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Study on the relationship between intervals among laser stripes and the abrasion resistance of biomimetic laser textured surfaces

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ABSTRACT

In our previous study, biomimetic laser hardening was proven to be a more promising method in improving the abrasion resistance of tribological loaded surface manufactured in brake shoe. In the present work, in order to study the relationship between the abrasion resistance of biomimetic laser textured surfaces and the intervals among parallel distributed biomimetic laser hardening stripes, steel samples were modified by laser stripes with different interval distances, and dry sliding wear tests for all these biomimetic samples were conducted. The result denotes that with the increase of interval distance from 2.5 mm to 5.0 mm, the abrasion resistance of samples undergone an increasing trend at first and a decreasing trend after that. The proposed wear mechanism indicates that the proportion of area of soft phases has strong correlation with the abrasion resistance of biomimetic surfaces. When interval distance among laser stripes became larger than 3.5 mm, with the increase of distance, the wear mass loss increased because damages on soft phases played leading roles in enhancing wear extent. However, when intervals ranged from 2.5 mm to 3.5 mm, the beneficial effect of soft phase reflected gradually.

1. Introduction

During millions years of evolution, natural creatures have obtained optimal surface structures to adapt changeable environment. After studying the cuticle morphologies of soil animals like dung beetles, some studies found that structures on cuticles could provide excellent abrasion resistance [1]. Other similar studies denoted that beside anti-abrasion properties, cuticles of soil animals also have hydrophobic abilities, which can be enhanced by their geometrically structured textures, and the combination of geometrically structured surface and the hydrophobic nature can even enhance the effects in preventing soil from sticking to cuticle [2]. Another example is non-smooth surface of mollusk shells, which is a kind of natural surface distributed with regularly hard ridges on soft substrate, and had been proven to have excellent abrasion resistance against sand and stones.

Excellent anti-abrasion abilities of biological surfaces are generally results of the coupling of many impact factors like structures, materials and surface morphologies. Surface optimization procedures in order to improve the wear resistance and fatigue limit of near surface material states is of great technical importance with regard to the improvement of the behavior and the endurance of engineering components [3]. Therefore, many researches had introduced the concept of "biomimetic coupling" and had combined biomimetic theory with other techniques for the purpose of improving mechanical performance of key components.

Because laser has many merits like high efficiency, high energy input and flexibility, biomimetic technique has developed to combine laser technique to create soft-hard alternate biomimetic characteristics on metal surfaces. For example, laser processed biomimetic units like convex domes, concavities and stripes have been studies for improving thermal fatigue resistance of cast iron, or strengthening tensile property of H13 die steels [4–6]. In order to investigate the effect of microhardness difference on dry sliding wear resistance of biomimetic samples, Pang et al. [7] created biomimetic samples with different microhardness difference between biomimetic coupling units and base metal. According to the result of wear tests at room temperature, the research founded that when the microhardness difference is less than 561 $HV_{0.2}$, the weight loss of samples is getting smaller with the increase of the microhardness difference. When the microhardness difference is more than 561 $HV_{0.2}$, the weight loss of samples is getting bigger with the increase of the microhardness difference. Chen et al. [8] designed a series of experiments and suggested that for biomimetic samples during wear, hard phases can resist deformation; soft phases can

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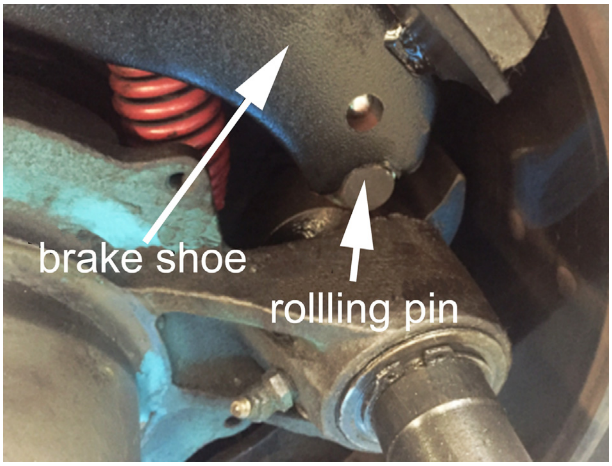

Fig. 1. The brake system of trailer.

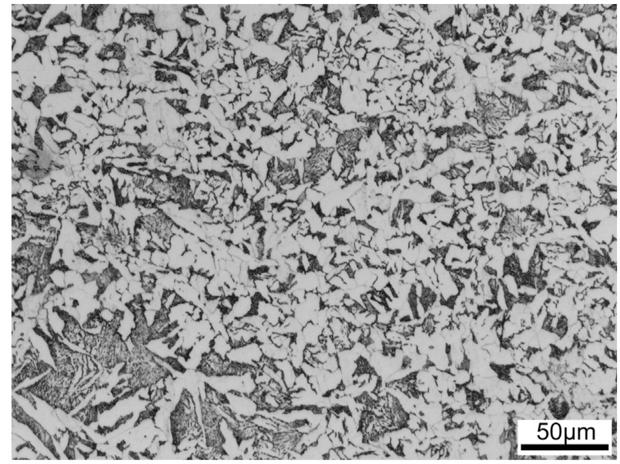

Fig. 2. Microstructures of the raw material.

release the deformation, and biomimetic units can play an important part in obstructing propagation of cracks.

Because steel component like brake shoe generally has face with severe dry sliding abrasion with its counterpart (rolling pin) in the brake system of trailer as shown in Fig. 1, it is necessary to find new methods to improve abrasion resistance of such kind of mechanical parts. As an effective approach for enhancing the tribological properties, laser surface texturing has attracted more and more attention for many years [9]. Therefore, a combination of laser texturing technique and biomimetic coupling theory is a new idea to improve service life of those components.

In our previous work [10], by utilizing biomimetic laser hardening, striated laser hardening tracks (laser stripes) with changeable intervals were created on steel samples cut from brake shoe. The effect of distribution ways of laser hardening tracks on anti-wear performance of textured surfaces had been investigated. However, after fixing interval distance between each two neighboring laser stripes, which kind of interval distance could lead to best anti-wear property was unknown nevertheless. Therefore, the purpose of this article is to specifically investigate the influence of interval distance on the dry sliding abrasion resistance of different biomimetic laser textured surfaces. In the experiment, the intervals of biomimetic samples were designed as about 2.5 mm, 3.0 mm, 3.5 mm, 4.0 mm, 4.5 mm and 5.0 mm to make sure the experimental results could have significant differences. Dry sliding wear tests on those biomimetic samples were carried out on a self-designed wear test apparatus as usually used in our previous experiments. After analyzing the wear mass loss, the micro-hardness of material, the micro-structures of textured stripes, the worn topographies of different samples, the relationships between the proportion of two kinds of phases (soft and hard phases) and the abrasion performance were discussed.

2. Experimental

2.1. Raw material

The raw material was obtained from a brake shoe by using electric spark cutting facility (Huadong, DK7732, China). Table1 approximately lists the main chemical composition (obtained form EDS) and the micro-hardness (obtained form Veker tester with 300 g pre-load). Microstructures under optical microscope (Zeiss, Germany) are shown in Fig. 2, from which, it can be seen that the microstructures of this kind of material are pearlite and ferrite. Therefore, after validating, we confirmed the material used for this experiment is the same to our previous one.

2.2. Laser parameters

The facility used for laser processing is a solid state Nd:YAG pulsed laser machine (Guangzhou, Liangdian, Ltd, China) with Gaussian output mode. While performing laser processing, the robot arm (NACHI, Japan) was fixed above the work-bench so that the laser beam could vertically irradiate on samples surfaces. Because the tribological loaded surface of brake shoe has relative higher requirement for surface roughness as we ever mentioned. All biomimetic laser textured stripes were carefully treated without showing too much remelted substrate on their surfaces.

The influence of laser scanning speed (scanning rate) on morphologies of laser stripes, studied by our previous laboratory tests indicates that with the increase of scanning speed, the cross-sectional depth of laser stripe could be decreased. However, besides the laser scanning speed, the laser energy and the laser pulsed width are two important impact factors for the final morphologies of laser stripes either. Therefore, the influence of the laser energy and the pulsed width were designed (Table 2). Fig. 3 shows the corresponding morphologies of laser hardened zone, from which, it can be suggested that with the decrease of the laser energy and the pulsed width, the depth of laser hardened zone decreased appreciably. Furthermore, when the laser energy and the pulsed depth reaching to about 25 J and 10 ms (parameter 1), the laser stripe finally got maximal cross-sectional depth.

Additionally, it should be noted that there are mainly two kinds of laser output modes for industrial laser facilities, one is pulsed laser mode and another is top-flat continuous laser mode. Though the laser hardened layer formed by the latter is deeper than that created by the former, there has little difference between these two modes in the case of validating effects of interval distance on sample's abrasion resistance under laboratory environment. Therefore, Nd:YAG pulsed laser output mode is available when speaking what the experiment described.

Table 1
Chemical composition (%) and micro-hardness of the raw material.

C	Mn	Si	Cr	P	S	Fe	Hardness (HV_{300})
0.26–0.27	0.52	0.21	0.03	0.02	0.01	Bal.	197