

## MAIN TOPICS, ABSTRACTS & KEY WORDS

### Real-time measurement of distortion in weld bead zone

GUO Nan<sup>1,2</sup>, LIANG Jin<sup>1,2</sup>, GONG Chunyuan<sup>1,2</sup>, WANG Xiaoguang<sup>1,2</sup> (1. State Key Laboratory for Manufacturing Systems Engineering, School of Mechanical Engineering, Xi'an Jiaotong University, Xi'an 710049, China; 2. Guangdong Shunde Xi'an Jiaotong University Academy, Foshan 528300, China) . pp 1-4

**Abstract:** The large plastic distortion occurs in the weld zone for bead-on-plate welding of thin-plate. A non-contact method was proposed to real-time measure the welding distortion in bead-on-plate welding and cooling process based on weak correlation technique of digital image. The study of full-field distortion law and dynamic distortion law of key points were measured in real-time. Bead-on-plate welding of Q235 steel plate by tungsten inert gas (TIG) welding were carried out to explore distortion law. The results show that the distortion in vertical direction is much larger than that in the other two directions. The thin-plate becomes a convex shape in the welding process and then turns to a saddle shape in cooling process. The full-field distortion of thin-plate is larger with welding current being increased. This method can verify the prediction of numerical simulation and reveal the mechanism of welding distortion in thin-plate, and has important guiding significance.

**Key words:** welding bead zone; weak correlation of digital image; welding distortion; measurement

### Numerical simulation of crack initiation under creep-fatigue interaction in P92 steel

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**Abstract:** By combining the theory of continuum damage mechanics with initial stress and strain fields and criteria for element failure and crack initiation, a predictive model of crack initiation under creep-fatigue interaction was constructed. Based on the model, a user defined material subroutine (UMAT) was compiled and creep-fatigue damage accumulation was investigated by the finite element method using ABAQUS codes. Crack initiation was simulated in a structure without initial defects under a creep-fatigue interaction. Factors affecting the time of crack initiation were investigated. In contrast to linear cumulative damage (LCD) theory, mutually promoting effects exist between creep damage and fatigue damage at crack initiation locations. Interaction between creep and fatigue shortens the time to crack initiation. The sequence of creep and fatigue loading greatly influences accumulation of damage at the crack initiation location. Cyclic loads cause larger damage after long periods of creep load compared with periods without creep load, hence time to crack initiation is shorter.

**Key words:** creep-fatigue interaction; damage; crack initiation; finite element simulation

### Microstructure and high-cycle fatigue properties of laser melting deposited TC11 titanium alloy repaired by tungsten argon arc welding

HOU Huipeng, TIAN Xiangjun, LIU Dong, WANG Huaming (School of Materials Science and Engineering, Beihang University, Beijing 100191, China) . pp 9-12

**Abstract:** Tungsten argon arc welding was used to repair

a TC11 plate fabricated by laser melting deposition. Duplex-annealing of the repaired sample was provided. Microstructure and high-cycle fatigue properties of the repaired sample were investigated. The results indicated that the repaired zone shows morphology of columnar grains, both heat affected zone and base metal show alternately arranged morphology of columnar grains and equiaxed grains. Before heat treatment, the repaired zone and heat affected zone show fine needle  $\alpha$  (hcp) distributed in the  $\beta$  (bcc) matrix, while base metal shows fine basket-weave microstructure. After heat treatment, all zones show microstructure with primary  $\alpha$  and transformed  $\beta$ . The primary  $\alpha$  phase laths in repaired zone were longer compared with those in other zones. Fatigue properties of the repaired samples were 7.1% lower than that of the base metal. Fracture analysis of the high cycle fatigue specimens shows that all fatigue sources are porosity in repaired zone. Crack initiation zone is characterized by the crystallographic cleavage facets of  $\alpha$  lamellae and tearing of  $\beta$  lamellae.

**Key words:** argon-arc welding; repair; laser melting deposition; microstructure; high-cycle fatigue

### Ultrasonic frequency pulse power supply and its parallel coupling with welding power supply

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**Abstract:** An ultrasonic frequency pulse power supply, applied to the composite ultrasonic frequency pulse arc welding, was designed and developed, and the frequency and amplitude of its output pulse current could be adjusted and controlled independently. A coupling method of ultrasonic frequency pulse power supply with direct current welding power supply was proposed, which is "parallel + auxiliary network". Based on the establishment of control model of output pulse current, the power conversion circuit of ultrasonic frequency pulse power supply was set up, which consists of a buck converter, a full bridge converter and a high frequency coupling transformer. The frequency regulation of pulse current can be achieved by controlling the switching frequency of the full bridge converter, and the amplitude of pulse current was controlled by means of two-stage feedbacks, that is the amplitude adjustment of the buck converter output voltage and the output pulse duty cycle regulation of the full bridge converter, to guarantee its accuracy and stability. The experimental results demonstrate that the frequency and amplitude of ultrasonic frequency pulse current can be adjusted quickly, accurately and steadily, and have a good coupling effect with welding arc.

**Key words:** coupling mode; ultrasonic frequency pulse current; frequency modulation and amplitude modulation; buck converter; full-bridge converter

### Bonding mechanism of friction stir spot welding of magnesium to galvanized steel

LIU Xiao, WANG Xijing, JING Wenxia, CHAI Tingxi (State Key Laboratory of Advanced Processing and Recycling of Nonferrous Materials, Lanzhou University of Technology, Lanzhou 730050, China) . pp 17-20

**Abstract:** The lap welding of AZ31B Mg alloy to DP600 galvanized steel were successfully achieved by friction stir spot welding (FSSW) and vacuum diffusion welding. Scanning electron microscopy, energy disperse spectroscopy and tensile tests were used to investigate the microstructures and mechanical properties of the welded joints at the best welding parameters. The results show that there is no keyhole found in the FSSW joint and the good weld appearance is obtained. The bonding mechanism of the joints are mechanical bonding and metallurgical bonding. Intermetallic compounds of Mg, Fe and O formed because of the diffusion at the interface of magnesium and steel during the metallurgical bonding process. In the mechanical bonding process, some of the steel insert into the magnesium alloy substrate like nails and there exists serrated combination morphology at the interface between Mg and steel, the others is mixed into the magnesium alloy under the stir effect of stir pin which greatly improved the mechanical properties of joint of magnesium alloy to steel. For both the kinds of bonding mechanism, about 75.9% of the mechanical properties is contributed by mechanical bonding and mechanical bonding is the main bonding mechanism in the FSSW process.

**Key words:** friction stir spot welding; AZ31B magnesium alloy; DP600 galvanized steel; mechanical properties; bonding mechanism

**Stability of short-circuiting transfer process based on GMAW dynamic model** WANG Ying<sup>1,2</sup>, LÜ Xiaoqing<sup>1,2</sup>, JING Hongyang<sup>1,2</sup> (1. School of Materials Science and Engineering, Tianjin University, Tianjin 300072, China; 2. Tianjin Key Laboratory of Advanced Joining Technology, Tianjin University, Tianjin 300072, China) . pp 21-25

**Abstract:** The dynamic process of short-circuiting transfer was simulated by the established model. The short-circuiting transfer frequency, the equivalent radius of contact droplet and residual droplet, the velocity and displacement of droplet and the change of liquid bridge shape were predicted. The relationship between the metal transfer parameters and its process stability was analyzed, and the optimal arc is successfully predicted, which provides the basis for the parameter optimization of the welding process. The results show that the welding parameters that corresponds to the highest transfer frequency are not the optimal parameters. Further, the equivalent radius of residual droplet is minimum, and the variation of droplet oscillation velocity and displacement is slight under the condition of optimal welding parameter. Meanwhile, the smaller the equivalent radius of contact droplet and the principal radius of liquid bridge, the better the stability of short-circuiting transfer process.

**Key words:** short-circuiting transfer frequency; equivalent radius of contact droplet; equivalent radius of residual droplet; oscillation velocity and displacement; liquid bridge shape

**Mechanism of sound source in laser deep penetration welding process** SHAN He<sup>1</sup>, LUO Zhen<sup>1</sup>, ZHANG Chengda<sup>2</sup>, AO Sansan<sup>1</sup>, MENG Fanliang<sup>1,3</sup> (1. Institute of Welding and Advanced Manufacturing Technology, Tianjin University, Tianjin 300350, China; 2. Tianjin Institute of Metrological Supervision and Testing, Tianjin 300192, China; 3. The second Oil Production Plant, Daqing Oil Field Co., Daqing 163459, China) . pp 26-30

**Abstract:** Acoustic signal is an important parameter in laser welding process, and the understanding of mechanism of the laser acoustic signal is not deep enough. A thorough research on the mechanism of sound source and keyhole profile during laser deep penetration welding process were carried out. By considering the Helmholtz effect in acoustics, the relationship between

the morphology of the keyhole and the intensity of the sound signal and the resonance frequency was obtained through the acoustic-electric analogy. CCD image acquisition system was used to obtain the actual shape of the hole, and the rationality of the results obtained from the theoretical study was verified. Through the acoustic signal acquisition system, the acoustic data in laser welding process were acquired, and the amplitude spectrum of sound field was obtained by the fast FFT transform. The results show that the experimental results are in good agreement with the theoretical values, and the proposed acoustic mechanism of keyhole is suitable for application.

**Key words:** laser welding; acoustic signal; mechanism of keyhole; keyhole profile; acoustic signal processing

**Effect of welding sequence on welding deformation of fork structure** HUANG Zunyue<sup>1</sup>, LUO Zhen<sup>1</sup>, AO Sansan<sup>1</sup>, DONG Jiantao<sup>2</sup> (1. School of Materials Science and Engineering, Tianjin University, Tianjin 300072, China; 2. Aerospace Machinery Company of Capital, Beijing 100076, China) . pp 31-34, 44

**Abstract:** Welding deformation has negative impact on the bearing capacity and precision of structures, especially for fork structure and other sophisticated structure, which will result in very serious consequences. In order to measure the welding deformation of fork structure precisely and to control it, a simplified model of a 1:3 titanium fork was produced. numerical simulation, digital image correlation techniques and three-dimensional scanning were used to measure the deformation in real-time and after welding. The simulation and experimental testing were combined closely, the actual engineering was taken into account, and the impact of welding sequence on welding distortion was quantified. At last the best welding sequence was found.

**Key words:** welding deformation; numerical simulation; digital image correlation techniques; three-dimensional scanning

**Analysis of corrosion performance of laser welded joint of tap based on in-situ tracking method** ZHOU Guangtao<sup>1</sup>, SU Liji<sup>1</sup>, CHEN Qiang<sup>1</sup>, FANG Hongyuan<sup>2</sup> (1. College of Mechanical Engineering and Automation, Fujian Provincial Key Laboratory of Special Energy Manufacturing, Huaqiao University, Xiamen 361021, China; 2. State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin 150001, China) . pp 35-38, 44

**Abstract:** The thin-shell tap was fabricated using new process of low-energy laser welding, instead of the traditional casting process which had high pollution and high energy-consuming. The corrosion resistance of the 304 and 310s stainless steel was investigated in boiling sulfuric acid and acid at room temperature, respectively. The microstructure of weld beam and fusion zone during corrosion process was observed by in-situ tracking method. The results showed that corrosion resistance of 310s stainless steel is better than that of 304 stainless steel. With the time increasing, grain boundaries of the fusion line do not widen obviously. Microscopic features of the fracture were dimples, which is indirect proof for its good corrosion resistance. Analysis indicated the chemical compositions in weld metal are close to that in the base metal. Cr content in corrosion ditch fell to 20.81%, but still more than 12%, ensuring the excellent corrosion resistance.

**Key words:** in-situ observation; stainless steel; tap; laser welding; corrosion resistance

**Droplet transfer in aluminum alloy laser-MIG hybrid welding coupled by high frequency pulses and its cladding characteristics** ZHU Zongtao, WANG Xuefei, YANG Xiaoyi,

GAO Jian, CHEN Hui (School of Materials Science and Engineering, Southwest Jiaotong University, Chengdu 610031, China) . pp 39-44

**Abstract:** High frequency pulses (HFPs) power source were parallelly connected with the power source of single-pulse mode MIG arc, which are applied to laser-MIG hybrid welding. The cladding on A7N01 aluminum alloy was executed to investigate the dynamics of droplet transfer and arc with the effects of coupled HFPs through high speed camera observation. The shaping-characteristic and microstructure of cladding layer were also studied by metallographic analysis. The results show that the arc length and voltage increase after HFPs being coupled. The base current of single pulse MIG arc decreases, while the peak current has little changes compared with that without HFPs coupling. In conventional laser-MIG hybrid welding, the droplets are partly transferred as meso-spray mode. The finger-penetration weld can be obtained, which probably causing defects in the weld root. After HFPs being coupled, partly meso-spray transfer changes to completely spray transfer. The surface of cladding layer becomes smoother with the disappearance of fish-scale pattern and finger-penetration depth. Although the grain size has no significant changes, the size of second phase particles becomes smaller and more uniformly distributed in grains as strengthened phase.

**Key words:** aluminum alloy; laser-MIG hybrid welding; high frequency pulses; droplet transfer; arc ultrasonic

#### Numerical simulation of effects of different driving force on surface deformation of weld pool

HUANG Yong, LI Hui, WANG Xinxin, YAO Yuhang, LU Suzhong (State Key Laboratory of Advanced Processing and Recycling of Non-ferrous Metals, Lanzhou University of Technology, Lanzhou 730050, China) . pp 45-49

**Abstract:** A three-dimensional transient mathematical model of weld pool for a stationary tungsten inert gas welding was established based on the fluid dynamic equations. In this model, enthalpy-porosity method was used to handle liquid-solid phase change, VOF method was employed to track the free surface deformation of the weld pool. By solving these equations, the deformation behavior of surface and the distributions of temperature and velocity were obtained under the independent action by buoyancy, Marangoni force, electromagnetic force and arc pressure, respectively. The results indicate that, at high welding current ( $I \geq 250$  A), a surface projection forms in weld pool when buoyancy, Marangoni force with positive temperature coefficient of surface tension and electromagnetic force were acted independently, while a surface depression forms under the action of arc pressure, Marangoni force with negative temperature coefficient of surface tension. At high welding current, weld pool depression phenomenon appears for both TIG welding and activated flux TIG welding. For TIG welding, there exists an inward vortex in the central zone of the weld pool, while an outward vortex appears in the periphery. For activated flux TIG welding, two inward vortices are induced by different factors in the central zone and periphery of the weld pool, respectively. The magnitude of surface deformation was not superimposed simply by each driving force.

**Key words:** VOF method; driving force; surface deformation; weld pool

#### Torque feature in bobbin tool FSW of 6061 aluminum alloy

CHEN Shujin, CAO Fujun, LIU Bin, HU Xiaoqing, LI Hao, XUE Junrong (Jiangsu University of Science and Technology, Zhenjiang 212003, China) . pp 50-54

**Abstract:** To investigate the torque characteristics in bobbin tool friction stir welding (BTFSW) of 6061 aluminum alloy,

the torque in BTFSW was measured, the frequency spectrum and the peak of torque were analyzed, and then the relationship between the torque oscillation and the surface shape of welded joint was also discussed. The research indicates that the torque in BTFSW is periodic. The major frequency of the torque is close to 2 times of the spindle frequency. The frequency difference illustrates that the stacking behavior exists between the tool and the metal flow at different velocity. The experimental results indicated that the peak of torque increases with welding speed being increased and decreases with rotation speed being increased when interface temperature of tool and workpiece was lower than 500 °C. Smaller torque oscillation will not affect the surface shape of welded joint, but if the interface temperature was higher than 550 °C, the torque will appear abnormal oscillation under adverse condition, such as the too short distance between top and back shoulders, slow travel speed, high rotation speed. This research will be useful to indicate the mechanism of BTFSW, 3-D force characteristics and the relationship between welding parameters and welding quality.

**Key words:** bobbin tool friction stir welding; welding torque; spectrum analysis; weld surface

#### Measuring residual stress of chain based on the method of digital image correlation

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**Abstract:** A stress measurement system was built based on digital image correlation method. The influence of speckle pattern quality on the measurement accuracy was analyzed, and the accuracy of this measurement system was verified through in-plane translation and the test of plane stress state. The results show that the measurement accuracy can be improved with the increase of the quality of speckle pattern to a certain extent. All the relative errors in the test of in-plane translation were less than 3.5%, which indicate that the system has high accuracy. When this measurement system was used to measure the welding residual stress of the chain, the results are basically the same with that from strain gauges. It's worth noting that, this stress measurement system has advantages such as simple operation and high accuracy, which can be used to measure the residual stress instead of strain gauge under certain conditions.

**Key words:** digital image correlation; welding residual stress; in-plane translation; plane stress; chain

#### Crystal orientation evolution of friction stir welding of 2024/7075 dissimilar aluminum alloys

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**Abstract:** The optical microscope and electron back scattering diffraction (EBSD) were used to comparative study the microstructure features, grain boundary characteristics and the evolution of the texture in friction stir welded joint and base metal of 2024/7075 dissimilar aluminum alloys. The results show that the content of low angle grain boundary in thermal mechanical affected zone at retreating side grain is significantly higher than that of the base metal, but there is no obvious change at advancing side. Dynamic recrystallization occurs in stir zone, and the content of high angle grain boundary increases significantly. 2024 aluminum alloy at retreating side has a weak orientation. 7075

base metal at advancing side, heat affected zone and heat mechanically affected zone have strong S texture  $\{123\} \langle 634 \rangle$ , brass texture  $\{011\} \langle 211 \rangle$  and R texture  $\{124\} \langle 211 \rangle$ . Stir zone is equiaxed recrystallization grain, and has no obvious preferred orientation.

**Key words:** dissimilar aluminium alloys; friction stir welding; crystal orientation evolution; electron back scattering diffraction

### Three distance method and its experimental verification for electrode displacement measurement in resistance spot welding

WANG Xianfeng, JIANG Zhongcheng, DUAN Huadong, PENG Zhangzhu (CRRC Zhuzhou Locomotive Co. Ltd., Zhuzhou 412001, China). pp 63-66

**Abstract:** For the traditional measurement methods including the upper electrode movement and long arm tooling in resistance spot welding, there are errors in measuring electrode displacement, which introduced by the deformation of welding torches caused by the welding thermal expansion force during resistance spot welding process. Therefore, the trapezoidal relationship measurement method and three distance measurement method were suggested, and their accumulative calculation errors were analyzed and compared. Then, the three distance measurement method with less errors was experimentally verified through using the inverted F type tooling and experimental monitoring and verification system for electrode displacement measurement using laser displacement sensors and data acquisition system of embedded industrial control computer with LabVIEW programming. The results showed that it is correct and feasible, and the deformation displacement of lower electrode of the C type welding torches is not the neglectful part of the electrode displacement introduced by the dynamic electrode force.

**Key words:** resistance spot welding, electrode displacement, trapezoidal relationship measurement method; three distance measurement method; experimental verification

### Micro-joint reliability of flip chip assembly under thermal shock-strain and stress

TIAN Ye (School of Mechanical and Electrical Engineering, Henan University of Technology, Zhengzhou 450011, China). pp 67-70

**Abstract:** The stress and strain of soldered joints under thermal shock were studied, and the crack growth in soldered joint were also analyzed. The results show that the corner soldered joint has the most accumulated plastic strain and plastic work density, which is the critical soldered joint in the assembly. The accumulated plastic work density is mainly located in chip sidenear Ni pad. The largest value is in the outside, and decreases along the Ni pad to inside, which indicate the crack formed on the chip side, and then grew along Ni pad from outside to inside, at last crossed through the whole soldered joint. The experimental result matched the simulation analysis well, and further proved the analysis of crack growth in soldered joint.

**Key words:** flip chip; micro-joint; thermal shock; reliability

### Gaussian pulsed MIG welding of aluminum alloy sheet

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**Abstract:** It is hard to weld aluminum alloy for its inherent features. A new welding method, which uses a Gaussian current waveform with a smooth curve and concentrated energy input, was applied to welding of aluminum alloy sheet. GAUSS-

MIG welding model was proposed, 2 mm and 3 mm aluminum sheet were successfully welded in experiments. Current and voltage waveforms were regular with no broken arcs or short circuits. Moreover, the arc voice sound was soft with low splatter. By contrast with double pulsed welding, GAUSS-MIG welding improves the mechanical properties of weld, weld seam appearances are bright with regular scaly stripes and proper weld reinforcement and penetration.

**Key words:** aluminum alloy sheet; Gauss function; pulsed metal inertia gas welding; current waveform control

### Effect of deposition path on microstructure and mechanical properties of plasma arc rapid prototyping of Inconel 625 alloy

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**Abstract:** In order to optimize the microstructure and mechanical properties of plasma arc rapid prototyped Inconel625 alloy, the alternating and cross paths were applied to forming the rectangular block sample. The effects of the two paths on the structure and properties of block samples were investigated, and the growth mechanisms of the as-deposited structures under the two conditions were analyzed. The results show that different heat input and heat dissipation directions result in different temperature gradient, and have an influence on the continuity of structure growth. The optimal forming quality and mechanical properties were obtained under the condition of alternating path. Although using the cross path can lead to the alternating structure growth, the formation of small dendrite and the disperse precipitation of Laves phase, the mechanical properties were not increased drastically because of serious element segregation, precipitation of brittleness phase and the coarsening of dendrite.

**Key words:** plasma arc rapid prototyping; deposition path; as-deposited microstructure; mechanical properties

### Analysis of intergranular corrosion of friction stir welded 2219 aluminium alloy

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**Abstract:** The intergranular corrosion behavior of friction stir welded 2219 aluminium alloy was investigated. Microstructure, micro-hardness, corrosion morphology and corrosion depth were studied to analyze the difference between BM and WNZ, and intergranular corrosion mechanism of FSW joint was preliminary discussed. The results show that WNZ consists of fine equiaxed grains, and the grain size on top surface is slightly bigger than that on root surface. The highest microhardness is located in the BM while the lowest in the WNZ on root surface. The corrosion resistance of WNZ is much superior than that of BM, and WNZ on top surface is slightly superior than that on root surface. The maximum corrosion depth in BM is 145.9  $\mu\text{m}$  while the maximum corrosion depths in WNZ on top surface and root surface are 46.3  $\mu\text{m}$  and 84.1  $\mu\text{m}$  respectively.

**Key words:** aluminum alloy; friction stir welding; intergranular corrosion

### Fatigue property of aluminum non-load bearing cruciform joint

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Welding and Joining, Harbin Institute of Technology, Harbin 150001, China; 2. Department of Naval Architecture and Marine Engineering, University of Michigan, Ann Arbor 48109, USA) . pp 83-86

**Abstract:** The structural stress of 7N01 non-load bearing cruciform joints with different geometrical magnitude under fatigue loading was calculated, and the corresponding master S-N curve was obtained. The results show that, compared with the nominal stress based S-N curve, master S-N curve based on structural stress method shows much better linear correlation for cruciform joints with different geometry. The influence of plate thickness on fatigue strength was then analyzed. The results show that the relationship between load bearing ability and plate thickness is nonlinear. When nominal stress remains the same, fatigue life is reduced when plate thickness is increased.

**Key words:** structural stress; fatigue; aluminum alloy; non-load bearing cruciform joints

**Defects and mechanical properties of refill friction stir spot welded joint of dissimilar aluminum alloys** ZHENG Min<sup>1</sup>, SHEN Zhikang<sup>1</sup>, YANG Xinqi<sup>1</sup>, YIN Yuhuan<sup>2</sup> (1. Tianjin Key Laboratory of Advanced Joining Technology, Tianjin University, Tianjin 300072, China; 2. Shanghai Spaceflight Manufacture (Group) Co., Ltd, Shanghai 200245, China) . pp 87-90

**Abstract:** Dissimilar aluminum alloys of 5052-H112 and 2024-T4 (2 mm) were successfully joined by refill friction stir spot welding. Defects-free joint was obtained under optimum welding conditions. However, the welding parameters window was rather narrow. At the high heat input, lots of defects such as ligament bonding, voids, cracks and kissing bonding appear, which accumulated at the interface and the path in which the sleeve plunges into the workpiece. The mechanical properties tests show that the preferable strength is obtained under lower heat input welding conditions, which is consistent with that the defects-free joint tends to form under lower heat input welding conditions. The failure of the joint occurred at the interface and the path where the sleeve plunges into the workpiece both under tensile and cross-tension loadings. The effective metallurgical bonding formed at the interface.

**Key words:** dissimilar aluminum alloys; refill friction stir spot welding; defects; mechanical properties

**Application and analysis on wave propagation in ultrasonic TOFD test of austenitic stainless steel weld** CHEN Zhenhua<sup>1,2,3</sup>, ZHANG Chong<sup>3</sup>, LU Chao<sup>3</sup>, YANG Xiangjie<sup>1</sup> (1. School of Mechatronics Engineering, Nanchang University, Nanchang 330031, China; 2. Fangda Special Steel Technology Co., Ltd., Nanchang 330012, China; 3. Key Laboratory of Nondestructive Testing of Ministry of Education, Nanchang Hangkong University, Nanchang 330063, China) . pp 91-95

**Abstract:** Ultrasonic TOFD testing of stainless steel weld is deeply influenced by the acoustic noise and attenuation produced by the weld structure, and which are the key problem needed be solved. Ultrasonic beams with different incident angle were formed, and the amplitude and noise-signal ratio of diffraction wave influenced by weld structure were analyzed to reveal the characteristics of ultrasonic propagation in the weld. The results indicate that the ultrasonic propagation in the weld show obvious anisotropy characteristics, and the incident angle of the ultrasonic beam and columnar crystal boundary in weld have a significant impact on the wave attenuation and scattering. Moreover, the mechanism of anisotropy was presented by constructing weld model, which gives reliable theory evidence for optimizing testing parameters in real testing. And then, there are two testing

methods include primary wave testing method and secondary wave testing method presented to achieve better testing results.

**Key words:** weld structure; noise-signal ratio; ultrasonic TOFD; anisotropy

**Effects of Si and Mg on mechanical properties of aluminum-steel welded-brazed joint** HUANG Jiankang<sup>1</sup>, LI Jie<sup>1</sup>, SHEN Limin<sup>2</sup>, SHI Yu<sup>1</sup>, GU Yufen<sup>1</sup>, FAN Ding (1. State Key Laboratory of Advanced Processing and Recycling of Nonferrous Metals, Lanzhou University of Technology, Lanzhou 730050, China; 2. Great Wall Motor Company Limited, Baoding 071000, China) . pp 96-100

**Abstract:** Dissimilar metals of 5052 aluminum alloy and galvanized steel were joined with lap joint by pulsed double electrode gas metal arc welding-brazing with ER4043 filler metal and ER5356 filler metal, respectively. The interfacial microstructures, fracture behavior and fracture morphologies of the joints were analyzed by scanning electron microscopy, energy dispersive spectroscopy and X-Ray diffraction. The results show that wetting angle of weld with Al-Mg filler metal is larger than that with Al-Si filler metal. Si atoms change the shape of intermetallic compounds and inhibit the formation of Fe<sub>2</sub>Al<sub>3</sub> intermetallic compound. The results of tensile tests show that the welded joints with Al-Mg filler metal mainly fracture along the interface between the intermetallic layer and the steel, and the fracture mode of the joints is brittle fracture. The welded joints with Al-Si filler metal mainly fracture in the fusion zone of aluminum alloy, and the fracture mode of the joints mainly is ductile fracture, but has the trace of brittle fracture. Hardness of joints with Al-Si filler metal was determined, the results show that the hardness of aluminum heat affect zone is obviously lower than that of the other zone, which leads to the joints with Al-Si filler metal failure in aluminum fusion zone.

**Key words:** aluminum-steel welding-brazing; intermetallic compound; microstructures and properties; fracture morphologies

**Spatial distribution measurement of gas tungsten arc current density based on image analysis** JIANG Qixiang, ZOU Yirong, DU Dong (Department of Mechanical and Engineering Tsinghua University, Beijing, 100080, China) . pp 101-104

**Abstract:** The spatial distribution of the arc current density is one of the key factors for revealing the thermal-force coupling in the welding process which determines the metallurgy and forming quality. A method to measure the spatial distribution of gas tungsten arc (GTA) current density was proposed. The GTA images acquired by monochromatic imaging were analyzed to calculate the temperature field using the Fowler-Milne technique, and then the spatial distribution of the current density was obtained by solving the partial differential equation of electric potential with the constraints such as the relationship between temperature and conductivity, the corresponding boundary conditions and the current conservation conditions, and so on. The result has good consistency with the data measured under the same experimental conditions in literature. The proposed method is able to measure the spatial distribution of the GTA current density in a non-invasive way, and therefore provides a basis for techniques of real-time monitoring and quality control of the welding process.

**Key words:** GTAW arc; spatial distribution of the arc current density; arc space temperature field; real-time monitoring of the welding process; non-invasive measurement

**Optimization of magnesium alloy TIG welding parameters under magnetic field** ZHANG Guiqing<sup>1</sup>, REN Yinglei<sup>1</sup>,

LIU Kai<sup>2</sup>, SU Yunhai<sup>1</sup> (1. School of Materials Science and Engineering, Shenyang University of Technology, Shenyang 110870, China; 2. Shenyang Blower Works Group Corporation, shenyang 110869, China) . pp 105-108

**Abstract:** NiCl<sub>2</sub> was selected as activating flux, and the longitudinal magnetic field was used in A-TIG welding process of AZ91 magnesium alloy plate. By adjusting the magnetic field current and the coating amount of activating flux their effects on the weld penetration depth, width, hardness and microstructure were studied to determine the best matching parameters. The results show that, in experiments, at the magnetic field current of  $I_c = 1.5$  A and the activating flux coating amount of 5 mg/cm<sup>2</sup>, the deepest weld penetration and the highest microhardness are obtained, which can reach up to 5.00 mm and 73.8 HV, respectively. The combined action of the magnetic field and the activating flux not only increases the weld penetration depth, but also improves the mechanical properties.

**Key words:** AZ91 magnesium alloy; A-TIG welding; longitudinal magnetic field; optimum design

### Low temperature brittle fracture resistance of asymmetrical synchronous double-sided arc welded joint of 10Ni5CrMoV steel

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**Abstract:** Low temperature brittle fracture resistance of asymmetrical synchronous double-sided arc welded (DSAW) joint of 10Ni5CrMoV steel was investigated by series temperature impact test, dynamic tear test and drop hammer test. The results show that DSAW joints of steel 10Ni5CrMoV have a practicable brittle fracture resistance. The impact energy value on the fusion line of DSAW joint meets the technical requirement of the 10Ni5CrMoV steel (i. e. ,  $Akv(-50\text{ }^\circ\text{C} \geq 47\text{ J})$ ) with a large allowance. Minimum of dynamic tearing energy at -1 °C is 1150 J, higher than the standard of 644 J DT work at 0 °C. Drop hammer test determines that the nil-ductility transition temperature of weld metal of 10Ni5CrMoV steel is -80 °C, elastic fracture transition temperature is -47 °C, full plastic fracture transition temperature is -14 °C.

**Key words:** 10Ni5CrMoV; low temperature toughness; double-sided arc welding

### Micro-zone performance of laser-MIG hybrid welded A7N01P-T4 Al alloy joints

YANG Xiaoyi, CHEN Hui, WANG Qiying, ZHU Zongtao (School of Materials Science and Engineering, Southwest Jiaotong University, Chengdu 610031, China) . pp 114-118

**Abstract:** Laser-MIG hybrid welded joint of 14mm A7N01P-T4 Al alloy for high speed train was investigated, the properties of WM (weldmetal), HAZ (heat affect zone) of joints and BM (base metal) were tested respectively, such as micro-zone tensile property, fracture toughness and so on, and the differences of micro-zone properties were analyzed by OM and SEM. BM has the best micro-zone tensile strength, while that of WM is the lowest. HAZ has the highest fracture toughness  $J_m(14)$ , which can reach up to 119.580 kJ/mm<sup>2</sup> and indicates an outstanding ability to resist crack growth in hybrid welded joints. Shapiro-Wilk normality test showed that fracture toughness of laser-MIG hybrid welded A7N01P-T4 Al alloy joints is extremely

reliable.

**Key words:** laser-MIG hybrid weld; A7N01 Al alloy; micro-zone tensile; fracture toughness

### Numerical analysis of elimination stainless steel welding residual stress by over load tension

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**Abstract:** The lumen parts of sterilizer pressure vessels are generally welded by austenitic stainless steel and there will be serious stress corrosion that caused by the common action by the welding residual stress and corrosion medium. Over load method can be used to reduce the residual stress. The finite element method (FEM) and experiment are adopted to quantitatively analyze the effect of over load tension on residual stress. At first, SYSWELD software is used to calculate the welding residual stress contour, and then Nastran software is used to simulate the over load tension process to investigate the variation of the residual stress. The simulation results show that with the increase of tensile strain, the maximum values of welding residual stress were reduced dramatically, and the welding residual stress contours become more uniform. However, once the value of tensile strain exceeds a certain critical value, the effect of reducing welding residual stress turn to being gradually weakened. The simulation results were agreed well with X ray measurement results, which shows that this method is feasible. Such research methods and results will provide reference for the elimination of welding residual stress and welding quality control.

**Key words:** austenitic stainless steel; welding residual stress; over load tension; numerical analysis

### Effect of ultrasonic impact treating on the fatigue properties of MB8 magnesium alloy butt joint

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**Abstract:** Surface treatment was carried out on the weld toe of welded butt joint of MB8 magnesium alloy with HJ-III type ultrasonic impact machine. The comparative fatigue test both for treated and un-treated specimens were carried out using EHF-EM200K2-070-1A type electro-hydraulic servo fatigue machine. The microstructure in the top surface layer of weld toe was characterized by means of optical microscope (OM) and transmission electron microscopy (TEM). Experimental results indicate that when the fatigue life is  $2 \times 10^6$ , the fatigue strength of treated specimen is 52.8 MPa, the strength has been increased about 37.5%. Compared to the un-treated specimen, the fatigue life of treated specimen has been increased 58-65 times. After impact treating, the stress concentration has been decreased, the severe plastic deformation in the surface of weld toe was formed, the thickness of the plastic deformation layer is about 70 μm, and the nano-grains were obtained on the treated surface. The tensile welding residual stresses can be reduced significantly, even change to compressive stresses. The fatigue life of MB8 magnesium alloy can be greatly improved by the ultrasonic impact treatment.

**Key words:** ultrasonic impact treating; magnesium alloy; butt joint; fatigue life