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Nd:YAG Laser Weldability of Al-Cu-Si-Mg High Strength Al Alloy†

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Abstract

Nd:YAG laser welding of A2014 Al alloy has been carried out to evaluate the tendency for weld defect formation and also the effect of post-weld heat treatment (PWHT) on the hardness and tensile strength for a fully-penetrated weld bead. Sound welds without cracking and porosity can be obtained by using Al-Si alloy filler wire at low welding speed, but porosity was likely to occur at high welding speed, especially with Al-Mg alloy filler wire. Significant recovery in the hardness and the tensile strength can be achieved by applying adequate PWHT and the joint tensile strength can reach 70 to almost 90 % of that of the base metal, 490MPa.

KEY WORDS: (Nd:YAG laser welding), (Al alloy), (Al-Cu-Si-Mg alloy), (Joint strength), (Post-weld heat treatment), (Aging)

1. Introduction

Al-Cu-Si-Mg alloy A2014 is a well-known high strength Al alloy used mainly in the air craft industry. Rivet and bolt joining processes are applied to this alloy, but conventional arc welding is not applicable due to cracking and softening in the welds[1]. In this study, the laser welding process has been selected as a potential fusion welding process with low heat input and narrow fusion zone and HAZ due to high energy density of the laser beam, and the laser weldability of A2014 alloy, in respect of defect formation, microstructure, hardness and tensile properties has been investigated for different welding conditions, filler wires and post-weld heat treatments.

2. Experimental Procedure

A2014 alloy plate with a specimen size of 100 x 150 x 3.5 mm and filler wires of A4043, A4047 and A5356 alloys of 1.2 mm of diameter were used, and chemical compositions are shown in **Tables 1** and **2**, respectively.

Nd:YAG laser welding with 3.3 kW power at the specimen surface was employed using a fiber of the diameter of 0.6 mm and Ar gas shielding of 40 l/min. A V-groove with 90 degree bevel angle and 1 mm depth was machined on the plate surface along a weld line for each specimen to ensure the supplying of filler wire into groove. **Figure 1** shows a setup of the laser head, a wire

Table 1 Chemical composition of A2014 alloy.

Base metal	Chemical composition (mass %)									
	Si	Fe	Cu	Mn	Mg	Cr	Zn	Zr	Ti	Al
A2014	1.10	0.38	4.46	0.92	0.62	0.02	0.04	<0.01	0.04	Bal.

Table 2 Chemical compositions of filler wires; wire diameter 1.2 mm.

Filler wire	Chemical composition (mass %)								
	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
A4043	5.80	0.24	0.02	0.01	0.01	0.01	0.01	0.01	Bal.
A4047	12.5	0.15	0.01	0.01	0.01	0.01	0.13	0.01	Bal.
A5356	0.01	0.20	0.01	0.12	5.00	0.09	0.01	0.10	Bal.

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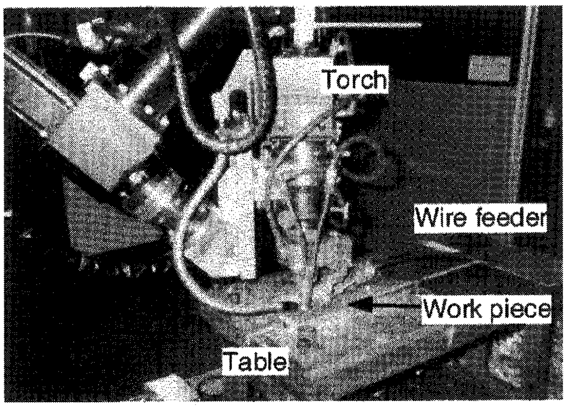


Fig.1 Setup of a work piece for laser welding.

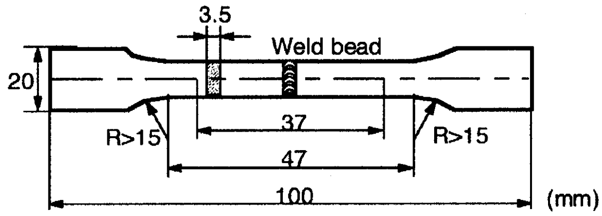


Fig.2 Shape and dimension of tensile test specimen.

feeder and a work piece on a machine table. Appropriate welding conditions to obtain a fully-penetrated weld bead was established by changing the welding speeds up to 2.5 m/min at different wire feed rates for each filler wire. Cracking and porosity in the welds were detected by X-ray radiography, and residual gases in the blowhole were analyzed with mass spectroscopy by drilling a weld bead in a vacuum chamber.

To evaluate the effect of post-weld heat treatment (PWHT) on the welded joint properties, microstructure observations, hardness measurements and tensile tests of the welded joint were carried out at the different PWHT conditions, namely natural aging (up to 60 days at room temperature after welding), artificial aging (180 °C x 10 h) and T6 treatment (solution treatment-water quenching-aging 180 °C x 10 h). **Figure 2** shows the dimensions of the tensile test specimen.

3. Results and Discussions

3.1 Weld bead formation

Preliminary experiments revealed that more than 3kW of laser power was required to obtain a full-penetration for this specimen. Thus, laser power was kept constant to 3.3kW at the maximum power of the laser equipment, and then wire feed rate was optimized to get a fully-penetrated weld bead with smooth surface for each welding speed. **Figure 3** shows surface appearances of top and root surfaces and macrostructures of the cross sections of the laser weld bead at different welding speeds with each filler wire. **Figure 4** shows their X-ray radiographs. No cracking was observed in each weld bead due to the modification of weld metal composition by

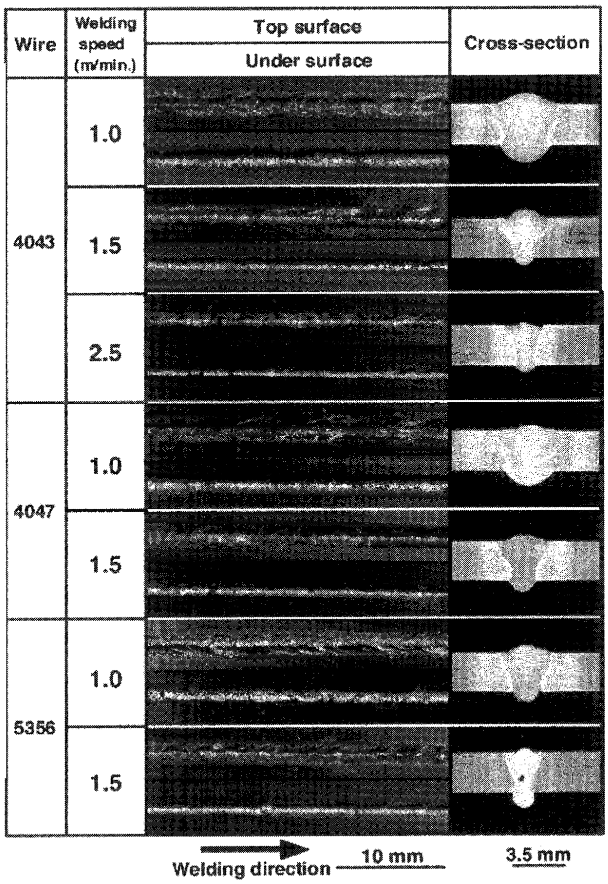


Fig.3 General appearance and macrostructure of cross-sections of laser welded beads.

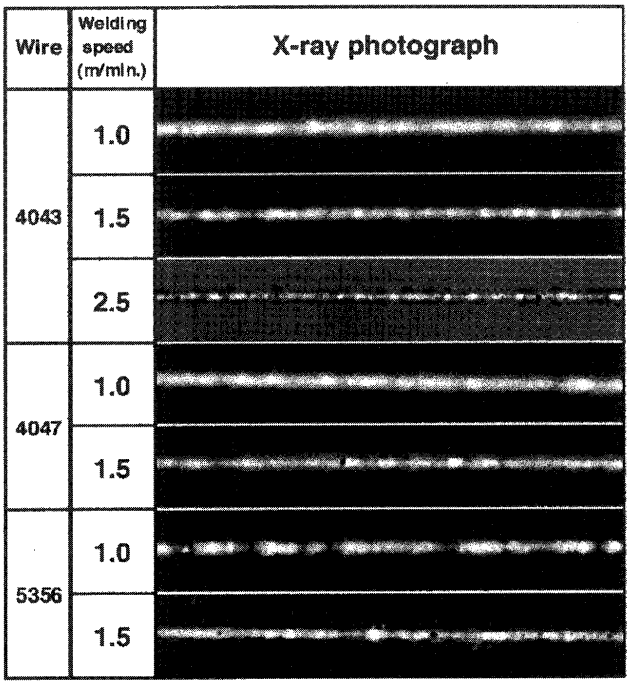


Fig.4 X-ray radiographs of laser welded beads at laser power 3.3kW.

Table 3 Result of residual gas analysis of blow holes in weld metal; 5356 wire, Welding speed 1.0 m/min.

Detected gas	Blow hole			
	No.1	No.2	No.3	No.4
H_2 (Vol. %)	1.43	3.97	7.54	3.96
N_2 (Vol. %)	0.65	0.10	0.19	2.90
Ar (Vol. %)	97.92	95.93	92.27	93.14
Total vol. %	100.00	100.00	100.00	100.00
Total volume (ml)	3.60 x 10^{-4}	3.39 x 10^{-4}	7.60 x 10^{-5}	2.30 x 10^{-4}

adding filler wires[2,3] and there was little deformation of the welded joint inherent in low welding heat input of laser welding. However, increasing welding speed caused an increase in porosity of the weld bead as well as an increase in its surface roughness. In particular, A5356 Al-Mg alloy filler wire showed much more porosity than A4043 and A4047 Al-Si alloy filler wires. This resulted in a keyhole instability caused by Mg vaporization during welding[4,5]. Gas analysis revealed that the dominant residual gas in blow holes was Ar with small amounts of nitrogen and hydrogen as shown in **Table 3**, which indicated that Ar as the shielding gas was entrapped in a keyhole together with a small amount of surrounding air and formed a blow hole. Much more spattering during welding was observed in the case of A5356 filler wire than in the case of Al-Si filler wires.

3.2 Hardness

In the welding of heat-treatable Al alloy, the weld zone is likely to be softened and this causes a reduction in the welded joint strength. **Figure 5** shows the hardness profiles collectively for different PWHT conditions for each filler wire. In the natural aging conditions, obvious reductions in the hardness were observed in weld metal and HAZ. Hardness in the HAZ near the fusion boundary was higher than that in the HAZ near base metal. This difference depended on different heat cycles in each part, namely solution treatment and over-aging treatment, respectively. There was no obvious effect of natural aging up to 60 days. However, the T6 treatment increased the hardness up to the same level of the base metal in all the weld zones. Artificial aging also increased the hardness. Particularly in the HAZ near the fusion the boundary the hardness increased to almost the same level of the base metal, since the HAZ near fusion boundary was heat-treated partially into the solution-and-quenched condition similar to the T6 treatment due to the rapid cooling rate in laser welding.

3.3 Joint strength

Figure 6 shows the effect of PWHT on the tensile strength of the welded joint made with each filler wire with the welding condition of laser power 3.3kW and welding speed 1 m/min. Tensile strength increased when

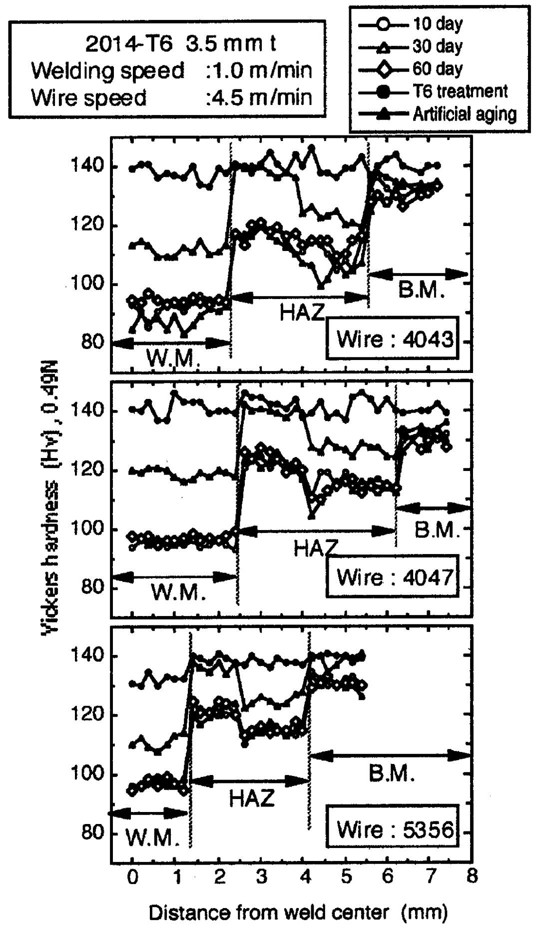


Fig.5 Hardness profiles of laser welded joints.

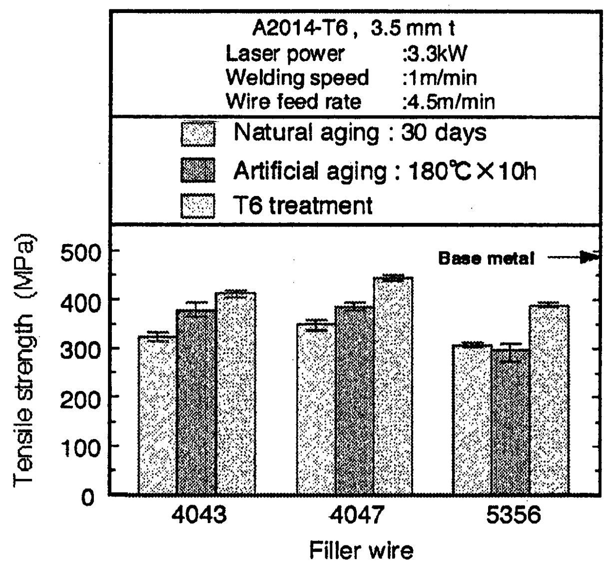
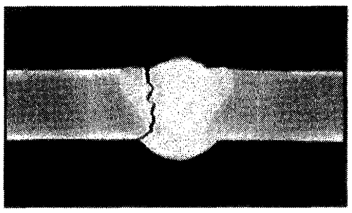


Fig.6 Effect of post-weld heat treatment on tensile strength of laser welded joints with different filler wires.

artificial aging and T6 treatment were used as PWHT. In particular, in the case of A4047 it recovered to about 70% and almost 90%, respectively, of that of the base metal, 490 MPa. The fracture position was in the weld metal in all the cases, irrespective of filler wire, as seen in **Fig.7** showing the macrostructure of the cross section of the welded joint after the tensile test. The comparatively low value of tensile strength with the A5356 filler wire was caused by the porosity in the weld metal. The elongation of the welded joint was as low as 2 to 4% irrespective of PWHT in comparison with that of the base metal, 12%, due to the deformation concentration restricted in narrow softened weld zone as well as the coarse columnar solidification structure in the weld metal.

4. Conclusions

As the conclusive remarks, this paper has proved that Al-Cu-Si-Mg A2014 high strength Al alloy is weldable with Nd:YAG laser welding by optimizing the welding conditions and that sound weld beads without cracking and porosity and with narrow softened zone can be made by using Al-Si alloy filler wire. Welded joint strength can be restored to 70% to almost 90% of the base metal by applying the appropriate post-weld heat treatment.



Filler wire : 4047
Welding speed :1.0m/min
Wire feed rate :4.5m/min

Fig.7 Macrostructure of cross section of laser welded joint after tensile test showing fracture position.

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