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Experimental Study on High Power Laser Welding of Ship Steel Plate

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Abstract

This article puts forward adopting the fast-flow axis high power CO_2 laser to weld the ship steel plate and mainly studies the influences of technical parameters to the seam. This article also analyzes and tests the welded products which are in the conditions of laser power of 8 kW, welding speed of 1m/min and focus position below 3mm of the workpiece. The results indicate that the distortion of laser welding is small, the ratio of depth and width are bigger than 2:1, and the structure is compact and has no deficiency and presents tiny martensite and few remnants austenite. Laser welding of ship steel plate can realize shaping double sides up one time with single side welding by choosing reasonable welding technical parameters. Therefore, the laser welding ship steel plate technique possesses high practical values.

Keywords: Laser welding, Penetration, Shipbuilding, Steel plate

1. Introduction

As the heavy industry with dense labor, capital and technology, the shipbuilding industry possesses important influences to the economic increase for countries in the world. In shipbuilding, the materials machining most are those steel plates with 3-12mm. Because macro heat input is used in the process of welding, so the welding components made by these steel plates will produce warp and distortion, which is the main problem faced by the traditional shipbuilding method (Guo, 2005, pp.81-84). When building the hull, about 25% of workload is to reprofile and flat the ship steel, and the traditional shipbuilding method is difficult to realize shaping two sides up once with single side welding comparing with the thick ship steel, usually needs to overturn the hull for welding, decreases the production speed and increases the workers' labor intensity. Comparing with the traditional welding method, the laser welding has high efficiency, small welding distortion, low labor costs and convenient construction, is easy to realize automatization, and can be the effective measure to enhance the shipbuilding quality and shorten the shipbuilding period, and the laser seams have high intensity of hauling (zhao, 2003, pp.5-8). However, this technique is still in the developing stage and many mechanisms need to be studied (S. Katayana, 2005, pp.193-198 & M. Kern, 2000, pp. 72-78 & X. H. Ye, 2002, p.1049). This experiment fully studies the laser welding technical parameters of ship steel plates, does the metallographic analysis, micro hardness analysis and mechanical performance test to the welding samples. The results can provide references for the production and application for the laser welding of ship steel plates.

2. Experimental conditions and procedures

This experiment adopts the RS10000RF fast-flow axis CO_2 laser which laser power is 0 -12kw and can be continually adjusted and which laser modes are TEM00+TEM01. The welding material is the ship steel plate St370-2 with thickness of 12mm, and which chemical composition includes 0.17% of C, 0.2% of Si, 1.40% of Mn, 0.04% of S, 0.30% of Cr, 0.30% of Ni and 0.30% of Cu. In order to reduce the requests of weld making precision and weld positioning precision, this experiment adopts single Y groove adding the welding wire which model is SG_2 and which chemical composition includes 0.07% of C, 0.84% of Si, 1.40% of Mn, 0.007% of P, 0.012% of S, 0.03% of Cr, 0.03% of Ni and 0.07% of Cu. Numerical control worktable with five axes can move the workpiece to adjust the laser welding speed. In the welding process, gas of He is the shield gas which blowing direction plumbs the laser beam, and it forms gas shade to protect the focusing system, and simultaneously it blows to single direction from the flank to block the forming of metal plasma.

In the process of experiment, we study the influences of main laser welding technical parameters including laser power, beam diameter, welding speed, focus error and side huffing flux to welding depth and width of seam, and observe and take pictures the melting area by metallographic microscope, and do micro hardness analysis and mechanical performance test.

3. Study on welding technology

The main technical parameters which influence the quality of laser penetration welding include laser mode, laser power density, beam diameter, welding speed, focus error, shield gas and its flux, where the beam mode has important influences to the quality of seams. Therefore, the quasi-fundametal mode or low-order mode should be adopted when welding.

3.1 Laser power

The laser power usually means the output power of the laser and the power density is one of most pivotal parameters in laser weld. The laser weld is closely correlative to the laser power density, and when the laser power density is lower than 10^6 W/cm^2, the laser weld belongs to category of heat exchange weld, and only when the laser power density achieves 10^6 W/cm^2, the deep penetration weld can be formed and "keyhole effects" appears. The "keyhole effects" is closely correlative to the laser power density which is more low, the "keyhole effects" is more unstable even can not be formed, and the melting pool is also small. The melting depth of laser weld is directly correlative to the laser output power density and which is the function of incidence beam power and beam diameter. Generally speaking, to a certain beam diameter, the melting depth increases with the increase of beam power, both almost present linear relation. Therefore, to enhance the power density, we can enhance laser power. Figure 1 shows the relation of melting depth and laser power when the beam diameter is definite, and the welding speed is 1 m/min. From Figure 1, we can see that the melting depth increases with the increase of power.

3.2 Beam diameter

This is a very important technical parameter, because in a certain output power, it will decide the density of beam power and the power density is the key factor for laser weld. But to laser beam with high power, it is difficult to measure, which is produced by the nature of the beam diameter. For laser weld, the condition of high effective deep penetration weld is that the power density on the laser focus must exceed 10^6 W/cm^2. We can adopt two methods to enhance the power density, one is to enhance the laser power, and the other one is to reduce the diameter of the beam. The power density has linear relation with the laser power, and has inverse-square ratio relation with beam diameter, so the effect of reducing beam diameter is better. In this experiment, to realize deep penetration weld, we choose beam diameter of 1 mm.

3.3 Welding speed

The welding speed mainly influences the melting depth and melting width of weld line, because in a certain laser power the weld melting depth almost has inverse-ration relation with the welding speed. When the welding speed is too fast, the "keyhole effects" will not be formed and so that the metal will not melt, the quenching speed is too fast, the intensity of seam is reduced, and pores of weld lines increase to influence the bending resistance intensity and surface of weld line because the harmful gases such as N_2, H_2, O_2 and CO are too late to transgress. So, the confirmation of welding speed upper limit is to prevent the metal has not been fully melt and the quenching speed is too fast so that the melt can not flow and fuse. Otherwise, the melting metal will incline to the top of the welded piece and form welding beads. However, when the welding speed is too slow, the bead produced by the superfluous heat exchange will extend to the side, and the heat influenced area will become too heat and extended, the seam metallographic structure crystal becomes thick, sometimes the cracking will appear, which will seriously influence the welding quality. When the welding speed achieves the lower limitation, the superfluous power absorption also will induce local evaporation loss and hollows.

3.4 Focus error

The focus error is the distance between the workpiece surface and laser focus, and when the workpiece surface is in the focus, the focus error is minus, whereas it is plus. The laser welding usually needs some focus error, because too high power density of the beam center at the laser focus is easy to vaporize and become bores. On various planes departing from the laser focus, the distribution of power density is relative well-proportioned. The focus error influences not only the laser beam on the weld piece surface, but also the incidence direction of beam, so it has important influences to the melting depth and seam shape. When the focus error reduces to a certain value, the melting depth will suddenly change, which will establish necessary conditions for producing penetration pores. The power density on laser stays point is biggest, and when the laser stays locate on the workpiece (plus focus error), the power density obtained by the workpiece decreases correspondingly, and the "nailhead" seam will be formed and melting depth will minish, and when the laser stays locates in the workpiece (minus focus error), the melting depth will increase, so the minus focus error often be adopted when welding. Figure 3 is the relation curve between the focus position below the workpiece surface and the weld melting depth. We can see that with the moving of focus below the workpiece surface, the weld melting depth increases gradually, and when the focus locates about 3mm below the workpiece surface, the melting depth is most, and when the focus continues to move down, the melting depth will rapidly become shallow. In addition, the seam metallography indicates that when the focus position is too low, part materials on the tie-in part of welding workpiece can not be fully melted and form apertures. Therefore, the focus should locate 3mm below the workpiece surface when welding.

3.5 Kinds and flux of shield gas

The shield gas of the laser weld can not only protect the seam metal avoiding harmful gas and dissipate the plasma shield produced by the high power laser weld, but protect focusing lens avoiding metal steam pollution and spatter of liquid fuse. In the process of high power density laser weld, metal is heated and gasified, and forms metallic steam cloud above the melting pool, produces ionization and forms plasmas under the function of electromagnetically field, and if the plasmas are too much, the melting depth will reduce and the melting width will increase. To some extent, the laser beam will be weakened by the plasmas which exist on the workpiece surface as the second energy. The size of the plasma cloud and melting depth of seam will change with different shield gas. The influences of different shield gas to the melting depth of high power deep penetration are seen in Figure 4. From the Figure, we can see that when we select the gas of Ar as shield gas, the welding width will be shallower than other gases because the gas of Ar is easy to produce ionization by the high temperature metallic plasmas cloud produced in the welding process, shields part laser beams to the workpiece and reduces the welding effective power. Because the gas of He has fewest ionizations and lightest proportion and can quickly dissipate the ascending metallic steams produced in the metallic pool, so when we choose it as the shield gas, the ionizations will be restrained to the maximal extents and increase the melting depth and enhance the melting speed (Guan, 1998, pp.121-124). The gas flux also has some influences to the melting depth. The melting depth increases with the increase of gas flux, but too much gas flux will induce the surface hollow even penetration of the melting pool.

4. Analysis of experimental results

4.1 Macrographs of laser seam

Figure 5 and Figure 6 are respectively photos of seam top and cross section of the laser welding ship steel plates. From these two photos, we can see that comparing with traditional welding technique, the laser seam is very narrow and has big ratio between depth and width which is bigger than 2:1 and the overheating influential area is mall (only 0.3 mm). The seam cross section basically presents Y structure. Because of the adding of welding wires, the seam top and bottom present small protruding and there is no undercuts. The seam surface presents circuits of scale welding lines, and we cannot find deficiencies such as cracking pores after exploring examining. That indicates laser can complete penetration one time for the ship steel plates and realize the technology of shaping up from both sides by one side welding.

4.2 Microstructure analysis

The laser seam structure mainly is composed by tiny cryptocrystalline martensite and few remnants austenite which is seen in Figure 7, because under the function of high power laser, substrate and filling materials melt quickly and transform to high temperature austenite. Though the substrate and filling materials are mild steels, but under the function of laser fast melting and coagulating, the mild high temperature austenite quickly cools and transforms to martensite. This martensite is different comparing with the conventional welding structure (Zou, 1994, pp.186-189), and it is mainly composed by abundant tiny batten martensite and other few tiny piece martensite, because the carbon contents in high temperature austenite are too late to be averaged in the laser quick melting and coagulating process, present distribution fluctuating of carbon component, and the batten martensite forms in the low carbon area and the piece martensite forms in the high carbon. These two kinds of tiny martensite coexist and mix, and form cryptocrystalline martensite.

Figure 8 is the SEM photo of laser welding substrate. We can see that it is composed of ferrite and pearlite.

4.3 Mechanical Testing

We use XHD-1000T Vickers sclerometer to test the hardness of laser seam and the load is 200gf. Figure 9 presents the microscopical hardness traverse distributions of seam top area A, middle area B and bottom area C which take the seam center line as the baseline and crosses from one side to the other side of the substrate. From the hardness distributions, we can see that the hardness distributions are basically equal in the laser seam, and hardness average value is HV380 and the basic hardness average value is HV200. When plumbing to the seam, hauling the tested piece, we can obtain the hauling intensity is 536 N/mm^2, and the rupture point locates in substrate and there is no cracking in seam. When plumbing to the seam, cold bending the tested piece, there is no rupture through 180^0 cold bending. The above mechanical tests indicate that the laser seam has better comprehensive mechanical performances which include not only good hauling resistance intensity but good bending resistance tenacity.

5. Conclusions

The experiment indicates the following aspects.

(1) The technical parameters including welding speed, power, focus error and side huffing gas flux have prominent influences to the welding depth and width, and these parameters connect and restrict each other.

(2) Taking the gas of He as the shield gas, when the laser power is 8 W, the welding speed is 1m/min and the focus locates 3 mm below the workpiece surface, it is feasible to continually weld ship steel plates of 12 mm for high power CO_2 laser, and the welding speed is fast and the welding is credible and small distortion and can realize shaping up from both sides by one side welding.

(3) The above results show that the laser weld possesses comprehensive performances such as good technology, structure and intensity and the technology of laser welding ship steel plates has better practical values.

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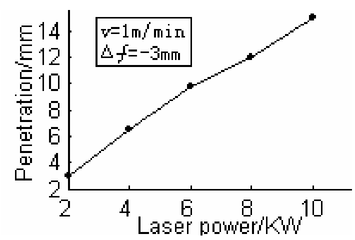

Figure 1. Laser Power vs. Weld Penetration

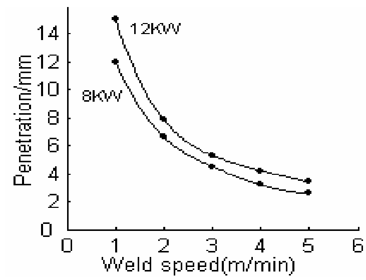

Figure 2. Effect of Weld Speed on Weld Penetration in Different Powers

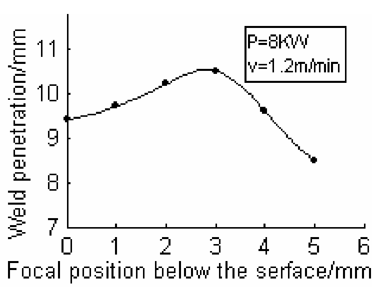

Figure 3. Effect of Focal Position on Weld Penetration

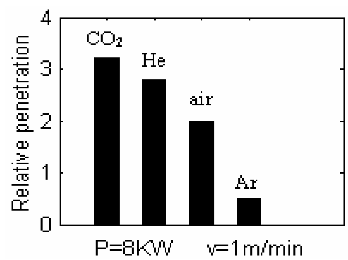

Figure 4. Effect of Different Shielding Gases on Weld Penetration

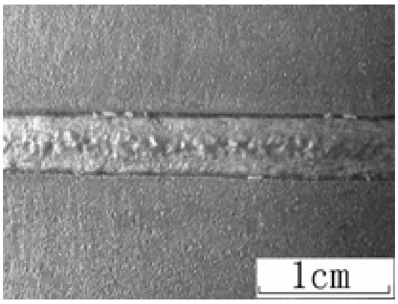

Figure 5. Macrographs of Welding Seam Top

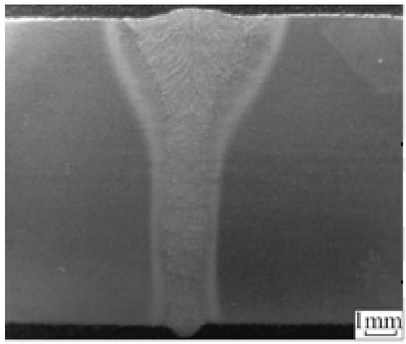

Figure 6. Macrographs of Welding Seam of Cross Section

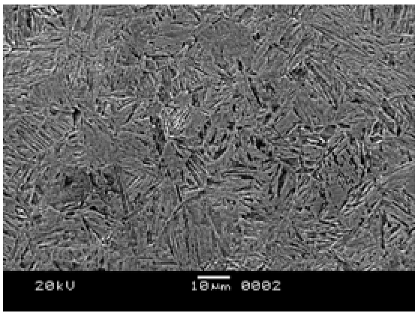

Figure 7. Microstructure of the Laser Welding Seam

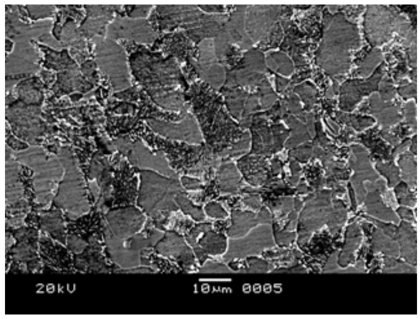

Figure 8. Microstructure of Substrate for Laser Welding

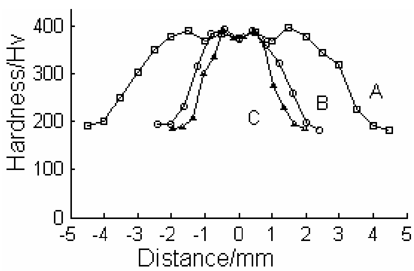

Figure 9. Hardness Traverse Distribution in the Laser Welding Seam