Optics and Laser Technology 107 (2018) 380–388

Contents lists available at ScienceDirect

Optics and Laser Technology

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

Full length article

Effect of the orientation of laser stripes on the abrasion resistance of biomimetic laser textured surfaces

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ARTICLE INFO

Article history:
Received 1 November 2017
Received in revised form 16 February 2018
Accepted 6 June 2018

Keywords:
Biomimetic
Laser
Abrasion
Orientation

ABSTRACT

In order to improve the anti-wear performance of the semi-arc of trailer's brake shoes, we utilized biomimetic laser texturing to fabricate special striated textures which can play roles in dispatching stress as researched in our previous studies. The orientation of biomimetic stripes was proven to be an important factor to the abrasion resistance of textured surfaces, thus blank samples cut from a brake shoe were modified with 0°, 30°, 45°, 60° and 90° angular distributed laser stripes on their surfaces. All samples undergone 10 hours of dry sliding experiments. The wear result indicated: (i) The biomimetic surface covered with 45° angular distributed stripes has the lowest wear mass loss and the wear resistance of all biomimetic surfaces shown an ascend trend at first and a descend trend at last with the increase of angle between stripe and the wear direction. (ii) When the angle between stripe and the wear direction is 0° (Stripes are parallel to the wear direction), the wear extent was most serious, however, when the angle was changed into 90°, we could deduce that the wear particles could be hindered and accumulated debris and particles would continuously plow softer surface. Only when the angle change into 45° can abrasives be hindered and dispersed in an effective way.

1. Introduction

The quality of abrasion resistance and safety directly determines the overall life of the equipment [1]. The classification of wear format such as two-body and three-body abrasive wear, low stress abrasion, high stress abrasion, soft abrasion and hard abrasion have been proposed over the years in order to describe the various types of abrasion processes [2]. The brake system of trailers is very important, and some inner parts like trailer's brake shoe and brake disk are generally faced with severe abrasion. To improve abrasion resistance of the working arc of trailer's brake shoe made by mild carbon steel, the heat treatment, the carburizing methods had been widely studied and applied by factories. Different from all these methods, laser treatment has features of low distortion, high precision, high productive rate and process flexibility capabilities [3].

Biomimetic design is one of the most effective methods to design and manufacture new materials in the future, and surfaces of some animals and plants are always have reasonable shapes and structures [4]. The living creatures from hundreds of million years of evolution are usually granted with several special capabilities so as to adapt to external surroundings. For example, biological surfaces like the surface of ground beetle and the surface of black ant shown in Fig. 1 generally feature with non-smooth characteristics from microscopic perspective. Specifically, ant's head is constituted with regularly distributed band-shaped ridges, and head of ground beetle is covered with regularly distributed hard convex. These special structures can play important roles in protecting soft substrates and resisting continuous plowing.

By mimicking those biological surfaces, biomimetic technique had been invented and applied in solving many engineering problems after combining with laser techniques. For example, Ren et al. [5] founded that biomimetic bulldozing plates designed and prepared by imitating the surface morphology of the top of the head of the dung beetle reduced 13.02% bulldozing resistance compared with conventional plates; Cong et al. [6] studied tensile properties of H13 die steel repair by a biomimetic laser technique and proved that the method of laser assisted repair based on biomimetic principles can improve thermal fatigue behavior of H13 steel; Tong et al. [7] mentioned that the biomimetic surface has beneficial effect on improving the thermal fatigue behavior of cast iron.

According to our previous study [8], to improve the serving life of trailer's brake shoes, biomimetic laser texturing, which can also be called as bionic laser hardening, perfectly combining laser technique with biomimetic theory, is applicable. In biomimetic coupling theory, the final mechanical property of biologies and

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https://doi.org/10.1016/j.optlastec.2018.06.020
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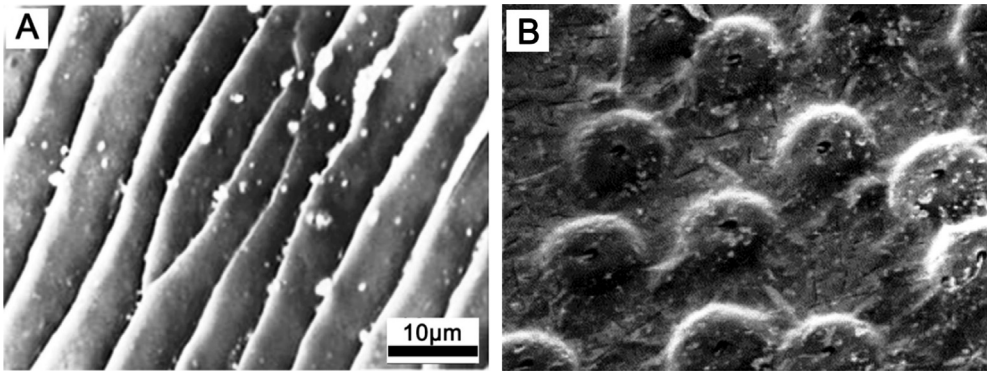

Fig. 1. Some magnified biological surfaces: (A) the surface of ant [4]; (B) the surface of ground beetle [5].

biomimetic processed structures are generally the outcome of the coupling of different impact factors. There, in our case, we have found two main impact factors for the wear resistance of biomimetic laser textured surface that can be determined as: the interval distance among laser stripes and the orientation of laser stripes. The effect of interval distance has been investigated by our previous laboratory tests, whereas the influence of orientation hasn't been studied so far. Therefore, the aim of this work is to exclusively investigate the relationship between the abrasion resistance of biomimetic surface and the orientation of laser stripes before applying this technique into processing brake shoe.

In the experiment, the orientation of laser stripes were set as vertical (90°), parallel (0°) and oblique (30°, 45°, 60°) by comparing with the wear direction. The dry sliding wear tests for all experimental samples were conducted on a self-designed reciprocating wear testing apparatus. The anti-wear ability was evaluated by wear weight loss conditions under the help of balance. The microhardness of cross-section was tested by a Vickers tester machine with 300 g pre-load. The microstructure of laser hardened zone and the worn morphology of samples were investigated by optical microscope (OM), scanning electron microscope (SEM) and optical profiler respectively. After these procedures, the wear results were analyzed and the wear mechanism was proposed and validated.

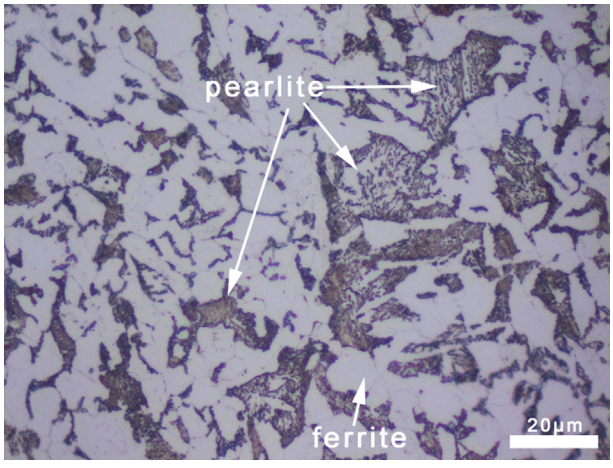

Fig. 2. Microstructures of as-received material.

2. Experimental procedure

2.1. Materials

The parent material is a kind of mild steel. The microstructure of this material is shown in Fig. 2. The main average chemical composition, obtained from three times of tests by spectrometer machine (AMETEK-SPECTRO MaXx LMF07, Germany), is shown in Table 1.

2.2. Sample preparation

For the experiment, blank samples with dimensions of 20 mm × 30 mm × 6 mm were cut from as-received brake shoe. Before laser processing, samples were ground and polished by varied sandpapers until obtaining uniform surface roughness (around 0.16 μm). There are two kinds of laser power distribution modes, including top flat intensity distribution mode and Gaussian distribution mode, but laser stripes fabricated by Gaussian mode laser is applicable for fabricating biomimetic laser stripes in our laboratory experiment. Therefore, a 500 W solid state Nd:YAG pulsed laser facility (Lang dian, Guan zhou), forming circular laser spot with Gaussian mode distribution, was utilized to generated biomimetic laser stripes on steel surfaces.

As B. Mahmoudi concluded, when choosing Nd:YAG laser parameter in treating steel surface, the scan rate is more effective than the laser pulse energy or the pulse duration [9]. In order to validate this statement in our case, the effect of scanning rate on the morphology of cross section of laser stripe was investigated before the formal experiment. Table 2 presents details of four laser parameters (A, B, C and D) with different laser scanning rates and

Table 2
Laser parameters.

Type	Energy (J/cm^2)	Pulse duration (ms)	Frequency (Hz)	Scanning speed (mm/s)
A	360.8	10	3	4
B	360.8	10	3	7
C	360.8	10	3	10
D	360.8	10	3	13

Table 1
Main chemical composition of experimental material (Mean value).

Elements	C	Mn	Si	Cr	P	S	Fe
Composition (%)	0.262	0.5256	0.206	0.029	0.020	0.011	Bal.