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Influence of laser energy input mode on joint interface characteristics in laser brazing with Cu-base filler metal

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Abstract: The flange butt joints of 1 mm-thick galvanized steel sheets were brazed with CuSi3 as filler metal at different laser heating modes. The microstructures and element distributions of joint interface were investigated by SEM and EDS. The results show that there is no obvious interface layer with the circular individual beam heating and lamellar Fe-Si intermetallic compound layer is found with dual-beam laser spot heating. With the irradiation of rectangular laser spot, the joint interface layer is also formed. The layer thickness is larger than that of dual-beam brazing and the layer shape is flat so that intermetallic compounds trend to grow into cellular crystals. Moreover, the interface layer shape also depends on its position in the joint. Under the high heat input, dendritic or granular intermetallic compounds dispersively distribute in brazing seam adjacent to the interface, which is caused by the melting or dissolving of the base metal. According to the results, the brazing quality can be controlled by laser heating mode and processing parameters.

Key words: laser brazing; interface characteristic; laser energy input mode; weld; galvanized steel

1 Introduction

Welding of galvanized steel sheet presents considerable difficulties because of the existence of Zn coat with low melting point and vaporization temperature [1−3]. The development of laser brazing method improves welding efficiency and joint qualities, such as joint strength, porosity, weld appearance and corrosion resistance[4−5]. In laser brazing, the great temperature gradient is obtained due to the rapid heating and low heat input. And the short existing time of melting filler metal on the surface of base metal can lead to some problems in wettability and spreadability of the filler material, and interface reaction between liquid brazing alloy and base metal.

Cu-base brazing alloy is often used as filler material in brazing process of galvanized steel sheets, including CuSi3, Cu3Si1Mn and 56Cu8Mn26Zn[6]. In Metal Inert-gas Arc Welding (MIG) brazing with CuSi3, the concentration of element Si at the joint interface was found, and Fe_2Si and Fe_5Si_3 intermetallic compounds layer was considered to form at the interface[7−9]. Zn-Al brazing alloy with lower melting point was also used as filler metal in order to protect Zn coat[10−12]. Higher joint strength with Cu-base brazing alloy can be obtained, but the process requires more rigorous brazing parameters. Improving the laser energy input mode to obtain the good interface combined with the protection of Zn coat adjacent to the brazing seam is the research focus in laser brazing.

In traditional laser brazing process, joint quality is completely dependent on the processing parameters, such as laser power and brazing speed. With the development of laser beam shaping technology, the control of laser power intensity spatial distribution in brazing process is possible, which may improve the brazing quality and extend welding conditions[13−15]. In this study, a CO_2 laser beam is formed into circular individual beam spot, dual-beam spot and rectangular spot, which provide different laser power density spatial distributions. With the irradiation of the three laser heat flux intensity, the brazing process is performed and the characteristics of joint interface, element distributions at the interface and the relationship with laser power density distribution are

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analyzed.

2 Experimental

CuSi3 wire was used as filler metal. The wire diameter is 1 mm and the compositions of the filler metal are listed in Table 1.

Table 1 Compositions of CuSi3 filler metal (mass fraction, %)

Si	Mn	Fe	Zn	Al
2.8−4.0	0.5−1.5	<0.3	<0.2	<0.01
P	**Pb**	**Sn**	**Cu**	
<0.02	<0.02	<0.2	Bal.	

Galvanized steel sheets were applied as base metal. The sheet thickness is 1 mm and Zn-coat thickness is 0.75 μm. The galvanized steel sheets were assembled as flange butt joints that were often used in the automotive industry. Fig.1 shows the sketch of laser brazing process.

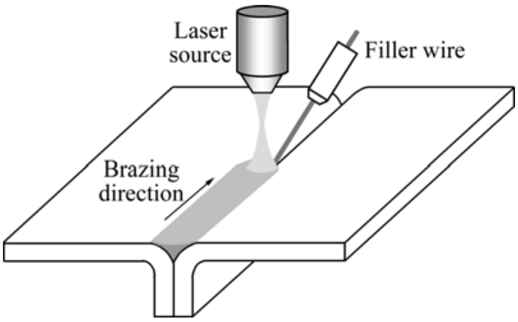

Fig.1 Sketch of laser brazing with filler wire

A 3 kW CO_2 slab laser was employed as brazing heat source. Circular individual laser beam with Gaussian energy density distribution was formed by a parabolic mirror and dual-beam spot was formed by a splitter mirror in which the focus distance of the two laser beams was 2 mm. Integrating mirror was applied to obtain the rectangular beam with the laser spot dimension of 2 mm ×4 mm. The sketch of energy density distribution of the three beam modes is shown in Fig.2.

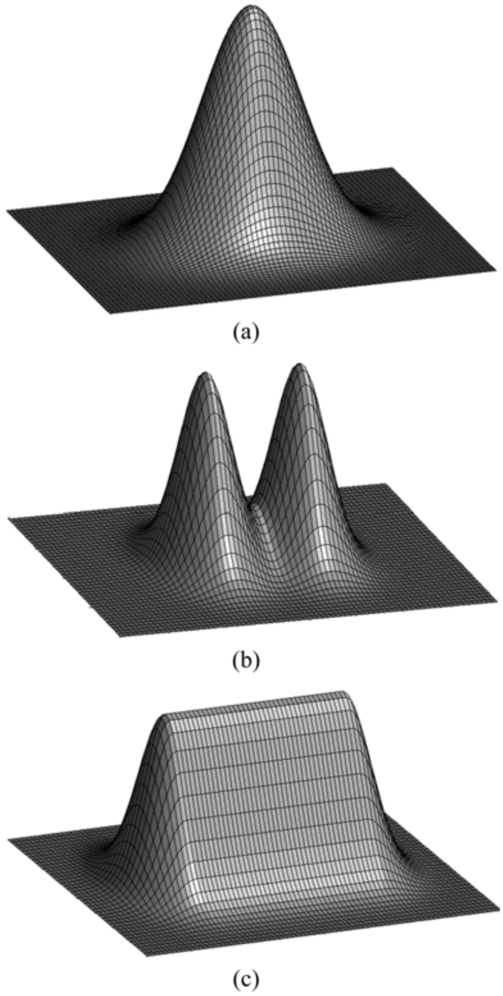

Fig.2 Laser power density distribution of three beam modes: (a) Circular individual beam spot; (b) Dual-beam spot; (c) Rectangular spot

3 Results and analysis

In laser brazing with filler wire, different laser spot power density distributions correspond to different processing parameters. And the experimental results indicate that the brazing process shows the corresponding characteristics with the change of laser beam energy spatial distribution. So, by comparing brazing effect of the three laser heating modes, the processing parameters are selected, in which the process is stable and good brazing seam appearance is obtained. Aimed at the joint interface characteristics, the influence of the three laser beam power density distributions on the brazing process is investigated.

3.1 Joint interface with circular laser spot heating of individual beam

Fig.3 shows the SEM images of the joint interface with the irradiation of individual laser beam. In these images, the left side is brazing seam, *P* represents laser power, and *v* is the brazing velocity. Fig.3(a) shows the sketch of observation interface position, Figs.3(b) and (c) show the interface of position A in different processing parameters. Figs.3(d) and (e) show the interface at position A and B, respectively, in the same joint. From Fig.3, it can be found that for individual beam heating, there is no obvious intermetallic compound interface layer and the interface transition region width grows with the increase of heat input. When brazing heat input is larger, at the upper part of the joint, the local base metal begins to melt (Fig.3(d)). At the same time, the interface reaction is still not sufficient at the joint bottom (Fig.3(e)).

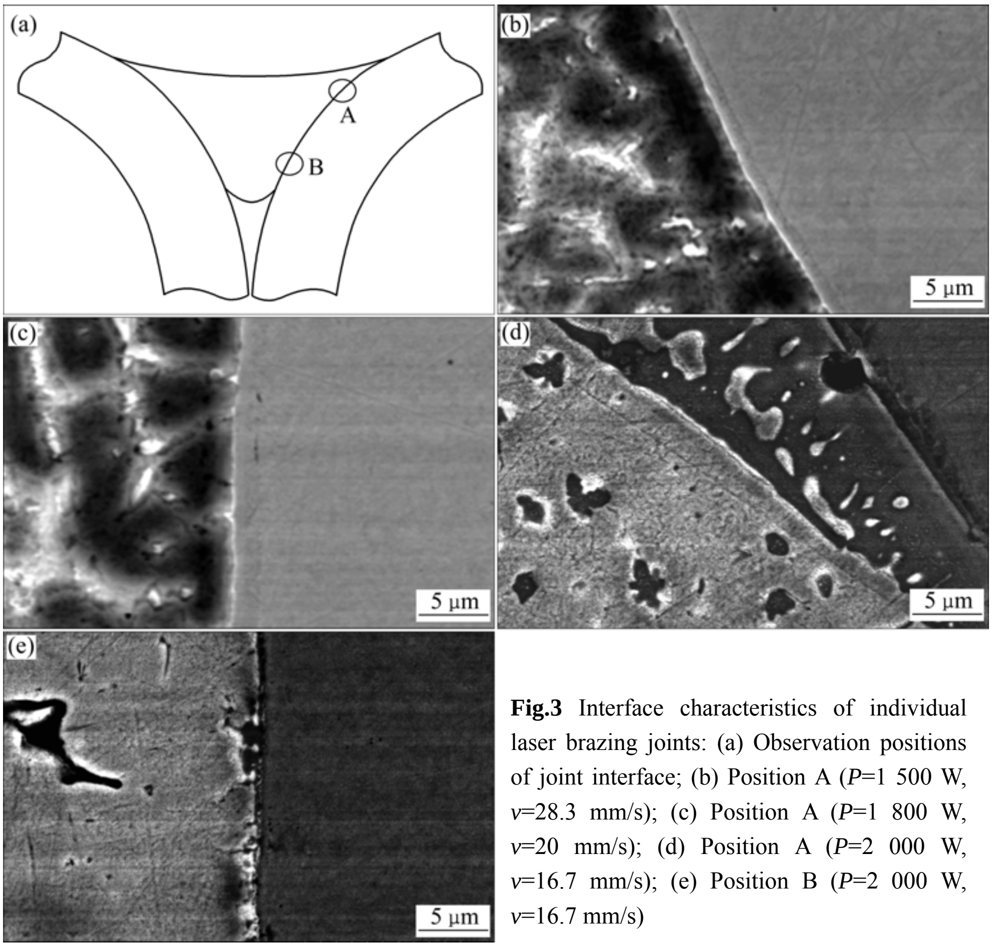

Fig.3 Interface characteristics of individual laser brazing joints: (a) Observation positions of joint interface; (b) Position A (*P*=1 500 W, *v*=28.3 mm/s); (c) Position A (*P*=1 800 W, *v*=20 mm/s); (d) Position A (*P*=2 000 W, *v*=16.7 mm/s); (e) Position B (*P*=2 000 W, *v*=16.7 mm/s)

It can be concluded that with the heating of individual laser beam, the brazing joint interface is not homogeneous.

For CO_2 laser beam with low power, the power density distribution of the beam spot is often considered to be Gaussian distribution, which means that there is great temperature difference between spot center and edge. Compared with dual-beam spot and rectangular beam spot at the same brazing velocity, the heating time of individual beam spot is short. And in this process for Si element in the filler metal, there is no enough time to diffuse to the interface and there is no obvious intermetallic compound layer at the interface. The EDS results of the element distribution show that element Si segregates at the joint upside interface only when the heat input is large. Moreover, as shown in Fig.3(d), granular intermetallic compounds dispersively distribute in brazing seam adjacent to the interface when the base metal begins to melt slightly.

3.2 Joint interface with dual-beam laser spot heating

Figs.4 and 5 show SEM micrographs and element distributions at upside interface of dual-beam brazing joint, and in these graphs, left side is base metal.

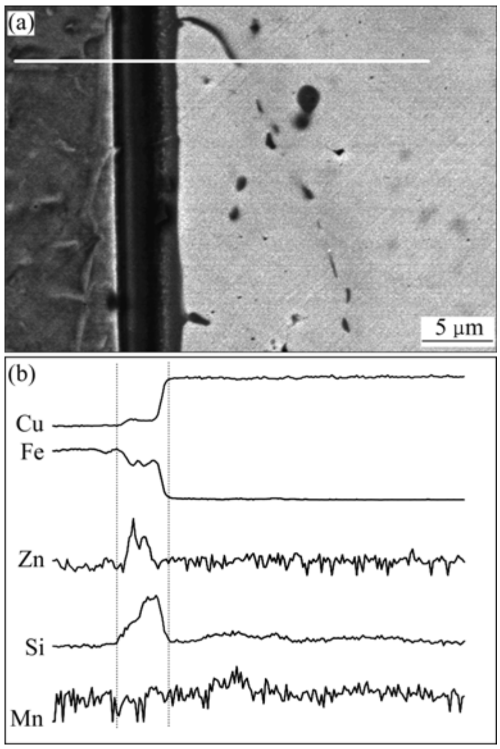

Fig.4 Characteristics of dual-beam brazing joint (*P*=850 W, *v*=6.7 mm/s): (a) Joint interface and EDS scanning position; (b) Element distributions

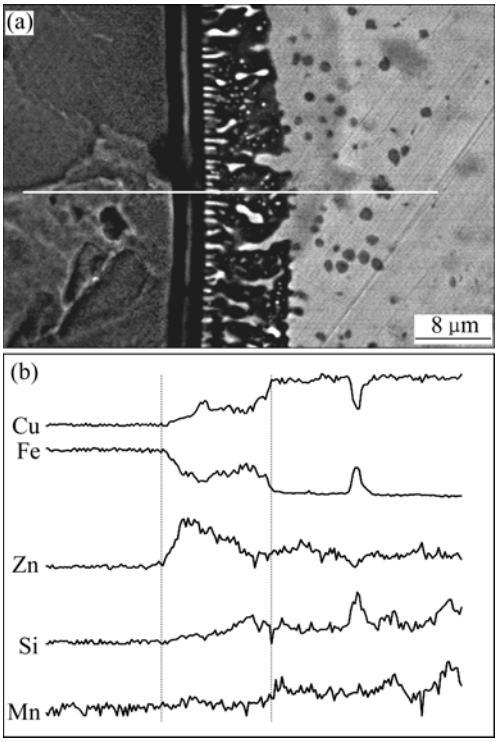

Fig.5 Dual-beam brazing joint interface characteristics (P=2 000 W, v=16.7 mm/s): (a) Joint interface and EDS scanning position; (b) Element distributions at interface

In Fig.4, it can be found that obvious interface layer is formed when the laser power is minor (P=850 W). The burning loss of Zn-coat is not complete, and elements of Zn and Si concentrate at the interface. With dual-beam spot irradiating, the heating length in brazing direction is extended, which means that the time of the filler metal in high-temperature region increases and Si can diffuse to the interface to form intermetallic compound layer with element Fe. However, because the heat input is low at 850 W, high temperature gradient is obtained at the interface. In this situation, only the plane Fe-Si(Cu) intermetallic compound layer can be formed. At the joint bottom, the interface layer with smaller thickness is also found, which can improve the joint bottom combination quality to a certain extent.

Fig.5 shows the joint interface characteristics with larger laser power (P=2 000 W). It can be found that the base metal begins to melt slightly. Because of the melting or dissolving of the base metal, element Fe can enter into the brazing seam and react with element Si, which is responsible for the appearance of intermetallic compounds in the filler metal. But in short heating time, the compounds can't grow up and the shape is granular.

3.3 Joint interface with rectangular beam spot heating

Compared with circular individual beam, the laser energy density distribution of rectangular beam spot is more homogeneous and the heating area is larger, which is beneficial to the combination of filler metal and base metal. Fig.6 shows the typical rectangular beam brazing joint interface characteristics at different joint positions.

In Fig.6, it can be found that the intermetallic compound layer is formed both at upper part and bottom of the joint. And at the bottom of joint, the combination of filler metal and base metal is satisfactory. As for the interface layer shape, at position A, base metal melts slightly (Fig.6(b)). At position B, the interface layer shape is flat, on which the intermetallic compounds occasionally grow into the melting filler metal and have the trend of forming cellular crystals. This phenomenon may be induced by the great temperature gradient when the melting filler metal begins to contact with cold base metal. In the initial solidifying stage, the interface layer at position B grows in the flat shape due to the great temperature gradient. With the heating of laser, the temperature gradient at the interface decreases, and Si element in the filler metal adjacent to the interface is deficient because of the combination of Fe and Si. When Fe element exists, the crystallization temperature of Fe-Si intermetallic compound based solid solution increases with the increment of Si concentration. So, at the interface of position B, the constitutional undercooling region at growth front appears, in which the Fe-Si intermetallic compound layer can grow into the melting filler metal occasionally. However, because of the high cooling speed, this growth is not sufficient before the filler metal solidifies. And the final layer shape is formed and shown in Fig.6(c).

At position C of joint bottom (Fig.6(d)), with the low peak temperature of filler metal, high temperature gradient and cooling velocity, the interface grows in the flat shape and the layer thickness decreases. Furthermore, as shown in Figs.6(b) and (c), the intermetallic compounds dispersively distribute in brazing seam adjacent to the interfaces, which is also considered to be related with melting or dissolving of base metal. The EDS analysis was carried out to obtain the components of positions A and B as shown in Fig.7 and the results are listed in Table 2.

It can be found from Table 2 that, compared with the situation at position A, the dispersive black substance at position B enriches in Fe and Si and its phase composition can also be considered as Fe-Si(Cu) intermetallic compounds. At the upper part of the joint, the quantity of the intermetallic compounds is plentiful, and scarce at the joint bottom. Moreover, at the upside of the joint, the shape of intermetallic compounds in the filler metal is dendritic, while at the joint bottom the compound shape is granular or small dendritic. This phenomenon is due to the more time that the filler metal

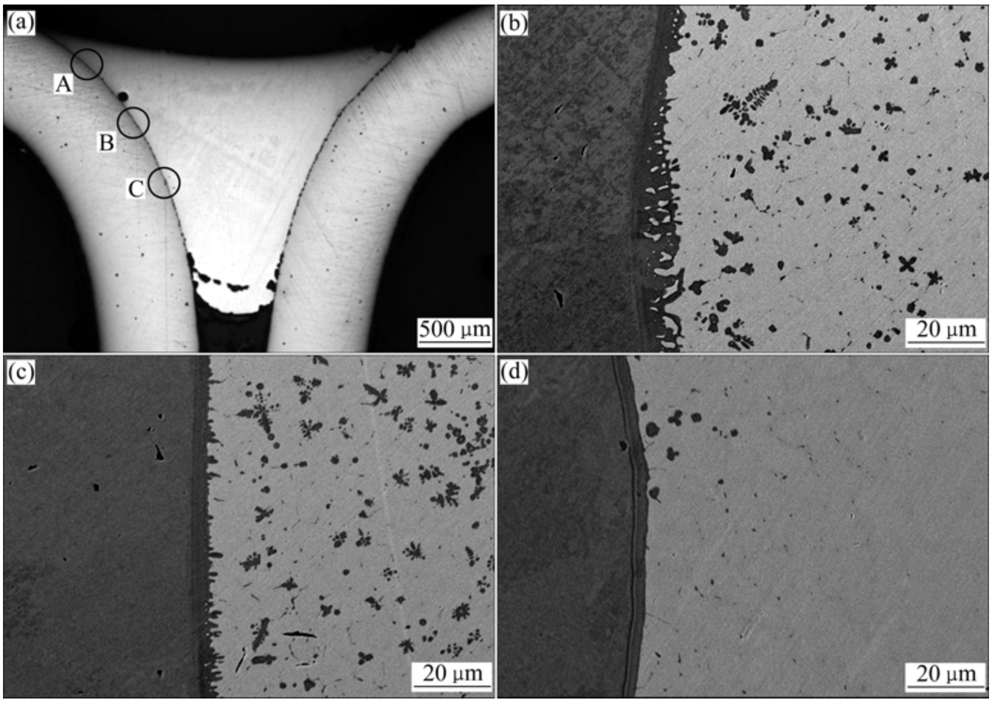

Fig.6 Morphologies of interface of rectangular beam brazing joint (*P*=1 500 W, *v*=5.8 mm/s): (a) Observation positions; (b) Position A; (c) Position B; (d) Position C

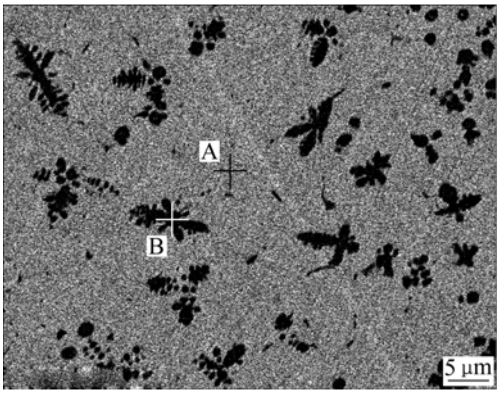

Fig.7 EDS analysis at different positions in filler metal

Table 2 Compositions of positions A and B in Fig.7 (mass fraction, %)

Position	Cu	Fe	Si	Zn
A	88.63	2.78	1.71	5.71
B	70.97	19.20	4.69	3.87

of the joint upside in melting stage and growth of the compounds. At the joint bottom, the speed of filler metal solidification is high and the intermetallic compounds have no time to grow up.

4 Conclusions

1) Through the selection of laser spot power density distribution, the interface reaction in galvanized steel sheets laser brazing process can be controlled.

2) With the circular individual laser beam heating, there is no obvious intermetallic compound layer at joint interface. Lamellar intermetallic compound layer forms in dual-beam brazing process. With the irradiation of rectangular beam, on the flat interface layer, the intermetallic compounds occasionally grow into the melting filler metal and have the trend of forming cellular crystals.

3) Interface reaction is related with not only brazing parameters but also joint position. When the rectangular laser beam with long heating time in brazing direction is employed as brazing heat source, the interface reaction at the joint bottom can be strengthened.

4) With larger heat input, granular or small dendritic intermetallic compounds dispersively distribute in brazing seam adjacent to the interface, which is induced by Fe entering into the brazing seam and melting or dissolving of the base metal.

References

[1] HEINRICH H. MIG-brazing of galvanized thin sheets and profiles [J]. Schweissen-Schneiden, 1998, 50(6): E102−E104.

[2] BELKACEM B. Low-heat process enhances joining of coated sheet metals [J]. Welding Journal, 2003, 82(1): 26−30.

[3] BERGMANN J P, WILDEN J, DOLLES M. Working zinc-coated steels and making steel-aluminium alloy joints using high power lasers-brazing and braze welding [J]. Welding International, 2006, 20(1): 37−44.

[4] HANEBUTH H, HOFFMANN P, GEIGER M. Laser beam brazing

using the twin spot technology [C]// Proceedings of the International Society of Optical Engineer. Vienna, Austria, 1994: 146−153.

[5] FENG Xiao-song, LI Li-qun, CHEN Yan-bin, ZHOU Shan-bao. Laser brazing with filler wire for galvanized steel sheets [J]. China Welding, 2005, 14(1): 9−14.

[6] YU Zhi-shui, QIAN Yi-yu, WANG Feng-jiang, QI Kai, LI Xiao-quan. Joint strength and fracture analysis of arc brazing with Cu-base filler metals [J]. Chinese Journal of Mechanical Engineering, 2001, 37(10): 88−92. (in Chinese)

[7] YU Zhi-shui, ZHOU Fang-ming, QI Kai, WU Ming-fang. Fracture behavior analysis of MIG brazed joint with Cu-Based filler metals [J]. Transactions of the China Welding Institution, 2001, 22(6): 29−32. (in Chinese)

[8] LI Rei-feng, YU Zhi-shui, QI Kai. Interfacial structure and joint strengthening in arc brazed galvanized steels with copper based filler [J]. Trans Nonferrous Met Soc China, 2006, 16(2): 397−401.

[9] YU Zhi-shui, LI Rei-feng, QI Kai. Growth behavior of interfacial compounds in galvanized steel joints with CuSi3 filler under arc brazing [J]. Trans Nonferrous Met Soc China, 2006, 16(6): 1391−1396.

[10] WILDEN J, BERGMANN J P. Low temperature brazing of zinc coated steel [C]// Brazing, High Temperature Brazing and Diffusion Welding. Aachen, Germany, 2004: 217−222.

[11] WILDEN J, BEEFMANN J P, DOLLES M. Use of zinc-alloys for low temperature soldering of zinc coated steels [C]// Sheet Metal 2005/Proceedings of the 11th International Conference on Sheet Metal. Eriangen-Nuremberg, Germany, 2005: 127−134.

[12] MATHIEU A, SHABADI R, DESCHAMPS A, SUUERY M, MATTEI S, GREVEY D, CICALA E. Dissimilar material joining using laser (aluminum to steel using zinc-based filler wire) [J]. Optics & Laser Technology, 2007, 39(3): 652−661.

[13] SAIDA K, SONG W, NISHIMOTO K. Laser brazing phenomena of heat-resistant alloys with brazing filler metals [J]. Materials Science Forum, 2007, 539(4): 4053−4058.

[14] LI L. The advances and characteristics of high-power diode laser materials processing [J]. Optics and Lasers in Engineering, 2000, 34(4/6): 231−253.

[15] LAUKANT H, WALLMANN C, KORTE M, GLATZEL U. Flux-less joining technique of aluminium with zinc-coated steel sheets by a dual-spot-laser beam [C]// Sheet Metal 2005/Proceedings of the 11th International Conference on Sheet Metal. Eriangen-Nuremberg, Germany, 2005: 163−170.

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