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MECHANISMS OF THE POROSITY FORMATION DURING THE FIBER LASER LAP WELDING OF ALUMINIUM ALLOY

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When joining the aluminum alloys, one of the biggest challenges is the formation of porosity, which deteriorates mechanical properties of welds. In this study, the lap welding was conducted on an aluminum alloy 5754 metal sheets with a thickness of 2 mm. The effects of various laser welding parameters on the weld quality were investigated. The porosity content was measured by X-ray inspections. The key is to control the solidification duration of molten pool. When the solidification duration of molten pool is large enough, more bubbles can escape from the molten pool and less remain as porosity.

Key words: aluminum alloy, lap welding, fiber laser, X-ray inspections, porosity

INTRODUCTION

Decreasing the weight of the vehicles has been receiving significant attention in recent years owing to its advantages such as low fuel consumption, fleetness, and less greenhouse gas emissions, etc. The material aluminum offers a high lightweight potential, which is particularly interesting for the car production.

Recent trends toward economically fabricating vehicle structures have led to the implementation of laser-welded lap joint instead of resistance spot welding because of its low heat input, high welding speed, high penetration, easy automation, high accuracy, etc. [1, 2]. Porosity is a serious problem in the high power laser welding of aluminum alloy, because it deteriorates mechanical properties, particularly tensile strength and elongation. Porosity rates on aluminum alloys have been reported by several authors, and the mechanism of porosity formation has been investigated.

Zhao et al. [3] studied the influence of various welding parameters on porosity formation during continuous wave Nd:YAG laser beam welding of thin plates of aluminium-magnesium alloys. The experimental results showed that the instability of the keyhole was the dominant cause of macro-porosity formation. At lower and higher welding speeds, few and no pores were generated. However, according to the research of Katayama et al. [4], it was found that a keyhole was liable to collapse at low welding speeds through X-ray transmission real-time observation.

Kim et al. [5] investigated the degree of porosity with various laser welding parameters during laser lap welding of Al 5052 sheets. It was found that the porosity decreased when the heat input is lowered.

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From a literature survey, the mechanism of porosity reduction was not fully understood.

In this paper, X-ray inspections were used to study the porosity content of welded joints with various laser welding parameters and analyse the reason for the changes of porosity content.

EXPERIMENTAL WORK

The base material used was 5754 aluminum alloy, which is a kind of typical Al-Mg alloys and its chemical composition is shown in Table 1.

Table 1 **Chemical composition of Al 5754 alloy / wt. %**

Mg	Si	Cu	Mn	Ti	Zn	Cr	Al
2,6-3,6	0,4	0,1	0,5	0,15	0,2	0,3	Bal.

The geometrical size of each sheet was 120 mm in length, 40 mm in width, and 2 mm in thickness. The lap length was set at 25 mm. The gap between two metal sheets was kept tight during welding, assuming that the gap was equal to zero. The configuration of overlap-welded joint is shown in Figure 1.

The backward welding at 11° along the welding direction was performed in order to avoid high back reflection which could stop welding process. The shielding gas nozzle, whose diameter was 12 mm, was fixed 2

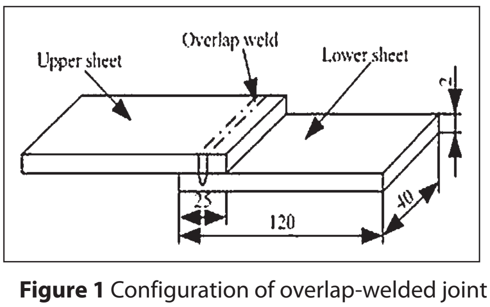

Figure 1 Configuration of overlap-welded joint

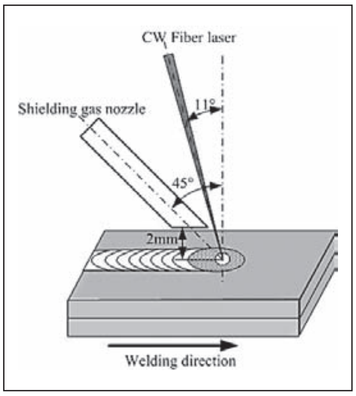

Figure 2 Schematic of experimental setup

mm above the workpiece. The shielding gas used was argon gas at a flow rate of 16 L / min. The laser welding experiments were performed using the 4 kW fiber laser (IPG YLR-4000). The laser beam was focused into 0,3 mm diameter with the lens of 250 mm focal distance. The focal point was set on the surface on the workpiece. The experimental setup is shown in Figure 2.

Before welding, strict chemical cleaning was applied to the alloy sheet in order to greatly reduce possible oxide film and oil stain on the workpiece surface. The workpiece was firstly immersed into dilute NaOH liquor for cleaning and then flushed with clean water; after that the workpiece was immersed into dilute Hydrochloric acid liquor for neutralization and then flushed with clean water again. The time for chemical cleaning should be not too long but should be enough to make the surface to have metallic luster. The workpiece was then baked in the furnace to remove possible water; and kept in the furnace after baking until the time for welding.

RESULTS

Effect of welding speed on porosity

The effect of welding speed on the porosity was investigated at a laser power of 3,5 kW and welding speed from 1 to 3 m / min. All the joint configurations were the partial penetrated overlapping joints.

After welding, X-ray inspections were carried out to estimate the porosity contents. To quantify the porosity rate, the following procedures have been used: (1) X-ray radiography on plane samples, (2) image analysis (Image Tools software) that gives us a total area of pores S_{pores}, and (3) a calculation of the ratio S_{pores} / S_{total} which is the surface rate of pores.

Figure 3 shows X-ray inspections and porosity content of bead welded with different welding speed.

The influence of welding speed on the porosity with a fixed laser power is shown in Figure 4.

As shown in Figure 4, it is obvious that welding speed has a significant impact on porosity content. With the decrease in the welding speed, the porosity content is decreased obviously.

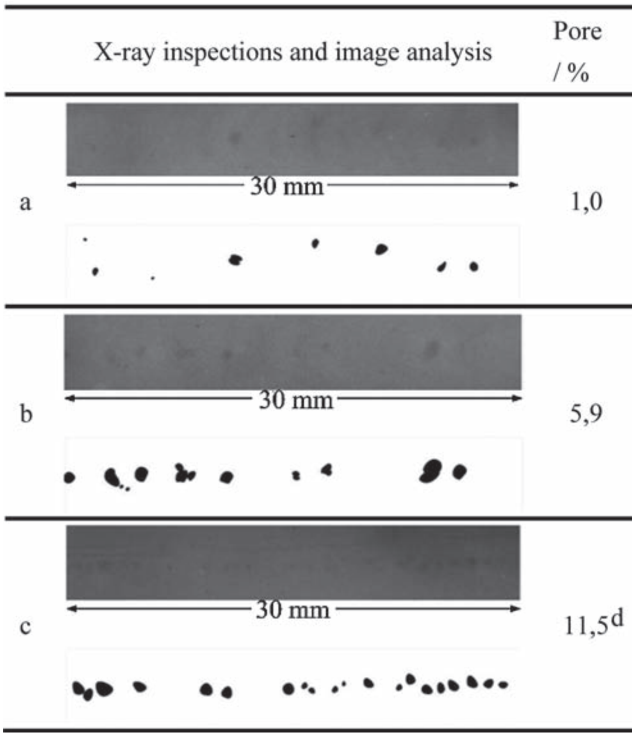

Figure 3 X-ray inspections and porosity content of weld bead in various welding speed (a - 1 m / min, 3,5 kW; b - 2 m / min, 3,5 kW; c - 3 m / min, 3,5 kW)

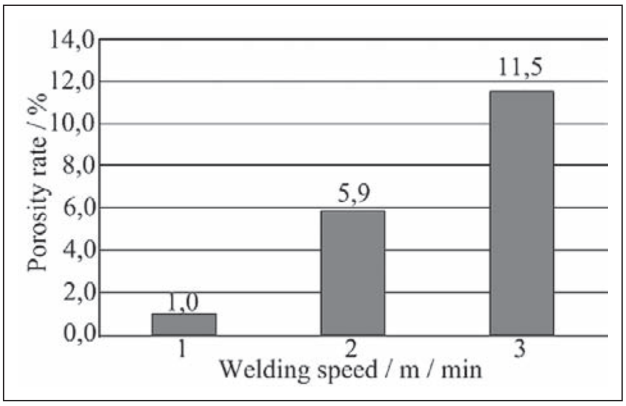

Figure 4 Effect of welding speed on porosity

Effect of laser power on porosity

The effect of laser power on the porosity was investigated at a welding speed of 2 m / min and laser power from 3 to 4 kW. All the joint configurations were the partial penetrated overlapping joints.

Figure 5 shows X-ray inspections and porosity content of bead welded with different laser power. The influence of laser power on the porosity with a fixed welding speed is shown in Figure 6.

DISCUSSION

In laser deep penetration welding, the keyhole was not stable but fluctuated considerably and this instability was closely related to the porosity formation [6]. The depth and shape of keyhole fluctuated violently, and large bubbles were intermittently formed at the bot-

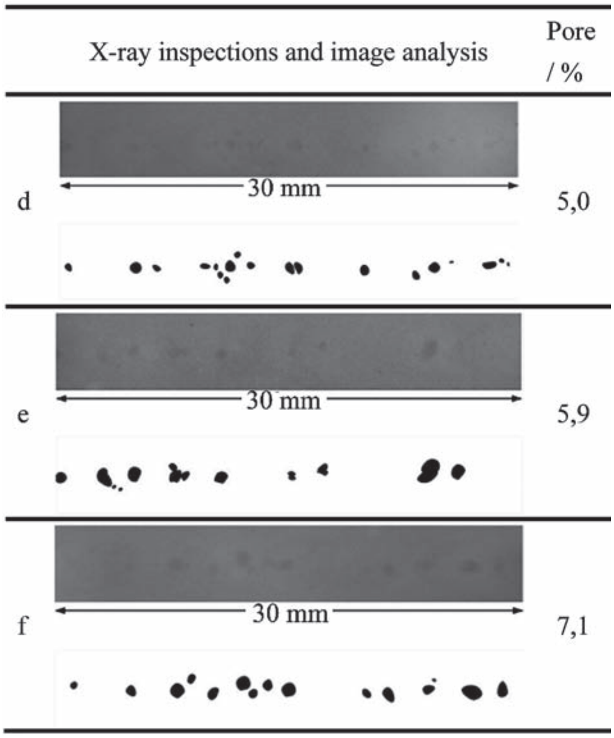

Figure 5 X-ray inspections and porosity content of weld bead in various laser powers (d - 3 kW, 2 m / min; e - 3,5 kW, 2 m / min; f - 4 kW, 2 m / min)

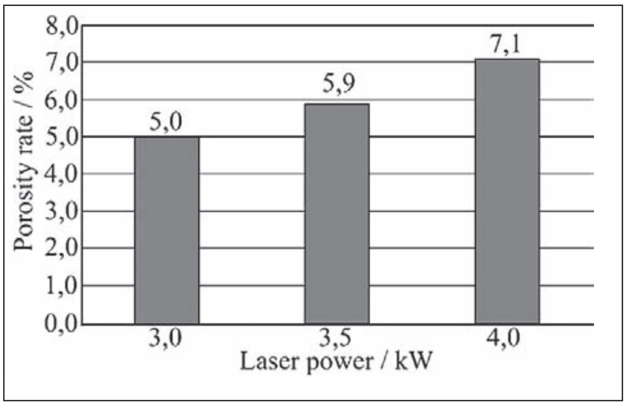

Figure 6 Effect of laser power on porosity

tom of keyhole, which were trapped by the solidifying wall during floating up and remained as porosity.

Because the bubbles can float out of the surface of weld pool before it solidified, large solidification duration benefit the floating of bubbles. As shown in Figure 7, when the welding speed is low, during the same time, more part of the molten pool is existed. More bubbles floats out of the molten pool and less pores remains in the weld bead. In other word, with the decrease in welding speed, the solidification duration of molten pool increase and this make the time for bubbles floating out of the weld pool increase.

As shown in Figure 8, the penetration depth decrease with the decrease in laser power ($H_0 < H_1$), and this makes the demanded time for bubbles floating out of the weld pool decrease. The effect is equal to increase the solidification of molten pool. More bubbles floats out of the molten pool and less porosity remains in the weld bead.

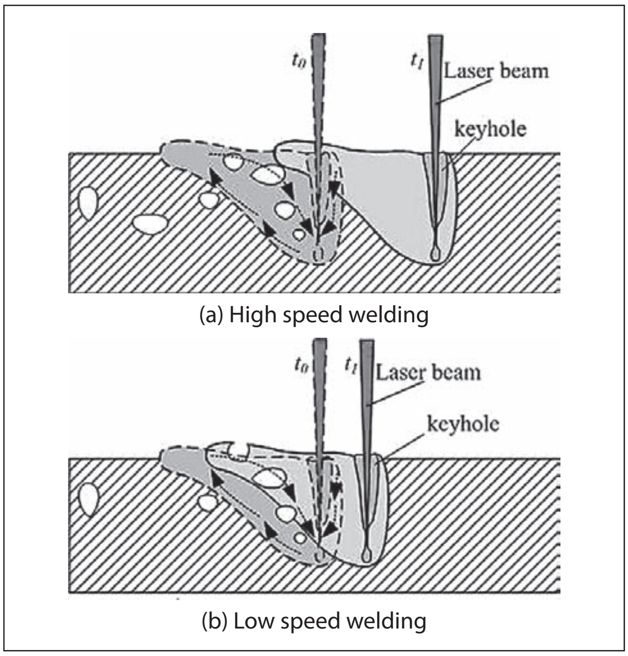

Figure 7 Formation of porosity in different welding speed (t_0 – a point in time during laser welding; t_1 – a following point in time)

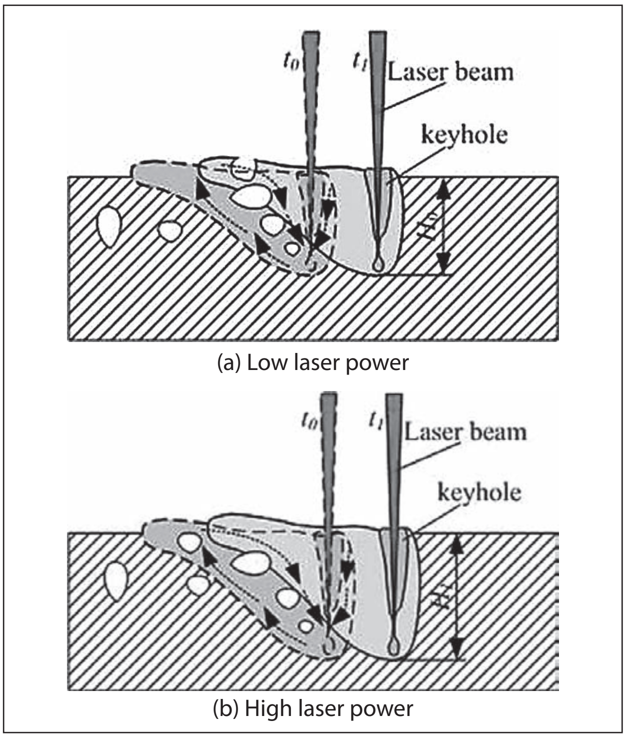

Figure 8 Formation of porosity in different laser power (t_0 – a point in time during laser welding; t_1 – a following point in time)

CONCLUSIONS

With the decrease in welding speed, the porosity content is decreased obviously. With the decrease in the laser power, the porosity content is decreased slightly.

When the solidification duration of molten pool is large enough, more bubbles can escape from the molten pool.

Acknowledgement

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Note: The responsible translator for English language is M.D. Shen – Wuhan Textile University, Wuhan, China