Mechanism of laser welding on dissimilar metals between stainless steel and W-Cu alloy

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CO_2 laser is employed to join a piece of powder metallurgical material (PMM) to a stainless steel in butt joint welding mode. The powder Ni35, as a filler powder, is used. The weld metal comes from three parts of stainless steel, powder Ni35, and Cu in W-Cu PMM. It is indicated that some parts of the W-Cu base metal are heated by laser and the metal Cu at the width of 0.06—0.12 mm from the edge is melted into the melting pool in the laser welding process. The formation of firm weld joint is just because that the melting liquid metal could fill the position occupied by metal Cu and surround the metal W granules fully. The analysis results indicate that the mechanism of the laser welding for stainless steel and W-Cu alloy is a special mode of fusion-brazing welding.

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The powder metallurgical material (PMM) is made by pressing and sintering process after mixing refractory, noble metals with other metals or the metals of non-wetted with each other. For the joining of PMM and other metals, some conventional non-fusion welding techniques, such as the brazing, the diffusion welding, and the friction welding, were used. A conventional fusion welding processing could hardly weld them reliably due to their big different properties referred to melting point, boiling point, heat expansion, and heat transfer coefficient[1−3].

Laser welding has attracted more and more attention in recent years on industrial application due to its special features such as small heat-affected zone (HAZ) and narrow weld bead due to the low heat input, welding at high speed, welding can be carried out in area of difficult access, contactless energy transfer, and welding in an exact and reproducible manner[4]. Laser welding of dissimilar metals in fusing welding mode has also been a topic of interest recently[5]. The data for laser welding between cemented carbides and steels show that the mechanism is laser dip soldering in which the metal liquid of melted steel would wet the cemented carbides[6]. In the present study, a high power CO_2 laser is employed to join a piece of PMM to a stainless steel. The joints are produced in two modes, the welding of laser scanning on the plate and with filler powder. The interfacial microstructure and metal elements distribution between the welded metal and PMM side are examined in order to explore the mechanism of laser weldings of PMM and stainless steel.

In the experiment, the materials are W-Cu PMM with the size of $20\times12\times1.2$ (mm) and 18-8 austenitic stainless steel with the size of $200\times12\times1.2$ (mm), whose chemical compositions are listed in Table 1. W-Cu alloy, as a kind of PMM, is just the material that the elements of W and Cu in the alloy are non-wetted each other at all, whether in the liquid or the solid states. We join the two metals reliably in butt joint welding mode in the cross-section of 12×1.2 (mm). The filler powder is powder Ni35 with the diameter of $0.06-0.04$ mm, whose chemical compositions are listed in Table 1. It is well know that the filler material used in the welding of dissimilar metal plays a very important role in making a successful joint. The reasons that the powder Ni35 is chosen as the filler material are: 1) to reduce the requirements for fit-up tolerance for laser welding; 2) to make it possible to join both W-Cu PMM and austenitic stainless steel because Ni35 powder could wet not only stainless steel and Cu but also refractory metal W; 3) to have a very similar melting temperature (less than 1100 °C) with metal Cu (1083 °C) and better fluidity because of a bigger liquid-solid phase temperature region; 4) to reduce the hot-cracking sensibility in austenitic stainless steel weld bead, through metal Cu dissolved in the austenitic stainless steel; 5) to improve the stress distribution of welding joint because of the high toughness of weld bead.

Laser welding was performed using the fast axial flow CO_2 laser (made in Trumpf) with a continuous power output up to 6 kW and a mode of TEM01*. The powder delivery adopted twin powder feeder and a home-made special powder feeder nozzle in order to keep the accuracy and homogeneity of feeding powder. Welding parameters and results are given in Table 2. The metallographic samples were prepared by standard processes including grinding, polishing, and etching. Optical microscopy, scanning electron microscopy (SEM) and energy dispersive X-ray analysis (EDX) were used to analyze major alloying elements.

Table 1. Chemical Compositions of the Base Metals and the Powders (wt.-%)

	C	Mn	Si	Cr	Ni	Fe	B	W	Cu
1Cr18Ni9	< 0.12	< 2.0	< 1.0	17 − 19	8 − 11	Balance	–	–	–
W-Cu FMM	–	–	–	–	–	–	–	80	20
Ni35	0.15	–	2.8	10	Balance	< 14	2.1	–	–

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Table 2. Laser Welding Parameters and Weld Results

Weld	Power (kW)	Speed (m/min)	Powder Feed Rate (g/min)	Powder Feed Gas (m^3/h)	Shielding Gas (m^3/h)	Result
A1	2000	2	24	0.4	0.4	Lack of Penetration
C1	2200	2	24	0.4	0.4	Lack of Penetration
F1	2500	2	–	–	0.4	Bad Shape of Surface
F2	2500	2	24	0.4	0.4	Smooth Surface

From Table 2, we can see that the filler powder (F2) with the power of 2500 W is the best choice for obtaining smooth surface of the weld in the condition of butt joint without a gap between two workpieces. The lack of penetration becomes the main defect when the laser power is lower than 2500 W because of insufficient energy input. Bad shape of the weld surface is given when laser welding is operating without filler powder, despite the other parameters are just the same as those of filler powder F2.

In the process of the laser welding with powder, the laser energy is used to melt both powder and substrate. Because the base metal consists of two kinds of metals with different properties especially some heat physical properties, the position of laser spot becomes a very important parameter in the welding of dissimilar metals. The proportion of the energy used in melting two different parts was tested and confirmed experimentally in order to meet their different demands for laser energy. The physical properties of some elements are listed in Table 3, and the results in different conditions are shown in Table 4. From it, we can see that the successful laser welding is only from the No. 2 because of the suitable heat distribution in the two parts of the sample. The others are failed owing to their bad connection qualities.

The microstructures of stainless steel side and weld part in the welding joint of No. 2 are shown in Fig. 1. A good connection quality appears with the normal microstructure characteristics in the joint. The SEM micrograph of W-Cu side at the same welding joint are shown in Fig. 2. Figure 2(b) shows the main chemical compositions, Fe-Cr-Ni-Si and a little Cu, of a white cross mark

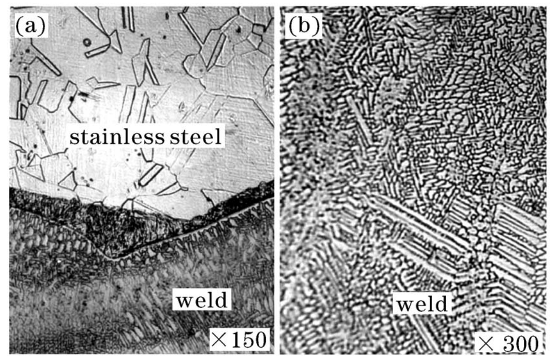

Fig. 1. Microstructures of the welding joint of the weld No. 2. (a) Stainless steel side; (b) weld part.

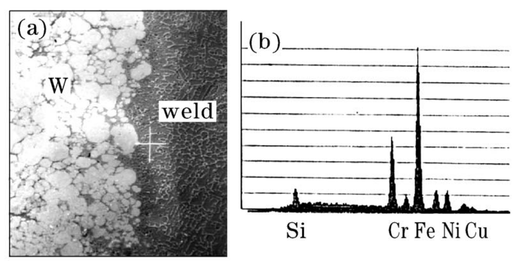

Fig. 2. (a) SEM micrograph of the welding joint of the weld No. 2; (b) spectrum of white cross mark in Fig. 2(a) by EDX.

Table 3. Physical Properties of Some Elements

Metal	Density (kg/m)	Melting Temperature (°C)	Boiling Temperature (°C)	Thermal Conductivity (W/(m·K))	Thermal Expansion Coefficient ($\times 10^{-6}$ K^{-1})	Specific Heat Capacity (J/(kg·K))
W	19.3	3380	5900	152.9	4.6	138
Cu	8.9	1084	2578	359.2	16.6	386
Fe	7.8	1537	2875	66.7	11.76	456
Ni	8.9	1435	2834	69.6	13.4	452

Melting temperature of Ni35 < 1100 °C.

Table 4. Results with Different Areas of Laser Spot

Weld	Power (W)	Proportion of Area of Laser Spot (%)		Result
		1Cr18Ni9	W-Cu FMM	
1	2500	20	80	Cracking Near and Parallel to Weld in HAZ
2	2500	40	60	Successful
3	2500	60	40	Lack of Penetration on the Side of W-Cu FMM
4	2500	80	20	Lack of Melting on the Side of W-Cu FMM

in Fig. 2(a) by EDX. In order to identify the function of the element Cu in the laser welding process, the composition of the weld detected with some other points by EDX was just the same with that of Fig. 2(b). It means that the weld metal comes from three parts of stainless steel, powder Ni35, and Cu in W-Cu PMM.

The fine characteristics of W-Cu side in the welding joint of No. 2 are shown in Fig. 3. It shows the white parts (metal W) near the weld and the deep color part surrounding them. Figure 3(b), by EDX at four white cross marks in Fig. 3(a), points out that the composition of the deep color part is the same with that of Fig. 2(b). It means that the deep color part is formed by melting liquid metal in laser welding. Further experiments prove that the melting liquid metal moves into the W-Cu base metal up to 0.06—0.12 mm. It is indicated that some parts of the W-Cu base metal are heated by laser and the metal Cu at the width of 0.06—0.12 mm from the edge in this area is melted into the melting pool in the laser welding process. The forming of firm weld joint is just because that the melting liquid metal could fill the position occupied by metal Cu before and surround the metal W granules fully. Owing to a very similar melting temperature, the wetting ability with metal Cu and metal W, and better fluidity, powder Ni35 could make it possible in the freezing process of the puddle.

It can be unpuzzled, based on the above-mentioned analysis, that both welds No. 3 and 4 are failed due to insufficient laser heating on the side of W-Cu PMM. The weld No. 1 is failed from the influence of overheating on the side, and more metal Cu, more than the width of 0.06—0.12 mm, was melted in the experiment. Subsequently, the melted metal Cu was so much that some of metal W granules were in isolated fettle with each other because the melting liquid metal could not fill in the interspace among the metal W granules and surround them instead of metal Cu. As a bad result, a narrow break-strip along the weld edge and parallel with the weld comes into being. Figure 4 shows the fracture position (the right part) at the narrow strip.

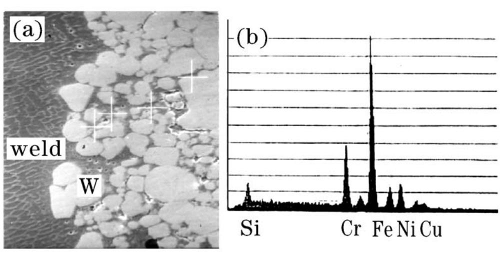

Fig. 3. (a) SEM micrograph of fine characteristics of the welding joint of the weld No. 2; (b) spectrum of four white cross marks in Fig. 3(a) by EDX.

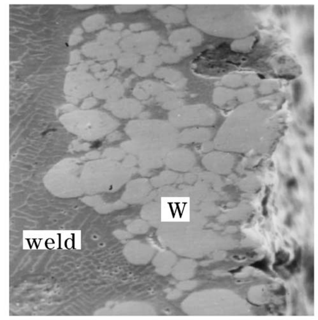

Fig. 4. SEM micrograph of fracture position of the welding joint.

In summary, laser welding with nickel based filler powder demonstrates advantages for the connection between the dissimilar metals of stainless steel and W-Cu alloy. The analysis results indicate that the mechanism of the laser welding for stainless steel and W-Cu alloy is a special mode of fusion-brazing welding.

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References

1. F. M. Hosking, J. J. Stephens, and J. A. Rejent, Welding Journal **78,** 127 (1999).
2. A. I. Koruk, N. Akdut, L. Cretteur, and G. Julian, in *Proceedings of the First International WLT Conference on Lasers in Manufacturing* 638 (2001).
3. Z. Liu and K. Liu, *Guidebook on Welding of Dissimilar Metals* (in Chinese) (China Machine Press, Beijing, 1997).
4. Z. Sun and J. C. Ion, J. Mater. Sci. **30,** 4205 (1995).
5. Z. Sun and T. Moisio, J. Mater. Sci. Lett. **13,** 802 (1994).
6. N. Tian and Q. Zheng, Chin. J. Lasers (in Chinese) **23,** 381 (1996).