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Effects of pre-placed coating thickness on thermal fatigue resistance of cast iron with biomimetic non-smooth surface treated by laser alloying

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ABSTRACT

In order to enhance the thermal fatigue resistance of gray cast iron with biomimetic non-smooth surface further, studies on laser alloying of Cr powder with different pre-placed coating thickness were performed to change both the composition and the microstructure of non-smooth unit. Additionally, the optimization of coating thickness was done based on the content of Cr in alloyed zone and the thermal fatigue behaviors of non-smooth samples. The results indicated that there was a critical coating thickness which corresponded to the increase of Cr content in alloyed zone under a definitive laser processing conditions, and the critical thickness was 0.3 mm in this paper. Any coating thicker than 0.3 mm would lead to the waste of alloying powder. The thermal fatigue resistance of non-smooth samples was better than that of smooth sample. In addition among all the non-smooth samples, the sample which was treated by the laser alloying of Cr had superior resistance to thermal fatigue compared with laser melting treated samples. And the thermal fatigue resistance increased with increasing of Cr content in alloyed zone which was caused by pre-placed coating thickening.

1. Introduction

Brake drum is one of the important parts in braking system for trucks and coaches. According to the braking principle, drums suffer giant pressure and static or kinetic friction force from brake disks. During braking, the huge friction force transforms to the heat energy absorbed by brake drum, and then the temperature of drum increases, even as high as 900 °C. Subsequently, due to the thermal conduction, drum is cooled again [1–4]. When vehicles move in the complex areas, especially in the mountainous areas, because of the huge braking force and frequent braking, the drum's loads are much bigger, and that may lead to its failure earlier than expected. Thermal fatigue caused by cyclic temperature gradients is an important life-limiting factor for many operating parts especially for those serving in fast heating and quickly cooling conditions [5]. Observations of many failure brake drums indicate that there are a lot of wide and deep cracks which distribute in their working surface. The initiation and propagation of cracks drove by thermal fatigue are considered as the main reason for drum's failure characteristics [6,7]. Therefore, study on improving thermal fatigue resistance of brake drums has become the all-important problem for enhancing their service life.

Although considerable interests have been done for improving thermal fatigue resistance of brake drum, they nearly all focus on improving or replacing of the component materials. Gray cast iron has long been used in trucks as the material for brake drums, because of its low cost and desirable properties such as low melting point, good cast-ability, and so on [2,8]. In order to enhance the strength of drum, alloying agent was used for increasing and refining the pearlite structure [9]. However, due to bad service conditions, the enhanced degree of thermal fatigue strength was not remarkable. Within the past few years, aluminum base composite has become a potential new material for brake drum [10–12], but the related researches are on late start, furthermore with the low output and the high cost. So it would take a long time for brake drum formed by aluminum base composite. To sum up, there is still a lack of an effective method for improving thermal fatigue resistance of brake drum at present.

Bionics has had a profound influence on materials science and engineering since the past two decades, because the unique structures, compositions and correspondingly excellent properties of biology have given researchers many clues to improve the properties of materials or increase the reliability of structural components. It is well known that the excellent properties of animals and plants mainly come from their evolution and optimization to adapt themselves to the environment for millions

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of years [13–15]. In fact, biology not only can adapt to the environment, but also can satisfy its survival with the lowest energy cost. Therefore, the new components or materials, which are designed and manufactured by biomimetic methods, also have advantages such as high efficiency and low consumption of energy. Since 1980s, Ren et al. in Jilin University have been dedicating to the study of biomimetic non-smooth surface and found that the bulldozer blades with these surfaces exhibited reduced sliding resistance against soil [16–18]. In recent years, the author had studied on the thermal fatigue resistance of gray cast iron with biomimetic non-smooth surface, and a laser melting (LM) technique was used for processing biomimetic non-smooth units on sample's surface. The results indicated that samples with non-smooth surface had higher resistance to thermal fatigue compared with smooth sample, whose surface was not treated [19–21]. However, the only disadvantage of this technology was that the enhanced degree of thermal fatigue resistance would be limited because of the fixed chemical composition of sample base. In order to enhance the thermal fatigue resistance of gray cast iron with biomimetic non-smooth surface further, studies on laser alloying (LA) of Cr powder were performed to change both the composition and the microstructure of non-smooth unit [22], because Cr is one of the strong carbide formation elements and it can form complex carbides with the carbon in the cast iron, which significantly enhances the strength, hardness and thermal-resistance properties [23].

In this paper, the selected method for adding alloy elements is pre placing coatings on the sample surface. It is well known that the content and distribution of alloy elements would be affected by the pre-placed coating thickness. Therefore, the influence of pre-placed coating thickness on thermal fatigue resistance was investigated; additionally the optimization of coating thickness was done based on the Cr content in the alloyed zone.

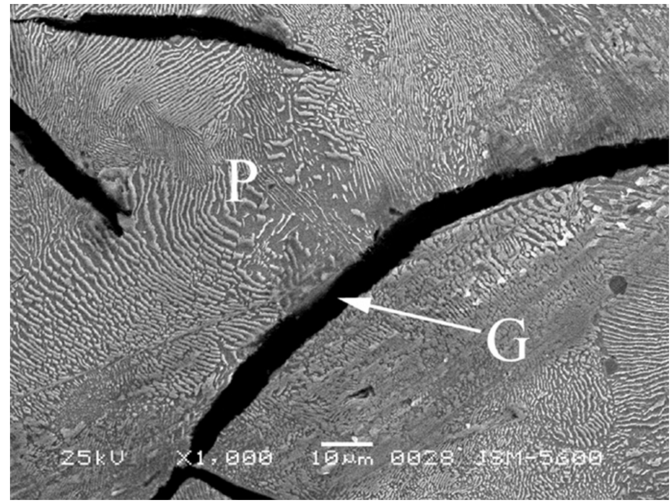

Fig. 1. Microstructure of HT200 gray cast iron.

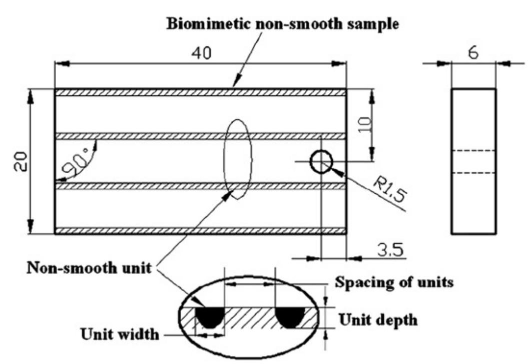

Fig. 2. Sketch of biomimetic non-smooth sample.

2. Experiment details

2.1. Materials preparation

In this study, a gray cast iron codenamed HT200 that was widely used for brake drums was applied. Its chemical compositions were given in Table 1, and the microstructure (etched by 2% nital) was shown in Fig. 1. It could be seen that HT200 was composed of pearlite (P) and flake graphite (G). The alloying material was Cr powder with purity of 99.9% and the powder size of 50–100 μm.

2.2. Sample preparation

Experimental samples of $40 \times 20 \times 6\,mm^3$ were cut by an electric spark machine, and a 3 mm in diameter round hole was drilled at one side of every sample, so that they could be fixed onto the thermal fatigue experimental machine. Meanwhile, the samples were mechanically polished, using progressively finer grades of silicon carbide impregnated emery paper before the thermal fatigue test to remove all the surface irregularities and machining marks. A solid state Nd-YAG laser with 1.06 μm of wavelength was used for partial surface alloying. The sample with a striated surface which was processed by laser was named as biomimetic non-smooth sample, because it had a continuously geometrical non-smooth surface to imitate the shape found on the rough surface of animals, which was different from the untreated smooth sample. Accordingly, the processed stripe was named as biomimetic non-smooth unit. Fig. 2 showed the sketch of biomimetic non-smooth samples.

Table 1
Chemical compositions of HT200 gray cast iron (wt%).

Compositions	C	Si	Mn	P	S	Fe
Content	3.250	1.570	0.920	0.060	0.059	Bal.

Before laser alloying, the samples were cleaned with alcohol and then coated with Cr powder using a cascophen diluted by alcohol. The thickness of pre-placed coatings on Nos. 1–6 non-smooth samples was varied to obtain alloyed layers of different depths and corresponding different Cr concentration; the detail data of thickness was listed in Table 2. The laser alloying parameters were: laser energy of single pulse of 9.408 J, pulse duration of 12 ms, frequency of 10 Hz, defocusing amount of +5.5 mm, and scanning speed of 0.5 mm/s. During laser alloying, a shielding gas of argon was used to protect the surface of samples, and through controlling the displacement of working-bench, the spacing between units was 4 mm.

2.3. Experimental details

After laser alloying, transverse sections of non-smooth units were cut parallel to the laser direction, and some standard metallographic methods were followed. Depth, width and area of the alloying zone were evaluated using an LEXT-OLS 3000 OLYMPUS laser confocal scanning microscope. Microstructure of non-smooth unit was characterized by a JSM-5500LV scanning electronic microscope. Phases and compounds formed in the alloying zone were identified by D/max-RC X-ray diffraction (XRD)