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Blue direct diode laser induced pure copper layer formation on stainless steel plate for reduction of heat affected zone

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Abstract

A pure copper layer was formed on a stainless steel substrate with blue direct diode laser at maximum output power of about 100W. The six lasers were combined by a focusing optical system at a focal point of 400 µm. At the same time, the pure copper powder, which had a particle size of 30 µm ϕ, was supplied on the focus point from a center nozzle. The powders absorbed the laser beam, and then melts and solidifies were occurred on the substrate. The substrate was placed on the XYZ stage in order to make the layer formation shape freely. After the laser irradiation, the Cu coated sample was cut with a micro-cutter to observe a cross section with an optical microscope in order to evaluate the thickness and heat affected zone. As the results, coating speed was obtained to 0.15 mm^3/s on stainless steel 304 substrate at the laser power density 74 kW/cm^2, a powder supply of 17mg/s and scanning speed of 5.0 mm/s.

Keywords: Blue direct diode laser.

1. Introduction

A copper is widely used for heat sinks and an electro circuit because of having properties of thermal conductivity and electrical conductivity. Currently, a technology for forming a copper layer on a dissimilar metal is required in order to improve the cooling performance in engine valves, molds and so on. Although a cold spray method and an electro less deposition method were widely used for copper layer formation,

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these methods have some issue such as low adhesive strength and poor layer. Recently a method of copper layer formation using a laser as a heat source has been reported. Mizoshiri et al. have reported that copper thin films were formed from CuO nanoparticle in the reduction reaction with a femtosecond laser, but a purity of copper became low since the CuO remained in the copper films. Thus, we focused on a laser cladding method which can form a dense and highly pure layer since it is possible to directly melt and solidify of coating material with a laser. The laser cladding is used for some lasers at a wavelength of infrared ray region, such as direct diode laser, disc laser, fiber laser and so on. However, it is difficult for high quality coating of pure copper having low absorptivity in IR region. Therefore, a blue direct diode laser with a wavelength of 445 nm has a attract attention because it has a highly absorption for copper. In our previous study, we have developed blue direct diode laser cladding system which uses multi laser combining method. In this study, in order to investigate coating speed and quality of this laser cladding system, pure copper coating was demonstrated on a stainless steel 304 substrate. As the results, it was found that the laser power density was depended on the coating speed.

2. Experimental method

Figure 1 shows the experimental set up for pure copper layer formation with blue direct diode laser cladding system. The blue direct diode laser module was employed in this study. An output power and wavelength of the one module were 20 W and 445 nm, respectively. The six lasers were guided to focusing head with every optical fiber, which core diameter is 100 µm. Beam profile at focal point of the combined six lasers was set a spot diameter of 400 µm by CCD camera, as show in Fig 1 (b). The focusing head has a function to supply a metal powder at a focal point from a center nozzle. When laser irradiation and powder supply are simultaneously performed toward to a stainless steel 304 substrate, the copper was melted and solidified on the substrate to form a copper layer. Here, the laser scanning speed v and laser power density was varied from 2.0 mm/s to 9.0 mm/s and from 47 kW/cm^2 to 74 kW/cm^2, respectively, as shown in Table 1. The pure copper powder was employed at an average size of 30 µm, as shown in Fig 2. The powder feed rate was set constant to 17 mg/s, and an Ar gas was flowed at 10 L/min as a shield gas to prevent from oxidizing. After coating, a sample was cut in vertical to the scanning direction and observed by optical microscope to investigate a cross section S. Moreover, a coating speed V was calculated as following equation.

$$V = S \times v \tag{1}$$

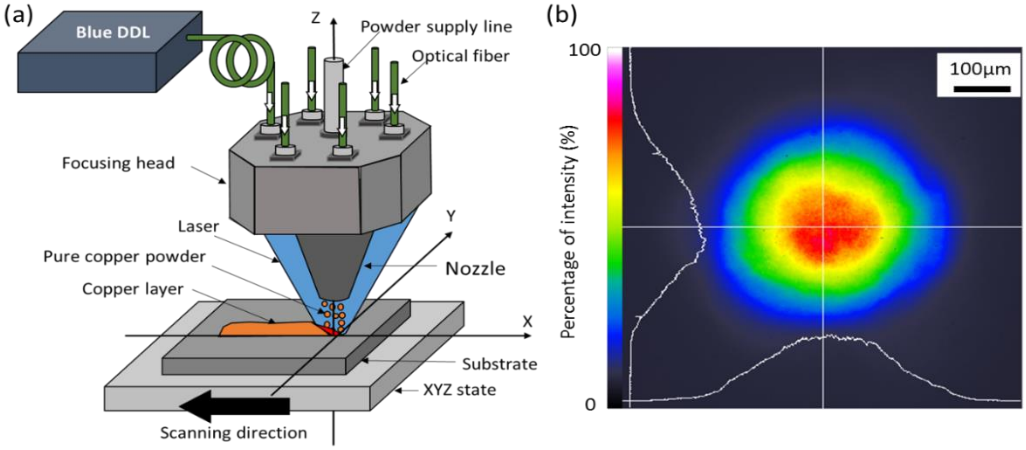

Fig. 1. Schematic diagram of Experimental setup for blue direct diode laser system in (a), beam profile at focal point in (b)

Table 1. Experimental condition

Laser wavelength nm	445
Beam diameter μm	400
Power density kW/cm^2	74, 62, 47
Scanning speed mm/s	2.0~9.0
Powder feed rate mg/s	17
Substrate	Stainless steel 304 50mm × 50mm × 3mm^t

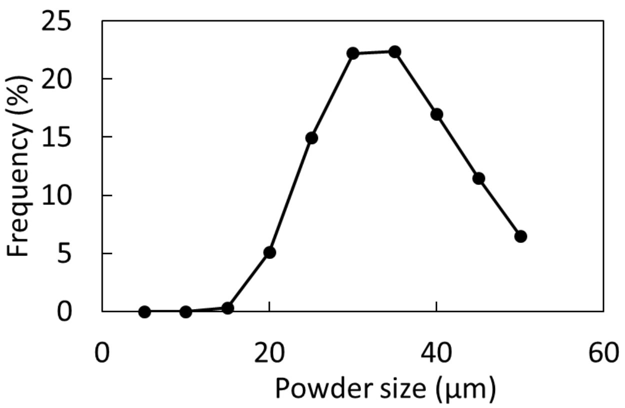

Fig. 2. Powder particle distribution of pure copper

3. Results and discussion

Figure 3 shows the correlation between the laser scanning speed and coating speed. The coating speed was depended on the scanning speed, where the maximal coating speed of 0.24 mm^3/s was obtained at scanning speeds of 3.0 mm/s. In order to compare with the laser power density of 74, 64 and 55 kW/m^2, the laser power density was strongly depended on the coating speed. And less than power density of 64 kW/cm^2, the copper layer was not formed on it. Figure 4 shows the surface and the cross section of the copper formation on stainless steel 304 substrate at the scanning speed of 3.0 and 5.0 mm/s. From Fig 4 (c), some pores were appeared in the cross section of the layer at scanning speed of 3.0 mm/s. On the other hand, at the scanning speed of 5.0 mm/s, the no-pore was observed, as shown in Fig 4 (d). Next, in order to evaluate a heat affected zone for coating layer, the line distribution of Cu of the film component and Fe, which is the substrate component, were measured by the energy dispersive X-ray spectrometry (EDX) analysis. The heat affected zone was defined as area mixed with Cu and Fe by EDX. As the results, a depth of heat affected zone was obtained to 14 µm at the scanning speed of 5.0 mm/s and laser power density of 74 kW/cm^2.

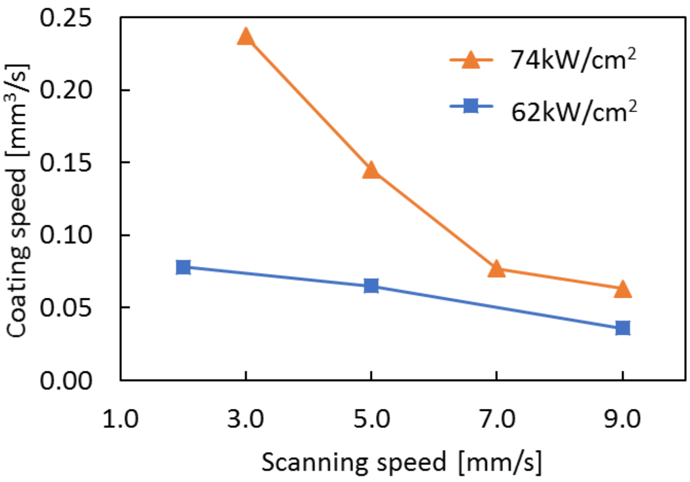

Fig. 3. Correlation between laser scanning speed and coating speed at the laser power density of 74 W/cm^2 and 62 kW/cm^2.

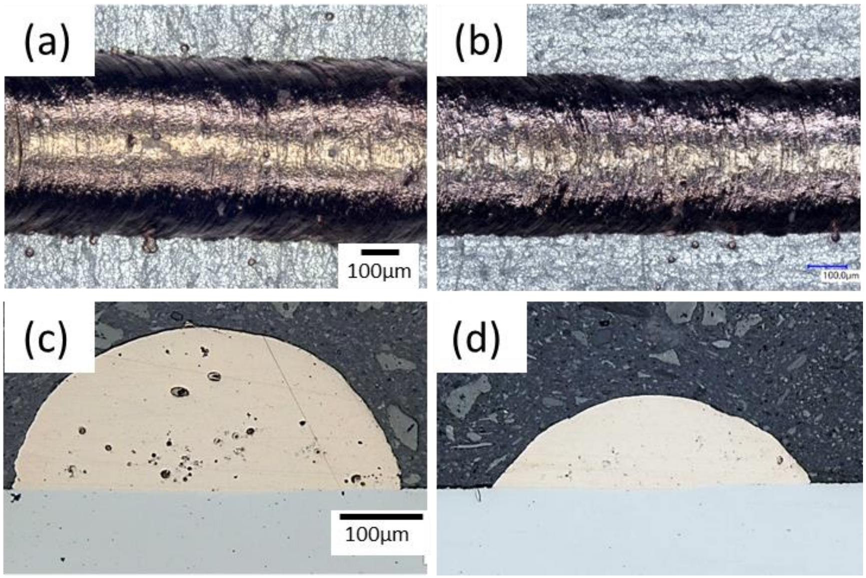

Fig. 4. Optical microscope images of pure copper formation on stainless steel 304 substrate with a scanning speed of (a) (c) 3.0 mm/s and (b) (d) 5.0 mm/s. (c) and (d) are a cross section of (a) and (b), respectively.

Summary

Pure copper layer was formed on the stainless steel 304 substrate by blue direct diode laser cladding system to evaluate correlation between laser scanning speed and coating speed. From results, it was clarified that the coating speed was depended on the laser power density and scanning speed. Additionally at the laser power density of 74 kW/cm^2, and scanning speed of 5.0 mm/s, no pores and voids were appeared in the copper layer.

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