Applied Surface Science 390 (2016) 540–549

Contents lists available at ScienceDirect

Applied Surface Science

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

Study on tribological properties of multi-layer surface texture on Babbitt alloys surface

Dongya Zhang [a,*], Feifei Zhao [a], Yan Li [a], Pengyang Li [a], Qunfeng Zeng [b], Guangneng Dong [b,**]

[a] School of Mechanical and Precision Instrument Engineering, Xi'an University of Technology, Xi'an, People's Republic of China
[b] Key Laboratory of Education Ministry for Modern Design and Rotor-Bearing System, Xi'an Jiaotong University, Xi'an, People's Republic of China

ARTICLE INFO

Article history:
Received 3 May 2016
Received in revised form 18 August 2016
Accepted 26 August 2016
Available online 29 August 2016

Keywords:
Babbitt alloy
Multi-layer
Surface texture
Friction coefficient

ABSTRACT

To improve tribological properties of Babbitt alloys, multi-layer surface texture consisted of the main grooves and secondary micro-dimples are fabricated on the Babbitt substrate through laser pulse ablation. The tribological behaviors of multi-layer surface texture are investigated using a rotating type pin-on-disc tribo-meter under variation sliding speeds, and the film pressure distributions on the textured surfaces are simulated using computational fluid dynamics (CFD) method for elucidating the possible mechanisms. The results suggest that: (i) the multi-layer surface texture can reduce friction coefficient of Babbitt alloy, which has lowest friction coefficient of 0.03, in case of the groove parameter of 300 μm width and 15% of area density; (ii) the improvement effect may be more sensitive to the groove area density and the siding speed, and the textured surface with lower area density has lower friction coefficient under high sliding speed. Based on the reasons of (i) the secondary micro-dimples on Babbitt alloy possesses a hydrophobicity surface and (ii) the CFD analysis indicates that main grooves enhancing hydrodynamic effect, thus the multi-layer surface texture is regarded as dramatically improve the lubricating properties of the Babbitt alloy.

1. Introduction

Babbitt alloys are generally either tin or lead-based alloys, and their micro-structures commonly consist of α solid solution of antimony and copper in tin, and/or cubic hard inclusions of β phase (Sb-Sn compounds) [1]. The characteristics of low melting point, high thermal conductivity, good embed-ability, and flexible conformability of Babbitt alloys [2–4] have been well utilized as bearing pads and/or bearing sleeves in ideal bearing components. However, even in a well-designed high speed rotating shaft system, oil film is also liable to failure when the bearing (i) suffers from periodically varying stress and (ii) is in the processes of start-and stop-stages [5]. Under such circumstance, the occurrence of direct contact and rubbing between Babbitt bearing pad and rotating shaft generates huge amount of frictional heat. This subsequently leads to severe adhesive wear and thermal-burn damage to the Babbitt pad. The various failures like adhesive wear, seizure wear and erosion are always susceptible to cause machine shutdown or sometimes even catastrophic accidence [6]. Efficient techniques to protect Babbitt alloy by improving the tribological properties of the journal bearing are definitely meaningful to the bearing and to the effective application of the automobile engine. The hardness and wear resistance of the Babbitt alloy can be improved by adequately incorporating soft metal or fibers into the matrix of Babbitt including copper [7], Zn or carbon fiber [8] or by spraying composite coating [9]. However, these molding processes are very complex and require large equipment investment. In addition, modifications of Babbitt alloy are done through trial and error, lead to high-test cost and long test period.

Surface textures, such as micro-dimples or grooves, have become a meaningful approach for improving the tribological properties of sliding pairs in engineering fields. Typical examples to be seen are: (i) the fabrication of concave arrays in the start/end regions of computer hard disc for preventing adhesive and static friction, which beneficially and successfully prolongs the lifetime of the hard disc [10], and (ii) surface textures on thrust slider bearing

* Corresponding author at: School of Mechanical and Precision Instrument Engineering, Xi'an University of Technology, Xi'an, People's Republic of China.
** Corresponding author at: Key Laboratory of Education Ministry for Modern Design and Rotor-Bearing System, Xi'an Jiaotong University, Xi'an, People's Republic of China.
E-mail addresses: dyzhang@xaut.edu.cn (D. Zhang), donggn@mail.xjtu.edu.cn (G. Dong).

http://dx.doi.org/10.1016/j.apsusc.2016.08.141
0169-4332/

for enhancing the carrying capacity and for decreasing the friction resistance [11], (iii) partial textured surface on seal system for improving the pumping rate and reducing side leakage [12], (iv) petaloid texture on artificial joints can enhance the film thickness and amplify the secondary lubrication effect [13]. A widely recognized possible mechanisms of surface texturing in improving the tribological performance are mainly: (i) the creation of secondary lubrication and micro-hydrodynamic action under hydrodynamic lubrication or boundary lubrication [14,15]; (ii) the stockpile and supply of oil under mixture or starved lubrication [16] and (iii) the reduction of nominal contact area, and (iv) the entrapping of wear debris/hard particles and enhance the wear resistance [17]. Up to now, as widely use of micro-dimples/grooves is also developed as one of prevailing geometric characteristics utilized for the surface texture. The geometric parameters of the texture such as width, depth and area density, meanwhile sliding orientations relative to the texture on the tribological behaviors are also studied [18–20]. In addition, some possible mechanisms are also performed by computational fluid dynamics (CFD) [21], and the above studies illustrate some useful conclusions which are conducive to the application of surface texture in the field of tribology.

The previous studies for understanding the influence of surface texturing on sliding surface yield positive tribologcial results. Unfortunately, these studies are mostly only focusing on textures with regular shapes like dimples and grooves. The multi-layer texture consists of main grooves and secondary dimples for the tribological performance improvement have not been analyzed and elucidated in detail. The main objective of this study is to investigate the tribological performances of Babbitt with multi-layer surface textures, and the influence of area density and groove width on the friction and wear properties was discussed in detail using a pin-on-disc tribo-meter. In addition, a CFD method is also employed to reveal the mechanisms of the lubrication associated with micro-grooves. On the basis of theoretical analysis of the tribological behaviors of Babbitt alloy, some relevant mechanisms for the experimental results are illustrated and deduced.

2. Experimental details

2.1. Surface texturing process

Tin-based Babbitt alloy, supplied by FAW Group, was applied as the main crankshaft bearing material in the engine, and its Vickers hardness was about HV 70 under a test loading of 4.9 N, and the alloy chemical composition is tabulated in Table 1. Prior to surface texturing, the specimens were cut with the size of 30 mm diameter and 5 mm thickness, and then were successively polished by sandpapers with grit sizes of 600, 800 and 1000#, resulting in a surface roughness Ra of about 0.2 μm. Those polished disc specimens were cleaned in an ultrasonic bath with acetone for 10 min successively thrice so as to ensure the proper removal of residual pollutants.

Laser fabrication has the advantages of well controllable shape and high machining efficiency, and it is an effective way to fabricating surface texture. In this study, the multi-layer surface textures consisting of the main micro-grooves and secondary micro-dimples were fabricated by a LSF20II laser machine with parameters of laser wavelength $\lambda = 1064$ nm, laser frequency $f = 5$ kHz, output current $I = 12$ A, and pulse width $w = 1.0$ ms. The area density (*Sp*) was calculated using a ratio of the groove width to the groove pitch, and the specimens with area density 10%, 20% and 40% were fabricated, respectively. The micro-groove parameters are listed in Table 2. During the laser pulse ablation process, the secondary micro-dimples were fabricated in the main micro-grooves specifically basing on the principles of beam diffraction effect.

Table 1
Composition of Babbitt alloy.

Element	Sb	Pb	Cu	Fe	Bi	As	Zn	Sn
Wt.%	10.50	0.35	6.8	0.05	0.06	0.10	0.01	Balance

Table 2
Geometrical parameters of micro-grooves.

Specimen No	Groove width (μm)	Area density *Sp* (%)	Depth (μm)
W0	–	–	–
W3-Sp10%	300	10%	14.6
W3-Sp20%	300	20%	14.6
W3-Sp40%	300	40%	14.6
W5-Sp10%	500	10%	13.8
W5-Sp20%	500	20%	13.8
W5-Sp40%	500	40%	13.8
W6-Sp10%	600	10%	14.2
W6-Sp20%	600	20%	14.2
W6-Sp40%	600	40%	14.2

2.2. Characterization

In order to eliminate the negative effects of the bulges or burrs around the groove rims on the tribological properties, gentle polishing with 1500 and 2000# sandpapers were applied to remove those bulges or burrs after laser pulse ablation.

The surface morphology and element component of the textured surface were detected by A JSM-6460LV scanning electron microscope and energy-dispersive X-ray spectroscope (EDS, Oxford INCA Energy, UK). A TMVS-1 hardness tester (TIMES Group, China) was used to measure micro-hardness of the textured areas. The hardness value for each specimen was the average value of at least five measurements, obtained by the tester under a loading of 4.9 N and holding time of 15 s. A PHILIPS X'pert MPD RRO type X-ray diffraction (XRD) apparatus was employed to examine the phase structure of the Babbitt alloy surface with the radiation Cu Kα ($\lambda = 0.15406$ nm), the scan range was from 20 to 90°at a scanning rate of 0.4 °/s.

Surface wettability is related to the surface tribological properties, an appropriate surface topography can improve the lubrication. The wettability of the multi-layer textured surfaces was descripted by static contact angle, and the static contact angle was measured in an automatic contact angle meter (Model: OCA20, Dataphysics Co., Germany). The drop size of the deionized water was controlled to 5 μL at room temperature, and the contact angles of the textured surface were evaluated by a computer program for drop shape analysis based on the Laplace-Young equation.

2.3. Tribological properties test procedure

Tribological properties of the textured Babbitt and un-textured Babbitt specimens were performed on a rotating type ball-on-disc tribometer under oil lubrication condition. 45# steel pins with the hardness of HRC 40, diameter of 2 mm and surface roughness of Ra 0.02 μm were applied as their corresponding upper specimens. Turbine L-TSA46 oil (kinematic viscosity 44.10 mm^2/s at 40 °C) was used as the lubricant and supplied to the interface between frictional pairs by a BT50-1J peristaltic pump. At least three friction tests under each experimental conditions were performed in order to minimize data scattering. The average value of fluctuant friction coefficient was calculated and used as the average friction coefficient for each test.

The tribological tests were carried out under the contact pressure of 5 MPa, sliding speed was in the range of 0.2–0.8 m/s, and sliding duration was 1800 s. Before any friction test, the upper and lower specimens were cleaned by acetone and ethyl alcohol in an ultrasonic bath for 10 min, and then dried by a blower. Each test