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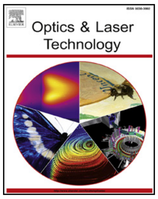

Full length article

Influence of laser parameters on graphite morphology in the bonding zone and process optimization in gray cast iron laser cladding

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HIGHLIGHTS

- The carbon atoms diffusion and the graphite refining mechanism were analyzed.
- The influences of laser power and scanning speed on graphite were investigated.
- The optimal process parameters were proposed.

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ABSTRACT

The surface modification of gray cast iron through laser cladding produces a high-performance surface with low-cost materials, thereby reducing the manufacturing cost. This approach may considerably alter the phases in the bonding zone. In turn, the morphology of the graphite and adjacent phases influence the reliability and surface performance of the cladding layer. To optimize this process, this study performed numerical analysis and cladding experiments to analyze the carbon atom diffusion in graphite and examine the effects of scanning speed and laser power on graphite environment temperature, structural transformation, and graphite morphology in the bonding zone. The results showed that, in the case of constant laser power, as the scanning speed decreased, the diffusion of carbon atoms increased and became highly refined, thereby inhibiting poor graphite morphology and reducing micro-crack generation. At a constant scanning speed, the laser power slightly influenced the structure and macro-morphology of graphite. Considering the macro-morphology in the cladding layer and the micro-cracks in the bonding zone into consideration, we proposed that a laser power of 350 W and a scanning speed of 300 mm/min are the optimal process parameters.

1. Introduction

Gray cast iron has been extensively applied in industrial production because of its excellent casting property, machining property, wear resistance, and low price. Given the technical features of laser modification technology (i.e., high process controllability, small thermal effect, and thermal deformation of the material), a modified reinforcement layer on the surface of gray cast iron can significantly reduce the manufacturing and maintenance costs of the equipment, thereby significantly expanding the application range of this low-cost material [1,2]. As such, gray cast iron has attracted considerable attention in research and industrial applications.

Compared with the laser cladding of other iron-based materials, the structural transformations of the melting and bonding zones of laser cladding, particularly the behavior of flake graphite, significantly influence the micro-cracking of the cladding layer, thereby implying that these two zones should be investigated [3]. Temperature markedly changes during cladding and causes complete dissolution of the graphite in the melting zone, ultimately forming a typical structure that differs from those of other material surfaces [4,5]. The carbon in the bonding zone mainly exists as cementite and graphite [6]. Graphite significantly contributes to the heat-resistant fatigue property of the specimen, and stress concentration is easily generated at the graphite tip where micro-cracks appear [7]. The main driving factors are

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transient and residual tensile stresses, and when an angular relationship appears between the flake graphite and the tensile stress, the stress concentration at this position reaches the maximum, causing crack generation [8,5]. Therefore, inhibiting the appearance and extension of micro-cracks is a major technical problem, which could be overcome by laser cladding on a gray cast iron surface. Laser remelting has been used to prepare bionic elements on a surface to prevent crack extension and bridging [9,10] to obtain a favorable anti-crack toughness for the anti-crack effect of the surface texture [11]. Nevertheless, the driving mechanism of internal micro-cracking must be elucidated. Thus, several studies have been conducted with various objectives, such as to eliminate the internal defects in the melting and bonding zones, to improve the processing quality and surface properties of the cladding layer through preheating or slow cooling, to explore the relationships between the graphite phase and adjacent materials during laser cladding, and to determine the influence of the graphite monomer morphology and the group distribution on thermodynamic response [3,12–17]. These works have provided new and effective strategies for optimizing the stress state of the cladding layer and improving the cladding quality.

According to literature, graphite morphology and the compositions of its adjacent phases in the bonding zone greatly affect the mechanical performance and reliability of the cladding layer surface. Thus, the process by which phase morphology can be adjusted and the effects of such changes on the behavior of the graphite phase must be explored. In this study, we analyzed the carbon atom diffusion in the graphite phase. We performed numerical analysis and experiments to examine the effects of scanning speed and laser power on the graphite environment temperature, structural transformation, and graphite morphology in the bonding zone. The optimal process parameters were proposed based on the results.

2. Experiment materials and methodology

2.1. Experiment materials

HT250 gray cast iron was selected as the substrate of laser cladding. Fig. 1 shows the microstructure of the substrate, which mainly consisted of flake graphite, pearlite, and ferrite. An excellent compatibility between the alloy powder and the cast-iron substrate can guarantee good cladding quality, and the iron-based alloy powder was partly composed of gray cast iron, resulting in a favorable bonding property [18,19]. Fe313 iron-based alloy served as the cladding powder with an expected particle size of 150–250 µm. Table 1 lists the chemical compositions of the HT250 substrate and the Fe313 alloy powder. The powders were paved on the substrate surface in advance through powder presetting method. The powder layer was approximately 10 mm wide and 1–1.2 mm thick.

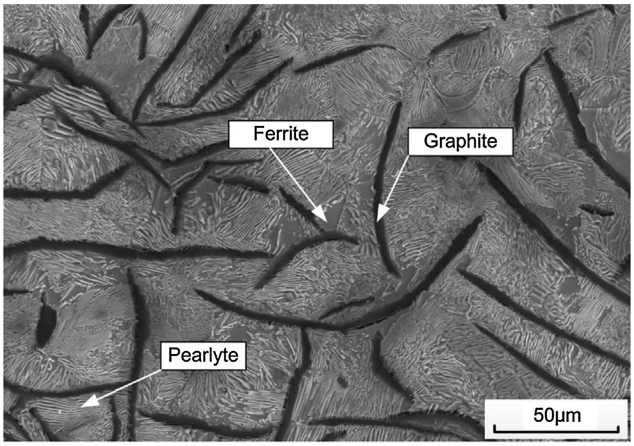

Fig. 1. Micro-structure of the cross section.

Table 1
Chemical compositions of the substrate and the alloy powder (wt.%).

	C	Si	Cr	B	P	S	Fe
HT250	3.55	1.58	–	–	0.09	0.08	Bal.
Fe313	0.1	1	15	1	–	–	Bal.

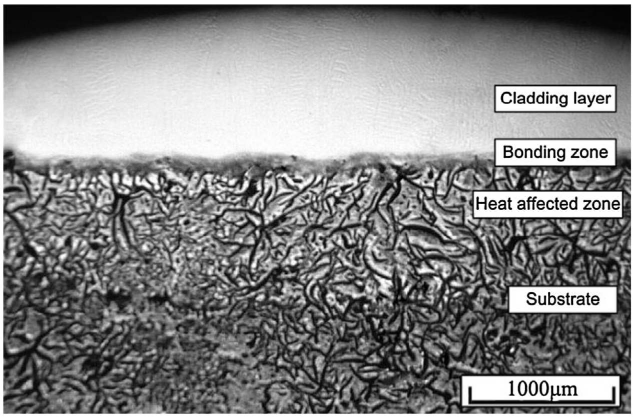

Fig. 2. Micro-structure with four zones.

The laser cladding experiment was performed by using a DL-HL-T5000 cross-flow CO_2 laser and a DL-LPM-IV multifunction laser numerical control machine with an output laser wavelength of 10.6 µm and a rated power of 5 kW. In view of the universality and processing efficiency of the cladding, 10 mm × 1 mm broadband rectangle spots were applied. After the cladding process was completed, the samples were prepared along the cross-section perpendicular to the scanning trace. The morphologies of the graphite and graphite-adjacent phases were observed under a LEICA-DM2500M microscope. Three samples are set for each process parameter, and several different positions are observed for every sample, so as to ensure the repeatability of the experiment.

Fig. 2 shows the cross-section of the microstructure of the cladding sample. The microstructure consisted of the following four distinct zones (from top to bottom): cladding zone, bonding zone, heat-affected zone, and substrate zone (SZ). The cladding zone was influenced by the flows and surface tension in the welding pool. Being the arc, the cladding zone was highest in the center (approximately 1.2 mm high) and lowest at the edges. The overall morphology was relatively flat. Below the cladding zone was the 0.5 mm thick bonding zone, underneath which was the heat-affected zone.

2.2. Experiment methodology

Experiment 1 intended to examine the influences of cladding speed on structural transformation and graphite morphology by maintaining a constant laser power while changing the scanning speed. The adopted process parameters and specific energies are shown in Table 2. In the experiment, the laser power was set to 3500 W, whereas the scanning speeds were 100, 200, 300, and 400 mm/min.

Table 2
Process parameters at changing speed and constant power.

Case	Laser power/P, W	Speed/V, mm/min	Specific energy/E, J/mm^2
1	3500	100	210
2		200	105
3		300	70
4		400	52.5