Optics & Laser Technology 90 (2017) 52–64

Contents lists available at ScienceDirect

Optics & Laser Technology

journal homepage: www.elsevier.com/locate/optlastec

Impact analysis of the thermal mechanical coupling characteristics of graphite morphologies during laser cladding of gray cast iron

Peng Yi[a,*], Yancong Liu[a,b], Changfeng Fan[c], Xianghua Zhan[a], Pengyun Xu[d], Tuo Liu[a]

[a] *College of Mechanical and Electronic Engineering, China University of Petroleum, Qingdao 266580, China*
[b] *Shengli College China University Of Petroleum, Dongying 257061, China*
[c] *Institute of Joining and Welding Technology, Technische Universitaet Braunschweig, Langer Kamp 8, 38106 Braunschweig, Germany*
[d] *Department of Mechanical and Industrial Engineering, University of Toronto, Toronto, ON, Canada*

ARTICLE INFO

Keywords:
Laser cladding
Cast iron
Graphite phase
Stress field
Crack

ABSTRACT

Cladding and numerical experiments on thermodynamic coupling were conducted to determine the thermal response features and microcracks of graphite and environment phases during surface laser cladding of gray cast iron. A micromodel of graphite–environment phase was established using numerical methods. On the basis of this model, a quantitative analysis on the thermal mechanical coupling characteristics of microstructures was realized, the relationship with microcracks at tip of graphite was established, and the influence of morphological difference on local stress concentration was obtained. Results showed considerable stress concentration at the tip of graphite during cooling stage, and on the whole, the stress concentration at both ends of graphite was in direct proportion to the length of the graphite. Moreover, sufficiently short graphite resulted in further increase in stress concentration. The influence caused by tip angle was more considerable than that of length, and sharpness was in direct proportion to stress concentration. For stress fields at both ends of dimer graphite, collinear distribution easily caused stress concentration, and more obvious stress concentration was observed when the two tips were closer. The interactive effect was weak and the influence on stress concentration was minimal when two graphite pieces were in parallel or vertical distribution.

1. Introduction

Laser cladding, as a kind of remanufacturing technology, has gradually become an important technique of material processing. Heavy equipment in petroleum and petrochemical fields are made up of various kinds of materials. In particular, cast iron materials are extensively applied and generally used under complicated working conditions and severe environment. Microcracks are easily generated on material surface and interior, and continuously developed into macroscopic defects, which will degrade the usability of the equipment quickly and then result in the final failure of the equipment. On account of the inherent characteristics of cast iron materials, the local restoration cost is typically high, and most damaged equipment should be directly scrapped. Hence, laser cladding technology should be used to improve the surface properties of equipment and directly prolong its service time effectively [1], which have significant industrial application values.

Laser cladding can strengthen equipment surfaces, such as large-scale box and revolving drum. However, as an important phase of cast iron materials, the behavioral characteristics of graphite phase are not given sufficient emphasis and studies; the characteristic presentation of this phase in cladding process is considerably significant to cladding quality, surface properties, and process formulation [2].

During laser cladding, a resultant force that rotates to certain degrees, induces graphite diffusion, resulting in continuous carbon diffusion and transfer during cladding process in the graphite phase and surrounding structures; thus, more martensite is created from cast iron substrate to the cladding layer but with less graphite [3]. The morphologies and parameters of graphite phase under different technological conditions are different. Cryptocrystalline martensite and many retained austenites exist around unmelted graphite. Furthermore, carbon diffusion refines graphite flakes. Melting time differs between zones, which are close and far from graphite, which results in a discontinuous distribution of martensite morphologies [4,5]. The carbon elements in the combined area are mainly in the form of carbon and graphite [6]. In heat-affected zone caused by drastic changes in temperature in the process of laser heat action, graphite carbon atoms gradually transfer to the surrounding martensite; additionally, the diffusion of carbon element causes the complex melting zone boundary [7] and makes the transformation mechanism

---

[*] Correspondence to: College of Mechanical and Electronic Engineering, China University of Petroleum, No.66 Changjiang West Road, Huangdao District, Qingdao 266580, China.
E-mail address: yipupc@gmail.com (P. Yi).

http://dx.doi.org/10.1016/j.optlastec.2016.11.011
Received 5 June 2016; Received in revised form 27 September 2016; Accepted 8 November 2016

around the graphite phase clear.

Many scholars have also carried out certain studies on the internal relationship among phase morphologies of cast iron-based materials, cladding quality, and material properties. The influence of graphite phase morphology is considerable, and its distribution and dimension should have direct relationship with its micronotch effect in materials [8]. Temperature in graphite phase zone during cladding process experiences drastic change, and stress concentration is easily generated at graphite tip [9]. When flake graphite and tensile stress are in the appropriate angle, the stress concentration at the tip of graphite can reach the maximum and eventually lead to crack initiation [10]. Experiment on cast iron surface to prepare bionic and coupling unit found that crack expansion velocity in flake graphite substrate is high, and the bionic unit could effectively prevent crack expansion and bridging, as well as improve cladding quality [11]. Another research adopted the preheating or slow cooling technology to optimize organizational structure of laser processing, and an in-depth study on the elimination of surface defects was conducted by combining newly designed experiment and numerical values. Consequently, the processing quality and surface properties are improved [12,13], and an effective approach for studying graphite phase morphology at cladding layer and improving cladding quality of cast iron is provided.

In summary, considering the large inventory of cast iron equipment in industrial application, a remanufacturing technology for cast iron material surface is urgently needed, and studies on laser cladding on their surfaces should comply with the current pressing technical requirements. Existing studies showed that as a significant factor limiting cladding quality, characteristic studies of graphite phase in cladding process are still insufficient, and research methods are lacking. Additionally, providing rapid and credible analysis results only through experimental study or qualitative analysis is difficult. Hence, the present study combines the experimental study and numerical calculation; an in-depth research on the thermodynamic characteristics of graphite–environment phase during laser cladding process is performed, and classification and comparative analysis of the influence of graphite phase morphologies are also conducted. The results of this study will provide theoretical support for further research and application of laser cladding technology in cast iron materials.

2. Laser cladding experiment with cast iron and microcrack defect analysis

To study the organizational characteristics of cast iron substrate in cladding region, a compatibility analysis of the two materials was carried out, which provided experimental data verification for subsequent numerical analysis. A laser cladding experimental scheme was designed, which carried out the experimental study.

2.1. Experimental scheme design

DL-HL-T5000 crosscurrent CO_2 laser was adopted in laser cladding experiment. This equipment was matched with DL-LPM-IV multifunction laser numerical processing machine with output laser wavelength of 10.6 μm, maximum output power of 5.2 kW, and a rated power of 5 kW. The laser cladding worktable is shown in Fig. 1.

HT250 gray cast iron material was selected as cladding substrate. After polishing the sample cross Section, 4% nitric acid alcohol was used to perform corrosion. Fig. 2 is the microscopic structure consisting of flake graphite, pearlite, and ferrite of the substrate. The cladding sample was a cylinder with a diameter and thickness of 50 and 10 mm, respectively, (Fig. 3).

A superior compatibility status between alloy powder and cast iron substrate guarantees cladding quality; iron-based alloy powder is similar to gray cast iron in compositions, and these two have sound associativity [14,15]. Hence, Fe313 iron-based powder was used with particle dimension within 150–250 μm. The chemical compositions of HT250 substrate and Fe313 alloy powder are shown in Table 1.

Fig. 1. Laser cladding worktable.

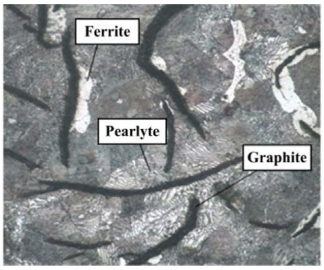

Fig. 2. Substrate microstructure.

Fig. 3. Gray cast iron samples.

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

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

Laser power is considerably important to the laser cladding quality of cast iron. Its instability causes the realization of a continuous and accurate regulation within a short time difficult. To guarantee cladding quality, power was selected as 3400 W. Laser scanning speed, which was selected as 240 mm/min, can also make an accurate setting through the numerical control program. Considering processing universality, light spot pattern was rectangular (10 mm×1 mm). After cladding, a cross-sectional sample which was vertical to the scanning track was prepared, and the structural morphologies of the graphite–environment phases were observed under LEICA-DM2500M optical microscope.

2.2. Microdefect analysis of graphite phase region

GM-JX2000 metallographic analysis was adopted for quantitative analysis of the graphite–environment graphite, as shown in Fig. 4. Austenite content and quantitative metallographic measurement modules were selected. Additionally, metallographs were imported into