



Effect of one-step laser processed biomimetic coupling units' degrees on rolling contact fatigue wear resistance of train track alloy steel



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ABSTRACT

The working life of train track is restricted by rolling contact fatigue wear. The rolling contact fatigue wear resistance of train track alloy steel is a majority in ensuring the safety of rail transit and prolonging the life of track. To improve the rolling contact fatigue wear resistance of train track alloy steel. The wearable surfaces assembled with different degrees' striation biomimetic coupling units were prepared on the alloy steel by one-step laser remelting processing. The microstructures and micromorphologies of bionic units were characterized by optical microscope, scanning electron microscopy and field emission scanning electron microscopy. The specimens with units were tested for rolling contact fatigue wear resistance. The surface appearances of the test specimens were compared to each other. By finite element analysis, mechanism of the unit on enhancing wear resistance was studied. A discussion on the wearable surfaces assembled with the different degrees' striation biomimetic coupling units was had. Due to shift of surface stress concentration, the specimens with the units presented better rolling contact fatigue wear resistance than the blank sample. And it attributed to different effective length support ratios that the specimens with striation units of 30° and 60° get better wear resistance than the one with striation units of 45°.

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1. Introduction

With the development of rail transit, train is playing a more important role in traffic. Safety and reliability are two key issues in the railway field [1]. The increase of transport capacity will make a higher requirement on the working life of train track. The improvement on wear resistance of railway surface in a simple and economical way has become a nonnegligible task.

When a train is running on the track, the contact type between the rollers of train and railway belongs to line contact. The wear is mainly caused by rolling contact fatigue (RCF) under the condition. The damage can lead to spalling of the railhead or complete failure of the rail [2]. A previous study from Josefson et al. said the surface-initiated cracks appearing arise due to repeated plastic deformation and consecutive accumulated damage on the rail surface [3]. Rolling contact fatigue can be defined as cracking and pitting/delamination limited to the near contact surface of bodies rolling against each other [4]. In the contact condition, typical damage includes pitting, spalling, cracking and 'squat-like' damage. There into, pitting is formed in all rolling pairs, and the others belong to the development of pits [5].

A series of research have been carried on to enhance the RCF wear resistance of materials surface. By finite element simulations, the principle of fatigue crack initiation under different rolling contact wear condition was discussed [3]. By comparing the cracks growth of two kinds of substrate materials on rolling contact fatigue, Franklin et al. studied the mechanism of the wear behavior [6]. At the same time, the ways of improving the matrix surface wear resistance by laser processing were proposed. Via unitizing the laser cladding to deposit Ni based amorphous matrix coatings on mild steel substrate, the microstructure and wear properties of materials would be improved significantly [7]. Laser surface alloying with silicon was employed to strengthen the wear resistance of mild steel surface [8].

In nature, creature with the proper shapes and structures can survive and multiply because of survival of the fittest. The best harmonious and adaptive system according to optimize and couple the factors consist of the best shape, structure and materials [9–11]. The phenomenon is called biomimetic coupling. Based on the principle, many studies have been carried out on improving the properties of material. By imitate the bionic morphology of lotus leaves, the super hydrophobic surface was prepared on aluminum alloy [12]. And the wear resistance can also be reformed by constructing non-smooth surface like shell [13]. Not only the mechanical properties, a new sound absorber was developed by the coupling absorption structure of a typical silent flying bird-owl [14], and the butterfly wings has been well understood as a model

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with outstanding light trapping property [15]. In the past few years, Zhou et al. have studied the fatigue wear resistance of cast iron and tool steel. According to previous reports, the facts that the wearable surface with units processed by laser can enhance the wear resistance of tool steel and cast iron under sliding wear condition significantly has been proved [16–18]. The surface with units presented the alternated hardness as the shape of ground beetles' elytrum or tree leaf, in which the units are identified as biomimetic units. The units processed by laser remelting has compacted structure and grain refinement, which results in excellent performance on the sliding wear resistance. Whether the train tracks alloy steel cured by the laser remelting can also present efficient enhancement on rolling contact fatigue wear resistance is to be expected.

In the paper, biomimetic units were prepared on the specimens of train track alloy steel by one-step laser processing. The microstructures of units were characterized by optical microscope (OM), scanning electron microscopy (SEM) and field emission scanning electron microscopy (FESEM). The stress analysis of the unit under rolling contact was shown by finite element analysis software. The wearable surfaces with different degrees' striation units were constructed on the specimens. Rolling contact fatigue wear test was carried on by a self-building wear tester. The wear resistance mechanism of the wearable surfaces was discussed. The effects of microstructure and degree of the units on the wear behavior of the surface under rolling contact were also studied.

2. Experimental

2.1. Materials

The chemical compositions of the train track alloy steel materials are given in Table 1. The substrate materials belong to high manganese steel, and the tensile properties and the microhardness of materials are also listed in the table.

The Fig. 1 shows the microstructure of the material matrix, which is composed of lamellar pearlite.

2.2. Sample preparation

Before laser remelting processing, the experimental samples for rolling contact fatigue wear test were cut from the train track above with dimensions of 120 mm length, 15 mm width and 5 mm thickness by a wire electrical discharge machining (Huadong Group, DK77, China), which was equipped with a computer numerical control system.

A solid state Nd: YAG laser of 1064 μm and maximum 300 W was employed to fabricate the bionic unit. The temperature in samples processing was 22 °C. The laser head was mounted vertically in the Z-direction and was adjustable. Movement along X and Y axes was used to process the bionic unit with varied surface shapes while that along Z axis was to adjust the desired defocusing amount [19].

The processing parameters were laser duration 5.0 ms, laser input energy density 210.39 J/cm², frequency 5 Hz, defocusing amount 14 mm, scanning speed 0.5 mm/s and a circular spot size 3.8 mm in diameter on the specimen surface.

The striation bionic units were assembled on the samples by laser remelting. According to the different degrees between the striation units and the long edge of the sample, Sample 1 (S1) was fabricated by the striation units of 30°, while Sample 2 (S2) assembled by the stripes of 45°. The striation units of 60° were spread on Sample 3 (S3). Through controlling the displacement of the workbench, the horizontal

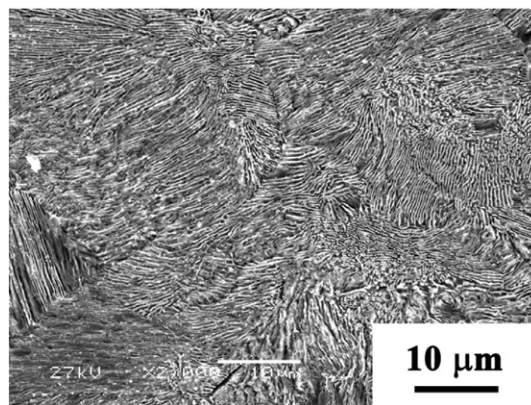


Fig. 1. The SEM of the matrix.

distance of the parallel striation units on the surfaces of the test specimens was kept on 6 mm, as shown in Fig. 2.

2.3. Characterization method

The cross-section of the unit was obtained after laser remelting processing, whose microstructure and dimensions were studied by optical microscope (Zeiss, Axio. Imager. A2m, Germany). The microhardness in the cross-section was measured by a Vickers hardness tester (Buehler, 5104, USA) with a 0.2 kgf applied load. The component phases of each unit morphology and matrix were characterized by scanning electron microscopy (JEOL, JSM-5600, Japan), field emission scanning electron microscopy (Zeiss, Supra 40, Germany) and X-ray diffraction instrument (Fangyuan, DX-2700, China).

2.4. Wear tests

A self-building rolling contact fatigue wear tester was used to serve the wear tests, whose schematic diagram is shown in Fig. 3 [20]. The applied loading in the tests was 8 kg. In terms of control variables method, levels of pitting were served as the standard to the RCF wear resistance of specimens by maintaining a constant time. The rotational speed of the electrical machine was 690 rpm, while the RCF wear time was 60 h. The wear test condition was built to simulate real train operating situation. By comparing difference in mass of the specimen before and after the experiment, the mass losses of the wear test samples were given. Above date was measured by a sensitive electronic balance with an accuracy of 0.0001 g.

3. Result and discussion

3.1. Microstructure

As shown in Fig. 4, X-ray diffraction is used for phase analysis of the unit and matrix. The phase compositions of unit present a mixed phase of martensite containing carbide and a small amount of ferrite, while that of the matrix appear to have the original phase of ferrite. The figure also shows X-ray full width at half maximum (FWHM). The FWHM of X-ray diffraction peaks of untreated matrix is 0.313°, while that of bionic units is 0.431°.

Table 1

The chemical compositions (wt.%), the microhardness (HV_{0.2}) and the tensile properties (Mpa) of the materials of train track alloy steel (wt.%).

C	Si	Mn	S	P	Ni	Fe	Hardness	Tensile properties	Fracture strength
0.77232	0.24486	1.23508	0.02843	0.01435	0.00952	Balance	312.2	968.6	888.25

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