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Investigation on laser welding of copper and aluminum by irradiation from copper-side

Yasuhiro Okamoto[a,*], Yuki Yamada[b], Akihiro Ochi[b], Akira Okad[a], Takeshi Yamamura[c], Katsutoshi Nagasaki[c], Kazunobu Mamemo[c], Norio Nishi[c]

[a]*Faculty of Environmental, Life, Natural Science and Technology, Okayama University, 3-1-1 Tsushimanaka, Kita-ku, Okayama 700-8530, Japan*
[b] *Graduate School of Environmental, Life, Natural Science and Technology, Okayama University, 3-1-1 Tsushimanaka, Kita-ku, Okayama 700-8530, Japan*
[c] *Kataoka Corporation, 140 Kuse-Tsukiyamacho, Minami-ku, Kyoto 601-8203, Japan*

Abstract

Laser welding of copper and aluminum is an important method to realize the low carbon society, and reliable and strong weld joint is required. In the laser welding of copper and aluminum, the generation of intermetallic compound (IMC) deteriorates the strength and the reliability of weld joint especially in the case of laser irradiation from copper side. High speed scanning and appropriately high intensity of laser beam could contribute the improvement in the stability of copper welding. The laser incident angle of 30 degrees resulted in the reduction of aluminum rich intermetallic compound and porosity, since the excessive spouting of molten aluminum into copper could be reduced. Moreover, uniform and thin IMC could be obtained by combining the angled irradiation and the superposition of near-infrared and blue lasers, which could increase the breaking strength in cross tension test by 80 %, compared with a normal irradiation method.

Keywords: Welding; Copper; Aluminum; IMC; Fiber laser, Blue laser

1. Introduction

In order to continue sustainable development of society, decarbonization and low-carbonization are required. Electric and hybrid vehicles are indispensable for the conservation of natural environment, and the

* Corresponding author. Tel.: +81-86-251-8039; fax: +81-86-251-8266.
E-mail address: Yasurhiro.Okamoto@okayama-u.ac.jp.

lightweight construction and the effective transfer of electricity become important, as mentioned by Pautasso, E et al., 2019 and Omahne, V. et al., 2021. Thus, copper and aluminum have been becoming important materials because of their excellent materials' properties. In the laser welding of copper and aluminum, the generation of intermetallic compound (IMC) deteriorates the strength and the reliability of weld joint especially in the case of laser irradiation from copper side. The high intensity of laser beam to generate the keyhole inside copper makes it difficult to control the amount of molten aluminum, because the melting point of aluminum is lower than that of copper. Therefore, mild heat input from copper to aluminum is important to reduce the formation of brittle IMC. Angled irradiation might result in the mild energy input to aluminum, because it can be expected that aluminum would be heated by the reflected light inside the keyhole generated in copper according to the high light reflection of copper. In addition, stable welding can be expected by the superposed irradiation of blue and near-infrared lasers, since the blue laser has a high absorption rate to copper, as mentioned by Yang, H. 2022. Therefore, the effect of angled and superposed irradiation of blue and near-infrared lasers was experimentally investigated to realize stable and strong joint of copper and aluminum by the copper side irradiation.

2. Experimental methods

Liner welding experiments of 15 mm length were conducted by the laser irradiation method as shown in 1. A multimode fiber laser (NIR laser) of 1080 nm wavelength and a blue diode laser (Blue laser) of 450 nm wavelength were used as oscillators, and oxygen-free copper (C1020 plate) of 1.0 mm thickness and pure aluminum (A1050) of 1.2 mm thickness were set on the XYZ-stage. The spot diameters of 167 µm and 800 µm were obtained on the specimen surface of copper for NIR laser and blue laser. In order to avoid the oxidation during the laser irradiation, an argon gas was supplied around the irradiation area with a flow rate of 40 L/min using a nozzle of 11 mm diameter at the standoff distance of 25 mm.

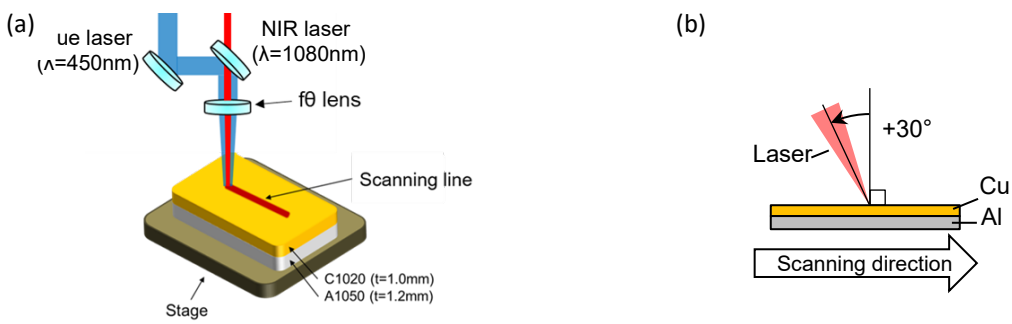

Fig. 1. Laser irradiation method. (a) superposed irradiation of blue and NIR lasers; (b) definition of angled laser irradiation

Fig. 2 schematically shows the setup of specimens for cross tension test. C1020 of 1.0 mm thickness and A1050 of 3.0 mm thickness were used as specimens for the evaluation of breaking strength, and 15 length welding line was created in the cross area of two plates. A larger thickness of 3.0 mm was employed for aluminum plate, because aluminum of 1.0 mm thickness was easily deformed during the test. The welded specimen was fixed by the clamping jig, and the breaking test was conducted by adding the tensile load in the perpendicular direction to the surfaces of copper and aluminum plates at a crosshead speed of 0.5 mm/min. The measured maximum breaking load was divided by the actual joint area, and the average value of three experiments was recorded as the joining strength.

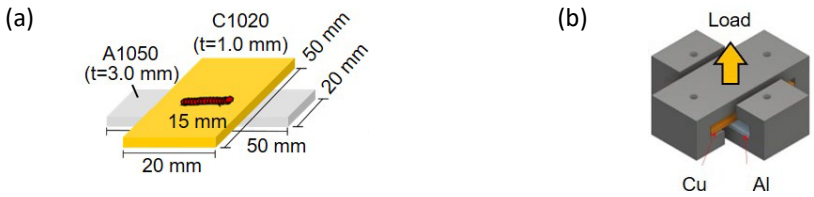

Fig. 2 Setup of specimens for cross tension test. (a) size of specimens; (b) clamping jig and loading direction

3. Results and discussion

Fig. 3 (a) shows the appearances of weld bead by perpendicular and angled irradiations of only NIR laser and superposition of NIR and blue lasers. In the case of perpendicular irradiation of only NIR laser, the edge line of weld bead fluctuates, and the uniformity of periodic mark is low. On the other hand, in the angled irradiation of only NIR laser, the weld bead has relatively uniform periodic marks, and the deviation of weld bead width is smaller than that by the perpendicular irradiation of only NIR laser. In the combination of angled and superposed irradiation of two wavelength, a weld bead width becomes the largest, and the most uniform width of weld bead can be obtained. In addition, the weld bead has V-shaped mark on the weld bead, since the molten metal would flow longer in the backward direction from the keyhole. As a result, a good quality welded surface was obtained by the combination of angled and superposed irradiation of two wavelengths.

Fig. 3 (b) shows the perpendicular and the parallel cross sections of weld bead. The perpendicular irradiation of only NIR laser results in ununiform penetration depth, and many large-size porosities were observed. A large amount of molten aluminum is flowed from aluminum to copper, which would form a large amount of aluminum rich IMC. On the other hand, in the angle irradiation of only NIR laser, the weld defects can be significantly reduced, although the penetration depth is periodically varied. The angle irradiation of NIR laser would reduce the direct heat input to aluminum around the bottom of keyhole. The reflected laser beam inside the keyhole would heat up around the bottom of keyhole, which would allow the mild heat input to aluminum. Thus, the gentle convection of molten aluminum results in the reduction of aluminum rich IMC, but the periodic variation of penetration depth has a difficulty in further reduction of IMCs. In the case of superposed irradiation, the perpendicular irradiation cannot avoid the generation of porosity, because the direct heat input to aluminum would be occurred. NIR laser of high power provides a large amount of heat input for the formation of keyhole, and blue laser enables additional heat input around the keyhole. In addition

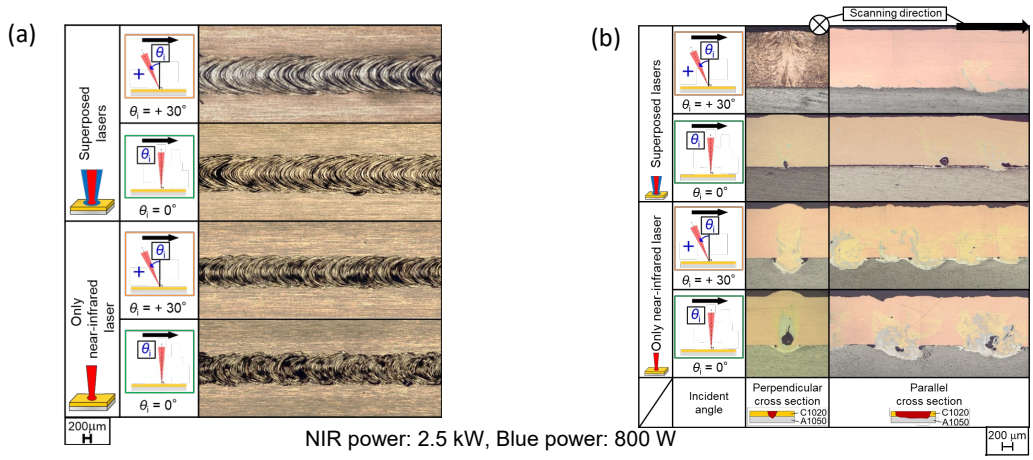

Fig. 3. Welding results. (a) appearances of weld bead; (b) cross section owe weld bead

to superposed irradiation of two wavelengths, the angled irradiation of NIR laser can avoid the direct energy input to aluminum, and no porosity is observed in the joining area. The mild heat input to aluminum can reduce the convection of molten aluminum to copper, and very thin IMCs layer would be formed. Therefore, high joint strength can be expected due to fewer weld defects and thinner IMCs formation.

Fig. 4 shows the breaking strength of welded joint by perpendicular and angled irradiations of only NIR laser and superposition of two wavelengths. The breaking strength by the angled irradiation is higher than that by the perpendicular irradiation in the case of only NIR laser irradiation, and the value of breaking strength by the angled irradiation of only NIR laser is almost equivalent to that by the perpendicularly superposed irradiation of two wavelength. Moreover, 80 % increase of breaking strength can be achieved by the combination of angled and superposed irradiation. The formation of aluminum rich IMC can be minimized with uniform penetration depth, and the largest breaking strength can be obtained by the combination of angled and superposed irradiation of two wavelengths.

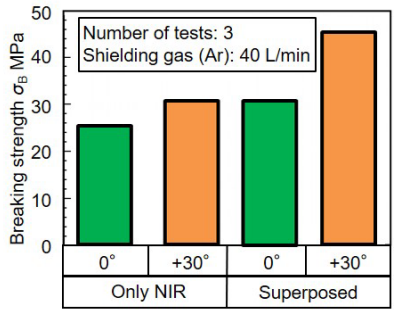

Fig. 4. Breaking strength of copper and aluminum joint in cross tension test.

Conclusion

The angled irradiation of 30 degrees resulted in the reduction of aluminum rich intermetallic compound and porosity, since the excessive spouting of molten aluminum into copper could be reduced. Moreover, uniform and thin IMC could be obtained by combining the angled irradiation and the superposition of near-infrared and blue lasers, which could increase the breaking strength in cross tension test by 80 %, compared with a normal irradiation method.

Acknowledgements

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