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SURFACE DAMAGE UNDER EXTREME CONDITIONS EXISTED IN AIRCRAFT BEARINGS

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ABSTRACT

The extreme conditions of aircraft bearing steel M50 have been simulated by a two-disk test rig for investigating the surface damage of the ball/raceway contact surfaces. The slide/roll ratio are 0.12 and 0.15, correspondingly, the rolling speed are 43.2m/s and 49.5m/s. Aircraft engine oil 4050 as the supplied oil has been maintained at approximately 80℃ in the tests. The ultimate Hertzian contact stresses of the surface damage obtained from the experiments are 3.8GPa in 0.12 slide/roll ratio and 3.5GPa in 0.15 slide/roll ratio. The damage mode is scuffing in 0.12 slide/roll ratio and it is oxidation, thermal fatigue and scuffing in 0.15 slide/roll ratio. Cracks in the contact areas originate from surface layer in the two slide/roll ratios.

INTRODUCTION

The bearings used in aircraft engines operate in extreme conditions such as high speed, heavy load and high temperature. The combination of speed, load, and temperature which exist in aircraft bearings will exceed the capability of conventional synthetic lubricants and materials. The contact surfaces of the parts always occur fatigue, scuffing and many other damage modes, these damages would result in severe wear and even catastrophe [1].

M50 steel is a main material used in aircraft bearings, its tribological behavior in extreme conditions is related to the reliability and life of bearings. Rolling contact fatigue experiments of M50 steel have shown that the orientation of surface micro-crack is related to the friction direction and asperity-scale micro-cracks as well as micro-spalls may evolve into macroscopic spalling under heavy load and rolling/sliding speed conditions[2]. Rosado, et al. [3-5] researched the rolling contact fatigue life and spall propagation of M50 steel used in bearings from three parts: experiment, FEA model of the stress and metallurgical examination. The reasons of the surface damage are complex, sliding speed, load, temperature, heat transfer of the parts, lubricant will affect it.

The study simulated the extreme conditions of aircraft bearings, the ultimate parameters and the damage modes of M50 bearing steel haven been obtained, and it focused on the characteristics of surface damage under different conditions.

APPARATUS AND PROCEDURE

The experiments have been carried out in a two-disk test rig as shown in Fig.1. The change of the slide/roll ratio and sliding/rolling speed though altering moving head speed, gears and diameters of the two disks. The oil jet was aircraft engine oil 4050 maintained at approximately 80℃ in all experiments.

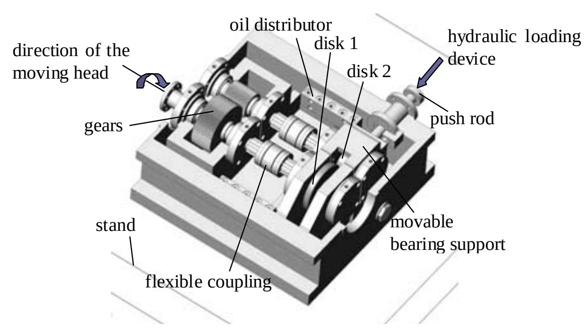


Fig.1 Principle of the test rig

In the tests, contact stress was a stepwise load which was increased gradually. The rapidly increase of the power consumption or the difference in temperature of disk1 and oil was the signal that surface damage had occurred.

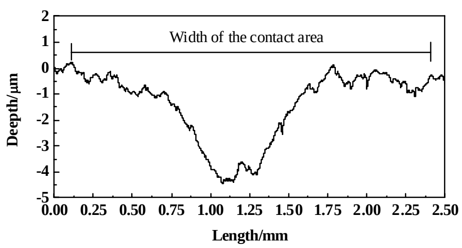
RESULTS AND DISCUSSION

The ultimate load, temperature and wear trace dimensions when the surface damage takes place are shown in Tab.1. The ultimate Hertzian contact stresses are 3.8GPa in 0.12 slide/roll ratio and 3.5GPa in 0.15 slide/roll ratio. It is shows that surfaces have better damage resistance in small slide/roll ratio. The reason of it is when contact surfaces come into big slide/roll ratio, the frictional heat will cause rapid rise in temperature, which result in the failure of the lubrication [6].

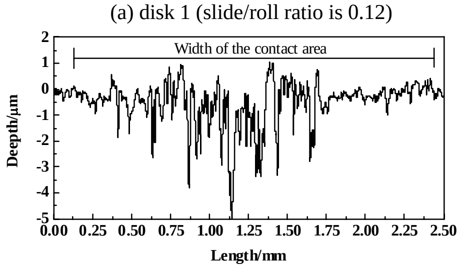
Fig.2 shows the profile of the wear tracks. There is a deep score in disk1 surface and some materials transferred to disk2 surface in 0.12 slide/roll ratio (as shown in Fig.2 (a), (b)). It indicates that scuffing occurred in the contact surfaces. There are some scores in disk2 surface as well as disk1 surface in 0.15 slide/roll ratio, depths of these scores are lower than the score in 0.12 slide/roll ratio. Comparing the height relation of the profiles in Fig.2 (c) and (d), the material mainly transferred from disk2 to disk1. The profiles of the contact surfaces show that material transferred from the low speed disk to the high speed disk and it accords with the characteristic of scuffing.

Tab. 1 Some parameters of the experiments

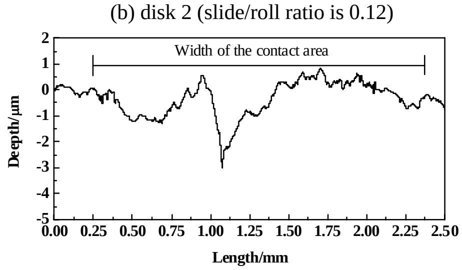
slide/roll ratio	0.12	0.15
rolling speed (m/s)	43.2	49.5
sliding speed (m/s)	5.276	7.424
disk 1 speed (m/s)	40.535	53.235
disk 2 speed (m/s)	45.811	45.811
ultimate Hertzian contact stress (GPa)	3.8	3.5
difference in temperature of disk 1 and oil at the ultimate Hertzian contact stress (℃)	59	50
calculated width of the wear scar at the ultimate Hertzian contact stress (mm)	2.334	2.147



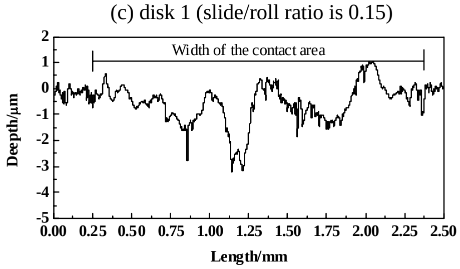
(a) disk 1 (slide/roll ratio is 0.12)



(b) disk 2 (slide/roll ratio is 0.12)



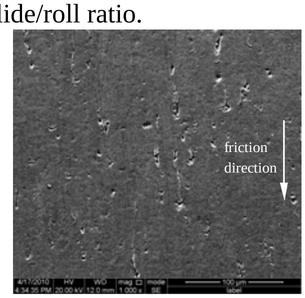
(c) disk 1 (slide/roll ratio is 0.15)

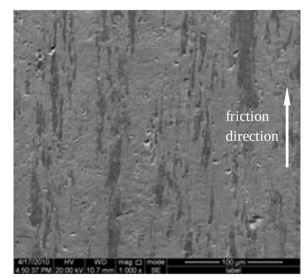


(d) disk 2 (slide/roll ratio is 0.15)

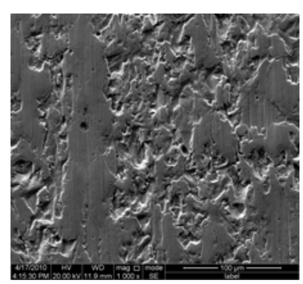
Fig.2 Profiles of the disk surfaces

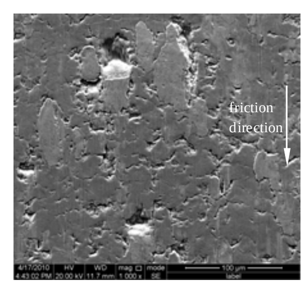
Fig. 3 shows the SEM morphologies of the wear scars in the two slide/roll ratios. As shown in Fig.3(a), cracks, spalls and some protuberances shaped as was prized exist in the wear area of the low speed disk1 in 0.12 slide/roll ratio. Fig.3(c) shows that material was torn out severity in the high speed disk2 surface. The wear area is very coarse and obvious plastic deformation can be observed. Additionally, there are furrows and cracks. The micrograph of the wear scar cross section shows that cracks mainly originate from surface layer and the spread direction is the acute angle with the surface. The contact surfaces are subjected to the alternating stress passed by oil film and the stress causes the fatigue cracks appear in the contact surface. As a result of the cracks expansion, spalls and the protuberances (such as shown in Fig. 3(a)) appear. The film thickness is reduced because of the protuberances existence, so, the contact opportunity of the asperities in the surface is increased. The friction heat accumulates continuously which causes the lubrication status deteriorated gradually. The adhesion and tearing will occur in the contact asperities when the oil film couldn't seclude the two contact surfaces. The frequency of the process is enhanced with increasing of the load, meanwhile, the dimension of the adhesion wear is increased. The surface damage mode is scuffing in 0.12 slide/roll ratio.





(a) disk 1 (slide/roll ratio is 0.12) (b) disk 1 (slide/roll ratio is 0.15)





(c) disk 2 (slide/roll ratio is 0.12) (d) disk 2 (slide/roll ratio is 0.15)

Fig. 3 Micrographs of wear area

It can be seen from Fig. 3(b) that the wear surface of the high speed disk1 in 0.15 slide/roll ratio is divided into two areas according to the colors. Fig. 5 shows the typical EDAX spectrum of the two areas. The peaks of elements oxygen, molybdenum, vanadium and chromium in black area are higher than that in white area, which indicates that oxidation in black area is severe and more oxide compounds are formed. The discontinuous oil film cause the oxidation take place in some regions. There are also cracks, spalls and furrows in disk1

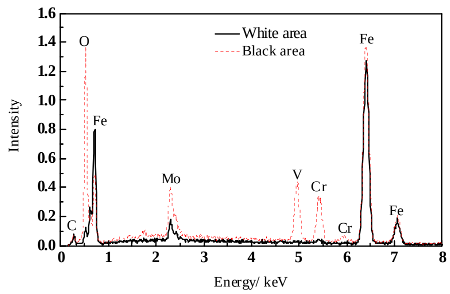


Fig.4 EDAX spectrum of disk1 (slide/roll ratio is 0.15)

surface. Fig.3(d) shows that wear track of the low speed disk2 in 0.15 slide/roll ratio covers with cracks both in transverse and longitudinal directions. The cracks distribute as surface crazing. There are massive spalls and plastic deformation traces in the bottom of the pits. It also can be seen that some wear particles embed the cracks. Compared with disk2 in 0.12 slide/roll ratio, speed of disk2 in 0.15 slide/roll ratio is invariable, but speed of disk1 is increased. It enhances the stress cycles and the changes frequency of the temperature, accordingly, rimous thermal fatigue easily present. SEM micrograph of the wear scar cross section shows cracks originate from surface layer, too. Heat produced at the interface can cause flash temperature which would makes the local temperature achieves the melting point of the metal. There are local melted hot-short areas which resulted by high temperature, as shown in Fig.5, they are intergranular fractures shaped as coarse grain structure in the bottom of the pits.

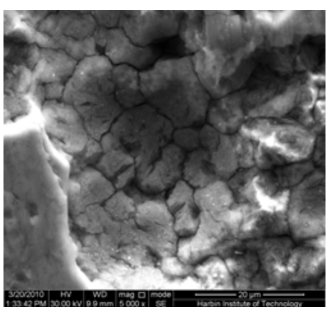


Fig. 5 Melting area in disk 2 surface (slide/roll ratio is 0.15)

CONCLUSIONS

The ultimate parameters of M50 steel surface damage under extreme conditions existed in aircraft bearings obtained from experiments show that contact surfaces have better damage resistance in small slide/roll ratio and low sliding speed. The ultimate Hertzian contact stresses in 0.12 and 0.15 slide/roll ratio are 3.8GPa and 3.5GPa respectively.

The micrographs of wear scar cross section shows that cracks mainly originated from surface layer in these two slide/roll ratios. The material happened evident transfer which have proved the main surface damage mode is scuffing in 0.12 slide/roll ratio. Under the conditions of high sliding speed and big slide/roll ratio, the frictional heat can raise the temperature rapidly even to reach the flash temperature. The surface damage modes are scuffing, oxidation wear and thermal fatigue in 0.15 slide/roll ratio.

ACKNOWLEDGMENTS

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