Study of technique and performance of laser beam welding for W18Cr4V and 65Mn

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In this experiment, we used 7-kW continuous wave (CW) CO_2 low order mode laser and YAG impulse laser to deeply weld high-speed steel (W18Cr4V) and spring steel (65Mn). To welded joint, we analyzed its microstructure, micro hardness and fracture appearance for different welding technology by metallography microscope, scanning electron microscopy and bending strength test, discussed its action of fracture and the relation between its structural transformation and strength. At last, we offered an optimum welding technology having no welding defect by the comparison and analysis of processing property.

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Laser welding is one of the laser processing techniques that develop faster in recent years. The mechanical properties of layer are no worse than parent material. This is a great process of welding qualities[1]. Both high-speed steel (W18Cr4V) and spring steel (65Mn) are high-carbon steel. They are uneasy to be welded. Their linear expanding coefficients and physical properties are different. When we weld these two types of steel, the flaws are easily formed in the welding zone. Especially, if two types of steel are quenched or tempered, the welding will be more difficult. So the traditional welding methods are unfit for welding this kind of high melting point metal. However, it is convenient to weld them using laser beam. Compared with the traditional welding method, laser welding has some good qualities such as small heat affected zone, clean, high welding speed, slight hot deformation. The high strength welding of heterogeneous materials become possible using laser beam.

To welded joint formed by the fusion of high-speed steel and spring steel which was quenched and backfired, we analyzed its microstructure, microhardness and fracture profile for different welding technology, discussed its action of fracture and the relation between its structural transformation and strength, offered a new way to weld these two types of materials. It has directive significance to butt sheet, for example, it can be successfully used in making plastic shaping blades.

The sample in this experiment is a kind of cutting tools used to cut plastic. The toolbit is made of high-speed steel (W18Cr4V), its sectional dimension is $40\times10\times1.5$ mm^3, its hardness is 62HRC. The knife-blade is made of spring steel (65Mn), the sectional dimension is $150 \times 40 \times 1.5$ mm^3, its hardness is 47HRC. To joint two metal materials, we adopted the technique which is called butt welding using laser beam.

The welding was conducted using a 7-kW crosscurrent and continuous wave (CW) CO_2 laser system. We used TEM_{01} low harmonic module, used argon as protecting gas and measured the torsional moment of postweld blade using torsion meter.

We analyzed the metallography microstructure of welded joint using metallography microscope, tested the microhardness of welded joint using micro hardness instrument and analyzed the fracture profile of bending fracture using scanning electron microscopy.

Fixing other conditions, we compared the different weld performance of having transition-layer (1Cr18Ni9Ti) and no transition-layer. The results are shown in Table 1.

For sample 13#, the bending fracture happened at the weld side of bond line of the high-speed steel. For sample 18#, the bending fracture happened in the heat affected zone near the weld of high-speed steel.

From Table 1, we can see the accession of transition-layer has increased the torsional moment of welded joint by 30%. It is because the accession of transition-layer decreases the hardness of weld.

Adopting a same transition-layer, we compared the weld performance under the condition of preheating and no preheating. The results are shown in Table 2.

Table 1. CO_2 Laser Welding Performance and Transition-Layer

Sample	Power (kW)	Welding Speed (mm/min)	Depart from Focus (mm)	Bend Strength (N/mm^2)	Transition-Layer
13#	1.5	800	−2	542	no
18#	2.0	1500	−1	708	Having

Table 2. CO_2 Laser Welding Preprocessing, Postprocessing and Welding Performance

Sample	Power (kW)	Welding Speed (mm/min)	Depart from Focus (mm)	Bend Strength (N/mm^2)	Warm-up/Backfire Temperature
15#	1.5	800	−2.5	117	Normal Temperature
18#	2.0	1500	−1	708	250/200 °C

Table 3. Techniques and Performance of YAG Laser Welding

Sample	Welding Speed (mm/min)	Voltage (V)	Width of Pulse (ms)	Frequency (Hz)	Depart from Focus (mm)	Warm-up/Backfire Temperature (°C)	Bend Strength (N/mm^2)	Transition-Layer
8#	150	0.5	9	10	−1	250/200	458	no
9#	150	0.5	9	10	−1	250/200	625	Having

From Table 2, sample 18#'s bend strength is higher by preheating 250 °C and postweld backfire 200 °C. We can see that preheating and postweld backfire are necessary for welding. The temperature gradient in welding zone was decreased by preheating. Backfire could get rid of welding stress. They were propitious to decrease the facture trend of weld[2].

Table 3 shows that, we get the reasonable technique by optimization. Compared with CO_2 laser, the YAG laser welding efficiency is lower for low moving speed and double side welding; the bend strength is lower; but it has a narrow heat affect zone and fine welding line.

The microstructures shown in Figs. 1 and 2 are the weld structures near the side of high-speed steel. From these two figures, we can find that the weld structure in Fig. 1 became lathy martensite and residual austenite because of the influence of transition-layer. In Fig. 2, there was no transition-layer. Because of the high carbon content and the alloy element in two parent materials, the weld structure was composed of high-carbon martensite, residual austenite and a lot quantity of carbide.

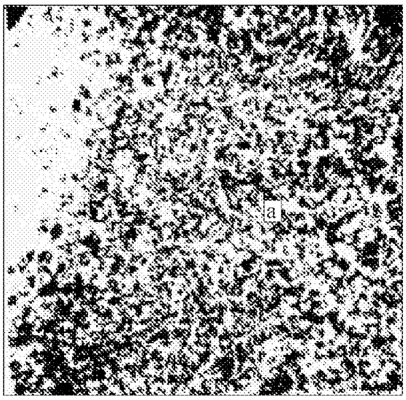

Fig. 1. Metallography microstructure of the 18# weld 400× (a: the zone near the weld of high-speed steel bond line).

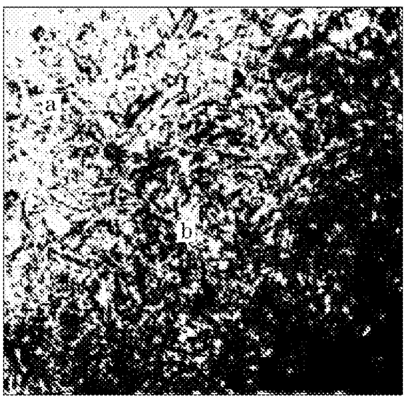

Fig. 2. Metallography microstructure of the 13# weld 400× (a: the zone near the weld of high-speed steel bond line; b: the weld of high-speed steel bond line).

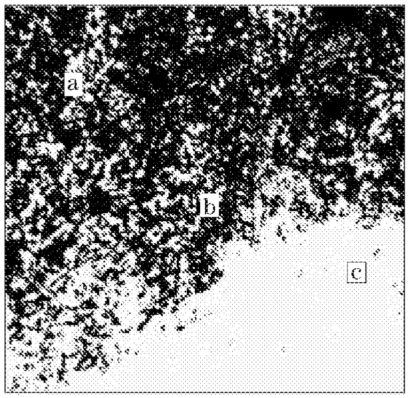

Fig. 3. 18# metallography microstructure 400× (a: the weld of high-speed steel bond line; b: the zone near the weld of high-speed steel bond line; c: the heat affected zone near the weld of high-speed steel).

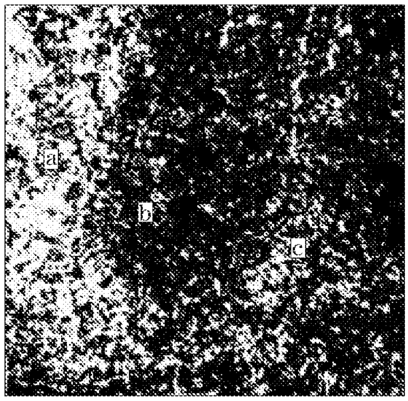

Fig. 4. 13# metallography microstructure 400× (a: the weld of high-speed steel bond line; b: the zone near the weld of high-speed steel bond line; c: the heat affected zone near the weld of high-speed steel).

Figure 3 shows the metallography microstructure around the bond line of high-speed steel welded joint which has transition-layer. The chemical component of transition-layer was different from that of parent material. The element Ni can form non-carbide and prevent carbon element diffusing from molten zone of parent material to molten pool. Because of the laser characteristic of rapid heating and cooling, after freezing, the structure in this zone was mostly high-carbon martensite, residual austenite and carbide.

Figure 4 shows the microstructure around bond line of high-speed steel which has no transition-layer. We did not find the column of crystal which was easily found in formal weld. It was because the carbide in existence prevented the growth of the column of crystal. Besides, W18Cr4V high-speed steel had high carbon content and strong ability of diffusion. The element Cr, V, W decreased the MS point and martensite transition rate, increased the austenite content. Thus, the structure in the zone near the weld of bond line was mostly high-carbon martensite, residual austenite and carbide.

The diffusion of carbon and alloy elements was inevitable since laser processing had the characteristic of rapid heating and cooling. The diffusing distance was about several hundred nanometers[3]. So, there were a lot of carbide at high-speed steel heat affected zone near the weld.

The welding process that does not use transition-layer is called self-fusion welding. Otherwise it will be called filler wires welding. The latter can change the component and structure of the welding zone, decrease the cooling speed and the hardness of joint. So, it also can prevent flaws from coming into being[4].

In Figs. 5 and 6, we can find the hardness of the fusion zone was higher than that of the weld. Especially to sample 13# (or 8#) welded joint without transition-layer, around the line of fusion, the hardness of the weld side was even higher than that of the zone close to weld. At the phase of molten pool, the carbon element diffused and exchanged between the liquid metal and parent material of the incomplete molten zone especially at the molten crystal boundary. At the molten pool phase and high temperature phase after freezing, the carbon content decreased in the zone of some width which was close to the line of fusion in the incomplete molten zone. In laser welding process, because the post weld cooling speed was very fast, the diffusing distance of carbon element was short. Carbon concentrated in the weld zone around the line of fusion. A large quantity of martensite formed in this zone, increased the hardness and strengthened its brittleness. The bending test indicated that the fracture happened in the weld side of high-speed steel.

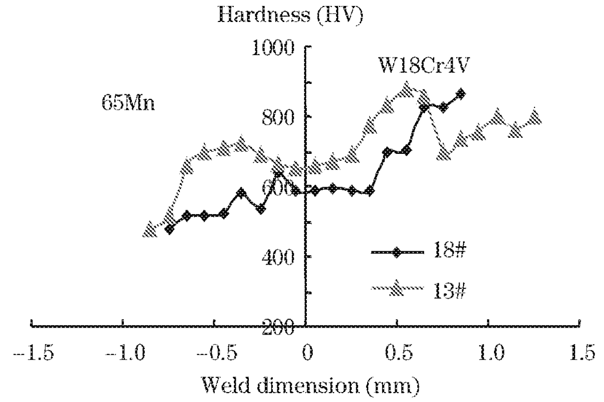

Fig. 5. The hardness distribution of CO_2 laser welded joint.

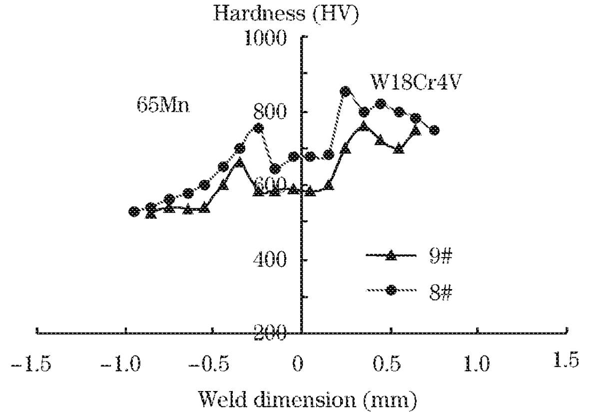

Fig. 6. The hardness distribution of YAG laser welded joint.

To sample 18# (or 9#) joint with transition-layer, the element Ni changed the diffusing characteristic of carbon and blocked the transfer of carbon. At same time, the alloy elements such as W, V decreased the active coefficient of carbon, weakened the transfer of carbon. This led to the higher hardness in the weld side of high-speed steel. But when the weld froze, because of the heat transition, phase transition happened in the heat affected zone, carbon and alloy element separated out from martensite and residual austenite then formed high-degree dispersing carbide. Martensite rehardened and residual austenite requenched. So, around the line of fusion, the hardness of the heat affected zone near the weld was even higher than that in the zone close to weld. Bending fracture often happened in this zone[5].

The welding joint was formed by the direct fusion of two types of steel, high-speed steel and spring steel. All the bending tests indicated that the fracture happened at the weld zone of high-speed steel bond line. The fracture was brittle crack. Because of the welding and the post-weld backfire, the carbon of the heat affected zone close to the fusion zone of high-speed steel moved and formed a carbon enriched layer at the weld side close to the line of fusion. Because there were a large quantity of residual austenite, the fracture profile took on quasi-cleavage crack and non-characteristic crack which can separate out carbide (Fig. 7). So, it belonged to combined crack mechanism.

During the welding procedure, by appending austenite stainless steel between two types of metals, we can decrease the dilution rate of high-speed steel parent material and strengthen the ductility; At same time, the element Ni in the stainless steel prevented carbon diffusing from the side of high-speed steel parent material to transition-layer during the phases of welding and post weld heat treatment. This greatly improved the ductility and toughness of the fusion zone. Thus, the point of fracture appeared in the heat affected zone near the weld of high-speed steel. The fracture profile mostly took on non-characteristic crack, as can be seen in Fig. 8.

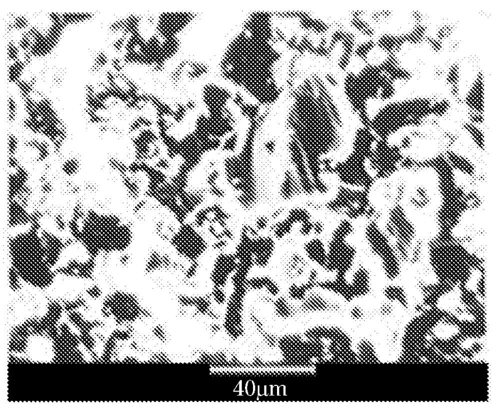

Fig. 7. Sample 13# fracture profile without transition-layer.

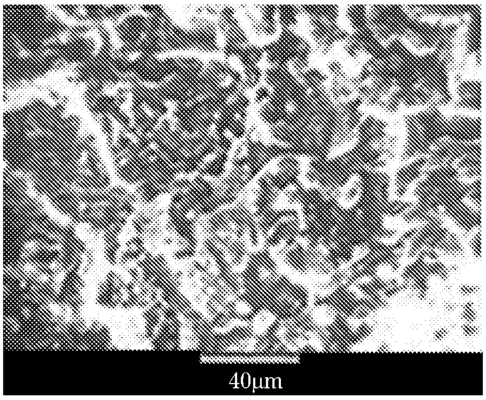

Fig. 8. Sample 18# fracture profile without transition-layer.

In conclusion, we get the following results.

1) Using transition-layer during the welding procedure, we can decrease the weld hardness, improve the ductility and toughness at weld and fusion zone. The strength can increase by 30%. The fracture of welded joint without transition-layer happened at the weld zone of high-speed steel bond line. The fracture profile took on quasi-cleavage crack and non-characteristic crack which can separate out carbide. So, it belonged to combined crack mechanism. The bending fracture of welded joint with transition-layer appeared at in the heat affected zone near the weld of high-speed steel. The fracture profile mostly took on non-characteristic crack.

2) Adopting the techniques of transition-layer, preheating and backfire techniques, the optimizing technique parameter is: 2 kW, 1.5 m/min for CO_2 low order mode laser system; and 9 ms, 10 Hz, 0.5 V, 0.15 m/min for YAG impulse laser. The former has high weld strength and weld efficiency; the later has fine welding line.

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