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**Code:** Q322

## MAIN TOPICS, ABSTRACTS & KEY WORDS

### **Effect of Weld Interface on Time— dependent Fracture Mechanics Parameters**

TU Shan-dong (Department of Mechanical Engineering, Nanjing University of Chemical Technology, Nanjing, China), GONG Jian-ming, LING Xiang, p1 ~ 5

**Abstract:** The basic assumption in the derivation of the high temperature fracture mechanics parameters is the homogeneity of materials. However, the material inhomogeneity introduced by welding is inevitable in engineering practice. How to characterize the creep crack growth with appropriate fracture mechanics parameters is rather challenging to the structural integrity assessment in the presence of weld interface. The influence of material mismatch on the stress field and the time-dependent fracture mechanics parameters of uniaxial welded specimens is studied in the present paper. The applicability of conventional  $C^*$  equation based on the load line displacement is reexamined. It is found that under the extensive creep condition  $C^*$  value of hard weld/soft parent metal specimen can be significantly higher than that of single weld metal specimen, and the material mismatch has little influence on  $C(t)$  in small scale creep in the studied cases. It is proposed that the  $C^*$  formula based on the load line displacement recommended by ASTM E1457 needs to be modified to interpret the creep crack growth (CCG) behavior of welded specimens.

**Key words:** material mismatch; time-dependent fracture; weld; creep crack growth; testing standard

### **Acquisition of Molten Pool Resonance in TIG Welding with Fluctuant Frequency Current**

YANG Chun-li (National Key Laboratory of Advanced Welding Technology, Harbin Institute of Technology, Harbin, China), HE Jing-shan, WANG Qi-long, ZHOU Tao, p 6 ~ 9

**Abstract:** This paper developed an experimental system based on arc light sensing. The molten pool is excited into oscillation by fluctuant welding current with linear increasing frequency in both stationary and traveling TIG welding of thin steel plate. When the frequency of external exciting current is equal to the natural frequency of molten pool, molten pool resonance happens. The amplitude of oscillating signal is acquired by arc light sensor. The feature signal of molten pool oscillation is then detected which is identified as reso-

nance signal and can be used to estimate molten pool size in real time. This research approach paves a new way for solution of penetration control in travelling TIG welding.

**Key words:** fluctuant frequency current; molten pool resonance; TIG welding

### **Effect of Aluminium on Properties of Self-shielded Flux-cored Wire**

WEI Qi (Beijing Polytechnic University, Material School, Beijing, China), HU Qiang, JIANG Jian-min, LIU Jian-ping, p10 ~ 13

**Abstract:** The effect of aluminium on the pore sensitivity, microstructure, mechanical properties and inclusion of the deposited metal were studied by changing the amount of aluminium powder in the flux core and the aluminium content in the steel sheath of the self-shielded flux-cored wire. The results show that with the increasing amount of the aluminium powder in the flux core of the wire, the content of oxygen and nitrogen in deposited metal and pore sensitivity of weld reduce obviously, but the content of aluminium and amount of inclusion in the deposited metal increase and the microstructure of deposited metal is deteriorated seriously, the toughness of the deposited metal goes down. When using the aluminium contained steel sheath, the harm of aluminium to the properties of deposited metal can be limited to some extent.

**Key words:** self-shielded flux-cored wire; aluminium; pore sensitivity; property

### **Numerical Model Method for Statistic Distribution of Ductile Fracture Toughness**

LIU Min (Nanjing University of Aeronautics and Astronautics, Nanjing, China), CHEN Shi-xuan, HUO Li-xing, ZHANG Yu-feng, p14 ~ 17

**Abstract:** Based on the experiment measuring principle of ductile fracture toughness, a numerical model method was promoted for statistic distribution of ductile fracture toughness in this paper. Because this method can deal with the effect of random factors on ductile fracture toughness very well and produce the large number sample of  $J_{1c}$  easily, the more accurate statistic distribution and parameters of ductile fracture toughness can be obtained by the manner. Meanwhile the method also analyzes the sensitivity of sample number.

The calculation results of S316L weld metal shows that the numerical model method is simple, effective and applicable. The sensitivity analyses demonstrate that the number of sample affects greatly the accuracy of statistic distribution and parameters of ductile fracture toughness in weld metal. When the sample number of the  $J_{1c}$  is less the more error well appear.

**Key words:** fracture toughness; numerical model; weld metal; statistic distribution

**De-noising in Electric Signals of Arc Welding Process via Wavelet Soft-threshold** XUE Jia-xiang (South China University of Technology, Guangzhou, China), ZHANG Xiao-nan HUANG Shi-sheng, p18~21

**Abstract:** During the practical measuring of the electric signals of CO<sub>2</sub> welding, the noise always can't be avoided. De-noising is a key link in analyzing signals. Wavelets have good time-frequency characteristics. The signals can be decomposed into different frequency components with different wavelet scales. For continuous signals, wavelet transform coefficient will increase in direct ratio with the scale. For noise, the coefficient will decrease in inverse ratio with the scale. On the basis of the principle, noise may be removed from original signal. The de-noising via wavelet soft-threshold is emphatically analyzed in this paper. The de-noising results of three kinds of methods for the practically measured electric signals of arc welding process are given out. De-noising by the traditional low pass filter and wavelet crude filter, the signals will show serious distortion in the breaking position. De-noising via wavelet soft-threshold can keep the break position of signals out of distortion as well as eliminate the noise in the signals. So this method can improve the effect of extracting the characteristic information from the signals.

**Key words:** electric signal; wavelet transform; soft-threshold; de-noising

**Design of Task-level OLP System for Arc Welding Robot** TIAN Jin-song (National Key Laboratory of Advanced Welding Production Technology, HIT, Harbin, China), WU Lin, DAI Ming, p22~25

**Abstract:** A structure of task-level OLP system is presented for arc welding robot, which consists of a modeler, a task programmer, a task planner and a robot motion simulator. We put forward a kind of classification for the features of welded structures, and on the foundation of AutoCAD14, using the technique of ObjectARX, develop the feature modeler for welded structures whose style is identical to the one of AutoCAD14. The synergetic expert system based on the combination of cases and rules is introduced to develop the task planner. Moreover, on the basis of 3DS MAX software, the essential robot motion simulator is developed with the language of MaxScript. The experiment shows that for some weld parts, efficient task-level OLP can be accomplished with our system.

**Key words:** arc welding robot; OLP; task-level; expert system

**Joining Tungsten Alloy-molybdenum Layered Flier-plates by Hot-press Sintering** SHEN Qiang (State Key Laboratory of Advanced Technology for Materials Synthesis and Processing, Wuhan University of Technology, Wuhan, China), WANG Chuan-bin, ZHANG Lian-meng, p26~28

**Abstract:** By inserting a mixture of W-Wo powders between the tungsten

alloy plate and molybdenum plate, a kind of layered flier-plate (LFP) with high parallelism and excellent densification was fabricated by hot-press sintering at 1573 K. Using sintering additives 4Ni-3Cu, dense W-Mo alloys can be achieved and the bonding of W to Mo was accomplished simultaneously. The mechanism of densification of W-Mo alloys and interfacial joining of this LFP was then investigated. It was found that at the sintering temperature, some sintering activator Ni could exist in liquid form due to the addition of Cu. This strengthened the sintering action of Ni on W and Mo, and thus enhanced the densification of W-Mo alloys. At the same time, liquid appeared at both interfaces of W/W-Mo and W-Mo/Mo during the sintering process which resulted in the diffusion of W and Mo through the interfaces by liquid and finally the joining of the tungsten alloy-molybdenum LFP.

**Key words:** tungsten alloy-molybdenum layered flier-plate; hot-press sintering; interfacial joining

**A New Residual Stress Reducing Method — pulsed Magnetic Treatment** TANG Fei (Department of Mechanical Engineering, Tsinghua University, Beijing, China), LU An-li, FANG Hui-zhen, LUO Xiang-jun, p29~31

**Abstract:** Pulsed magnetic treatment is a entirely new non-heating method to reduce residual stresses. The tests show that properly strongly pulsed magnetic treatment can lead to stress relaxation in both rigid restrained tensile specimen and welded specimen. Especially, the longitudinal and the transverse residual stress distributions indicate a feature of whole reduction. In addition, the number of time of magnetic treatment has the influence on the effects.

**Key words:** residual stress; welding; magnetic treatment; stress relaxation

**Ultrasonic Peening Equipment Used for Improving Fatigue Strength of Welded Joints** WANG Dong-po (Tianjin University, Tianjin, China), HUO Li-xing, CAI Guo-yu, ZHANG Yu-feng, p32~35

**Abstract:** It's a new method to increase fatigue strength of welded joints and structure by peening toe of weld with ultrasonic peening equipment. In this paper we have researched the ultrasonic peening equipment and a new ultrasonic peening prototype was manufactured. The prototype was fitted with the ultrasonic power supply which can be used specially for ultrasonic peening equipment of the kind of piezoelectric ceramics. The new idea has been held out to keep the output amplitude in constant so as to control the quality of ultrasonic peening. Accurate frequency tracing has not only been realized successfully under the situation that the peening load varies strongly, but the quality and efficiency of the ultrasonic peening and safety of the equipment system has been ensured as well.

**Key words:** fatigue strength; ultrasonic peening welded joints; equipment

**Simulated Stress-strain Distributions for Weld Metal Solidification Cracking in Stainless Steel** WEI Yan-hong (National Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin, China), LIU Ren-pei, DONG Zu-jue, p36~38

**Abstract:** This paper has simulated the driving force of solidification

crack of stainless steels, namely the stress-strain field in the trail of molten-weld pool. Firstly, the effect of the deformation in the molten-weld pool was eliminated after the element rebirth method was adopted. Secondly, the influence of solidification shrinkage was considered by increasing thermal expansion coefficients of the steels at elevated temperature. Finally, the stress-strain distributions of different conditions have been got and analyzed. Furthermore, the driving force curves of the solidification crack of the steels have been obtained by converting strain-position curves into strain-temperature ones which found a basis for predicting welding solidification crack.

**Key words** welding solidification crack; welding solidification crack driving force; stress-strain field; numerical simulation

#### A Direct Assessing Method of Heated Widths During Local PWHT

WANG Jian-hua (Shanghai Jiao tong University, Shanghai, China), LU Hao, Hidekazu Murakawa. p39 ~ 42

**Abstract** Local postweld heat treatment (local PWHT) is usually performed for tempering and relaxation of residual stresses. Many factors have an influence on PWHT procedures and the heated width is the most important parameter controlling the effectiveness of local PWHT. However, the determination rules of this parameter are very different in the different codes. In this study, a direct method to assess the effectiveness of local PWHT was used based on the thermal-visco-elastic-plastic FEM with the consideration of creep phenomena. This method clearly shows the whole history of stress relief during PWHT and a critical heated width can be obtained. The pipe with original welding residual stresses is analyzed under different conditions of PWHT. Investigations show that the maximum residual stress after PWHT decreases when the heated width increases. When the heated width becomes large enough, the residual stress after PWHT changes very slowly and a critical heated width can be found which gives a residual stress close to the value obtained from the uniform PWHT. A series of different PWHT conditions are studied to find the critical heated width by using this method. It is found that a heated area of  $5\sqrt{r_0q}$  centered on weld seems reasonable from the view of stress relief.

**Key words** postweld heat treatment; residual stress; heated width; finite element method

#### Influence of Processing Parameters on Geometrical Features of Powder Feeding Laser Cladding

ZHANG Qing-mao (The Quartermaster University of PLA, Changchun, China), LIU Xi-ming, WANG Zhong-dong, GUAN Zhen-zhong. p43 ~ 46

**Abstract** The influences of laser processing parameters with auto-feeding on the geometrical features of cladded coating by cladding Ni60A powders on steel Q235 plate have been investigated. The rules of the combined parameters (such as laser energy density  $P_w$ , interaction time  $T$ , powder feeding rate and scanning speed  $V_s$ ) on the sizes of the coatings have been emphatically discussed. In order to express the relationship between the processing parameters and the macroquality of cladded coating, the equation expressing the relationship between the covering rate and the processing parameters was derived. By varying the powder feeding rate and scanning speed under definite

laser power and beam spot dimensions, coatings with different thickness were obtained. The covering rate was calculated approximately based on metallographical measurement. The results show that the cross-section  $S$ , width variable and contact angle are mainly controlled by the laser energy density and interaction time, they all become larger with the increase of laser energy density and interaction time.

**Key words** metallographical measurement; laser energy density; covering rate

#### J-Integral of Surface Crack in Overmatched Joint

LI Ji-hong (The Institute of Welding, Xi'an Jiaotong University, Xi'an, China), ZHANG Jian-xun, PEI Yi. p47 ~ 50

**Abstract** The part-through surface cracks exist widely in practical welded structure, and the investigation of the elastic-plastic fracture mechanics parameters (eg.  $J$ -integral) of this three-dimensional mechanical heterogeneity is not enough. In this paper, the  $J$ -integral of surface cracks in overmatched weldment with different matching ratios has been investigated by using direct evaluation method. The influences of matching ratio of joints on the crack driving force ( $J$ -integral, crack mouth opening displacement CMO) and strain distributions along the contour have been discussed in detail. The results indicate that the comprehensive effect of crack position and the matching ratio of welded joint dominate the distribution of strain. With the increasing of load, the obvious strain concentration may be produced in the parent metal zone close to weld. Moreover, with the decreasing of the matching ratio, the degree of the strain concentration grows, the deformation of weld metal decreases to a certain extent, and the crack driving force increases.

**Key words** welded joint; surface crack;  $J$ -integral

#### Analysis of Metal Transfer and Usability of High Cellulose Electrode

LIU Hai-yun (Taiyuan University of Technology, Taiyuan, China), WANG yong, WANG Bao. p51 ~ 54

**Abstract** By using high-speed photographic method and usability experiments, the metal transfer form and usability of high cellulose electrode have been analyzed. The results show that the metal transfer forms of high cellulose electrode contain spray transfer, explosive transfer and short circuiting transfer. The spatter forms include big and small droplet spatters. The transfer and spatter of big droplets show obviously periodic characteristic, and the small droplet spray transfer and spatter exist through whole welding. Strong and regular spray transfer form is advantageous to the usability. The big droplet spatter is the main reason for bad usability, e.g. low deposition efficiency, unstable arc etc., and it should be analyzed and prevented further.

**Key words** high cellulose electrode; metal transfer; usability

#### Discuss on Principle of Relieving Welding Residual Stress

WANG Zhe-chang (Institute of Metal Research, Chinese Academy of Sciences, Shenyang, China). p55 ~ 58

**Abstract** According to traditional viewpoint, for the mechanical stress relieving method, the low temperature stress relieving method, the rolling stress relieving method and Low-Stress Non-Distortion Welding Technology,

the residual stress relieving principle is to compensate the compressive plastic strain in the weld with tensile plastic strain which is produced in the welding process. In this paper, a new stress and strain developing process is given. The weld metal always bears tensile stress and there is no compressive plastic strain being produced in the welding process. In the brittle temperature zone, the maximum tensile stress appears in the fusing line and it decreases sharply far from the fusing line. The stress-relief principle is to reduce or eliminate elastic strain with plastic strain. In general case, the principle is to reduce or eliminate the original tensile elastic strain with tensile plastic strain. In this paper, the principle of all kinds of residual stress relieving methods is also discussed. It also is satisfactorily interpreted why the transverse liquation crack appears in the adjacency to fusing line and it is very short.

**Key words:** welding residual stress; stress relieving; plastic strain; elastic strain; liquation crack

#### Investigation of an Engineering Simplification Approach for LOP's $J$ -integral Calculation

MENG Xiang-feng (Ocean University of Qingdao, Qingdao, China), WANG Wei-qiang, ZHANG Xua-li, GUO Jian-zhang, p59 ~ 62

**Abstract:** The lack of penetration (LOP) is a very common type of discontinuities in welds, so that how to simplify it more scientifically and reasonable and therefore to conduct its fracture analysis are a problem continuously interested to engineering and academic circles. In this paper, several common root shapes were chosen among the photos of LOP's root profiles and five typical sorts of notches with regular root shapes were obtained after some extent simplification to the LOP's root shapes. Based on this, the elastic-plastic finite element method was adopted in the paper. The finite element calculations were conducted by taking the geometrical shapes and sizes of notch root as parameters and a series of  $J$ - $L_r$  curves were gotten. Through analyzing the curves, the main factors influencing the value of  $J$ -integral can be found, they were the notch width or the notch root curvature and the shapes of notch, and finally the root shape with the maximum  $J$ -integral value was derived to be the flat end shape. Therefore, the values of LOP's  $J$ -integral can be calculated simply and conservatively by adopting the notch with a flat end proposed in this paper, and furthermore the engineering calculations of LOP's  $J$ -integral values can be realized.

**Key words:** lack of penetration;  $J$ -integral; finite element analysis; engineering simplification method

#### New Model Cu-Ni Alloy PTA Surfacing Material and Its Corrosion Resistance

Ji Jie (Tianjin University, Tianjin, China), ZHANG Wen-yue, ZHANG Shu-sheng, LIU Li, p63 ~ 66

**Abstract:** By putting some alloy elements into white copper B30, through weldability examination, static corrosion trial and polarized curve test, a kind of corrosion resistance alloy powder to be used for plasma surfacing has been studied and prepared. The reason of reducing the corrosion-resisting property of the white copper alloy B30 after adding alloy elements has been also investigated by means of SEM, AES, XPS.

**Key words:** Cu-Ni alloy; powder plasma arc surfacing; corrosion

**Infrared Telecontrol of IGBT Arc Welding Inverter** PI You-guo (The Automation Engineering E/R Center of Guangdong Academy, Guangzhou, China), HU Dao-ming, HUANG Shi-sheng, p67 ~ 69

**Abstract:** The design of infrared telecontrol IGBT converting welder is presented in this paper and the designs of the system, power circuit, infrared system hardware and software are presented in detail also. The controlled distance is as far as 10 meters and the control scope is as wide as  $\pm 45^\circ$ . The welder has its output current 250 A, both good static and dynamic characteristics and can stably work in welding workshop.

**Key words:** infrared telecontrol; converting welder; IGBT

#### Switching Welding Power Source Controlled by Microcomputer

WU Wan-hua (Shanghai Jiaotong University, Shanghai, China), YAO Shun, YU Hai-long, p70 ~ 73

**Abstract:** The paper introduces the real value of the switching power source designed by authors and the systemic analysis of the principle and constitution of the power supply including the microcomputer controlling system. The authors put forward some viewpoints about the new welding power source. The power source which is controlled by the microcomputer system in this paper adopts the giant transistor (GTR), and have it work in both the condition of "on" and "off". Therefore, it overcomes lower efficiency of analogue transistor power source and keeps a stable operation state. In the meantime, the power source makes use of single chip microcomputer controlling technology and realizes the function of previous setting up the welding parameters. This power can also modify the welding voltage  $U_f$  through feedback controlling so that gets constant voltage characteristic.

**Key words:** microcomputer control; switching type; pulse width modulation

#### Measuring Normal Deformation Produced by Residual stress in Friction Welding Joint Using Double-exposure Holography

LIU Xiao-wen (Northwestern Polytechnical University, Xi'an, China), DU Sui-geng, LIU Xiao-zhong, WANG Guo-zhi, p74 ~ 76

**Abstract:** The principle of measuring normal deformation of the surface of friction welding joint is analyzed. When the experimental system meets some conditions, the interferometric fringe obtained from double-exposure hologram reflects the amplitude of normal deformation. In experiment, a Q-switched ruby laser is used as light source, and a double-exposure hologram of friction welding joint is obtained. In this paper, the holographic interferometric fringe is collected through a CCD image process system and stored into computer. After using computer to process these data, the amplitude of normal deformation of the surface of friction welding joint is obtained.

**Key words:** double-exposure holography; friction welding joint; normal deformation

#### Rotational Regression Experimental Study on High Velocity Arc Sprayed Stainless Steel Coatings

TIAN Bao-hong (Surface Engineering Research Institute CMES, Beijing, China), XU Bin-shi, MA Shi-ning, LIANG Xiur

bing, p77 ~ 80

**Abstract** A comparative study of porosity, oxide contents, bond strength and wear resistance of 3Cr13 stainless steel coatings deposited by high velocity and regular arc spray processes was carried out. An orthogonal and rotational regression experimental method and an ordinary single-factor experimental method were adopted to evaluate the coating hardness with respect to the effect of processing parameters. The quantitative formula of processing parameters with coating hardness was obtained by means of microcomputer. The results show that, compared with the regular arc spray process, a dense coating with lower porosity, higher bond strength and higher oxide contents were produced by a newly developed high velocity arc wire spray process. The bond strength is higher than 40MPa, which is increased by 52 percent than that of regular arc sprayed coatings. The orthogonal and rotational regression experimental results show that the spray distance and the interaction of spray distance and arc current had significant effects on the coating hardness. The results also indicate a great difference between the orthogonal and rotational regression experiment and the single-factor experiment.

**Key words** high velocity arc wire spray; coating; rotational regression

#### Functions of Output Filter Inductor in CO<sub>2</sub> Gas Shielded Arc Welding

**Inverter** HUANG Peng-fei (Beijing Polytechnic University, Beijing, China), LU Zhen-yang, CHEN Shu-jun, YIN Shu-yan, p81 ~ 84

**Abstract** The functions of the output filter inductor in inverter CO<sub>2</sub> gas shielded arc welding machine is studied. Based on theory analysis the method that electronic inductor takes the place of the traditional inductor is given out. Demonstrated by calculation and related experiments, the paper puts out conditions that limit the minimization of filter inductor, the results indicate that the functions of the filter inductor in inverter are different from those in traditional welding machine. Excellent dynamic characteristics can be achieved by using electronic inductor, the filter inductor has little effect on short circuit current or arc energy, but it is important for inhibiting the over current at the beginning of the short circuit which will lead to big spatter. Small inductor will also result in arc going out at the beginning of the short circuit or arc burning.

**Key words** CO<sub>2</sub> gas shielded arc welding; electronic inductor; filter inductor

#### Multi-sensor Information Fusion and Control of Robot Spot Welding

CHANG Yun-long (Shenyang Polytechnic University, Shenyang, China), XUE Jia-xiang, HUANG Shi-sheng, p85 ~ 89

**Abstract** Spot welding quality is always one of questions under study, to which many welding scholars in the world devote themselves. It has not been solved satisfactorily at present. The complex nature of spot welding process, undeterminedness of grown nugget and singleness of control method decide that stabilizing quality is a much difficult task. The limitations of describing

how the nugget growing up in view of single-sensor information source is analyzed in the paper. An idea of using multi-sensor information fusion for spot welding quality control is presented for the first time. The information fusion model for weld spot nugget is established through parameter selecting and characteristic information extracting. Heat and time adjustment of spot welding process are made through the best fusion arithmetic adapting combined-average and decision-making methods. The spot welding experiments indicate that the new quality control method can better compensate various factors influence in the welding process and assure the spot welding quality stabilization.

**Key words** robot spot welding; information fusion

#### Arc Spraying Coating and Its Sliding Wear Behavior

LUO Hong

(BTC Corporation, Beijing, China), p90 ~ 93

**Abstract** The arc spraying coating and its tribology property are investigated in this paper. The binding force of the coating grain of steel consists of the mechanical force and the molecular force etc. The structure of boundary of coating grain is the oxide of iron and the micro-cavity. The binding force between the coating grains of QA19-2 consists of micro-welding and so on. Owing to the existence of micro-hole in the coating of arc spraying, the excellent property of friction and wear can be obtained, especially under the condition of a rapider sliding speed. The wear mechanism of coating of steel is the stripping wear of coating grain.

**Key words** arc spraying; coating sliding wear

#### Diffusion Welding Cu to $\alpha$ -Al<sub>2</sub>O<sub>3</sub> with Nb Film Interlayer

LIU Wei-ping

(Dept of Materials Science and Engineering, Dalian Railway Institute, Dalian, China), G. Eksner, p94 ~ 96

**Abstract** The diffusion welding behavior of single-crystalline Cu to single-crystalline  $\alpha$ -Al<sub>2</sub>O<sub>3</sub> with a Nb film interlayer and the joint microstructure properties were studied by TEM, SEM/EDS analyses and four-point bend testing. The Nb film interlayer deposited by electron beam evaporation on the ceramic side prior to diffusion welding was found to be polycrystalline and fiber-textured after diffusion bonding, with the close-packed plane (110) being parallel to the (0001) basal plane of  $\alpha$ -Al<sub>2</sub>O<sub>3</sub>. The fracture energy of Cu/ $\alpha$ -Al<sub>2</sub>O<sub>3</sub> diffusion-welded joints was greatly increased by the introduction of the thin film Nb interlayer whereas diffusion welding can be performed at a relatively low temperature (900°C). The increase in fracture energy of the joints with Nb film interlayer was attributed to the strong adhesion of Nb to  $\alpha$ -Al<sub>2</sub>O<sub>3</sub> combined with larger plastic deformation in the metal side during fracture. TEM observations showed large amounts of dislocations existing at the interfacial regions.

**Key words** ceramic-metal joining; diffusion welding; interface structure; fracture energy