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A Study of microstructure and mechanical properties of 5083 Al-alloy welded with fiber laser welding

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Abstract: *Based on the lightweight design of high-speed vehicles, IPG YLS-5000 optical fiber laser was used for welding test of 5083 aluminum alloy. The influence of laser power and welding speed on the weld forming is carried out, and also analyze the microstructure and mechanical properties of the welded joint. It indicates that the welding process of fiber laser welding of 5083 Al alloy was instability and easy to produce the defects such as undercut, bite edge; Laser power and welding speed have larger influence on the weld forming state; The microstructure of the welding joint near the fusion line is columnar and in the center of the weld is the fine equiaxed dendrites crystal, and there is a certain degree of segregation; The microhardness of welded joints are fluctuated, its hardness value than that of base metal; The tensile strength of joint is about 289MPa, the fracture position is located in the weld, and belongs to ductile fracture.*
Key words: *5083 Al alloy，fiber laser welding ，weld forming，joint microstructure，mechanical properties*

I. Introduction

Aluminum are widely used in aerospace structural materials and high-speed trains and urban rail transportation vehicles due to its light weight, high strength, corrosion resistance, and good ductility[1-3] .Many welding methods have been used to aluminum welding, among which metal inert gas welding (MIG) is widely used in the manufacture of high-speed train body .However, this method with a large welding deformation, coarse grains, joints soften and low productivity problem due to the high welding heat input and low welding speed [4-5]. In recent years, laser welding technology has been rapid developed with the emergence of high power and performance laser processing equipment. Compared with traditional welding methods, laser welding with high energy density, low heat input, narrow weld and heat affected zone, high welding speed and small deformation after welding [6].

More and more researchers pay attention to Fiber laser because of its high brightness, high efficiency, low operating cost, small size and high processing flexibility [7] and other advantages. While some welding defects such as weld porosity and undercut due to the welding keyhole unstable characteristics, because the laser welding with high reflectivity and high thermal conductivity [8-10] .At present, laser and arc hybrid welding is widely use to the welding of aluminum alloy, this method due to the heat input of the arc and the process with poor stability and easily lead to instability and deformation of weldment weld pool.

5083 Al-Mg alloy are widely used in aerospace, defense, construction departments, containers and packaging, transportation, electrical and electronic industry, machinery manufacturing and petrochemical, due to its high strength, good ductility, corrosion resistance, ease of processing advantages of forming and low price [11,12]. In this paper, pure fiber laser welding will be used to the welding of the 5083 Al-alloy with 4 mm thick, the influence of the welding process parameters on weld law and the appearance of laser welds,the microstructure and mechanical properties were systematically investigated .

II. Experimental procedure

The material used in this investigation was 5083 aluminum alloy sheet with 4mm thick. The chemical composition of the base metal was listed in Table 1,the tensile strength of base metal was approximately 310 MPa. A butt joint was made between two base metal 5083 Al-alloy sheet. A schematic diagram of the welding joint section and the sampling area for metallography is shown in fig.1.

Table 1 Chemical composition of 5083 aluminum alloy(wt.%)

Mg	Fe	Cu	Mn	Si	Cr	Zn	Al
4.0~4.9	0.40	0.10	0.40～1.0	0.4	0.05～0.25	0.25	--

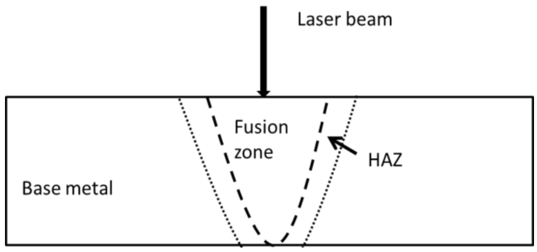


Fig.1. Schematic diagram of the welding joint

Welding systems include YLS-5000 fiber lasers with German KUKA robots were used in the welding test of the 5083 Al-alloy laser welding. The maximum power of the laser is 5 KW and the focal length is 300 mm.The argon(Ar) was used as the shielding gas during the laser welding, the welding parameters shown in the Table 2.Before the welding ,the base metal should be cleared with acetone to remove surface oil and the sodium hydroxide solution was used to remove the surface oxide filmand then a solution of nitric acid was used to neutralize the remaining lye. The welding area surfaces shoule be dry and should be wiped with acetone before laser welding.

VHX-600 deep microscopy optical microscope and S-3400N scanning electron microscope were used to analyzed the microstructure of the 5083 laser welding joints. The Micro-hardness was tested by HXD-1000 Vickers hardness tester with 50gf and loading 15s. Test samples were welded by continuous laser and butt welding joint, since aluminum has a high reflectivity to the laser, if the laser beam is irradiated to the workpiece or welding vertical angle is too small, the sample surface is irradiated laser beam is reflected back to the laser, causing laser damage. Therefore, the angle of the laser welding of welding are made 5 °.Tensile strength test of the welded specimens was used the tensile testing machine - IBTC-300 tensile testing machine.

Table 2 Laser welding parameters

Number	Laser Power（KW）	Welding speed（m/s）	Defocus（mm）	Shielding gas type	Gas flow（L/min）
1	2.5	0.1	0	Ar	25
2	3.0	0.1	0	Ar	25
3	3.5	0.1	0	Ar	25
4	4.0	0.1	0	Ar	25
5	3.5	0.06	0	Ar	25
6	3.5	0.08	0	Ar	25
7	3.5	0.12	0	Ar	25

III. 3.Result and discussion

3.1 Effect of laser welding parameters on weld shaping

The irradiation on the sample surface by the laser beam with different laser power density, the surface area of the material will occur various changes, these changes include surface temperature, melting, vaporization, forming apertures and generating laser induced plasma and so on. With different laser power densities effects, different variations of the physical condition of the surface area will greatly affect the interaction between the laser and the workpiece material.The defects of the weld joint after laser welding of 5083 Al-alloy were shown in the fig.2. The undercut on the weld surface (fig.2(a))and the pore at the bottom of the weld (fig.2(b)) have been shown by the arrows.

The laser weld penetration (melting width) varies with different welding parameters were shown in the fig.3. the penetration and the melting width increased with the laser power increase, and the greater the power ,the more obvious on the trend(fig.3(a)). While as the increase of the welding speed ,the penetration and melting width decrease and the weld width gradually stabilized(fig.3(b)). When the welding speed is low, the weld penetration and weld width are large, this is because when the welding speed is small, the amount of weld heat input is increased, resulting in the increase of the temperature in the keyhole zone and at the same time, the metal vapor hole pressure increases in the zone keyhole, resulting in an increase the size of keyhole and the absorption of laser light,so that the weld pool solidification speed is decrease. In the heat conduction effect, the weld width and weld penetration would be increased .With the increase of the welding speed, the heat input decreases resulted the weld penetration and weld width decreased.

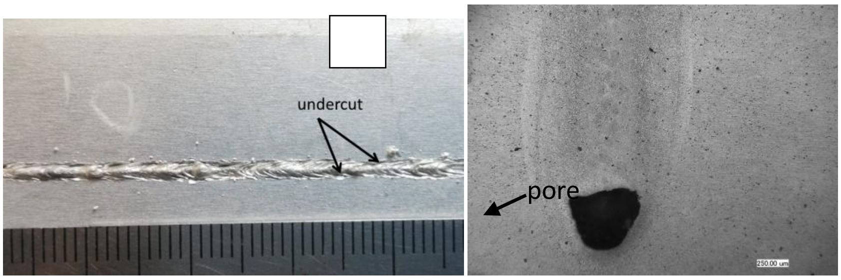
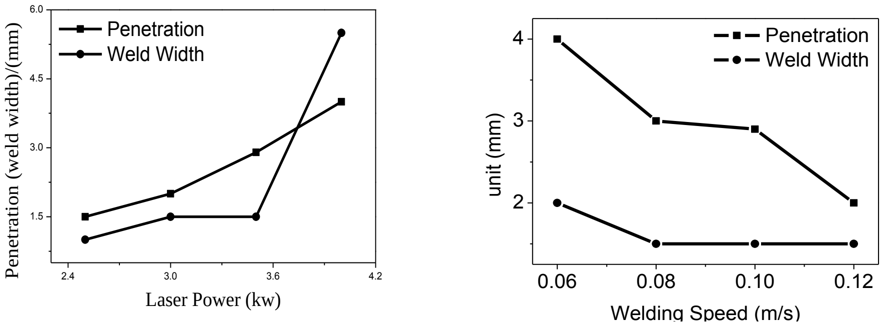


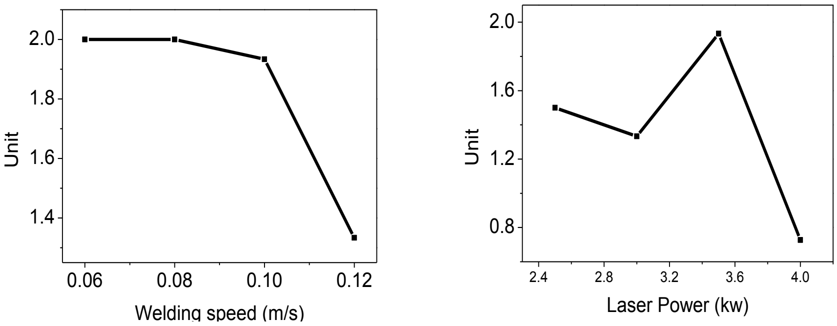
Fig.2. the defects of the weld joint: (a) underct,(b)pore.



(a) (b)

Fig.3. laser weld penetration (melting width) varies with different welding parameters: (a) laser power,(b) laser welding speed.

Laser welding aspect ratio (penetration / melting width) with the relation between welding speed and laser power are shown in Fig. 4. As can be seen from the fig.4, when the laser power is about 3.3 ~ 3.6kw, welding speed is about as 0.06 ~ 0.08m / s, its depth and width is ideal.



(a)effect of welding speed on the aspect ratio (b) Laser power on the aspect ratio

Fig. 4 .Effect of welding speed, laser power on the aspect ratio of welded joints

3.2 Microstructure of Welded Joints

Because of the time of interaction between the laser welding process and material is short, the laser welding process experience the thermal effect of rapid heating and rapid cooling process, so the laser weld seam was narrow and the grain was relatively fine. The welded joint of 5083 aluminum alloy after laser welding include weld zone (WM), the fusion zone (FZ) and the heat-affected zone (HAZ). The microstructures of different zone in the weld joint were shown in fig.4. Fig.4(a) shown the base metal evenly distributed along the rolling direction. Fig.4(b) shown the microstructure changes in the transverse direction of the weld zone. It can be seen that the organization of the weld base metal, heat affected zone and weld area has significant difference. The growth direction of the columnar crystals was along the heat diffusion direction near the fusion line. During laser welding, near the weld pool edges, the liquid metal have larger undercooling, so the crystallization was easy attachment unmelted base metal nucleation, crystal growth along the radiating direction and formed columnar crystals. and then gradually transition to dendrites as the distance decrease from the center of the pool, and finally formed equiaxed at weld center area(Fig. 4(c). Dendrite interface is easy to form solute segregation zone, and it will seriously affect the mechanical properties of the region. Fig.4(d)shown the strengthening phase mainly along the grain boundaries and the base material strengthening large phase was dispersed and form more than the base material. The strengthening phase along the grain boundary is easy to cause crack initiation leaving the joints become weak links.

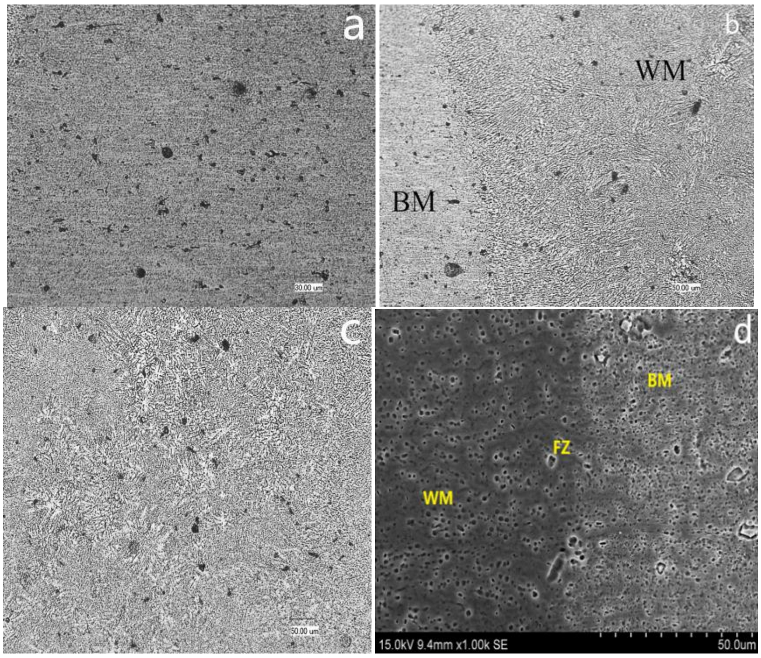


Fig.5. microstructure of welded metal: (a) base metal,(b) weld zone,(c) weld center,(d) fusion line.

3.3 Mechanical properties

The micro-hardness of the 5083 Al-alloy joint by fiber laser welding were shown in Fig.5. The hardness of weld zone of 5083 aluminum alloy welded joints is lower than the hardness of the base metal, it is approximately 83HV. This is because during the laser welding, a high-energy laser beam is irradiated to the surface of the material, result the metal material surface melt, vaporize and form a plasma. Since the boiling point of magnesium is lower than that of aluminum, which makes a lot of magnesium in the form of metal vapors escaping from the pool during the welding process. And magnesium is the main strengthening phase element in the Al-Mg alloy, thus causing lower weld joint hardness. In the zone that the distance is 1.2 mm from the center of the weld area, the hardness decreased rapidly with increasing distance and then gradually increased with the distances change from the weld center. It indicated that the presence of softening joint in the HAZ. Since 5083 is a non-heat strengthened aluminum alloy, with the weld thermal cycles in different areas, the hardening effect will be reduced or even eliminated, so that there is a certain degree of hardness lower.

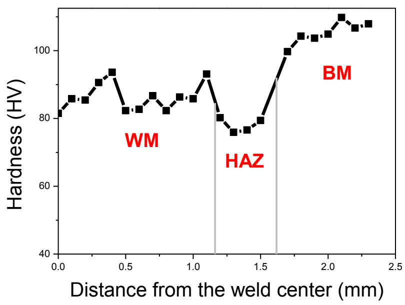


Fig. 5. Microhardness of 5083 aluminum alloy joint

The tensile test results of the 5083 aluminum alloy base metal and weld joint have been listed in Table 3. As can be seen from Table 3, the tensile strength and elongation of 5083 laser welded joints is lower than the base material ,and it was about 93% of the base material and drawing off at the welds.

Table 3 Mechanical properties of 5083 Al alloy and its welding joint

Sample	σ_b /MPa	$\sigma_{0.2}$ /MPa	δ /%
5083 joint	289	186	3.0
5083	310	223	6

Fig.6. showed the SEM image of tensile fracture sample in 5083 aluminum welded joint. It showed obvious dimple fracture characteristics(fig.6(b)) and it is possible to determine fracture toughness. In addition, there are pore can be seen in the fig.6(a) , which also reduced the mechanical properties of the material.

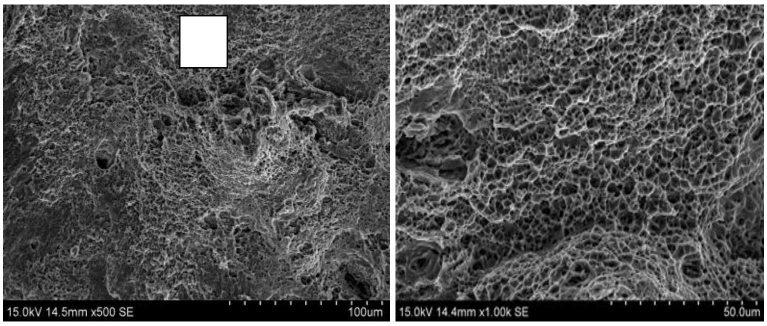


Fig.6. SEM image of tensile fracture sample in 5083 aluminum welded joint

IV. Conclusions

(1) As the evaporation of magnesium makes the weld appearance emerge a certain degree of concave and undercuts and other defects; both welding speed and laser power have great impact on the welding seam forming, and as the laser power increases, penetration, weld width are increased, while with the increase of welding speed and penetration, weld will decreased.

(2) The 5083 Al-alloy weld joint include weld zone, fusion zone and the heat-affected zone, and the heat affected zone is narrow,;columnar structure organization in the fusion zone along the growth direction of the cooling direction, and the weld zone mainly with dendrite equiaxed and there is a certain degree of segregation.

(3) Due to the burning of the main strengthen element Mg, The hardness of 5083 aluminum laser welded joint weld zone is significantly lower than the base metal; the heat affected zone due to the cold hardening effect reduce makes the lowest hardness;the tensile strength and elongation of weld joints were lower than the base material and the fracture is ductile fracture characterizes.

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