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Microstructure and wear resistance of composite layers on a ductile iron with multicarbide by laser surface alloying

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ABSTRACT

Multicarbide reinforced metal matrix composite (MMC) layers on a ductile iron (QT600-3) were fabricated by laser surface alloying (LSA) using two types of laser: a 5 kW continuous wave (CW) CO_2 laser and a 400 W pulsed Nd:YAG laser, respectively. The research indicated that LSA of the ductile iron with multicarbide reinforced MMC layers demonstrates sound alloying layers free of cracks and porosities. The microstructure, phase structure and wear properties of MMC layers were investigated by means of scanning electron microscopy (SEM), transmission electron microscopy (TEM) and X-ray diffraction (XRD), as well as dry sliding wear testing. The microstructure of the alloyed layer is composed of pre-eutectic austenite, ledeburite, spherical TiC, Cr_7C_3 and $Cr_{23}C_6$ with various morphologies. TiC particles are dispersed uniformly in the upper region of MMC layers. The average hardness of LSA layers by CO_2 laser and pulsed Nd:YAG laser is 859 $HV_{0.2}$ and 727 $HV_{0.2}$, respectively. The dry sliding wear testing shows the wear resistance of ductile iron is significantly improved after LSA with multicarbide.

1. Introduction

Ductile iron (DI) has been an attractive kind of ferrous metals widely used in the manufacture of machine tool beds, cams, pistons, cylinders, etc., because of their low cost and desirable properties like low melting point, good fluidity and cast-ability, excellent machinability, good wear resistance and good mechanical properties [1,2]. However, especially under severe service conditions, its performance and reliability can be limited due to wear. This problem can be overcome by improving the surface properties of DI. Laser surface engineering offers several advantages over other surface-modification techniques. The most important one arises from the fact that laser surface modification is a nonequilibrium method involving high cooling rates (10^3–10^8 K s^{-1}) which produce metastable phases by exceeding the solid-solubility limit beyond the equilibrium phase diagram; super-saturation increases due to nonequilibrium solidification. This leads to the development of a wide variety of microstructure with novel properties that cannot be produced by any conventional processing technique [3]. Laser surface modification involves laser-quenching [4], laser surface alloying (LSA) [5,6], laser melting [7–9] and laser cladding [10,11]. LSA is used to modify the surface properties of metals and ceramics, which is achieved by localized melting, the addition of a second material, followed by solidification of a new alloy. Recently, there has been significant interest in this process for producing composite microstructures; where, hard particles such as carbides, borides, and nitrides are used to strengthen the deposit [12–14].

In order to improve further the wear resistance and corrosion resistance, several investigators have tried to modify the surface of DI. For example, Benyounis et al. [2] carried out surface melting of a nodular cast iron by Nd:YAG laser and found that a laser beam of maximum power 100 W led to dissolve most of the graphite nodules. Chen et al. [15] fabricated a layer on the surface of DI using laser surface treatment by an Nd:YAG laser. Nevertheless, there were no performances testing such as wear resistance or corrosion resistance of the surface layer. Alabeedi et al. [16] melted surface of a nodular cast iron by a 3 kW CW CO_2 laser and the results showed that laser melting led to complete dissolution of the graphite nodules while on solidifying created an interdendritic network of eutectic ledeburite with good homogeneity and high hardness. Zeng et al. [17] have studied LSA of pure copper to improve the corrosion resistance of high nickel austenitic ductile iron (ADI) using a 2 kW CW CO_2 laser with two processing conditions. Their work revealed that distribution of the copper in the alloyed zone was fairly uniform across the depth of the pool and the corrosion resistance of high nickel austenitic ductile iron was improved.

In general, laser processing is characterized by a number of applications in different engineering fields. Each application has its own demands to the output characteristics of the lasers and

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Table 1
Chemical composition of as-received DI (QT600-3).

Substrate	C	Si	Mn	P	S	Mg	Cu	Fe
QT600-3	3.0–3.5	2.4–2.8	0.3–0.5	<0.1	0.03–0.035	0.045–0.05	0.35–0.40	Bal.

thus reflecting the different types of high power laser available. There are two advantages of pulsed Nd:YAG laser in laser processing [18]. One is the temporal limitation in energy coupling into the target, generating a very limited depth of heat conduction into it, often resulting in reduced heating of the work-piece, and thus in higher quality. The other is the high pulse peak power and thereby high intensity, obtainable, resulting in improved light coupling in some materials, especially metals and thereby enables or improves the processing. The major disadvantage of pulsed laser processing is processing capability decreased compared to CW CO_2 laser processing.

To the knowledge of the authors, little literature has been reported with regard to LSA MMC layer on DI using pulsed Nd:YAG laser and CW CO_2 laser by introducing process and comparing the characteristics. Due to the matrix being soft, it will be required to increase the amount of ceramic particles in MMC layers for increasing hardness and the wear resistance of DI surface. However, it is difficult to produce high volume fraction of ceramic particles in MMC layers within a short time during laser irradiation. Then, it will be expected to increase the hardness and the wear resistance of MMC layers by adding both ceramic particles and alloying element. In this paper, multi-pass LSA with TiC and Cr_2C_3 was carried out using two types of lasers. The aim of the present study was to fabricating multicarbide reinforced Fe-based matrix composites layers on DI to increase wear resistance.

2. Experimental details

2.1. Specimen preparation and laser irradiation

Chemical composition of the DI (QT600-3) used in this investigation is shown in Table 1. The specimens were machined into plates in the dimension of 100 mm × 80 mm × 40 mm as the substrates for LAS treatment. The as-received LSA powers was commercial coating named HG-04 (Wuhan Huagong Complete Equipment Co. Ltd., China), which contained superfine TiC and Cr_2C_3 carbides particles with content of 12.5 wt.% and other alloying elements. Before being coated with LSA powers, surfaces of the substrates were ground by 400 μm grit paper and then sand blasted to decrease surface reflectivity. The roughness was about 10 μm. The LSA powders were dispersed in acetone and sprayed onto the substrate surface with thickness of 0.15 mm.

The first series of trials was performed on a Nd:YAG laser, wavelength λ = 1.06 μm, frequency range 1–200 Hz, pulse length 1–20 ms, peak output power 400 W and a focal length of 100 mm. The laser-generated pool was protected using a nozzle [19] to ensure that laser cladding process was carried out under the circumstance of nearly pure shielding gas. The second phase of work was performed on a CW CO_2 laser, λ = 10.6 μm, 5 kW maximum power, operating in continuous wave mode, spot diameter 5 mm and a focal length of 200 mm. In both cases, the samples were moved under the stationary beam using a numerically controlled

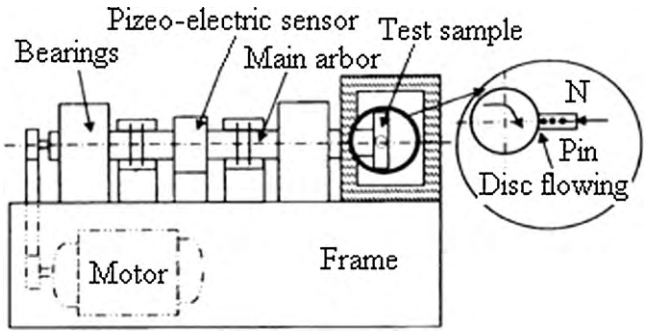

Fig. 1. Schematic diagram of the wear tester (MMS-1G).

X–*Y* table, continuous flow of argon (15 l/min) was applied onto the specimens' surface to protect the melted region from oxidation and undesirable contamination and multi-pass treatment at an overlapping ratio of 40% was carried out.

In order to optimize the LSA parameters, a number of tracks were irradiated at different processing parameters. First, the irradiated tracks were examined visually. The process parameters were chosen that led to better surface quality and little splash. Table 2 summarizes the optimized parameters of the LSA layers used in the experiments to analyze phases and microstructure.

2.2. Specimen analysis and testing

After LSA, transverse cross sections were obtained from the optimized parameters specimens which were examined for microstructure and microhardness. The cross sections of LSA samples (polished to 3 μm) were characterized by a scanning electron microscopy (SEM) of type JSM-5610LV incorporating energy dispersive X-ray analysis (EDX). The corresponding component phases of MMC layers were determined using X-ray diffraction (XRD) with Cu-Ka radiation. Thin foils were prepared by linear cutting to slices (0.4 mm thick) from MMC layers paralleling to the laser tracks. The slices were ground mechanically to 50 μm thickness. Discs of 3 mm diameter were punched mechanically and then dimpled from the side by means of a Gatan Model 656 Dimple Grinder. Only one side of the thin disc was ground to give a final thickness of about 15 μm. The dimpling procedure could produce a thin central region in the disc while leaving a thick supporting rim to protect the sample from damage. Conventional electron microscopy of thin foils was performed in a Hitachi H-800 transmission electron microscope (TEM) at 160 kV. Microhardness measurements across the MMC layers were carried out using a Buchler-3 microhardness tester with an applied load of 100 g of 15 s.

Wear resistance of alloying coatings were evaluated using a pin-on-disc sliding friction and wear tester (MMS-1G) as shown in Fig. 1. The apparatus can be used for measurements in high-temperature environments. The disc of friction components with a dimension of Ø400 mm × 30 mm was hardened GCr15 with a hardness of HRC

Table 2
Optimized laser parameters used in LSA experiment.

Sample	Type of laser	Scanning velocity (mm s^{-1})	Laser power (W)	Spot size (mm)	Shielding gas flow rate (l min^{-1})	Laser pulse duration (ms)	Laser frequency (Hz)
A1	Nd:YAG laser	12	300	1	15	1.1	60
A2	CW CO_2 laser	20	3000	5	15	–	–