The white etching cracking phenomenon:

how to minimise it and keep your wind turbines turning

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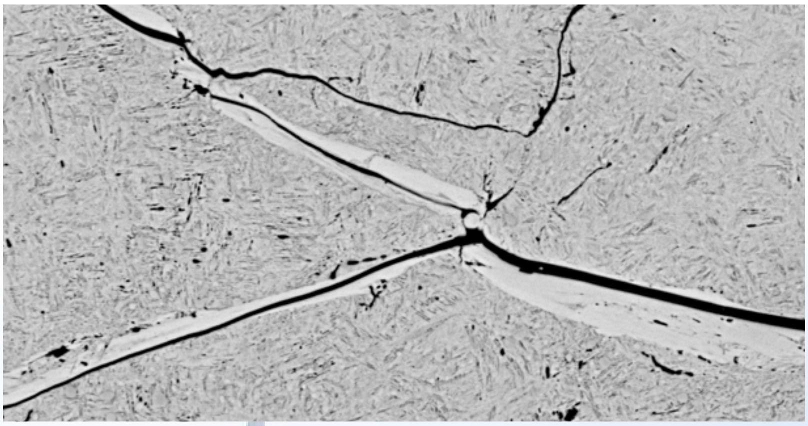
1. Introduction

White etching cracking (WEC) is a major cause of bearing failures in wind turbines. Its exact cause remains unclear although research suggests that lubricants may play a role. However, it is possible to select gear oils that don't contribute to the phenomenon, explains Thorsten Süling, European EB/OEM manager, ExxonMobil.

White etching cracking (WEC) is a common cause of bearing failure in the gearboxes of wind turbines: around 60% of the industry's high speed bearing failures are caused by the phenomenon. The condition, which gets its name from the appearance of the white fissures in the micro structure of steel after natal etching, can result in costly parts failure. Given that the cost of repairing a wind turbine gearboxes is expensive, compounded with the associated cost of downtime, it is little wonder that multiple investigations have been conducted to determine the cause of WEC.

Worryingly, WEC happens without warning. As the issue occurs below the surface of a bearing it is not possible to detect, even with a visual inspection. And once WEC damage reaches the surface of a bearing it is too late – the resulting component failure can require extensive and costly maintenance to put right, particularly off-shore.

No definitive trigger has yet to be established, although WEC is most likely the result of a complex interaction between a number of mechanical, electrical, operational and chemical factors. The scale of this tribochemical reaction – the chemical changes that occur to a lubricant and a lubricated surface when separated by a thin tribofilm, generated as a result of interactions between lubricant additives and lubricated surfaces – is not well understood. Speculation has centred on the activity of hydrogen in the subsurface 'WEC zone', which can have a role in the bearings becoming brittle.



Around 60% of the industry's high speed bearing failures are caused by white etching cracking

2. Hydrogen embrittlement

The combination of a tribofilm and high frictional forces drives hydrogen into the WEC zone. Increased friction induced energy dissipation due to thick, patchy tribofilms can produce more pronounced changes to the steel – the formation of fine grain structures and potentially even micro cracking. It can get worse in the presence of hydrogen, which can initiate hydrogen embrittlement and/or Hydrogen Enhanced Localised Plasticity (HELP), resulting in WEC failure.

The exact source of the hydrogen remains unclear although the gas can be generated by lubricants or degraded lubricant components. However, research indicates that the damaging hydrogen could be derived from water contamination, not from lubricant breakdown. In order to ascertain the facts, ExxonMobil, in partnership with a leading bearings manufacturer, set about testing to see if lubricant formulation was a contributing factor and to ascertain if changes in oil type could actually help limit/minimise this type of contact fatigue from occurring.

One area of investigation was to look at the development of a tribofilm or coating that acts as a diffusion barrier. The influence of non ferrous diamond like carbon (DLC) coatings and black oxide layers (Fe3O4) on the bearings and fatigue mechanisms have already been considered. Several studies showed that a black oxide coating can extend bearing life. Its hardness is lower than steel and consequently this might reduce contact stress (friction), damping vibrations and deterring hydrogen diffusion.

However, applying barrier coatings is time consuming and expensive. Therefore, reducing the probability of WEC formation with improved lubricants is highly desirable. ExxonMobil and a major bearing manufacturer compared a range of lubricant formulations to a reference oil that has been reported to generate WEC in bearings. The influence of additives on tribofilm formation, friction response, and their influence on WEC initiation, propagation and bearing failure were all recorded.

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3. Tests and measurements

The measurements were carried out using the FE8 test, which is used to examine lubricating oils and greases with regard to their wear and friction behaviour under lubricant and bearing-specific influences, and MTM-SLIM, to measure sub-micron tribofilms.

Bearings that failed within the first 200 hours of testing clearly exhibited WEC, defined by the characteristic white area adjacent to the crack. No such signs were observed in specimens of bearings that lasted longer than 200 hours of FE8 testing. In this case, cracks propagated in the lateral as well as outward radial direction reaching to the surface, suggest non-WEC related failures as a result of surface fatigue.

Based on this observation the FE8 test results were grouped into two categories: average hours to failure below and above 200 hours triggered by oils that cause WEC and those that do not contribute to WEC formation (referred to as WEC oils and non-WEC oils) respectively. Tests that reached 500 hours were stopped manually.

4. The role of additives

Oils with metal containing components (reference oil), along with metal-free candidate oils, were formulated and tested in the FE8 WEC analysis. In this study, oils containing ZDDP (Zinc diakyldithiophosphate, a commonly used anti-wear additive), irrespective of the presence of other metallic or non-metallic additives, resulted in WEC failure in the FE8 tests. WEC formation was also observed when combining Na and Ca alkyl sulfonates (surfactants), even in the absence of ZDDP.

Lubricant blends containing Na, Ca, or Mg alkyl sulfonates resulted in WEC only when these components were introduced in increased (x2) concentrations. No WEC failures were recorded for formulations based on zinc dialkyldithiocarbamate (ZnDTC), ashless phosphate anti-wear additives and/or non-metallic additive packages. The experiments conducted in this work show that certain metal containing additives cause WEC, but their contribution to WEC formation can depend on their concentration in the lubricant.

Bearings that failed within the first 200 hours of testing clearly exhibited WEC

5. The influence of friction

Tests using the MTM SLIM apparatus probed the relationship between the formation of tribofilms and their influence on friction. ZDDP containing oil that caused WEC in the FE8 bearing was used in the MTM SLIM analysis.

Significantly, the MTM SLIM results indicated that once WEC has started, the switch to a non WEC oil delayed the WEC events but could not avoid the failure.

These results have major implications in applications, i.e. to assess the turbine bearings' susceptibility to WEC failure, operators need to assess the oil history of the gearbox and not only the oil currently in use.

6. The role of water

A number of methods has been proposed to explain how water can cause hydrogen embrittlement and/or HELP, eventually resulting in WEC failure. For example, water may enhance corrosion by transforming sulphur phosphorus extreme pressure additives into acids, creating a corrosive environment. Hydrogen could also be present as the result of the formation of hydrogen peroxide, especially when water is exposed to iron surfaces.

ZDDP, Na/Ca/Mg alkyl sulfonates are hygroscopic in nature, i.e. water molecules will be trapped in higher concentrations in the tribofilm. Thick and patchy tribofilms causing increased friction formed by metal containing additives could help detach water molecules on the freshly generated metal surfaces. A sufficient amount of hydrogen radicals in combination with high friction tribofilm induced sub surface stress can lead the WEC failure.

7. Lubricant insights

WEC oils showed consistent bearing failure after less than 200 hours of testing, while non-WEC oils did not result in WEC failure in FE8 tests. Also, oils formulated with metal-containing additives showed strong tendencies toward WEC failure. This is linked to the growth of relatively thick (~120nm) tribofilm and high frictional forces during the formation of the tribofilm and onwards. Significantly, WEC and non-WEC oils showed marked difference in water content, suggesting that hygroscopic metal containing additives can cause significant water ingress in lubricants.

Metal-containing additive concentration in lubricants is sufficient to induce critical friction and provide adequate film thickness promoting WEC. Base-stock type did not show any impact on WEC occurrence and although higher viscosity base-stocks delayed WEC formation, they did not prevent it.

FE8 tests confirmed the early incubation period can cause changes that determine if WEC will form after further loading. These changes take place in less than 20 hours of FE8 operation. Short duration tests followed by sub-surface microscopy studies confirmed the early initiation of WEC sites.

Thermal desorption spectroscopy, which is used to detect molecules released from a surface as the temperatures rises, showed that oils saturated with heavy water was a significant source of hydrogen contributing in WEC formation.

8. The findings

Taken as a whole, the findings suggest that there is a mechanism for water separation during the initial tribofilm formation. The generation of nascent metal surfaces, accompanied by tribochemical reactions, resulted in thick tribofilms that generated an increase in friction during the initial incubation period (~20 hours for FE8 test). Water in lubricants is exposed to nascent surface asperities and separates under high friction. Hydrogen generated from water is absorbed into the metal sub-surface, causing WEC failure.

9. Partner to success

WEC is a complex engineering/scientific challenge. However, it is possible for the wind turbine industry to off-set potential issues and maintenance costs through the use of high performance lubricants. ExxonMobil's Mobil SHC™ Gear 320 WT is the first wind turbine gear oil to have received a 'design evaluation' certification from DNV-GL, one of the world's leading certification bodies for renewable energy projects. The award, which was granted after extensive review by DNV-GL, is in recognition that Mobil SHC™ Gear 320 WT does not contribute to the oil-related effects of WEC.

RENEWABLES CERTIFICATION
DNV·GL
Design Evaluation
DE-DNVGL-SE-0074-05128

ExxonMobil continues to work side-by-side wind farm operators and leading industry OEMs to ensure it offers its customers the service expertise and products they need for reliable and efficient turbine operation.

To find out more, visit: **www.mobilshcgear320wt.com**

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