Surface & Coatings Technology 286 (2016) 64–71

Contents lists available at ScienceDirect

Surface & Coatings Technology

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

Diode laser cladding of Fe-based alloy on ductile cast iron and related interfacial behavior

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ARTICLE INFO

Article history:
Received 12 September 2015
Revised 6 December 2015
Accepted in revised form 11 December 2015
Available online 12 December 2015

Keywords:
Cast iron
Laser cladding
Interface behavior
V-groove bevel

ABSTRACT

In this research, repairing of V-grooves on ductile cast iron substrates has been successfully completed with diode laser cladding technique using Fe-base self-fluxing alloy powder as the cladding material. The repaired samples are free of any defects such as pores and cracks with appropriate process parameters and the V-groove bevel. The bonding interface behavior at different power levels and the effect of the V-groove bevel on the cracking sensitivity of the coatings have been investigated. Optical microscopy, scanning electron microscopy, energy dispersive microanalysis and X-ray diffraction were used to characterize the cladded layers and bonding interfaces. Microhardness of the repaired samples was evaluated after cladding. The results revealed that good bonding interface with discontinuous fusion zone can be achieved at a lower laser power. The cracking sensitivity of the cladded layer is closely related to the V-groove bevel and the V-groove with larger bevel can be repaired with no cracks and pores. The cladded layers consist of austenite and martensite while some carbides such as Cr_7C_3, Fe_7C_3 and Fe_3C are formed in the bonding interface. Microhardness is rather homogeneous throughout the cladded layers and much higher than that of the substrate.

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1. Introduction

Ductile cast iron is widely used as molds, cams, machine tool beds, pistons, etc. in different industries because of its good fluidity, low cast, excellent machinability and good combination of strength and toughness. However, under formidable conditions involving abrasion, compact and various forms of erosion, it is liable to break down, which leads to enormous economic losses. In order to reduce the loss of the damaged components, a lot of conventional repairing methods are widely adopted such as TIG welding [1], shielded metal arc welding [2–4], powder welding [5] and flame spray welding [6,7]. However, these methods have crucial drawbacks, such as being time-consuming, large heat affectation, poor bonding strength, large amount of porosities and cracks, or high dilution and distortion of the substrates. Especially, cracks are liable to be generated at the bonding interface and the heat affected zone as the large heat affectation [5].

To solve this problem, laser cladding technology is an appropriate surface repair technology to be chosen due to the advantages such as high efficiency, high flexibility, and narrow heat affected zone, resulting in a strong metallurgical bond with minimum dilution of the substrate, etc. [8]. In the laser cladding process, high-energy laser beam is focused onto the substrate to create a molten pool, metal powders are simultaneously delivered into the focal zone by the powder delivering nozzles, and then rapidly melted and solidified. A clad is formed with the motion of the laser in the X–Y plane. A uniform coating is obtained by partially overlapping individual clads.

In recent years, laser repairing technology has been conducted by various investigators. Song et al. repaired V-grooves on medium carbon steel substrates with laser cladding forming technology and the mechanical properties of the repaired layers have been greatly enhanced in comparison with those of the substrate [9]. Wen et al. used laser hot wire cladding to repair martensite precipitation hardening stainless steel [10]. The cladded layer is free from any pores or cracks. Furthermore, the tensile strength and impact toughness are respectively 96% and 86% of those of the substrate. Borrego et al. reported the repairing of the base materials used in mold production by Nd-YAG laser. Research showed that the fatigue strength of laser repairing welded joints is significantly weaker than base materials [11]. Laser repairing technology for industrial application has been used in various equipment, but there still exist some difficulties in laser repairing of cast iron components, such as how to eliminate the cracks that are liable to generate at the bonding interface. When the laser heat is absorbed by the substrate, the high carbon concentration on the surface of the cast iron will lead to the generation of brittle ledeburite and carbides [12], which is harmful to the cracking resistance of the coating.

Xu et al. used Nd:YAG laser cladding high speed steel coatings on nodular cast iron rolls [13], and the result showed that a lot of microcracks were generated in the coated layer with the thickness of 0.2 mm. A 1-kW ytterbium fiber laser has been used to clad Ni-based

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http://dx.doi.org/10.1016/j.surfcoat.2015.12.031
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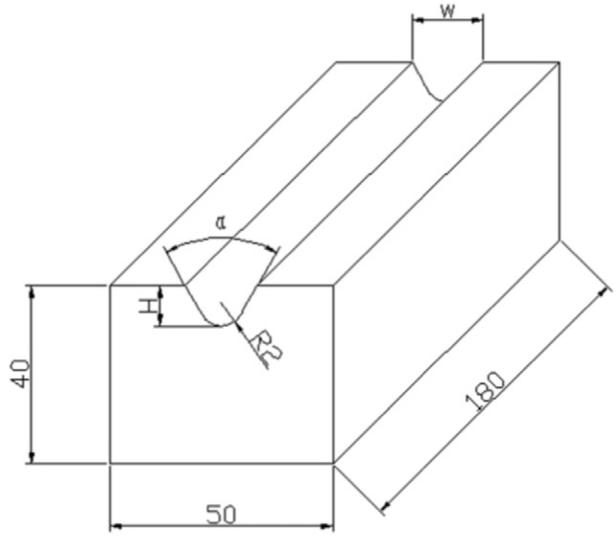

Fig. 1. Schematic of V-groove design.

Table 1
The dimensions of the V-grooves.

	W (mm)	H (mm)	α (°)
A1	16	10	80
A2	20	8.5	100
A3	27.5	8	120

alloy and high speed steel powders on nodular cast iron [14]. Numerous cracks occurred at the interface between the coating and the cast iron, and the cracks can be reduced by preheating the cast iron substrate with the laser beam. In order to eliminate the cracks at the interface of the repair weldments on ductile cast iron with Ni-based alloy powder by fiber laser cladding, Chandra [15] used laser melting surface pretreatment to reduce the number of graphite nodules on the surface of the specimen. Laser surface processing technology has been used by many researches to improve surface properties of cast iron. Yi et al. designed a dynamic local self-preheating in laser cladding Fe-based alloy powder on gray cast iron with CO_2 laser to reduce the thermal stress and better manage the microstructure [16]. The self-preheated cladded layer exhibits no cracks and pores. Although these surface pretreatment and self-preheating devices can reduce the cracks of the coatings, when considering practical repairing conditions, the complicated shape of the damaged surface region and production efficiency must be taken into consideration.

In this paper, the laser cladding process was carried out using a 3 kW DILAS diode laser. Ferrous metals show high absorptivity to diode laser at a wavelength of 980 nm [17], which can save laser energy and cause very small heat-affected zone on the substrate. Furthermore, the uniform energy distribution of diode laser can provide a smooth heating and cooling cycle during the cladding process, which can reduce the thermal stress and dimensional distortion during the process. These characteristics are beneficial to decrease the cracking sensitivity and other defects. In order to simulate the irregular damaged surface, deep V-grooves with different bevels are designed on the ductile cast iron substrates. Laser multi-layer cladding has been carried out to recover the damaged substrates. Macro-quality and microstructure of the repaired layers, especially the bonding interface structure were investigated.

2. Material and experimental procedure

The substrate used in this investigation was a ductile cast iron QT-500 (3.6 wt.%–3.8 wt.% C, 2.0 wt.% Si, 0.411 wt.% Mn, 0.370 wt.% Cu, and the balance Fe) with the dimension of 180 mm × 50 mm × 40 mm. Fe-based self-fluxing alloy powder (0.1 wt.% C, 14.92 wt.% Cr,

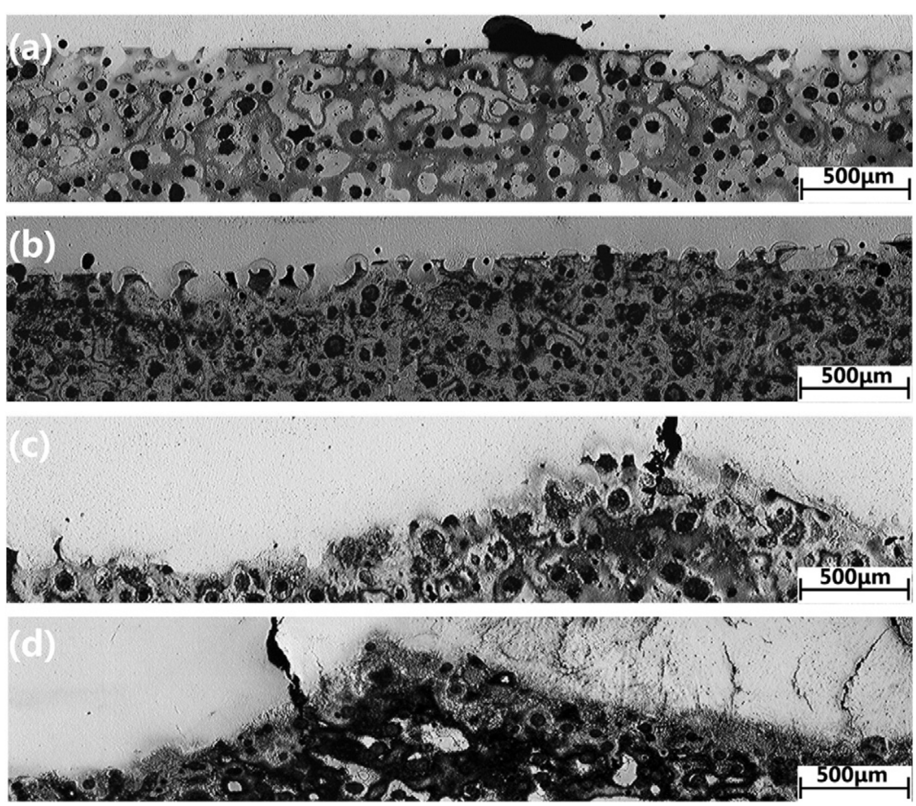

Fig. 2. Morphology of the bonding interface by different laser power (V_s = 5 mm/s, V_p = 11 g/min). (a) 1.3 kW, (b) 1.5 kW, (c) 1.7 kW, and (d) 1.9 kW.

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