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Influences of single laser tracks' space on the rolling fatigue contact of gray cast iron

Zhi–kai Chen [a], Ti Zhou [a], Peng Zhang [a], Hai-feng Zhang [a,b], Wan-shi Yang [a], Hong Zhou [a,*], Lu-quan Ren [c]

[a] The Key Lab of Automobile Materials, The Ministry of Education, Jilin University, Changchun 130025, PR China
[b] The Department of Mechanical and Automotive Engineering, Changchun University, Changchun 130025, PR China
[c] The Key Lab of Terrain Machinery Bionics Engineering, The Ministry of Education, Jilin University, Changchun 130025, PR China

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ABSTRACT

To improve the fatigue wear resistance of gray cast iron, the surface is modified by Nd:YAG laser to imitate the unique surface of soil creatures (alternative soft and hard phases). After laser treatment, the remelting region is the named unit which is mainly characterized of compact and refinement grains. In the present work, the influence of the unit space on the fatigue wear resistance is experimentally studied. The optimum space is proven to be 2 mm according to the tested results and two kinds of delamination are observed on samples' worn surface. Subsequently, the mechanisms of fatigue wear resistance improvement are suggested: (i) for microscopic behavior, the bionic unit not only delays the initiation of microcracks, but also significantly obstructs the propagation of cracks; (ii) for macroscopic behavior, the hard phase resists the deformation and the soft phase releases the deformation.

1. Introduction

The rolling contact fatigue (RCF) is a common failure type of the components which are subjected to the repeated stress, such as railroads, rolling guide ways, gears, etc. Various surface damages occur and also cracks develop in the machine units, thus leading to loss of serviceability of the units under roller contact. Typical damage in roller contact fatigue under dry friction or boundary lubrication includes pitting, spalling, and cracking and 'squat' like damage that in most cases evolves into a main crack through the roller body [1]. Since the failure of these components, it is necessary to change or scrap the damaged components for the safety and quality of production. Not only large cost would be spent on these works, but also huge waste would be caused. Therefore, it is necessary to improve the fatigue wear resistance (FWR) of materials based on the considerations of economical and effective.

Previously, many papers have focused on the RCF behaviors of ferrous materials, such as rail steel [2] and nodular cast iron [3], and many works have been done to improve the FWR of ferrous materials, for example bearing steel [4] and austempered ductile iron [5], which are verified to thoroughly understand the RCF behaviors and significantly prolong the service life. However, few studies on gray cast iron (GCI) have been performed and the effective approaches to promote the FWR of GCI have not been reported. GCI is one of the most widely used engineering materials with the characteristics of low cost, cast-ability, good wear resistance and toughness. The unique feature of GCI is prominence in shock-absorbance as flake graphite disperses in pearlite matrix. On the contrast, the existence of flake graphite leads GCI to be more complex than other ferrous materials because the concentrated stress prefers to occur at the graphite tip. Consequently, the improvement of FWR and the studying of RCF behaviors of GCI are imperative.

In decades, Nd:YAG laser is widely used in industrial manufacture because it has a shorter wavelength and thus normally does not need to coat the surface that is to be treated compared with CO_2 laser. Additionally, laser surface melting (LSM) has its advantages over the conventional surface processes, including minimum distortion, high hardness, narrow heat-affected zone and more easily controllable, and the energy can be delivered to component surfaces by fiber optics. According to Grum and Sturm [6], who had proven the harden mechanism to be the occurrence of refined martensite and ledeburite in melt zone, the laser processing therefore could be considered to be useful for surface modification. However, Iino and Shimoda [7] had proposed that the occurrence of tempered effect would be investigated as the overlapping laser track resulting in the reduction of microhardness, and therefore the way treated by laser on the whole surface is impossible to promote the FWR of GCI.

Enlightened by surface of some soil creatures whose apparently common characteristic is soft–hard alternative, the group of Zhou

* Corresponding author. Tel.: +86 431 8509 4427; fax: +86 431 8509 5592.
E-mail address: chenzhikai2004@126.com (H. Zhou).

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[8–10] has devoted to improving the materials' properties according to imitate the surface by laser surface remelting. Although many properties of materials have been confirmed to signally improve, including thermal fatigue resistance [8], wear resistance [9] and tensile resistance [10], the research works on FWR of GCI have not been carried out. The authors' previous works [11] have verified that the type of soft–hard alternative is positive to FWR and the distribution angles of units dramatically affect the FWR. The diverse angles of laser tracks with constant horizontal space corresponded to the change of hard phase space in rolling direction. However, the influence of the change on RCF has not been explicitly introduced in previous works. This paper aims to exclusively investigate the fatigue behavior of GCI with laser track in different spaces. The surface characteristic of treated sample is modified with laser tracks which are continuous in width while they are isolated in length of sample. Subsequently, according to observations and detections, the mechanisms of FWR improvement are discussed and the fatigue behaviors are suggested.

2. Experimental

2.1. Experimental materials

For this work a common GCI, cut from machine tool by electric spark machine (DK7732) was used. And its chemical composition, microhardness and tensile properties are illustrated in Table 1. In terms of the original microstructure, the flake graphite is surrounded by pearlite and ferrite, and the percentage of pearlite is more than that of ferrite. What is more, the average width of flake graphite in 'A' type is about 4 mm and the length is uncertain.

2.2. Sample preparation

Samples (120 mm × 15 mm × 5 mm) were cut by electric spark machine, and the corners were ground to arc-shape to embed into the load station of the wear experimental system. To enable the effect of space (s) on the RCF life of treated samples to be studied, the samples were divided into six groups according to the unit space and each group contained three indiscriminate samples for repetitive test. Among the classification, the group without treatment called smooth sample was marked No. 1 and the groups with units space (s) ranged between 1 mm and 5 mm were marked Nos. 2–6, respectively. The stripes unit perpendicular to the rolling direction was processed by Nd:YAG laser in the same parameters. The strips were to form the geometrical non-smooth surface to imitate the rough surface of soil animals. It should be noted that the remelting region was named units in the paper. The sketch of treated sample was shown in Fig. 1. As known, the percentage of treated region increased by the decrease of unit space.

The surface of samples was performed by Nd:YAG laser with wavelength of 1.06 μm and a maximum export power of 300 W, using a circular pattern Gaussian beam and set under an argon gas shield with a flow of 5 L/min. The working-bench moved at 0.5 mm/s. The parameters of laser were the pulse duration of 3 ms, frequency of 7 Hz, and the energy of a single laser point was about 2.28 J. After laser deposition, the size parameters of unit were listed in Table 2.

To identify the microstructure of the unit, the standard method of metallography was performed on the transverse section after the laser processing. Optical microscope, scanning electron microscopy (SEM) and X-ray diffraction (XRD) were utilized for these investigations. The microhardness was measured in loading of 0.2 kg with a holding time of 10 s by Vickers microhardness test (Model 5104, manufactured by Buehler Co. Ltd., USA). Additionally, the tensile test was performed on the sample with single laser track along tensile direction to learn the reinforcement of unit.

Fatigue wear tests were carried out by home-made machine in the air atmosphere, as shown in Fig. 2. The rolling bearing and an eccenter were connected by a metal rod, and the samples were mounted at the back of loading station that was always supported by 10 rollers ($\varphi5 \times 11$). The constant loading of 80 N would be transformed to samples' surface through the narrow contact area, in which the generated pressure was well below that necessary to cause yielding. When the eccenter rotated, the roller bearing was actuated on the samples' surface back and forth. The rotating speed of the eccenter was set at 30 rpm, corresponding to horizontal velocity (v) of the roller bearing expressed as

$$v = \omega.\, l.\, \sin\varphi \tag{1}$$

where ω represented the angular velocity of drive wheel, l was the eccentric distance (35 mm) that indicated the amplitude of back and forth path to be 35 mm, and φ was the deflection angle ranging 0–360° as shown in Fig. 2. Depending on the calculation of v, the positive and negative were implied the forth and back of roller, respectively.

Prior to wear tests, the specimens were mechanically polished with fine emery paper sequentially, followed by ultrasonic cleaning in acetone. The weights of samples were measured by the electronic balance with a precision of 0.1 mg. Every 10 h, the samples were interrupted at regular intervals for mass loss measurement, and the above procedure was followed besides polishing to record the mass until 60 h. Additionally, the final roughness of the specimens after

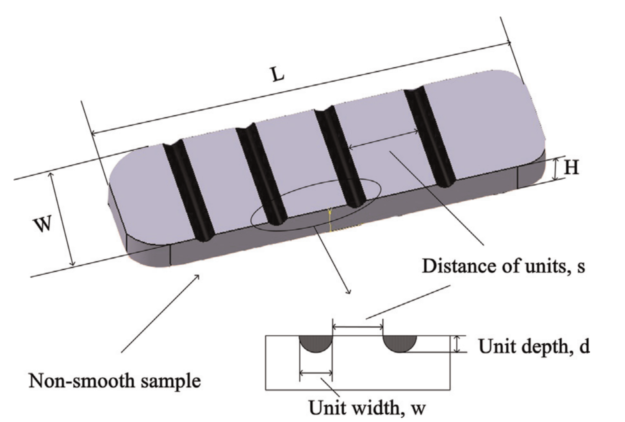

Fig. 1. The schematic of the treated sample and the form of unit distribution.

Table 2
Dimensions of unit's cross section.

Width (mm)	Depth (mm)	Area (mm^2)	Fit equation of unit's edge
1 ± 0.1	0.33 ± 0.03	0.22	$Y = 1.32x^2 - 0.33$

Table 1
Nominal chemical composition (wt%), the micro-hardness ($HV_{0.2}$) and tensile properties (MPa) of the base material.

C	Si	Mn	P	S	Fe	Hardness	Tensile strength	Fracture strength
3–3.2	1.5–1.8	0.7–0.9	< 0.15	< 0.12	Bal.	260	135	90