid welding at myriawatt level is an important research direction in the field of laser processing. Characteristic of laser-MAG hybrid welding, laser-TIG hybrid welding with filler wire and laser-MAG hybrid welding with filler wire were systematically analyzed by studying the plum and spatter which were produced in the welding process and investigated by a high speed camera when laser power increases from 5kW to 30 kW. The results showed that both the mean value of plum and spatter area and their fluctuation increased with the laser power increase. The addition of cold wire reduces the weld penetration and makes the stability of laser-MAG hybrid welding process become worse. The stability of the laser-TIG hybrid welding process with filler wire is better than the other two welding method. The scattering and absorbing of laser by the high temperature plume is the essential reason for the weld penetration increase slowly and weld width increase fastly in high power laser-arc hybrid welding.

Key words: ultra-high power laser; plume; spatter; hybrid welding

Research on forming and welding technology of thick wall structure arc added material manufacturing

WANG Tianqi, YANG Zhuang, LI Liangyu, HE Junjie (Advanced Mechatronics Equipment Technology Tianjin Area Laboratory, Tianjin Polytechnic University, Tianjin 300387, China). pp 78-82

Abstract: The welding technology of prefabricated parts with suspension characteristics was studied by combining the augmented material manufacturing with arc welding robot technology. Firstly, the algorithm of prefabricated parts forming dimension prediction is optimized to realize the prediction of forming height and width. Aiming at the phenomenon of downward flow of suspended weld, the influence of inclination angle of welding torch on weld formation was studied, the optimum inclination angle range of welding torch was determined, and the forming method was validated by design and experiment. The forming quality of suspended weld surface is effectively improved. Based on this, an algorithm for predicting inclination angle of welding torch was proposed to realize the prediction of inclination angle of welding torch in suspended weld process. Finally, welding prefabricated parts with suspension characteristics verifies the accuracy of prediction algorithm and forming method. The test results showed that the surface forming quality of prefabricated parts is good and the forming size error is less than 1 mm.

Key words: arc welding robot; additive manufacturing; suspended feature; size prediction; inclination angle of welding torch

Arc behavior of flux bands constricting arc welding for high strength steel sandwich panels T-joints

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China; 2. State Key Laboratory of Advanced Processing and Recycling of Nonferrous Metals, Lanzhou University of Technology, Lanzhou 730050, China). pp 83-90

Abstract: The arc behavior of high-strength camera and welding electric signal acquisition system in the process of constrained arc welding of high-strength sandwich plate T-joints were studied. The results showed that the flux bands not only effectively solves the arc climbing problem in the welding process, but also changes the arc shape and heating characteristics, and significantly increases the arc stability; when the arc voltage is controlled at 23 ~ 29 V, and the welding current is controlled at 240 ~ 320 A, the groove width is controlled at 5 ~ 7 mm. Within the range of process parameters, the flux bands has a moderate melting height, and the arc can be well constrained. The distance from the arc to the bottom of the groove is equivalent to the distance from the arc to the side wall of the panel, mainly on the slope. The bottom of the mouth and the root of the side wall are stably burned, and a good T-joint with a fusion of the panel and the core plate can be obtained.

Key words: sandwich plate T-joint; flux bands constricting arc welding; arc behavior; cross-section morphology of joint

Analysis on characteristics of welding pressure, microstructures and mechanical properties of friction stir welded 1561 aluminum alloy WEN Linxiu[1,2], ZHAO Yunqiang[2], DONG Chunlin[2], WANG Chungui[2], YI Yaoyong[2] (1. Guangdong University of Technology, Guangzhou 510006, China; 2. Guangdong Welding Institute (China-Ukraine E. O. Paton Institute of Welding), Guangdong Provincial Key Laboratory of Advanced Welding Technology, Guangzhou 510651, China). pp 91-96

Abstract: 4 mm thick 1561 aluminum alloy was friction stir welded by the constant pressure controlling mode. The characteristics of the welding pressure, the microstructures and the mechanical properties of the joints were studied. The results indicated that in the plunging stage, the welding pressure alternately experienced increase, decrease and then increase. In the stable welding stage, the welding pressure changes as a sinusoidal periodic trend induced by the variation of the mechanical property of the welded metal. Fixed the welding speed at 200 mm/min, when the rotation speed is lower than 800 r/min or higher than 1 800 r/min, the void defect formes in the weld. When the rotation speed is higher than 1 000 r/min, the "S" line appeares in the stir zone. The tensile strength of the FSW joint is depended on the material strength of the joint when the rotation speed is relatively low. When the rotation speed is relatively high, the "S" line has significant effect on the tensile strength of the FSW joint. With the increase of the rotation speed, the tensile strength of the joint firs increases and then decreases.

Key words: friction stir welding; 1561 aluminum alloy; welding pressure; microstructure; mechanical property

Study on creep properties of deposited weld metal in nuclear class 316H pipe ZHANG Bojun[1,2], YU Huajin[3], JING Hongyang[1,2], XU Lianyong[1,2], ZHAO Lei[1,2] (1. Tianjin University, Tianjin 300072, China; 2. Tianjin Key Laboratory of Advanced Joining Technology, Tianjin 300072, China; 3. China Institute of Atomic Energy, Tianjin 300072, China). pp 97-101

Abstract: Microstructure evolution, creep damage and fracture mechanism of deposited weld metal in muclear class 316H Pipe were studied based on uniaxial creep tests at 525℃ under various stress. The results showed that creep curves consist of three typical stages, including: transient stage, steady-creep stage and accelerated creep regime. Power-law creep dominates the creep deformation behavior of the deposited weld metal. After creep, three types of precipitates can be observed in fractured samples. The Laves phase is considered as the main strengthening phase, which precipitated inside the δ ferrite; the σ phase and the chain-like $M_{23}C_6$ precipitated around the interface between the δ ferrite and the austenite, facilitating the formation and growth of cavities, which caused the failure for the weld metals. Uniform equiaxed dimples are found in fracture surfaces, indicating that the ductile fracture mechanism occurs in deposited weld metal after creep rupture.

Key words: 316H; precipitates; fracture mechanism

Numerical simulation and experimental analysis of magnetic field distribution of magneto-optical imaging in weld defects DAI Xinxin, ZHENG Qiaoqiao, JI Yukun, GAO Xiangdong (Guangdong Provincial Welding Engineering Technology Research Center, Guangdong University of Technology, Guangzhou 510006, China). pp 102-108

Abstract: Taking the weld defects of laser butt welding as the object, the analysis method of magnetic leakage field of weld defects was studied based on numerical simulation. The three dimension finite models of the weld defects detection of laser butt welding was established by Magnet. The relationship between different geometrical defects and their leakage magnetic field signals was compared and analyzed by using the theory of leakage magnetic field, and verified by experiments. The numerical simulation results show that the deeper the crack depth is, the larger the magnetic induction intensity is. The magnetic induction intensity decreases with increase of the angle and width of unfused and concave pits. Magnetic leakage signal can be used as the basis

of weld defect detection. Besides, the magneto-optical image was segmented by RGB segmentation method and the features were extracted. Fuzzy c-mean clustering (FCM) was used to identify different weld defects. The results show that the recognition rate is good.

Key words: leakage magnetic field detection; defect types; finite element analysis; image segmentation; feature extraction

Microstructure and properties of linear friction welded joint of hyperoxia TC4/TC17 dissimilar titanium alloys

CHANG Chuanchuan, ZHANG Tiancang, LI Ju, LIU Jianjun (Aeronautical Key Laboratory for Welding and Joining Technologies, AVIC Manufacturing Technology Institute, Beijing 100024, China). pp 109-114,120

Abstract: The linear friction welding test was carried out on the hyperoxic TC4/TC17 dissimilar titanium alloys, the analysis of the microstructure evolution of different areas of joint, the diffusion behavior of the alloying elements at the weld line interface and the properties of joint were analyzed. As shown in the results of the test, the phase transformation and dynamic recrystallization occurred in the weld zone during the process of linear friction welding, and eventually forming fine equiaxed grains. The needle-shaped martensite is formed in the weld zone of the hyperoxic TC4 side, while the TC17 side is mainly composed of the metastable β phase. The grains in both sides of the thermos-mechanically affected zone are broken, and elongated along the oscillation direction. During the cooling process of welding, the diffusion behavior of alloy elements appeared near the weld line, and the diffusion area is narrow. The micro-hardness at the center of the weld is up to 420 HV, while decreased gradually as approaching to the base material in the side of TC4. On the contrary micro-hardness of the TC17 side increased rapidly as moving away from the weld center. The tensile test results showed that the tensile strength of the joint is equal to that of the hyperoxic TC4 parent.

Key words: linear friction welding; dissimilar titanium; microstructure; micro-hardness; tensile properties

Mechanism of spatter defects in resistance plug welding of dissimilar steel

CEN Yaodong[1], CHEN Furong[2], CHEN Lin[1] (1. Inner Mongolia University of Science and Technology, Baotou 014010, China; 2. Inner Mongolia University of Technology, Hohhot 010051, China). pp 115-120

Abstract: Resistance plug welding was used to weld dissimilar steels. Orthogonal test was used to optimize welding parameters and range method was used to analyze the key factors affecting spatter defects. Then impulse tests were carried out on all resistance plug welded joints. The formation of molten pool, the law of resistance distribution and the electrode were studied. The mechanism of spatter of resistance plug welding was studied in the aspects of pressure and heat change. The results showed that spatter has a great influence on the impact absorbing power of the resistance plug welding joint. The impact absorbing power of the spattered blocking welded joint is greatly reduced. The process of resistance plug welding includes filler heating, filler voltage leveling and nugget. In the three stages of nucleation, the contact resistance increases, decreases and increases again with the welding process and the change of filler shape; at the end of the flattening stage, the instantaneous heat surge is the main reason for the splash on the outer edge of the solder joint; and during the flattening process, the large gap between the two kinds of steel contact surface is the main reason for the splash on the joint surface.

Key words: dissimilar steel; resistance plug welding; spatter; impact absorbing energy

Stress corrosion crack sensitivity of ultra-thick TC4 titanium alloy electron beam welding joints

FANG Weiping[1], XIAO Tie[2], ZHANG Yupeng[1], Xu Wanghui[1], YI Yaoyong[1] (1. Guangdong Provincial Key Laboratory of Advanced Welding Technology, Guangdong Welding Institute, Guangzhou 510650, China; 2. Institute of Metal Research Chinese Academy of Sciences, Shenyang 110016, China). pp 121-128

Abstract: Slow strain rate tensile method was adopted to evaluate the stress corrosion crack (SCC) sensitivity of 100 mm ultra-thick TC4 titanium alloy electron beam welded (EBW) joints under artificial seawater. The corrosion mechanism was studied by observing the microstructure and fracture morphology of the joint. The results showed that the base metal have no SCC sensitivity in seawater. However, the upper, middle and lower parts of the weld showed slight SCC sensitivity at room temperature under the condition of strain rate $\varepsilon = 1 \times 10^{-6}$ s^{-1}. In seawater, anodic dissolution accursed in the weld metal, which increased the Ti ion concentration in the solution at the crack tip, then, H atoms are evolved and absorbed at the crack tip. The diffused hydrogen then promotes dislocation emission and increases the dislocation density at the α' phase boundaries and in the α' phase. The crack initiation and propagation are results of the accumulation of highly hydrogen. At the same time, hydrogen enhances mobility of dislocations, then the crack propagates at a lower stress level.

Key words: electron beam welding; titanium alloy; stress corrosion crack; microstructure; fracture morphology

Study on additive manufacturing of BC-MIG for marine aluminum/steel welded joints

MIAO Yugang, LI Chunwang, YIN Chenhao, WEI Chao (Harbin Engineering University, Harbin 150001, China). pp 129-132

Abstract: The 4043 aluminum wire with a diameter of 1.2 mm was employed as additive material deposition on the

2 mm thick Q235 low carbon steel plates to study BC-MIG arc additive manufacturing process. The T-shaped structure obtained by welding aluminum/steel welded joints with 6061 aluminum alloy plate was beautiful in appearance. The microstructure and hardness distribution of the joint were analyzed by optical microscope and microhardness tester respectively. The results showed that due to the difference of temperature gradient and cooling rate, the aluminum side of the interface layer is a dendritic structure that grew vertically upwards, the middle part showed a relatively cluttered crystal structure, and the top grain is finer and has no directional growth. Along the steel base material area to the intermediate layer of the interface, and then to the aluminum alloy area, the hardness of the joint first increases and then decreases to a gentle degree, and the hardness of the joint layer in the aluminum/steel interface reaches a maximum of 142 HV.

Key words: aluminum/steel welded joint; BC-MIG; additive manufacturing; microstructure; microhardness

Microstructure and mechanical properties of linear friction welding joint of TC21/TC4-DT ZHANG Chuanchen, ZHANG Tiancang, JIN Junlong (Aeronautical Key Laboratory for Welding and Joining Technologies, AVIC Manufacturing Technology Institute, Beijing 100024, China). pp 133-137

Abstract: High strength TC21 and medium strength TC4-DT Ti-alloys with dissimilar damage tolerance were linear friction welded (LFW). Different heat treatments were selected for the joints. The microstructure and mechanical properties of the welded joints were studied after heat treatment. The results showed that good flash is formed on both side of the base metal after LFW. The surface of the flash is smooth and no defects are found at the root of the flash. The microstructure of the weld zone (WZ) is widmanstatten in as-welded condition. Precipitated acicular α phase is distributed in the weld zone after heat treatment. With heat treatment temperature increasing the precipitated α phases are coarsened. The impact properties and fracture toughness properties rises at the first and goes down latter with α coarsened. Tensile strength of the joints is equal to TC4-DT base metal. The high cycle fatigue limit of the joint is 558MPa at the temperature of 700°C for 3 hours which is equal to TC4-DT base metal. Due to the fine microstructure of WZ the fatigue limit increases.

Key words: linear friction welding; Ti-alloys; microstructure; mechanical property

Crystallization control and microstructural properties of laser welded $Zr_{67.8}Cu_{24.7}Al_{3.43}Ni_{4.07}$ bulk metallic glasses MA Yanyi[1,2], WANG Haiyan[1], ZHANG Yupeng[1], YI Yaoyong[1], DONG Fuyu[2] (1. Guangdong Provincial Key Laboratory of Advanced Welding Technology, Guangdong Welding Institute (China-Ukraine E. O. Paton Institute of Welding), Guangzhou 510651, China; 2. Shenyang University of Technology, Shenyang 110870, China). pp 138-142

Abstract: Laser welding was employed to weld $Zr_{67.8}Cu_{24.7}Al_{3.43}Ni_{4.07}$ bulk metallic glasses (BMGs). The effects of laser power and welding speed on the microstructures of different regions in the joints were studied. The crystallization control law of laser welded BMG joints is expounded, and the relationship between microstructure characteristics and hardness of as-welded joints is discussed. The results showed that the laser welding technology with high welding speed and high energy density is beneficial to maintain the amorphous structure of the molten zone in $Zr_{67.8}Cu_{24.7}Al_{3.43}Ni_{4.07}$ BMG joints, accompanied by some nano-grains forming. The crystallization happening in heat affected zones is severe. Laser power has a great influence on the complete penetration of as-welded joints. The degree of crystallization in heat affected zones can be effectively controlled through lowering laser power or increasing the welding speed to reduce heat input. Vickers hardness tests reveal that the hardness of the molten zones of the welded joint is slightly higher than that of base material, and the hardness of heat affected zones is significantly lower than that of the base material.

Key words: laser welding; bulk metallic glass; crystallization; microstructural properties; hardness

Microstructure and properties of TC4 titanium alloy by direct underwater laser beam welding QIN Hang[1], CAI Zhihai[1], ZHU Jialei[2], WANG Kai[2], LIU Jian[1] (1. National Engineering Research Center for Mechanical Product Remanufacturing, Army Academy of Armored Forces, Beijing 100072, China; 2. Beijing Institute of Petrochemical Technology, Beijing 102617, China). pp 143-148

Abstract: An optical fiber laser was used to fabricate TC4 titanium alloy welding by direct underwater laser beam welding. The purpose of increasing the penetration depth and protecting the weld were realized by presetting a weld auxiliary to the surface of TC4. The microstructure and mechanical property was analyzed, and the results showed that both the penetration depth and the welding threshold increases, while the cracks reduces. The weld center is mainly composed of primary α and martensitic α' phases, and there is still a large β grain boundary at the bottom of the molten pool. Due to the quench effect of water, the weld underwater has quenched structure, and its microhardness is much higher than that of TC4 base metal. The tensile test specimens of underwater welding are all fractured at the weld joint, and the average tensile strength of the welded joint is 439 MPa, showing brittle

fracture.

Key words: TC4 titanium alloy; direct underwater laser beam welding; microstructure; mechanical property

Effect of ultrasonic impact strength on fatigue life of welded joints BAI Yili, WANG Dongpo, DENG Caiyan, GONG Baoming (Tianjin University, Tianjin 300072, China). pp 149-153

Abstract: The fatigue life of Q345B steel cross joint was treated by ultrasonic impact treatment, and the fatigue life of the welded joint under two kinds of amplitudes was compared and analyzed. The results showed that the fatigue life of welded joints at 25 micron amplitude is 4.3 ~ 7.6 times higher than that at 18 micron amplitude. The reasons for the difference of ultrasonic impact fatigue life extension under different amplitudes were compared and analyzed in terms of macro-morphology, micro-fracture and surface structure of impact area after ultrasonic impact treatment, and the finite element model was established to simulate the stress field of welding temperature field and stress field. By comprehensively comparing and analyzing the test results with the finite element calculation results, the results showed that the greater the amplitude, the deeper the compressive stress layer and the greater the surface compressive stress of the specimen under the same impact condition.

Key words: ultrasonic impact treatment(UIT); finite element method; welding residual stresses(WRS); fatigue life

Study on Heat-treated microstructure of GH4169 superalloy deposited by UHFP-GTAW JIA Zhihong, WAN Xiaohui, GUO Delun (Aeronautical Key Laboratory for Welding and Joining Technologies, AVIC Manufacturing Technology Institute, Beijing 100024, China). pp 154-160

Abstract: Thin wall test specimen of GH4169 superalloy has been deposited by UHFP-GTAW, and two kinds of heat treatment methods were formulated. The specimens were divided into 3 groups: specimens without heat treatment, specimens with solution and aging heat treatment and homogenizing heat treatment, respectively, and their microstructures has been compared and analyzed after the electrochemical corrosion. The results showed that large size dentrite is the main microstructure of specimens without heat treatment, with a large amount of interdendritic Laves phase, which exits in a smaller size in the UHFP-GTAW specimens than the CP specimens. A mass of lamellar δ phase, γ″ phase, a certain amount of γ′ phase and some Laves phases which remained on the dentrite can be observed on the γ matrix of the specimens treated by solution and aging heat treatment. The microstructure of specimens that are treated by homogenizing and aging heat treatment is mainly a large amount of graininess γ″ phase and γ′ phase, and some small size Laves phases and MC type of carbide, while the δ phase has almost disappeared.

Key words: ultra-high frequency; additive manufacturing; superalloy; heat treatment; microstructure