Investigating Bearing Subsurface Microstructural Damage of White Etching Areas and Butterfly Wing Cracks

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Abstract. This paper investigates subsurface microstructural damage of raceways observed in samples cut from two failure wind turbine gearbox bearings. Using optical microscopy and scanning electron microscopy, subsurface crack networks and butterfly wing cracks at non-metallic inclusions are observed. The 3D butterfly damage structure, microstructure and hardness of white etching areas are analysed and evaluated.

Introduction

Wind turbine (WT) gearbox bearings are subjected to variable loading conditions due to wind speed changes and variable speed controls of the turbine. Raceways of the bearings are subjected to rolling contact fatigue (RCF) and premature failures of the bearings have been reported. Microstructural observation of the failed bearing raceway samples has shown the surface spalling of the raceways is often initiated from the subsurface RCF crack networks associated with damaged non-metallic inclusions. White Etching Areas (WEAs) have been found to be decorated along subsurface RCF crack networks. WEA decorated cracks initiated from an inclusion often have cracking damage shape similar to butterfly wings, as shown in Fig.1. As WEA damage increases hardness and decreases the toughness of the steel matrix, it promotes the propagation of localised RCF cracks significantly. It is generally considered that the WEA damage formation is affected by multiple factors including stress concentration at inclusion, and shearing and local heating of the cracked surfaces. It has been evidenced that the maximum Hertz contact pressure, surface traction and lubrication have a significant influence on the formation of the WEA damage. However, the formation sequence of WEA damage and RCF cracks is still being debated. Further investigation of the WEA damage formation is necessary.

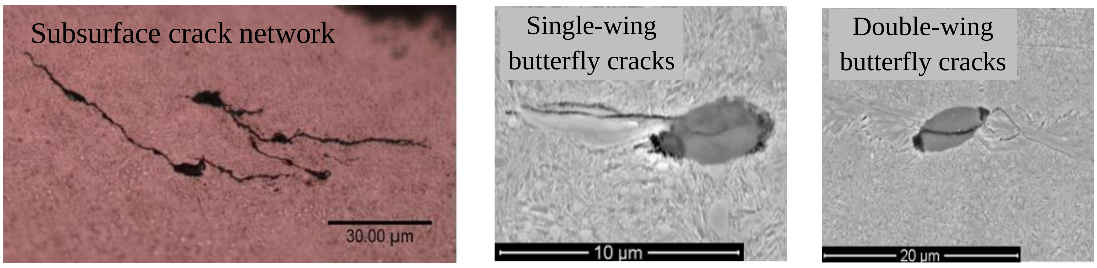

Fig.1. Bearing raceway subsurface crack network and butterfly wing cracks with WEAs

Experimental Method and Results

Samples cut from raceways of two failed planetary bearings of a 2MW WT are observed and analysed by optical microscopy and Scanning Electron Microscopy (SEM). Energy Dispersive X-ray spectroscopy analysis shows that 90% of the inclusions found within butterfly wing cracks is MnS inclusions.

To study the 3D structure of butterfly damage, a sample with a WEA of 20 µm in length is polished and etched four times. As can be seen in Fig.2, after the second polishing/etching, the WEA damage has changed from a single wing, in Section a, to a butterfly with two wings, in Section b. After the third polishing/etching shown in Section c, the length of the left-wing is reduced while the length of the right-wing is increased, probably caused by shape differences of the inclusion in different observing planes. The inclusion geometry and size is determinant for stress concentration thus affecting the size of WEAs. After the fourth polishing/ etching, no butterfly damage is found within the steel matrix, as the entire butterfly damage is polished away.

In order to determine whether the microstructure of WEAs in RCF crack networks is different from that in butterfly wings, SEM is used to magnify both types of damage by 60,000 times. Fig.3 shows that both WEAs have dense ferrite structures. The only difference is that the WEA in the crack network does not have the significantly elongated grains like that in the butterfly wing WEA, which may be caused by shear deformation during the formation of the butterfly wing. Based on these observations, it can only be concluded that WEA is composed of a dense ferrite structure, but the cause of its formation could not be confirmed.

Nano-indentation tests are carried out to measure the hardness of both bearing steel matrix and WEA, and a four-wings butterfly is selected. One test measures the hardness of the 100Cr6 steel matrix and another for the WEA. As shown in Fig.4, the butterfly WEA of an ultra-fine ferrite structure has a much higher average hardness of 13.15 GPa than that of the steel with the martensite structure, accelerating RCF crack propagation.

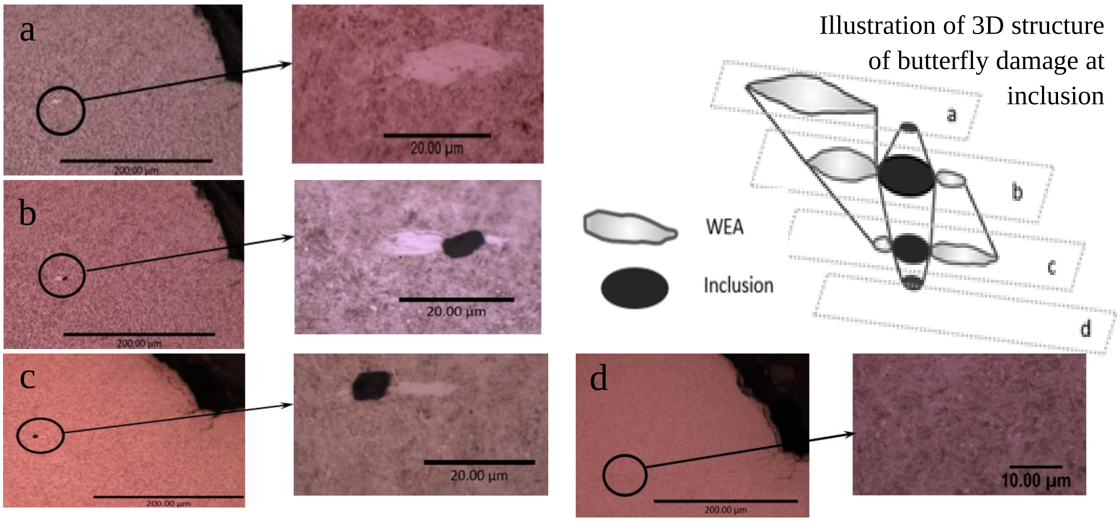

Fig. 2 Four sectional planes, three with 2D butterfly damage (a, b, c); and 3D illustration of the inclusion geometry and associated butterfly wing shapes

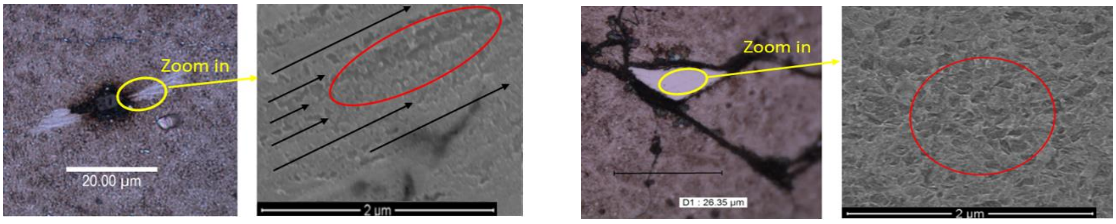

Fig. 3 Comparison of WEA microstructure in a butterfly wing (left) with that in a crack network (right)

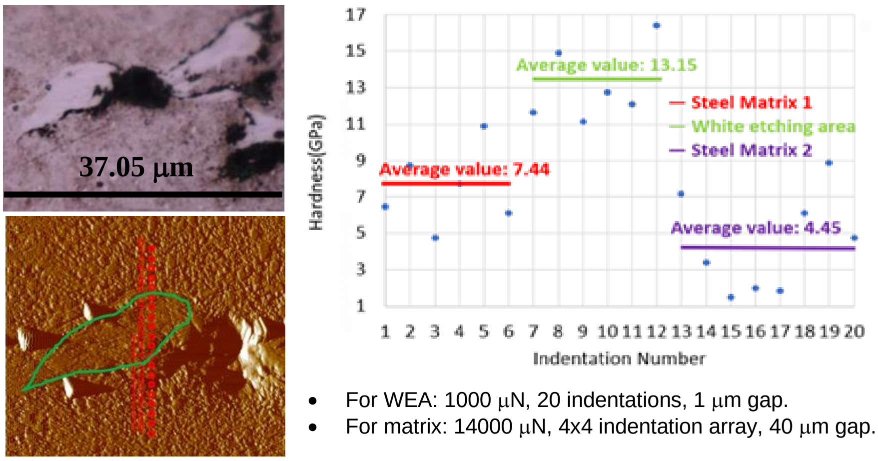

Fig. 4. Nano-indentation tests for hardness measurements of bearing steel matrix and white etching area

Conclusions

- Microstructure butterfly damage has shown a 3D structure and each 2D sectional plane of the butterfly damage has different lengths of cracking wings as well as different inclusion shape and size.
- WEAs are observed in both butterfly wing cracks and RCF crack networks; they have the same dense ferrite microstructures but only WEAs in butterfly wing cracks have shown significantly elongated grains.
- Hardness measurements by nano-indentation tests show that WEAs in the butterfly wing damage has an average hardness of 13.15 GPa, much harder than the surrounding steel matrix. Therefore WEAs are prone to brittle fracture to promote accelerated propagation of localised RCF cracks**.**

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