Lasers in Manufacturing Conference 2019

Influence of laser wavelength on melt pool behavior in welding of thin pure copper plate with blue diode and fiber lasers

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Abstract

Bead-on-plate welding of copper plate with a thickness of 50 µm were carried out with near infrared (NIR) fiber and blue diode lasers. Output powers of NIR fiber and blue diode lasers were 300 W and 50 W, respectively. Spot diameters of them were 100 µm. Welding speed was varied from 15 to 30 mm/s. The molten pool was observed with high speed video camera. For NIR fiber laser, the molten pool became larger and the hole was formed at the welding speeds in the range of 20 to 25 mm/s. For blue diode laser, the molten pool size was constant during the laser irradiation. Experimental results suggested that the absorption rate was increased as the temperature was increased for NIR fiber laser. On the other hand, in the case of the blue diode laser, they suggested that the absorption rate didn't depend on the temperature raise.

Keywords: blue diode laser; near infrared laser; pure copper; absorption rate; molten pool

1. Introduction

Pure copper is used in parts of electric vehicles such as electric parts, lithium ion batteries, and coils of motors, because of its excellent electric conductivity and thermal conductivity. In order to improve the performance of electric vehicles, processing techniques for pure copper used in these parts are required. In order to join pure copper foils used in lithium ion batteries, the demand for lap welding of pure copper sheets is increasing. Welding of copper alloys has been performed by arc welding by Daia et al., 2018. However, no report has been made on pure copper thin sheet welding.

Laser welding can perform both heat conduction and keyhole welding, and heat conduction welding is expected as an effective means for welding thin sheets. In the past, NIR lasers have been used for laser

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processing, and it is effective for nickel alloys and stainless steel other than pure copper, and welding with a plate thickness of 50 µm has been reported by Abe et al., 2005 and Mehrpouya et al., 2018. The NIR laser has a low absorption rate of 10 % to pure copper, and the energy efficiency of welding is poor by laser society, 2005 in the text. The absorption rate depends on the temperature of the base material by Spisz et al., 1696 and by Sidler et al., 2003. Therefore, in laser processing, the temperature of the base material rapidly rises, so that the absorptivity of the base material increases during processing, and the heat input to the base material rapidly increases. In the processing of pure copper using a NIR laser, it is considered that the rapid increase in heat input causes the formation of unstable beads and generation of spatter to cause deterioration of the weld quality. In the past, welding of pure copper using an NIR lasers have been conducted by various tests to improve energy efficiency and quality. By using oxygen-argon gas as assist gas in pure copper welding of NIR laser, thin oxide film was formed on the surface and welding efficiency was improved by Biro et al., 2003. However, when the oxygen concentration is increased, copper is oxidized to cause embrittlement. It has been reported that by applying a copper-based nanomaterial that is an absorber to a pure copper surface, the reflectivity of the pure copper surface is reduced to 15 %, and the energy efficiency of welding is improved by Chen et al., 2015. It has also been reported that spattering during welding can be reduced by changing the welding sweep method by Miyagi et al., 2017. However, there has been no report on the welding of a pure copper thin sheet with a thickness of several tens of µm using an NIR laser. On the other hand, a blue diode laser has a high absorptivity of about 60 % to pure copper, and an absorptivity is about 6 times higher than a NIR laser. In the wavelength of the blue diode laser region, the light reflectance hardly changes depending on the temperature of the base material up to 200 ℃ by Spisz et al., 1696. In the wavelength of the blue diode laser region, the absorption due to interband transitions is predominant by Shiga in the text 2015. Therefore, there is a possibility that the absorption rate does not change due to the temperature rise of the base material. If the change in the absorptivity due to the temperature change of the base material is small, it is easy to control the heat input to the base material. Therefore, high quality welding in which the bead width does not change during the laser irradiation is expected in the blue diode laser.

In this study, in order to perform high quality welding in which the bead width does not change during processing, bead-on-plate welding was performed on a 50 µm-thick pure copper thin sheet using a blue diode laser. In order to investigate the process window of high quality welding of pure copper using a blue diode laser, the power density was set constant, and the heat input was controlled with the welding speed as a parameter, and bead-on-plate welding was performed. The observation of the beads revealed the process window of high quality welding of 50 µm thick pure copper sheet. In order to investigate the behavior of the molten pool during the laser irradiation, it was observed with a high speed video camera. Next, in order to equalize the heat input to pure copper, bead-on-plate welding using a NIR fiber laser whose power density is six times that of the blue diode laser was performed without changing the spot diameter. In order to confirm the behavior of the bead width and the molten pool was observed in the same procedure as for the blue diode laser. As a result, in the welding using a blue diode laser, the bead width hardly changed during welding, and high quality welding with a narrow bead width was achieved. On the other hand, in the case of NIR fiber laser, the molten pool increased rapidly during welding. It has been found that the blue diode laser could weld a high quality pure copper thin plate with a constant heat input even when a rapid temperature change such as laser processing occurred.

2. Experimental procedures

2.1. Bead-on-plate welding

The experimental setup is shown in Fig.1. Table1 shows the experimental conditions for bead-on-plate welding. A blue diode laser or NIR fiber laser was condensed by a collimating lens to make the spot diameter 100 µm on the surface of pure copper. In order to perform welding at a constant speed from the welding start position, the laser was irradiated outside the pure copper sheet and then the laser was swept in the X-axis direction. A shield gas nozzle with an inner diameter of 17 mm was placed at an angle of 45 ° from the X-Y plane, swept simultaneously with the laser, and argon gas was blown at 15 L/min. The heat input was controlled by changing the sweep speed while keeping the laser output constant. The behavior of the molten area at the time of laser irradiation was observed using a high speed video camera installed at an angle of 45° from the surface in the X-Z plane

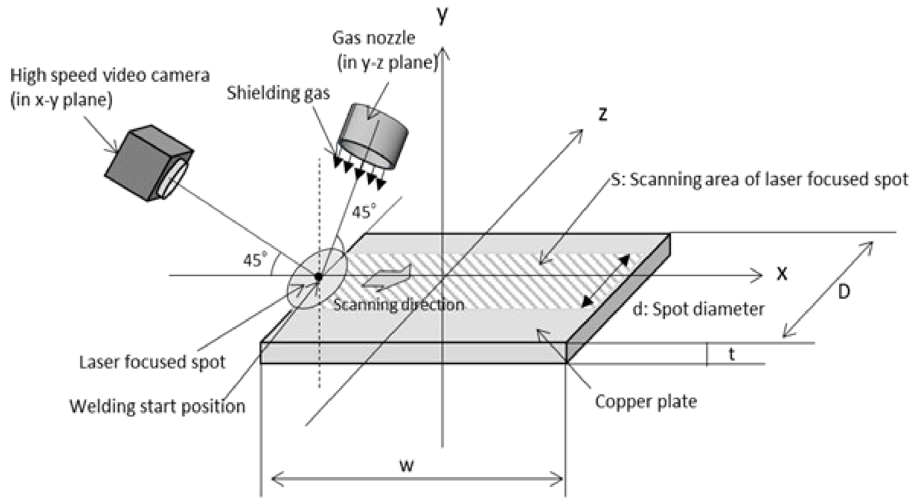

Fig. 1. Experimental setup

Table 1. Experimental conditions for bead-on-plate welding

	Blue diode laser	NIR fiber laser
Wavelength (nm)	450	1070
Laser power (W)	50	300
Laser power intensity(W/cm^2)	0.64×10^6	3.8×10^6
Input energy	3.8×10^5	
Spot diameter (µm)	100	
Sweep speed (mm/s)	15, 20, 25, 30	
Heat input (kJ/cm^2)	1.0, 1.2, 1.5, 2.0	
Material (Sheet)	Pure copper	
Purity (%)	99.9	
Sheet sizes(mm)	(w) 15 , (D) 50, (t) 0.05	
Shield gas flow rate(L/min)	*15*	

3. Experimental results and discussion

3.1. Observation of molten pool using high speed video camera

A high-speed video camera image of the molten pool is shown in Fig. 2 when bead-on-plate welding was performed with blue diode or NIR fiber laser at input energy of 1.5 kJ/cm^2. (a) of Fig.2 is the observation results of the molten pool using a blue diode laser, and welding was possible with almost no change in bead width during the welding. Figures 2 (b) show the observation results of the molten pool using a NIR fiber laser. The molten pool gradually increased at 4.0 mm from the welding start position.

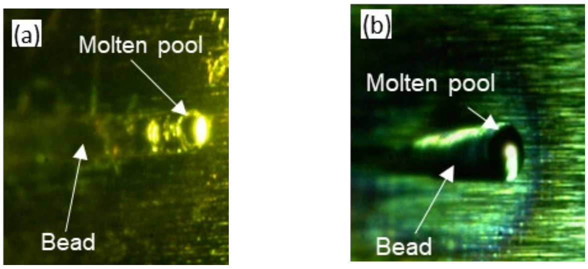

Fig. 2. A high-speed video camera image of the molten pool at input energy of 1.5 kJ/cm^2 (a) blue diode laser (b)NIR fiber laser

It has been found that, even with laser processing in which the temperature of pure copper changed rapidly in a blue diode laser, the heat input during welding remained constant without changing the width of the bead. This result suggested that the blue diode laser had a small change in absorptivity during processing. In welding using a NIR fiber laser, the bead width was increased rapidly during laser welding, so it has been found that the heat input was increased during welding.

4. Summary

In the condition of forming a bead with a NIR fiber laser, the molten pool became large rapidly on the way and cutting occurred. In the case of welding using a blue diode laser, high quality welding was obtained, in which the bead width did not change during welding, for thin pure copper of 50 µm thickness.

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