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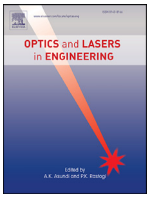

The effect of particle size on the heat affected zone during laser cladding of Ni–Cr–Si–B alloy on C45 carbon steel

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ABSTRACT

Laser cladding is one of the most useful surface coating methods for improving the wear and corrosion resistance of material surfaces. Although the heat input associated with laser cladding is small, a heat affected zone (HAZ) is still generated within the substrate because this is a thermal process. In order to reduce the area of the HAZ, the heat input must therefore be reduced. In the present study, we examined the effects of the powdered raw material particle size on the heat input and the extent of the HAZ during powder bed laser cladding. Ni–Cr–Si–B alloy layers were produced on C45 carbon steel substrates in conjunction with alloy powders having average particle sizes of 30, 40 and 55 µm, while measuring the HAZ area by optical microscopy. The heat input required for layer formation was found to decrease as smaller particles were used, such that the HAZ area was also reduced.

1. Introduction

Laser cladding is an advanced surface modification technique for the production of metallurgically bonded coatings [1,2]. Compared with conventional surface modification techniques, such as plasma transferred arc welding (PTA), coating layers produced by laser cladding exhibit minimal dilution from the substrate into the coating layer, only minor distortion of the substrate and a good metallurgical bond to the substrate [3,4]. A number of laser cladding studies have been performed, investigating microstructural evolution [5], phase transformation [6], wear properties [7], corrosion resistance [8], and optimization of the processing parameters [9,10]. In a previous study, we examined a basic laser cladding process using a diode laser with a flat-top beam profile [11,12]. Powder material became droplet by using Gaussian-like beam. When powder material became droplet, dilution and surface roughness of cladding layer. The results demonstrated that it is important to control the laser beam profile at the focus spot, and that a flat-top beam can produce a cladding layer with low dilution and a smooth surface.

C45 carbon steel is widely used in industrial components, even though the wear and corrosion resistance of this material are low. As noted above, laser cladding is a useful means of applying a coating to improve this material, and a Ni–Cr–Si–B alloy is generally used in hard facing alloys due to its good wear and corrosion resistance. As such, it would be beneficial to be able to apply a Ni–Cr–Si–B alloy layer onto a C45 carbon steel substrate by laser cladding. However, because laser cladding is a thermal method, this process tends to generate a heat affected zone (HAZ) in the steel substrate, and so the heat input associated with cladding must be reduced as much as possible. In our previous work, we produced cladding layers using average particle diameters of 30 or 55 µm, and a powdered raw material with an average diameter of 30 µm was found to reduce the heat input required for the formation of the cladding layer [13]. The temperature of melting particle was increased by using particle with small diameter [14]. These result showed that the heat input was reduced when using a smaller size of powder, and so it was anticipated that both the heat input and the HAZ could be decreased by reducing the particle diameter.

In this study, Ni–Cr–Si–B alloy powders with average particle sizes of 30, 40 and 55 µm were deposited on C45 carbon steel substrates. Cladding layers were produced at various heat inputs and using several particle sizes so as to investigate the effect of particle size on the HAZ area. The formation of each cladding layer was observed with a high-speed video camera, while the surface and the cross section of each layer were examined by optical microscopy. Vickers hardness values were measured using a hardness tester and the HAZ areas were determined by optical microscopy.

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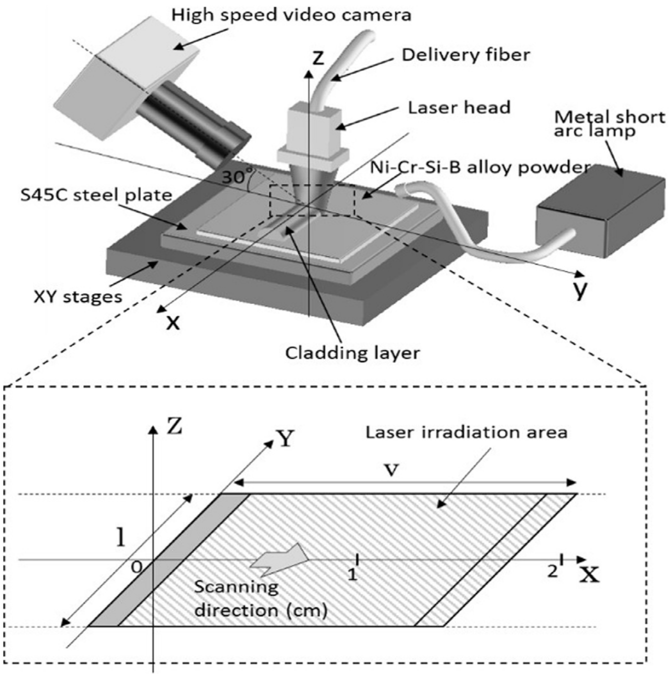

Fig. 1. Schematic diagram of experimental setup.

Table 1
Composition of Ni-Cr-Si-B alloy.

	Chemical composition (wt%)					
	Ni	Cr	Si	B	Fe	C
Ni–Cr–Si–B alloy powder	Bal.	16.3	4.3	3.3	4.2	0.9

2. Experimental

Laser cladding experiments were carried out using a diode laser system with a flat-top beam, as shown in Fig. 1. This system consisted of a laser head, a high-speed video camera with a metal short arc lamp, and an XY stage. The maximum output power of the diode laser was 600 W. The spot shape and spatial intensity profile of the laser at the focal position are shown in Fig. 2(a) and (b). The focused spot is seen to be rectangular, with dimensions of 2600 × 300 µm. Fig. 2(b) presents the cross section of the beam profile at the point labeled “a1” in Fig. 2(a). Here the horizontal axis indicates the length of the beam while the vertical axis shows the intensity. As noted, Ni–Cr–Si–B alloy powders with average particle sizes of 30, 40 and 55 µm were used in conjunction with C45 carbon steel as the substrate, and Table 1 summarizes the composition of the Ni–Cr–Si–B alloy powder. Scanning electron microscopy (SEM) images of the alloy powders are shown in Fig. 3, from which it is evident that the particles had a spherical morphology. The particle size distributions for the powders are summarized in Fig. 4, and are seen to be narrow. In preparation for the laser cladding, a 200 µm high bed of the alloy powder was placed on a C45 carbon steel substrate with dimensions of 50 × 50 × 3 mm. The laser beam was subsequently focused onto the powder and scanned along the width of the bed using the XY stage. The power density of the laser beam was 3.9×10^4 W/cm^2, and cladding layers were produced at various heat inputs. Herein we use the heat input, E (J/cm), rather than the laser fluence, F (J/cm), because the fluence is defined as $F = p/(vl)$, where P (W), v (c/ms) and l (cm) are the laser output power, scanning velocity and the long dimension of the laser spot, respectively. This equation may be rewritten as $F = (p/v)(1/l)$, and $1/l$ was constant in these experimental trials since the long dimension of the focused laser spot was constant at 2600 µm, as described above. Therefore, we can instead write $F = (1/l)\,E$, where E (J/cm) is the heat input, defined as:

$$\mathrm{E} = \frac{P}{v}. \tag{1}$$

For an output power of 300 W, varying the scanning velocity from 1.2 to 2 cm/s changed the heat input from 150 to 250 J/cm.

The surfaces and cross sections of the resulting cladding layers were observed by optical microscopy and the layer formation process was tracked using a high-speed video camera at 1000 fps, employing a short metal arc lamp for illumination. The observation direction was perpendicular to the scanning direction, and the camera was angled at 30° relative to the horizontal plane. The HAZ area was measured by optical microscopy and the Vickers hardness of each layer was determined via a hardness tester, applying a load of 0.2 N.

3. Results and discussion

Fig. 5 shows optical micrographs of sample surfaces produced for various E values and using different alloy particle sizes. Cladding layers were not formed for an E of 150 J/cm when using the 30, 40 or 55 µm size particles, due to poor wetting. It is considered that powder material was not heated enough. Increasing the heat input to 162.5 J/cm generated a cladding layer with a smooth surface when using the 30 µm particles, as shown in Fig. 5(a). Cladding layers were also formed for heat inputs of 200 and 250 J/cm with the 40 and 55 µm alloys, respectively, as seen in Fig. 5(e) and (i). These results indicate that cladding layers could be produced at lower heat inputs as the particle size was reduced; the 30 µm particles formed a cladding layer at a heat inputw 0.65 times that required in the case of the 55 µm alloy.

Fig. 6 presents high-speed video images of the laser cladding process with both 30 and 55 µm size particles for an E value of 162.5 J/cm. In these trials, the laser beam was initially focused at the center of the image and scanned from right to left. The molten powder is seen to have spread over the substrate to form a smooth cladding layer with the 30 µm alloy, as shown in Fig. 6(a). However, when the 55 µm particles were

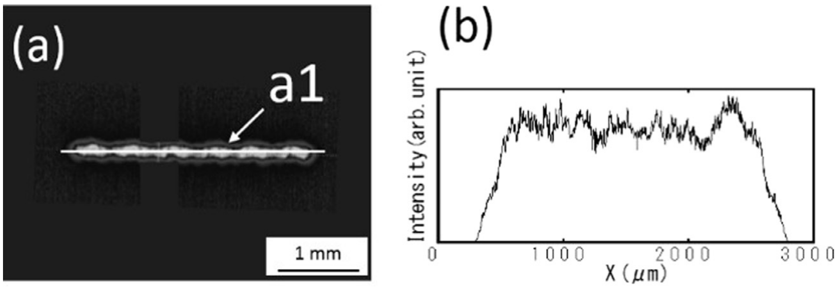

Fig. 2. Diode laser (a) beam profile and (b) cross section profile.