Study of fiber laser welding for DP980 high strength steel

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Key words: Fiber laser; Laser welding; High strengthen steel

Abstract: Welding experiments of DP980 high strength steel plate with fiber laser have been processed. The influence of welding parameters on welding quality has been investigated. As well as microstructure and mechanical character of welding seam has been analyzed. It is showed that the joint appearance of DP980 high strength steel welded with fiber laser has good performance and the mechanics property is good. The microstructure of weld bead is columnar crystals; Heat-affected zone is narrow and the grain grows with little size; the measured micro-hardness values of the sample decrease smoothly from weld center to base metal.

Introduction

Dual Phase Steel referred to a kind of high-strength steel obtained from low-carbon steel or low carbon alloy steel which has critical section heat treatment or controls a rolling process. Its microstructure contains two metallurgical structures, which one is soft phase that can provide good formability and the other is hard phase to provide material strength. Since the existence of two-phase, dual phase steel has excellent mechanical properties, such as strength, ductility and work hardening ability and so on. At the same time, dual phase steel also has good weldability, moderate hardenability and welding softening insensitivity [1-4]. Therefore, the dual phase steel becomes an important development material in automotive industry.

Recently, researchers have done much about laser welding applications for high strength steel [5-7], and have accumulated some information, but it is not enough still. Therefore, laser welding of high strength steel, especially the welding quality and defect analysis, need further study and research.

In this paper, welding experiments of DP980 high strength steel plate with fiber laser have been processed. The influence of welding parameters on welding quality has been investigated. As well as microstructure and mechanical character of welding seam has been analyzed.

Experimental

The composition of the DP980 steel was showed in Table 1.

Table1 Elements of DP980

Element	C	Si	Mn	P	S
Amount [wt%]	0.14-0.16	0.4-0.6	2.3-2.5	0.01	0.01

The experiment was carried out on a laser machining system YLR-6000 with a capacity of 6000 W. It is multimode fiber laser, and the fiber diameter and the numerical aperture of the processing fiber is 200mm and o.22 respectively which is determining the BPP for the process. The BPP is 8mm.mrad.

The sample was cleaning with acetone before welding, and then was fixed on weld jig, with the fit-up gap less than one-tenth of thickness. Argon was used as protection gas. Welding equipment is shown in Figure 1. Output power welding speed, defocusing distance, shielding gas flow and assembly space, were changed to study the influence of parameters on the welding quality.

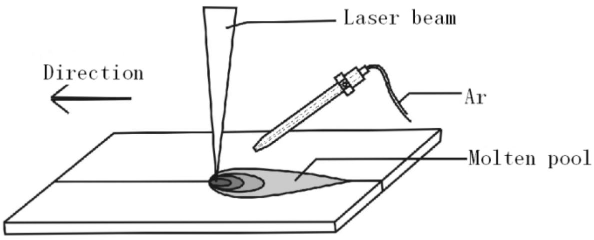
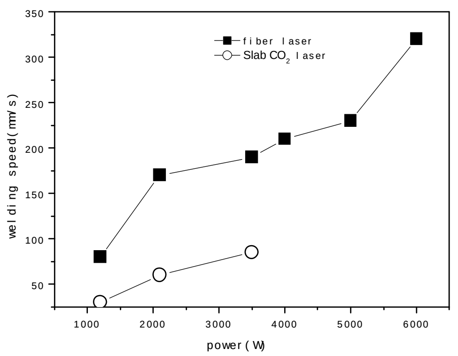


Fig.1 Schematic of laser welding

Results and discussion

Effect of parameter. Effect of power to welding velocity was shown in Figure 2. It can be seen that the welding speed increases with the power. While, as power increases, the impact of the plasma and laser beam on the weld pool stirring increased, so spatter is serious, and weld width increases, even undercut or staying.



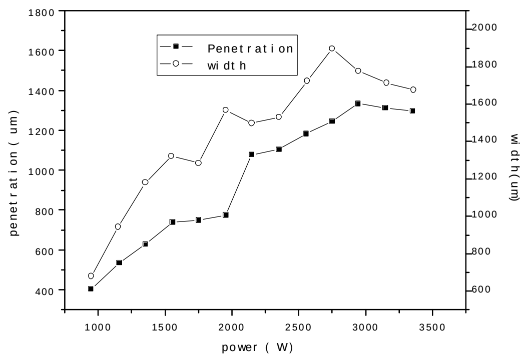


Fig.2 Effect of power to welding velocity Fig.3 Effect of laser power to Penetration and width

Effects of laser power to penetration and width were shown in Fig.3.It can be seen from that penetration increases with the power when laser power is from 1000W to 2000W and here it is main heat conduction welding. Penetration increases suddenly when the power is 2200W. This is because the mode of welding changes into deep penetration welding. A sign of deep penetration welding mode is holes. Absorption of material increases rapidly when holes emerge, which result in more laser energy can be absorbed in unit time and the laser beam irradiation on the bottom of the hole is stronger. All would make the increase of weld penetration. On the other hand, when the power is too high, the laser energy is too strong that can lead to evaporation metal is ionized and the plasma shielding effect to laser is serious [8-10]. Therefore, the weld depth reduced and even the hole collapsed, resulting in the stop of the welding process. Effects of laser power to width are similar to penetration.

Effects of velocity to penetration and width were shown in Figure4. It can be seen from that penetration became shallow as welding speed increased at the same power. Generally, sheets or materials with good weldability should adopt high-speed and thick plate or materials with bad weldability should reduce the welding speed.

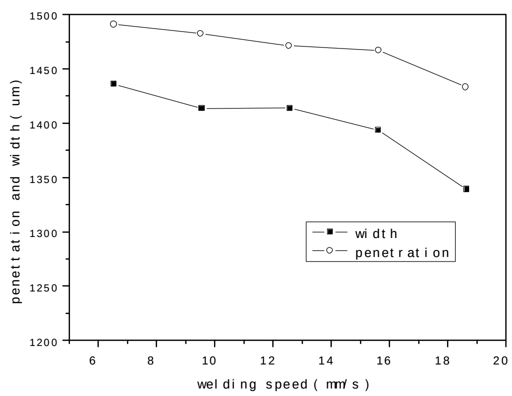


Fig.4 Effect of velocity to Penetration and width

Results of Tensile Test. Tensile test was carried on with loading speed 1mm/min. Strength of weld seam is higher than base metal and the fracture occurred on base metal.

Figure 5 shows the fracture of base metal. It is mainly dimple and a little quasi-cleavage.

The different chemical composition of base metal, such as C, Si, Mn, S, P and so on, can affect the mechanical properties, especially toughness. Carbon equivalent (Ceq), thermal cracking sensitivity(Pcr) and cooling cracking sensitivity(Pcm) were calculated respectively. Ceq of DP980 is 0.54~0.6 which result in poor weldability. Pcr is 0.3965～0.4365, which is greater than the standard value, 0.35. But the contents of Sulfur and Phosphorus are low and Manganese is high which help to inhibit the generation of thermal cracks. Pcm is 0.305, less than the standard value, 0.36. So there is no cooling cracks. Except the chemical composition, welding procedure also can affect the welding results. Weld heat input is the most important parameter. Welding heat cycle change caused by weld heat input will lead to changes of the austenite grain size in joints. At the same time, the structure changed as cooling rate changed. Both impact the toughness.

$$Ceq=C+Mn/6+(Ni+Cu)/15+(Cr+Mo+V)/5\ (\%) \quad (1)$$
$$Pcr=C+0.25S+P/2.5+(Si-0.4)/5+(Mn-0.8)/6+Ni/6+Cu/8+(Cr-0.8)/8\ (\%) \quad (2)$$
$$Pcm=C+Si/30+Mn/20+Cu/20+Cr/20+Ni/60+Mo/15+V/10+5B\ (\%) \quad (3)$$

Microstructure. Fig.6 shows the inclusion in the base metal. It contains a small amount of inclusion. Fig.7 shows the microstructure of the weld center. It can be seen from Figure 7 that the microstructure of weld center is columnar crystals, mainly lath-shaped ferrite, needle-like lower bainite and a small amount of martensite. Fig.8 shows the microstructure of heat affected zone. It can be seen from Figure 8 grain growth of DP980 steel effected by heat cycle is not obvious and the heat affected zone width is very narrow. This is because DP980 steel contains much more Mn and Si elements which can prevent crystal boundary migration effectively. At the same time, compounds Mn-rich and Si-rich can be precipitated in the crystal boundary which also can prevent the diffusion of Fe atoms As a result, fine austenite can be obtained. The width of HAZ is about 130 μm only.

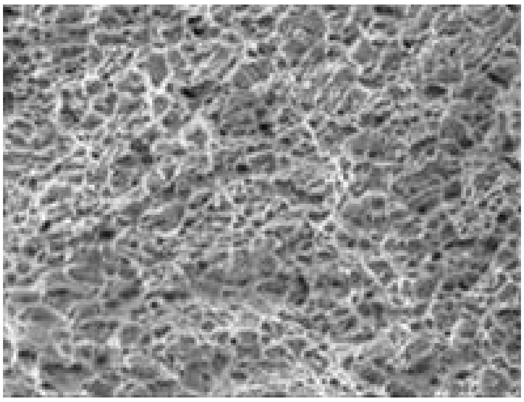


Fig.5 Fractography of base metal

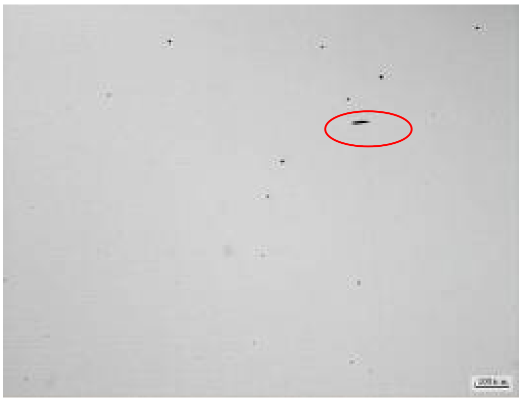
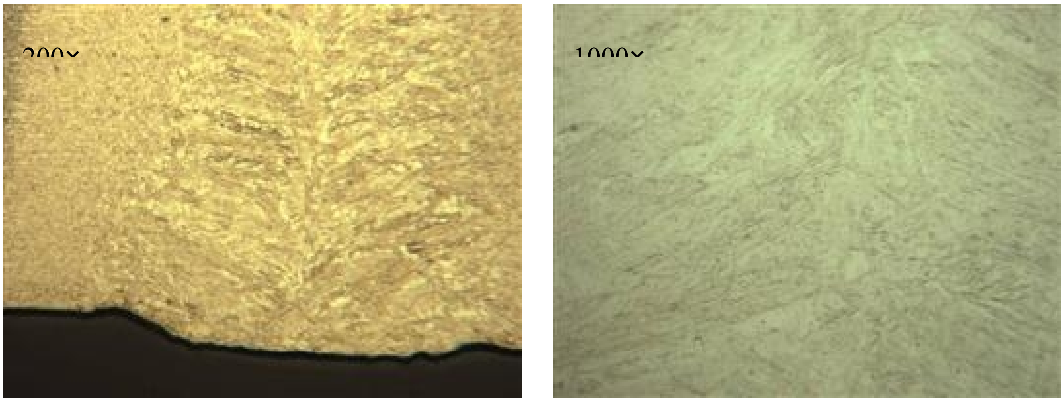
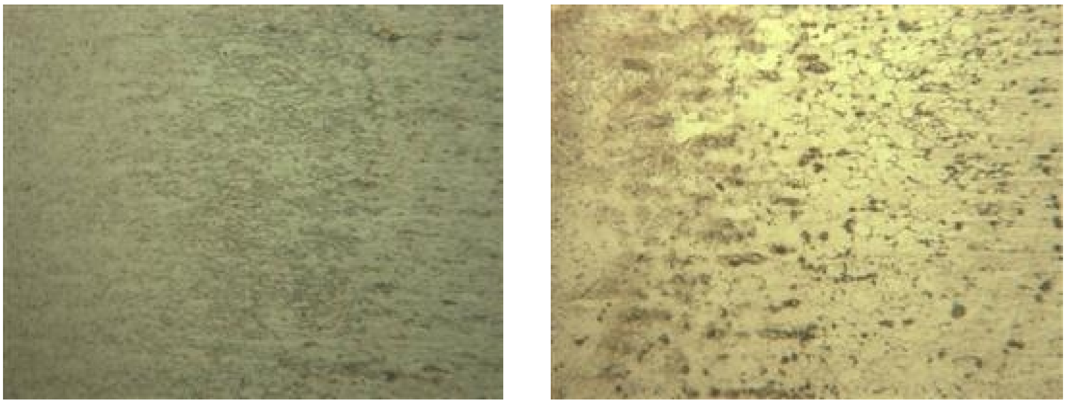


Fig.6 Inclusion of base metal



(a) (b)

Fig.7 Microstructure of Weld center



(a) (b)

Fig.8 Heat-affected zone

Hardness distribution. Hardness test was carried out with an applied load of 0.1 N and a continuous load time of 10s. Fig.9 shows the distribution of hardness. It can be seen that weld seam had maximum hardness and hardness decreased from the weld center to the base material without softened zone.

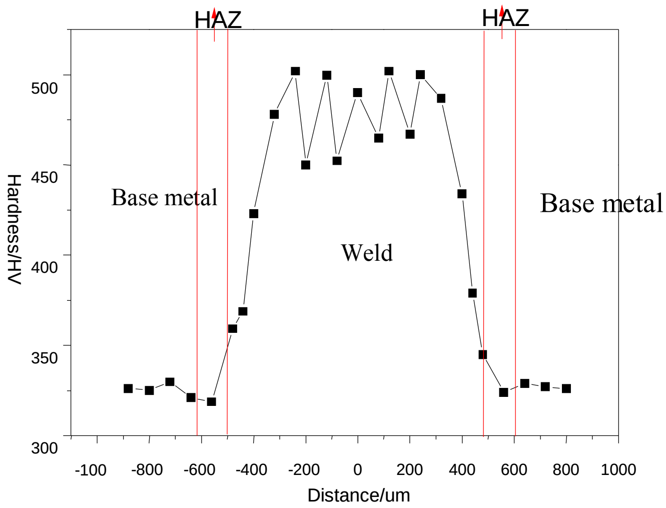


Fig.9 Microhardness distribution across of the weld

Conclusions

(1)DP980 high strength steel plate(thickness is 1mm) can be welded by YLR-6000 fiber laser and the weld seam is good;
(2)Welding speed increases with the power; penetration and weld width increases first and then decreased with the laser power; at the same experimental conditions, the penetration increases with the welding speed decreases;
(3)The microstructure of weld center is columnar crystals, mainly lath-shaped ferrite, needle-like lower bainite and a small amount of martensite. Heat affected zone is narrow and the grain growth is not obvious.
(4)Strength of weld seam is higher than base metal and the fracture occurred on base meta.
(5)Weld seam had maximum hardness and hardness decreased from the weld center to the base material without softened zone.

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