Study On Microstructures And Properties Of 7A52 Aluminum Alloy Joints In Laser-MIG Hybrid Welding

HUANG Hao, YANG Bing, MO Jingfang, GENG Yangmo, ZHOU Honggang, ZHANG Fenping
Jianglu Machinery and Electronics Group Co., Ltd., Xiangtan, China
Corresponding author’s e-mail address: 394050497@qq.com

Abstract: The 7A52 aluminum alloy of 10mm thickness was welded by laser-MIG hybrid welding. The microstructures and properties of the welded joints were studied. The results show that: The morphology of the weld section is “glass shape”, and the “cup body area” of the top of the weld is formed by the arc thermal melting base material, with typical MIG welding characteristics. And the “cup foot area” of the bottom weld is produced by the keyhole effect and has the characteristics of laser deep fusion welding. The Zn and Mg elements have different degrees of evaporation and loss in the MIG welding zone and laser welding zone. The hardness from the center of the weld to both sides base metal is a u-shaped distribution. The average tensile strength of welded joints reached 304.7MPa, which is 74.3% of the base material.

1. Introduction
The 7A52 aluminum alloy is a kind of medium strong weldable aluminum alloy with good comprehensive performance, and widely used in aviation, spaceflight, armored vehicles, etc. At present, the medium-thick aluminum alloy are preferred to be welded via the main methods of gas single-wire or double-wire metal arc welding\[1-2\]. The traditional welding method of 7A52 aluminum alloy is argon arc welding, which is more prone to softening phenomenon due to the divergence of arc welding heat source\[3\]. For the softening of the welded joints, the relevant scholars\[4-5\] studied laser welding method on 3mm and 4mm 7A52 aluminum alloy, and obtained a better welding effects. For example, Chen chao, Chen fu-rong, Zhang hui-jing, et al\[6\] studied the effect of welding heat input on structure and properties of fiber laser welded joints of 7A52 aluminum alloy, the maximum tensile strength of the joint is 341Mpa, which is about 69.8% of the parent metal.

The single laser welding efficiency of the aluminum alloy is low and the welding thickness is not high at one time because of high reflectivity and low absorption of aluminum alloy against the laser beam\[7\], so it is difficult to meet the welding requirements of the thick aluminum alloy. Laser-MIG hybrid welding technology concentrated the advantages of the laser and electric arc heat source, and it overcomes the deficiency of the single laser in welding aluminum alloy; on the other hand, laser-MIG hybrid welding has big welding penetration, stable welding process, and adjustable weld composition and many other advantages, so it has important application prospects in the field of aluminum alloy welding.

In this work, the 7A52 aluminum alloy of 10mm thickness was welded by laser-MIG hybrid welding. Weld appearance was examined to evaluate weld quality using an optical microscope. Hardness and strength tests were carried out to identify mechanical properties of the laser-MIG hybrid welded joint. Finally, fractography analyses with scanning electron microscopy were conducted with special attention on the porosities. Moreover, relevant mechanisms were also discussed.
2. The materials and the experiment method

2.1. The materials
The experimental materials were 7A52 alloy that were all sheared into the same dimension of 200mm×100mm×10mm. Y-type welding groove of 45° were prepared to fabricate laser-MIG hybrid welding joints, and ER5356 with a diameter of 1.2 mm as the filler metal. The chemical compositions of 7A52 aluminum alloy and ER5356 wire are described in Table 1, and the mechanical property of 7A52 aluminum alloy are described in Table 2. Before welding, the oxidation film and greasy dirt on the surface of substrates were eliminated by a series of mechanical and chemical cleaning methods.

| Table 1 Chemical compositions of 7A52 aluminum alloy and ER5356 wire (w%) |
|------------------|---|---|---|---|---|---|---|---|---|
| Materials | Zn | Mg | Cu | Mn | Cr | Ti | Zr | Fe | Si |
| 7A52 | 4.0 | 2.0 | 0.05 | 0.2 | 0.15 | ≦ | ≦ | ≦ | ≦ |
| | ~4.8 | ~2.8 | ~0.2 | ~0.5 | ~0.25 | 0.18 | 0.15 | 0.3 | 0.25 |
| ER5356 | ≧ | 0.1 | 4.5 | 0.05~ | 0.05 | 0.06 | ≦ | ≦ | ≦ |
| | ~5.5 | 0.1 | 0.2 | ~0.2 | ~0.2 | — | 0.1 | 0.25 | Bal |

| Table 2 Mechanical property of 7A52 aluminum alloy |
|------------------|---|---|---|
| Material | Tensile strength/Mpa | Yield strength/Mpa | Elongation/% |
| 7A52 | ≧ 410 | ≧ 345 | ≧ 7 |

2.2. Experimental procedures
The experiments were carried out with an IPG YLR-4000 fiber laser with a peak power of 4.0 kW, an ABB IRB4400 robot, and a Fronius TPS4000 arc welding machine. To avoid possible damages to the optical components, laser beam was inclined with an angle of 6° to the welding direction while the angle between welding torch and the specimen was set to 45°. The composite way of laser prior to arc was used in the welding process. The specific experimental set-up is presented in Fig.1. The workpieces were pressed tightly together using jigs. Argon (99.99% pure) was used as the shielding gas for the top surface of the weld, and other welding process variables based on preliminary experience accumulation are showed in Table 3.

| Table 3 The main process parameters in laser-MIG hybrid welding |
|------------------|---|---|
| Variable | Unit | Value |
| Laser power | kW | 3, 3.5, 3.8, 4 |
| Welding speed | m/min | 0.9, 1, 1.1 |
| MIG welding current | A | 120, 130, 140, 150 |
| Laser-arc distance | mm | 2 |
| Shielding gas flow (Ar) | L/min | 25 |
| Defocus amount | mm | ~1, 0 |
After welding, the samples were cut transversely from the welds by wire cutting, and then mechanically grinded and polished to obtain a mirror plane. The Keller’s reagent was used to etch the sample. The microstructures were observed by LWD300LMDT optical microscope. Vickers microhardness measurement was tested by HVS-1000A digital microhardness tester from the weld zone (WZ), passing through the heat-affected zone (HAZ), to the base metal (BM) with a spacing of 0.3 mm using a load of 100g, and a dwell time of 15s. Tensile specimens were machined from the middle of the welded plates with the optimal processing parameters, and the dimensions of the specimen are presented in Fig.2. The tensile properties of the joints were tested by using the AG-100kN material testing machine. Sirion200 scanning electron microscope was used to test the fracture morphology.

3. Test results and analysis

3.1. Microstructure analysis
The metallographic structure of 7A52 alloy laser-MIG hybrid welded are shown in Fig.3 to Fig.6. As shown in Fig.3, The microstructure of the base material is a banded structure parallel to the direction of plate rolling. This paper analyzes the best sample weld (welding parameters: P=4kw, V=1m/min, I=140A, Δf=0mm). Fig.4 shows the cross-section diagram of the weld under this parameter. And Fig.5 is made up of two sections: "cup body area" of MIG weld and "cup foot area" of laser weld. As it can be seen from the figure, the microstructure of the weld seam are mainly composed of equiaxial grains. In the "cup body area" of MIG weld, there are some pores in it, that because during the cooling possess, the solubility of hydrogen decreased and the evaporation of elements such as Zn and Mg can be saved in the form of pores in the weld due to fast welding speed. In the transition zone, as shown in Fig. 6a), the "cup body area" of MIG weld has large columnar structure, and its growth direction is carried out along the heat dissipation direction of the weld; and the heat affected zone maintains the rolling structure of the
parent material, but the grain is brought up to a certain extent due to the influence of the welding heat cycle. However, there is no feature like "cup body area" in the "cup foot area" of laser weld, as shown in Fig. 6b).

3.2. Component analysis

![Component analysis](image)

**a) "Cup body area" of MIG weld  b) "Cup foot area" of laser weld  c) Base metal**

Fig.7 EDS analysis results of the welded joint

Fig.7 shows the analysis of component energy spectrum in different regions of welding joints. As we known from the figure 7a): Mg content is 2.42%, and Zn content is 2.22% in the "cup body area" of the MIG weld, and compared with base metal, the Mg, Zn content in the "cup body area" of MIG weld decreased evidently. Because the temperature gradient in the "cup body area" of the MIG weld is small, and the heat dissipation is slow, the element can be burnt easily; At the same time, the filler wire in the MIG weld dilutes alloying elements contents in the "cup body area", therefore, the content of Zn and Mg elements in this area is lower than other places.

The Mg content in the "cup foot area" of laser weld is 2.45% and the Zn content is 3.04%. Compared with the parent metal, the Mg and Zn elements decreased less in the "cup foot area" than in the "cup body area". As we can see from Fig. 7b): Because the boiling point of Zn (906℃) is lower than Mg (1107℃), the burning loss of Zn element is greater than Mg.

3.3. Microhardness analysis

![Microhardness analysis](image)

Fig.8 shows the microhardness of the"cup body area" and "cup foot area" measured along the black and red line, respectively. As it can be seen from the figure that the microhardness distribution of the welded joint is along the welding line, and the microhardness is higher in heat affected zone, and lowest in weld center. Both FZ and HAZ have higher microhardness than the weld zone has, and microhardness in weld center is the lowest. The results suggested that the hardness distribution presented evidently inhomogeneity across the weld. In the "cup body area" of MIG weld, the mean hardness value of the weld zone was about 85.6HV while the average value of 90.4HV was found in "cup foot area" of laser weld. Apparently, compared with the BM, WZ, and HAZ underwent a deep drop in hardness. Moreover, the decrease emerging in the"cup body area" seemed severer than that in the "cup foot area".

![Microhardness distribution curve](image)

Fig.8 Hardness distribution curve of welded joint.
It can be seen from the diagram that the hardness in the "cup body area" of MIG weld is lower than "cup foot area" of laser weld, and its width and softening degree of the heat affected zone are also greatly increased. Compared with "cup body area" of MIG weld, the microstructure in "cup foot area" of laser weld is finer, and the hardness is higher. The heat affected zone is softened as the strengthening phase dissolved near the fusion line or growing up away from the fusion line.

Because the heat input in the "cup foot area" of laser weld is less than the "cup body area" of MIG weld, and the heat affected zone temperature gradient in "cup foot area" of laser weld is larger than the "cup body area" of MIG weld, and its thermal effect time is short; Therefore, the dissolution and growth of the strengthening phase in the heat affected zone of the "cup foot area" of laser weld are relatively small and the softening degree is decreased.

3.4. Joint tensile properties and fracture morphology

It can be seen from table 5 that the average tensile strength of laser-MIG hybrid welded joint is about 304.7MPa, reaching 74.3% of the base material, and the average elongation is 7.8%, which is higher than the base material.

Table 5 Tensile strength of joints

| Number | Tensile strength (MPa) | Elongation (%) | Fracture position |
|--------|------------------------|----------------|--------------------|
| 1      | 305.5                  | 7.5            | Welding zone       |
| 2      | 310                    | 8.7            | Welding zone       |
| 3      | 298.6                  | 7.2            | Welding zone       |

![a) "Cup body area" of MIG weld](image1)

![b) "Cup foot area" of laser weld](image2)

It can be seen from the fracture morphology of MIG weld in the "cup body area" that the dimples are shallow, and it indicate that there is no obvious plastic deformation before the MIG weld fracture in the "cup body area", and it is a tough-brittle mixed fracture. But in the "cup foot area" of laser weld, dimples are deep, and the tear edge is obvious. It is indicated that the "cup foot area" of laser weld is completely ductile fracture.

4. Conclusions

1) Welding speed of 1m/min, laser power of 4 kW, defocus amount of 0mm, and welding current of 140 A are suitable welding parameters for 7A52 aluminum alloy laser-MIG welding joint.

2) Affected by the cooling rate and the temperature gradient of the molten pool, there is a coarse crystal area in the MIG weld fusion line in the "cup body area".

3) The Zn and Mg elements in "cup body area" are higher than the "cup foot area" in laser-MIG welding.

4) The average strength of the joints reached 304.7MPa, and it is 74.3% of that of the BM.
References
[1] YU Jin, WANG Ke-hong, XU Yue-lan, LIU Yong. Microstructures and properties of 7A52 aluminum alloy welded joint by twin wire welding[J]. Welding Institution, 2005, 26 (10):87-89.
[2] YANG Chun-li, GANG Tie, LIN San-bao, CUI Hong-bo. Tandem MIG welding of high-strength thick aluminum alloy plate[J]. The Chinese Journal of Nonferrous Metals, 2004, 14 (21):259-264.
[3] ZHANG Youyi, LIU Hua, ZHU Xiaobin. Microstructure and Property of Welded Joint of 7A52 Al Alloy by MIG Welding Process[J]. Hot Working Technology, 2013, 42(19):172-174.
[4] ZHANG Zhi-hui, DONG Shi-yun, WANG YU-Jiang, et al. Microstructure and Properties of fiber laser welded 7A52 Al alloy joints[J]. Applied Laser, 2014, 34(6):567-571.
[5] QIAN Lijiang, ZHOU Qi, CHEN Li, et al. Microstructure property analysis of 7A52 aluminum alloy fiber laser welding joint[J]. Welding, 2014(9):49-52.
[6] CHEN Chao, CHEN Furong, ZHANG Huijing. Effect of welding heat input on structure and properties of fiber laser welded joints of 7A52 aluminum alloy[J]. Welding, 2017(1):35-38.
[7] SUN Cheng wei, LU Qisheng, FAN Zheng xiu. Laser irradiation effect[M]. Beijing: National defence industry press, 2002.