Bearings in large industrial gearboxes or drive train applications, such as paper mills, crusher mill gearboxes, lifting gear drives or especially in wind turbine gearboxes are often subjected to a wide variety of operating conditions that may push them, under certain circumstances, beyond their limits. Damage may occur in bearings, resulting in a failure mode often described as white etching cracks (WEC), sometimes also called white structure flaking (WSF).

In [1][2] it has been shown that not one single parameter, but several parameters associated with WEC/WSF exist, e.g.

- hydrogen related
- corrosion related
- stray current related
- lubrication & mixed friction related
- tensile stress related
- or high load/stress related.

Looking to above mentioned applications that can be affected by premature failures, a tentative common ground can be seen related to the large variety of operation conditions, by means of stresses that might exceed strength (e.g. loading, dynamic/non-steady state conditions) as well as environmental and/or other factors (e.g. lubrication, contaminants such as water, stray current) that might reduce material strength.

One factor for a potential “material strength reduction” or “weakening” effect in the near-surface region, is the chemical effect of the lubricant which impacts the performance [3]. This would imply that boundary friction alone does not always predict performance; which is today the view mostly encountered, and in literature referred to as mechanical effect. According to Klüber research [4] friction conducts to sliding planes at the near-surface which lead to a refined structure of a few microns under the surface; see figure 1-a. The differences induced in the near-surface, detected in the FIB cross sections after using wind turbine (WT) commercial oils, can be linked to the surface appearance (crack formation) in ball-on-disc experiments. In figure 1-b, the refined microstructure depth is roughly three times larger for Oil A compared to Oil B, while the oil viscosity and testing conditions were identical. The friction registered during these tests showed variations from oil to oil, but in most of the cases could not always be related to the refined microstructure depths; supporting the assumption of an additional lubricant chemical effect on material near-surface.
Fig. 1: Secondary ion images taken in cross sections using Focus Ion Beam (FIB) after bearing test [4] (a); and after ball-on-disc tests with two wind-turbine oils (b).

To investigate the lubricant impact on material weakening, which consequently may lead to WECs appearance, different preservative oils were investigated in component tests. One of them in particular, namely overbased Calciumsulphonate (ObCaSu) indicated a significant worsening in the performance. It is reported that ObCaSu additives may be most influential on WEC formation mechanisms by favoring nascent surface formation and hydrogen permeation [5].

SKF tests carried out on 81212 bearings showed that ObCaSu presence as ingredient in certain commercial oil is causing premature failures and WECs formation (see figure 2-a). Additional bearing tests with CRTB (81105TN) were carried out at a four-ball machine modified [6] (see figure 2-b), with surface roughness designed to induce quick damage accumulation to the surface and near-surface [7].

Fig. 2: WEC occurrence in 81212 bearing test (a). Picture and schematic representation of four-ball machine modified for bearing arrangement (b).

The tests showed clear differences in the reaction layer composition between ObCaSu mixed in the test oil and ObCaSu used as preservative oil for the bearing parts only. In the case when ObCaSu was mixed in the test oil, the formation of a reaction layer containing CaS was detected as well as a decrease in performance (by means of an increased micropitting, friction and wear).

These findings as well as more thorough investigations of endurance tested bearings motivated the authors to distinguish between WEC generation due to bearing rolling contact fatigue on the one hand and on the other hand accelerated rolling contact fatigue, by means of WEC generation when "stresses are higher than anticipated", when "the strength is lower than anticipated", or a combination of both (see figure 3).
Although not fully clarified and strongly discussed in the material science community [8]-[12], the authors are convinced that the occurrence of WEC needs to be placed at the end of the failure chain, being a natural product of crack networks in failed bearings. In other words, WECs are a symptom of bearing failure but not the root cause. The events that lead to the occurrence of WEC are suggested and illustrated in figure 4.

As schematically illustrated, the difference of premature failures (often interpret as WEC failures in industry) and bearing fatigue can be found in the time scale that is needed for the occurrence of the different events until spalling. In addition, compared to endurance testing or ‘normal’ rolling fatigue, premature failures are often associated to crack initiations at several locations/areas. The reasons for crack initiation in bearing steel can be different (see figure 3) and accelerated in case of higher stresses, or in case of strength reduction due to environmental effects; for example due to an ingress of hydrogen into the steel. Once crack nucleons are generated (sometimes associated with the occurrence of DER, dark etching regions) then a rubbing process across the crack faces is leading to transfer of material from one side of the crack to the other. This leads to a meandering crack, which accumulates white-etching microstructure on the receiving side of the crack.

Fig. 3: Simplified distinction between WEC occurrence due to rolling contact fatigue or due to ‘accelerated’ fatigue.

However, the White Etching Area (WEA) development depends also on the orientation of the crack in the subsurface that can be related to acting internal forces and deformation modes. This is why WEAs are sometimes found more in horizontal oriented cracks (parallel to the raceway), whereas the vertical oriented parts of the crack show often less WEA decoration (see figure 5). Furthermore, the generation of WEAs depends additionally on the interspace between crack faces, the amount of stress cycles as well as the internal stress state in the material.
Therefore, the authors believe that the search for a common condition that leads to WEC is delusive, because WEC generation is secondary; pinpointing the need to carefully evaluate each premature bearing failure case in the light of the corresponding application.

Fig. 5: WEA decoration in a step-like crack; left SKF in-house test (with reduced strength via hydrogen charging), right from field [13].

REFERENCES


KEYWORDS
Rolling Bearings: Rolling Element Bearings, General, Wear: Fatigue