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Bio-Tribology Properties of Bionic Carp Scale Morphology on Ti6A14V Surface

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Abstract. In order to improve the bio-tribology properties of Ti6A14V surface, the bionic carp scale appearance pattern on Ti6A14V surface was prepared by laser surface texturing technology. The ball-disc reciprocating linear tribological experiment under different lubricants with dry friction was carried out by MRTR multifunction friction and wear testing machine using ZrO2/Ti6A14V as friction pair. The wear scar morphology of the sample surface was observed by SEM. The results show that for dry friction, the friction factor of the bionic carp scale morphology Ti6A14V reduces by 0.23 than those without bionic carp scale morphology, a decline of 45%. Under different lubrication conditions, the friction factors of samples with the bionic carp scale are increased in varying degrees with the increase of size of bionic texturing. The friction factor with same specimen under different lubrication conditions according to the ascending order are 0.5g/dl of sodium hyaluronate +0.5g/dl-yglobulin and 0.5g/dl mixed aqueous solution of sodium hyaluronate solution and artificial saliva. The wear volume also showed a similar variation.

1. Introduction

Ti6Al4V alloy has many advantages, such as high specific strength, good corrosion resistance, and high temperature resistance and so on. It is widely used in the manufacture of high temperature parts such as Aeroengine Blades [1, 2]. At the same time, titanium alloy has many disadvantages, such as high friction coefficient and poor wear resistance, which seriously affects the safety and reliability of the structure [3]. Therefore, researchers are now focusing on improving the surface of the material to reduce friction factors and improve tribological properties.

Zhang et al [4] found that laser surface treatment can effectively improve the hardness, wear resistance and corrosion resistance of the material. Lian et al [5] found that the hydrophobic Ti6Al4V surface conformed to the Wenzel state after laser processing and low surface energy modification. Under the condition of loading, the friction coefficient decreases with the increase of surface hydrophobicity. Sorin-Cristian et al [6] found that surface texture can significantly reduce the friction coefficient and can effectively act on the actual mechanical components. Tang et al [7] developed a biomimetic robotic fish tail fin that gave the robotic fish a greater thrust and was more stable with

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amplitude and frequency. Li et al [8] established a model of bionic jet surface by imitating the gummy shark skin, in order to achieve drag reduction and energy-saving effect. These studies show that the bionic technology has great potential at present.

To sum up, it is not difficult to find that the surface structure of many biological tissues can be applied to the material surface to optimize the performance of drag reduction and friction reduction. The non-smooth structure of the surface of animal body is common, and the carp scale is beneficial to buffer its external force, and it has a protective effect on the body. At present, studies on the tribological properties of carp scale have not been reported [9-11]. Therefore, this paper aims at using a new technique to fabricate the shape of carp like scales, so as to reduce the friction effect.

2. Experimental materials and methods

2.1. Selection and simplification of scale shape of bionic morphology

Figure 1 (a) is the local tissue topography of carp, It can be observed that the carp scales are arranged in an orderly arrangement of irregular ellipsoids. At present, the studies on the morphology of carp scale mainly focus on the ellipsoids structure and arrangement [12]. Therefore, this paper takes the scales of elliptical carp as the object of study, and the irregular ellipsoids structure of carp scale is simplified into regular ellipsoids structure, As shown in Figure 1 (b).



Figure1. Design of the bionic pattern (a) Local scales of carp (b) Bionic design sketch (c) The bionic morphology after polishing

2.2. specimen preparation

Ti6A14V alloy was processed into the sample with the size of $10 \times 10 \times 5$ mm, which then underwent accurate grinding by 600#, 1200#, and 2000# sandpaper, respectively. Next, diamond paste was used to polish it to mirror surface. The sample surface was under bionic surfacing treatment by HGL-LSY50F laser process equipment, whose laser wavelength was 1064 nm, operating voltage AC220 V, output power 75 W, and output current 12.5 A. a total of 4 groups of samples, respectively, numbered A, B, C, D, detailed parameters in Table 1. Four groups of samples of bionic carp scales was polished slightly so that laser process residues were removed. Afterwards, the samples underwent ultrasonic cleaning for 30 min in acetone solution, followed by hot-wind drying before it was placed in a dryer at the ready. Figure 1 (c) shows the micro-morphology of the bionic carp scales sample.

Samples	а	b	С	d	е
А	0.07	0.05	0.08	0.072	0.035
В	0.14	0.1	0.16	0.144	0.07
С	0.21	0.15	0.24	0.219	0.105
D	Non-textured sample				

Table 1. The sample number and desi	gn size /mm
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2.3. Lubrication conditions

Artificial saliva (produced in accordance with the ISO1021 Standard), 0.5 g/L sodium hyalurate, and 0.5 g/L sodium hyalurate $+\gamma$ -globulin were used separately as the lubrication for the bio-tribological test. There are four test conditions for dry friction and three kinds of lubricating fluid, which are numbered No.1, No.2, No.3 and No.4 respectively.

2.4. Bio-tribological tests

Bio-tribological tests at room temperature, the ball-plate reciprocating bio-tribological test was undertaken on MRTR multi function tribometer, and the friction pair chosen ZrO2 ball with 72~74 HRC and the diameter of 5 mm. The external load was 10 N, the one-way distance 5 mm, the reciprocating velocity 100/min, and the test period 10min. Under the same test parameters, four groups of samples were subjected to friction and wear tests under dry friction and three different lubrication conditions.

3. Results and discussion

3.1. Friction Properties of Ti6Al4V Alloy with Morphology of Bionic carp scales

Figure 2 is the changing curves of friction coefficients for A, B, C and D samples with sliding time under No.1, No.2, No.3 and No.4 lubrication, respectively. Table 2 is the steady-state friction coefficients that are calculated from the changing curves in Figure 2. The friction coefficient of D sample under dry friction fluctuates between 0.47~0.59, The steady-state friction coefficient is 0.51; the friction factor of B sample under dry friction is between 0.23~0.32, and the steady friction coefficient of B sample is smaller than that of D sample, and the steady-state friction coefficient drops by 45%. The pits of the bionic carp scales have the effect of collecting debris under dry friction[13,14], and the debris also acts as a solid lubricating particle, thereby significantly reducing the fluctuation range of the friction factor[15,16].

Under the condition of No.1, No.2 and No.3 lubrication, the steady - state friction factors and fluctuation range of biomimetic carp scales increased with the increase of bionic structure size. Among them, under No.1 lubrication, the fluctuation ranges of friction factors of A, B and C samples are 0.26~0.41, 0.30~0.45 and 0.26~0.48, respectively. The steady-state friction factors are 0.35, 0.38 and 0.39 respectively; Under No.2 lubrication, the fluctuation ranges of friction factors of A, B and C samples are 0.26~0.32, 0.25~0.36 and 0.27~0.41, respectively. The steady-state friction factors of A, B and C samples are 0.36~0.31~0.41, 0.32~0.45 and 0.37~0.45 respectively, and the steady friction factors of A, B and C samples are 0.31~0.41, 0.32~0.45 and 0.37~0.45 respectively, and the steady friction factors are 0.37, 0.39 and 0.43 respectively; The size of the bionic structure is small, the whole area of the bionic texture is large, the cumulative effect of the lubricating medium in the hole area and the pumping effect will be more obvious, which leads to the strong dynamic lubrication effect, and the dynamic pressure lubrication will reduce the bionic Structural Friction Factors and Fluctuation Range[17,18].

The same sample under No.1, No.2 and No.3 lubrication, the steady state friction factors are related to the lubricant, As can be seen from the data in Table 2, the friction steady-state factors were the lowest under the No.2 lubrication, and the friction steady-state factors were the highest under No.3 lubrication. The reason for the minimum friction factor in No.2 lubricating fluid is that the bionic scales have a certain streamline shape and the frictional resistance of water and scale is rapidly converted into water with the action of γ -globulin water mucus Frictional resistance of mucus. A water

film is formed between the water and the mucus, reducing the fluid resistance to the scale, thereby reducing the friction factor of the sample [19-21].



Figure 2 The friction factor of sample changing with time under different lubrication conditions

Table 2. The steady state factor of scale sample of bionic carp under different lubrication conditions

Samples	No.1	No.2	No.3	No.4
А	0.35	0.29	0.37	Х
В	0.38	0.30	0.39	0.28
С	0.39	0.33	0.43	×
D	×	0.47	×	0.51

3.2. Analysis of the scratch morphology

Figure 3 is the scratch morphology of A.B.C.D samples under No. 1, No. 2, No. 3 lubrication . respectively. As shown in Figure 3 (g) and (L), the surfaces of the non-textured specimen are obvious scratches. In most areas there are furrow scratches. As shown in Figure 3 From 3 (a) to (c) and (h) to (j), the bionic morphology of the sample surface is covered by the debris, which proves that No.1 and No.3 are only part of the anti-friction effect. The flow of lubricant leads to the sliding of debris with sliding friction, which affects the deposition of debris. As can be seen from Figure3 (d) to (f), specimen surface scratch the smallest degree, the bionic cavities to maintain the most complete, in the process of friction and scratch, No. 3 in the γ -globulin on the surface of the biomimetic sample has a very good anti-friction effect. In addition, compared with figure 3 (d), (e) and (f), with the increase of the surface area and size of the specimen, the surface cavities are gradually increased the degree of damage. This indicates that under the same lubrication conditions, the smaller the surface and size of the biomimetic sample, the better the scratch resistance in the lubricating fluid.

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Figure 3 Scarlet morphology of Ti6Al4V bionic carp surface under different lubrication

As can be seen from figure 3 (k) and (l), under the dry friction condition, the bionic morphology of the sample B is better, and the surface of the sample D is seriously damaged. The surface showing a large number of furrow scratch.

4. Conclusions

1) Under dry friction, the steady-state friction factor of D sample is as high as 0.51, and the steadystate friction factor of B sample is only 0.28. The friction reduction properties of Ti6Al4V surface can be improved significantly by simulating the morphology of carp scale.

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2) Under the lubrication of No.1, No.2 and No.3, the friction factor of the sample with the shape of carp scale increased with the increase of the size of bionic structure. The size of bionic topography significantly affects its friction factors.

3) Under the lubrication of No.1, No.2 and No.3 in the same sample, the friction factor under No.2 lubrication is the smallest, followed by No.1 lubrication, the maximum under No.3 lubrication, and the wear volume also showed a similar variation.

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