Optics & Laser Technology 91 (2017) 55–62

Contents lists available at ScienceDirect

Optics & Laser Technology

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

Full length article

Wear resistance of machine tools' bionic linear rolling guides by laser cladding

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ARTICLE INFO

Keywords:
Rolling wear resistance
Bionic linear rolling guide
Laser cladding

ABSTRACT

In order to improve the rolling wear resistance (RWR) of linear rolling guides (LRG) as well as prolong the life of machine tools, various shape samples with different units spaces ranged from 1 to 5 mm are designed through the observation of animals in the desert and manufactured by laser cladding. Wear resistance tests reproducing closely the real operational condition are conducted by using a homemade linear reciprocating wear test machine, and wear resistance is evaluated by means of weight loss measurement. Results indicate that the samples with bionic units have better RWR than the untreated one, of which the reticulate treated sample with unit space 3 mm present the best RWR. More specifically, among the punctuate treated samples, the mass loss increases with the increase of unit space; among the striate treated samples, the mass loss changes slightly with the increase of unit space, attaining a minimum at the unit space of 4 mm; among the reticulate treated samples, with the increase of unit space, the mass loss initially decreases, but turns to increase after reaching a minimum at the unit space of 3 mm. Additionally, the samples with striate shape perform better wear resistance than the other shape groups on the whole. From the ratio value of laser treated area to contacted area perspective, that the samples with ratio value between 0.15 and 0.3 possess better wear resistance is concluded.

1. Introduction

High precision, efficiency and automation are the features that machine tools face with the rapid development of modern industry, which make a higher requirement on the precision and service life of machine tools. As LRG have many advantages such as high stiffness, smooth motion and low friction coefficient compared with sliding contact guides, they have been widely used for precise positioning devices to transport machine parts through a linear path in machine tools and X-Y tables etc. As the key part of machine tool, LRG's wear resistance level determines the precision level of machine tools to great extent. Due to the excellent properties such as cast-ability, low melting point, low cost and toughness, grey cast iron (GCI) has been utilized as an engineering material for applications where the applied loads are extremely high and cyclic. Additionally, GCI is better as a shock-absorber owing to the amount of flake graphite spread in the iron matrix. But as the presence of graphite, component such as rolling guide made by GCI, which is typically suffered high alternating stress, will be easy to fail if it's used directly without any treatment.

Based on survival of the fittest, nature provides species a multi-functional structure so that they can survive in the complex environment. The function adapt to living environment is the result of coupling factors on morphologies, structures and materials of living things to the optimization of the biological function. During the past many years, great progress has been made on applied sciences by imitating the biological structures or habits of plants and animals in nature [1–3]. Evidence is provided to demonstrate that the biomimetic structure possesses excellent properties on mechanical behavior [4,5]. Moreover, scientists have carried on many experiments concerning the effect of bionic structure on wear resistance, and the experiment results manifest that the wear resistance of bionic coupling samples is better than that of untreated sample [6–10]. Previous theoretical and experimental study [11–13] suggests that GCI performs satisfactorily under rolling contact fatigue after laser remelting. However, a considerable drawback to laser remelting is the formation of heterogeneous microstructures due to the non-uniform distribution of carbon, which limits wear resistance improvement. Laser cladding, as a new laser surface modification technology, sample surface covered with WC is coupled by high-energy laser beam, has a better performance in many applications compared

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http://dx.doi.org/10.1016/j.optlastec.2016.12.015
Received 11 May 2016; Received in revised form 15 August 2016; Accepted 17 December 2016
Available online 22 December 2016
0030-3992/

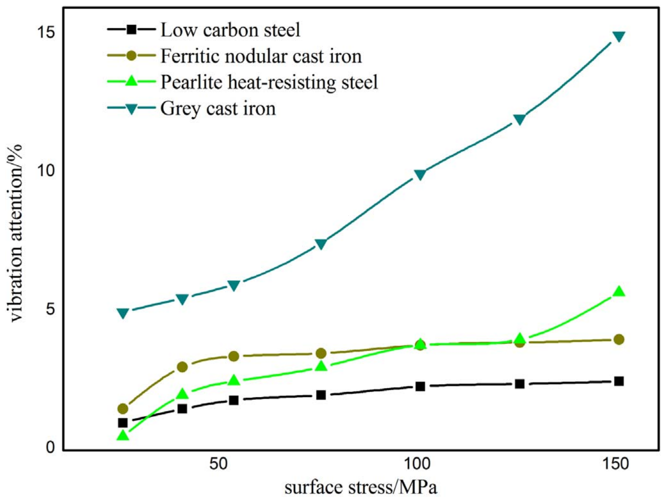

Fig. 1. Vibration attenuation of different materials.

Table 1
The nominal chemical compositions of HT300 (wt%).

Elements	C	Si	Mn	P	S	Cu	Cr	Fe
Content (%)	3.200	1.690	0.940	0.130	0.096	0.500	0.270	Bal

with laser remelting. It is thus significance to examine the wear resistance of machine tools' bionic LRG by laser cladding.

Through the observation of some sand creatures such as the snake, lizard and camel's sole, whose cuticles moving against sands possess high favorable wear resistance, the authors find that the apparently common characteristic of those creatures' cuticles is soft-hard alternately. Enlightened by it, samples with different bionic coupling units are designed and manufactured by laser cladding. As we know, wear resistance is not an intrinsic property of the materials, but a tri-bosystem property where the materials in contact, type of reciprocal movement, relative speed, load levels, environmental conditions, presence of abrasive particles and lubricants can play crucial roles in the wear behavior of a component. Based on the truth, in order to improve the RWR of LRG as well as prolong the life of machine tools, it is advisable test the wear resistance of LRG reproducing closely the real operational condition from an engineering point of view. Subsequently, a linear reciprocating wear test machine made by the ball screw feed drive system is designed and manufactured. Both the wear pressure and speed are adjustable.

2. Experimental

2.1. Preparation of original samples

As GCI presents excellent performance on the vibration attenuation compared with other materials shown in Fig. 1 [14], GCI is chosen as the raw material. The used GCI is cut from the rail of a machine tool by electric spark machine. The nominal chemical compositions are given in Table 1. Samples are cut with dimensions of 60×50×8 mm (L×W×H) by electric spark machine which is equipped with a computer numerical control system, then removed cutting trace and oil on the surface of the sample by sand papers to obtain a smooth and clean surface.

2.2. Bionic shape design

By studying the cuticle morphologies of some animals in desert such as the snake, lizard and camel's sole, the authors find that these structures on their surfaces are different. Enlightened by them, samples with different bionic shapes are concluded and designed. The bionic shapes are divided into punctuate, striate and reticulate as shown in Fig. 2. In order to study the effect of unit space on the wear resistance of treated samples, each kind of shape is divided into five samples ranged from 1 to 5 mm. Among the classification, as shown in Figs. 3–5, the punctuate shape with units space ranged from 1 to 5 mm are marked Nos. 1–5, the striate shape with units space ranged from 1 to 5 mm are marked Nos. 6–10, the reticulate shape with units space ranged from 1 to 5 mm are marked Nos. 11–15, the untreated sample used as the reference is marked No. 16, respectively.

2.3. Laser cladding

The laser cladding experiments are performed with a 300 W Nd:YAG laser, which is equipped with CNC and cooling system as shown in Fig. 6. The laser head is vertically mounted in the Z-direction, while the workbench is able to move along X, Y and Z axes, or rotate on a given X-Y plane. The WC powders are pre-coated on the substrate to form a pre-layer with the thickness of 0.3 mm. During the laser cladding, the pre-coated samples are placed on the workbench. Movement along X and Y axes is used to process the bionic units. Due to the variety of processing parameters set, accordingly, the characteristics of bionic unit present diversity, which increase the difficulty of quality control in the manufacturing process. The criteria for determining the optimum quality for the coating were based on a compromise of hardness, volume, homogeneity and pores [15]. On the base of these criteria, the best laser cladding processing parameters are listed in Table 2.

2.4. Wear tests

The rolling contact wear tests are performed by using a rolling wear facility at room temperature. An illustration of the wear tester is shown in Fig. 7. The samples are fixed on the base by the screws passing through the transition pieces as shown in Fig. 8. Rolling slider whose 9 rollers (φ10×38) are always supported by samples, is mounted under the load platform as shown in Fig. 9. The photo of IKO SR rolling slider composed by 26 rollers is given as shown in Fig. 10. The space between rollers is 0.2 mm. In the accelerated wear test, a constant load of 250 N is transformed to samples' surface through a narrow contact area under

Fig. 2. Three kinds of bionic shapes: punctuate shape, striate shape, reticulate shape.