INVESTIGATING OF PITTING FORMATION ON GEAR TOOTH AND EVALUATING LIFE TIME OF GEARS USING SEM

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ABSTRACT

Many gears under goes fatigue loads, which may result in the damage of the gear teeth, by pitting-type failure. Mechanical properties, Microstructural features, and residual stresses have strong influence on the pitting resistance of the material. Suitable additives in the gear box lubrication oil are added to improve the pitting resistance. A coating is given to gear teeth for protecting the teeth from pitting. In this paper, investigation is done by applying cuprous oxide coating on gear teeth for delaying pitting initiation. A Comparison is drawn on pitting initiation without coating and with coating. The results allow the evaluation of the stress components that may lead to the pitting failure. .the intention of this paper is not to provide detailed description of the causes of gear failure but it focused on the different type's methodology that is used by the various researchers in the past recent year to find out causes of failure in gear and what is final result of that to reduce the failure in gear. The failure zones were examined with help of scanning electron Microscope equipped with EDX facility. For further investigation An analysis through SEM was carried out close to the crack initiation, it was found that the damage in the gear were by fatigue fracture.

Keywords: Gear Failure, Pitting, Gear Teeth, Cuprous Oxide, Life Time

1. INTRODUCTION

Pitting is a common failure mode for gear teeth because they are subjected to high Hertzian contact stresses and many stress cycles. For example, through-hardened gears are typically designed to withstand contact stresses of approximately 700 MPa (100 ksi), while the contact stresses may reach 2100 MPa (300 ksi). In addition, a given tooth on a pinion that is revolving at 3600 revolutions/min accumulates over 5 × 106 stress cycles every 24 h.

Pitting is a fatigue phenomenon that occurs when a fatigue crack initiates either at the surface of the gear tooth or at a small depth below the surface. The crack usually propagates for a short distance in a direction roughly parallel to the tooth surface before turning or branching to the surface. As cracks progress further into the surface, the rate of propagation increases. This increase is related in part to lubricant (under contact pressure) being forced into the crack and wedging it further open, but it mostly is due to the high shear stresses produced by the contact load. At some point below the surface, in the region of 100 to 500 μm (0.004 to 0.020 in.) or deeper, depending on contact geometry, shear stresses produced by the contact load become high enough to promote rapid crack propagation. Progressively larger pieces break away from the surface, leaving yet larger cavities. This condition is termed pitting or macropitting.

When the cracks have grown to the extent that they separate a piece of the surface material, a pit is formed. The material is torn away from the damaged area by the relative motion of the contacting parts; thus, the cavity becomes wider and deeper in the direction opposite to sliding, leading to an arrow shape. As pits become larger, they eventually cause a readily detectable increase in dynamic loads. A loss of material that reaches this level is frequently termed spalling and is considered failure. There is no endurance limit for Hertzian fatigue, and pitting occurs even at low stresses if the gears are operated long enough. Because there is no endurance limit, gear teeth must be designed for a suitable finite lifetime. To extend the pitting life of a gear set, the designer must keep the contact stress low and the material strength and lubricant specific film thickness high. There are several geometric variables, such as diameter, face width, number of teeth, pressure angle, and so on, that can be optimized to lower the contact stress. Material alloys and heat treatment are selected to obtain hard tooth surfaces with high strength. Maximum pitting resistance is obtained with carburized gear teeth because they have hard surfaces, and carburizing induces beneficial compressive residual stresses that effectively lower the load stresses. The drawbacks to using carburized gear teeth are that they are relatively expensive to produce and that they must be finished by grinding.

Pitting may initiate at the surface or at a subsurface defect, such as a nonmetallic inclusion. With gear teeth, pits are most often of the surface-initiated type because the lubricant film thickness is usually low, resulting in relatively high metal-to-metal contact. The interaction between asperities or contacts at defects, such as nicks or furrows, creates surface-initiated, rather than subsurface-initiated cracks. For high-speed gears with smooth surface finishes, the film thickness is greater and subsurface-initiated pitting, rather than surface-initiated, may 4 predominate. In these cases, pitting usually starts at a subsurface inclusion, which acts as a point of stress concentration. Cleaner steels, such as those produced by vacuum melting, prolong the pitting life by reducing the number of inclusions.

Contamination from water in the lubricant is believed to promote pitting through hydrogen embrittlement of the metal, and abrasive particles in the lubricant cause pitting by indenting the tooth surfaces, causing stress concentrations, and disrupting the lubricant film. At present, the influence of lubricant additives on pitting is unresolved. The following recommendations serve as guidelines for preventing the onset of pitting in gear sets:

- Reduce contact stresses by reducing loads or optimizing gear geometry
- Use clean steel, properly heat treated to high hardness, preferably by carburizing
- Use smooth tooth surfaces produced by careful grinding or honing
- Use an adequate amount of cool, clean, and dry lubricant of adequate viscosity

One of the most important types of failure in gear is the contact fatigue [1]. The contact fatigue results from a Hertzian stress state, in which the maximum pressure is established at the center of the contact due to two common assumptions: a) circular, elliptical or line contact surface area between curved tooth surfaces and, b) parabolic pressure distribution. A hydrostatic component occurs in the subsurface state of stress, which inhibits tensile fracture. The development of carbon profiles in steel case hardening, and the generation of compressive residual stresses are solutions to improve the resistance to pitting-type damage to gear tooth [1]. Improved mechanical properties wear and fatigue resistances can be obtained by conducting different manufacturing processes. Approaches were made based on hardness and residual stress profiles in the gear tooth, the microstructural features, the shot peening parameters [2], the residual stresses [3,4] and the case depth [5]. Nevertheless, the hardness and the residual stresses are hard to be measured and present a wide range of values.

The effect of residual stresses in the tooth subsurface fatigue fracture was analyzed [6], in which the crack is initiated due to the combined action of the alternating stresses from the idler usage of the gear and the residual stresses. In addition, numerical and experimental analyses were conducted to evaluate material parameters affecting gear tooth [7, 8].

This work deals with the evaluation of stress simulation throughout the contact gear teeth and its relation with material hardness profile and the residual stress. A gear, presenting a cuprous oxide coating surface was characterized X-ray diffraction method.

2. LITERATURE REVIEW

M. Fonte et al [5], a failure analysis investigation of two helical gear wheels of a ducted azimuth thruster is performed in this paper. The determination of the damage root causes of material including fracture examination is performed during this research work. At the start of failure analysis two broken teeth of two helical gear wheels were kept under observation. For micro level analysis, scanning electron microscope (SEM) was used. It is concluded that failure was caused by localized overstress on the teeth surface. By observation it is concluded that the fatigue crack initiation started at the root of coast side flank of the gear teeth, followed by the crack growth, and final fracture. Mode of failure for both gear wheels is clearly the same. In assistance with a poor lubricating oil performance in a gearbox, a continuous overloading of the thrusters is also the main root cause for this failure. An inappropriate lubrication caused the severe contact stress on gear teeth were clearly analyzed in SEM. The premature failure also gives the evidence of a possibility of misalignment between the pinions and the gear wheels.

Myounggu Park [6], in this paper an accessory gear box of a turbojet engine was investigated. The material used for the manufacturing of drive bevel gear is AISI: 8617. The fracture is the probable mode of failure. With the visual inspection of the fractured surface it is clear that the cracking mode was fatigue. In this paper also SEM is used for the micro level study. From that it is clear that there is no surface defect. The fatigue crack initiation took place at the upper root area of the gear teeth and propagated intergranularly. The cracking route indicates the way of typical tooth bending fatigue. This is due to the improper surface heat treatment. Analysis at micro level indicated that the failed gear was not properly case hardened and because of that the surface hardness decreased drastically. All these evidence indicates that it was a typical tooth bending failure.

S.K. Bhaumik et al [7], the investigation of failure analysis took place over a helicopter which caught with an accident. The reason found was the failure of an intermediate gear box. Examination showed that the driving gear was fractured due to fatigue cracking with ultimately leads to gearbox failure. The teeth of the gear were severely damaged. This type of damage only occurs in hardened material under severe load. Its evidence proves that it is due to spalling. Micro level observation reveals that there was more than one fatigue crack initiation at the tooth root regions. Improper assembly and misalignment of two mating gears shaft may also lead to teeth failure and ultimately gear failure.

Nauman A. Siddiqui et al [8], the failure of any component in an aircraft structure or in engine leads to the failure of whole assembly and it may cause accident and as a result of this there will be loss of human lives. Most of the accident cases which take place in aircrafts are due to the failure of power transmission unit or any component in power transmission assembly. Most of the gear failures occur due to design errors, manufacturing error, assembly error, maintenance error, etc. The investigation of the cause of failure of bevel gears in an engine train of an aircraft has performed to avoid this sort of loop holes in future. The microstructural investigation indicates the transformation of retained austenite into untempered martensite under higher internal shear stress. Using DEA in the case the availability of internal stresses was validated. Subsurface cracks were developed within the altered orientation of DEA under the effect of this stresses. The variation in loading induces concentrated higher shear stress at the crack front and non-uniform fatigue distributions were produced in the crack propagation region combined with overloading. In this study mode of failure founded was contact fatigue. The continuous rolling action of gears resulted in tooth bending which produced crack at the fillet root. The drastically change in hardness at die etching area between case and core which resulted in the complete detachment of case after sever deformation of core. The case of the driven gear teeth was removed and excessive wear also took place. This happened only because of simultaneous rolling and sliding of meshing gear teeth in the existence of dust and rust particles. Higher internal stresses cause the formation of un-tempered martensite from retained austenite and micro-cracks. These all can be eliminated with the use of proper surface hardening between core and case of the gear and post heating processes. So now the condition is that there is gradual change in hardness from case to core at die etching area.

Tezcan Sekercioglu et al [9], in differential gear box spiral bevel gear play an important role in transmitting motion and power.

Investigation of spiral bevel gear fracture used in truck differential gear box manufactured from case hardened steel is included. Visual inspection, case and core hardness, chemical analysis and different metallurgical tests were performed on the specimen made from the spiral bevel gear to identify the cause of failure. It was observed that there were pitting on gear surfaces. The fracture was considered under the effect of micro structure. Hardness values at core and case were found lower than what required. The obtained contact stresses were higher as compared to the permissible stresses. From this study it is said that to get same hardness and microstructure, similar chemical composition is necessary for the two mating gear materials. Case hardness is quite low as compared to the requirement so it should be increased. The case should also be properly carburizing heat threatened to get the required and proper depth of the case. As there were quite higher contact stresses and the gear was against overloading the gear geometry should be optimized to reduce the contact pressure. As the contact pressure was higher so proper lubrication should be provided to eliminate the pitting occurrence at the surface of the gear.

R.C. Yin et al [10], in this paper, investigation was made with the use of SEM, metallographic and micro hardness testing. It was examined that the gear was subjected to serious pitting and associated tooth breakage. Because of that a spiral bevel pinion inside a gear reducer was failing. A spiral bevel pinion suffered under repeated contact stress and repeated bending stress. Due to all these stresses the pinion surface was under severe stress resulted in surface pitting. In gear or pinion failures there is not a case that always gear fails due to material deficiency or poor mechanical properties of the material. It may also fail due to misalignment between to two mating gears or due to a design error or manufacturing error. All these things also lead to the premature failure of the gears so alignment of the gear should also be checked at the time of assembly.

N.Mohan Raj et al [11], this paper show the three dimensional fillet stress analysis of bevel gear tooth using FEM and APDL. Uniformly varying load and a concentrated load are applied at pitch point to evaluate the stress distribution at the root of the tooth. Load distribution on pitch the line and the stress distribution at the root of fillet is also included in this study. 3D model and analysis of the bevel gear is done with the use of ANSYS. Two different conditions are used to evaluate the influence load on the root stress in straight bevel gear. From that it is found that the stresses are higher at toe side and comparatively lower at heel side in a gear tooth.

Vilmos Simon et al [12], in this paper, to minimize tooth contact pressure and transmission error, the modifications are to be made by changing head-cutter geometry and machine tool settings to get optimum tooth geometry. So misalignment will be produced between driver and driven gear and point contact is replaced with line contact. The correlation between pinion tooth modification and contact pressure is also studied.

Faydor L. Litvin et al [13], this study mainly focuses on the improvement of the bearing contact, transmission error, reduction of noise, vibration, to avoid severe contact stresses and results of experimental tests of bevel gears. It also includes the design, manufacturing, stress analysis and reduction in value of transmission error. FEM is used to get the tooth contact analysis and stress analysis. From the all above study, it is concluded that proper approach to design, simulation and stress analysis leads to the optimal solution of contact, reduced transmission errors, reduce in severe contact stress, noise, vibration, to obtain an oriented path of contact, to avoid or reduce area of severe contact stresses. With the use of Top-Rem blades, the endurance of spiral bevel gear drives can be increased.

3 EXPERIMENTAL PROCEDURES

200Nano cuprous oxide powder is thoroughly mixed with quich setting paint at 150^0 for about 10 minutes and the mix is coated on the gear teeth. Natural air cooling is provided [11] for the coating to settle on the surface of teeth.

Microstructural characterization and mechanical properties measurements are evaluated based on a gear made of 35 Mn 2 Mo 28 Manganese molybdenum steel

The microstructure of the section of a gear tooth is characterized by scanning electron microscopy (SEM) after metallographic sample preparation, which consisted on grinding and polishing up to 1 μm.Further, the sample was etched, with Nital (3% HNO3), to reveal microstructural features. X-ray diffraction (CuKα radiation) was run up to a depth of 30 µm, allowing the estimation of planar residual stresses based on peak shift measurements.

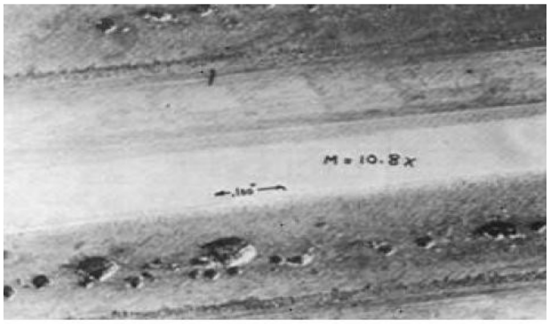


Figure.1: Pitting Action on Gear Tooth.

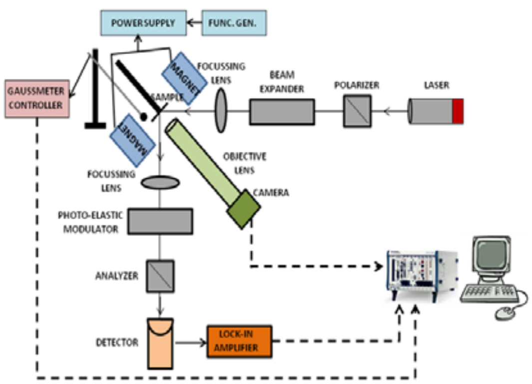


Figure 2.SEM Apparatus

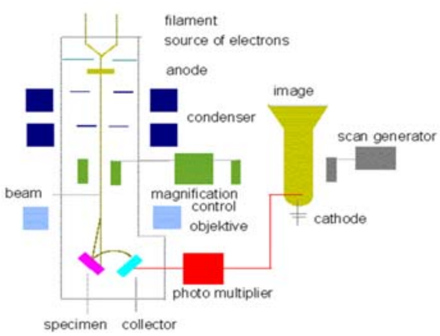


Figure.3: SEM Analysis Process

Extensive pitting, spalling and surface cracking can be seen at the crack origin in Fig. 1. In addition, scoring marks along the circumference of the web can also be seen. A proper sample piece was cut from the gear close to the crack origin. The cracked surface of the failed spur gear was examined in a scanning electron microscope to identify the cause of fatigue crack initiation.

4 RESULTS AND DISCUSSIONS

During the inspection of the gearbox, 21 out of 25 from the gear found to be damaged. The crack surfaces of gear teeth were examined by using SEM is shown in Fig. 4. SEM examinations by using secondary electron imaging technique make visible by uncovering the crack surface of the sun gear teeth. The presence of microscopic fatigue grooves at higher magnifications showed the [18,19] growth of fatigue cracks which are reliable with mechanical fatigue failure of the sun gear teeth which are subjected to severe kind of fatigue loading. A recent study showed that majority of service failures in sun gear occur by fatigue and gear loading is critically vital fact.

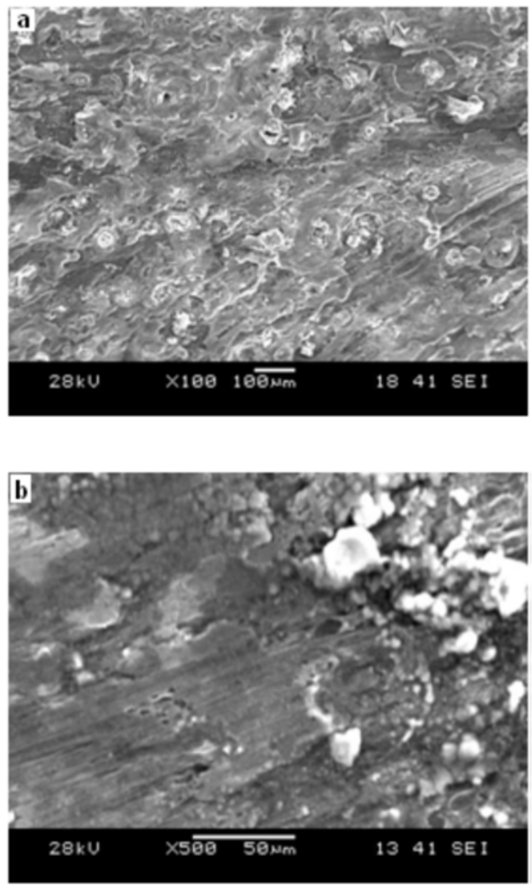
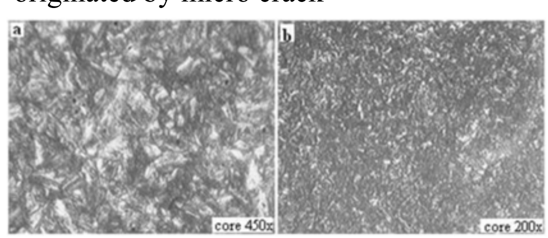


Figure 4(a, b). SEM showing the fatigue crack originated by micro crack



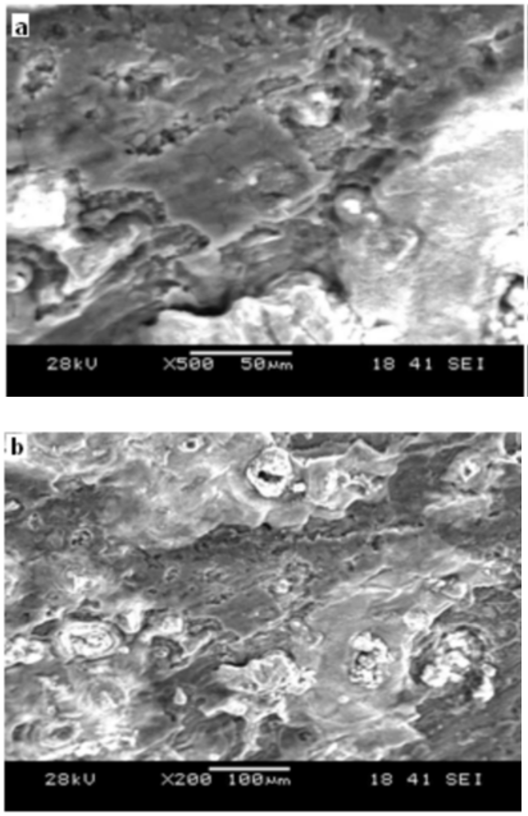


Figure. 6. (a, b) SEM showing the pitting at the magnification

SEM examination indicated that although there were destructive pitting and spalling area on the active side of the gear tooth in the area of the pitch line (Fig. 10), there was micropitting in some areas in the dedendum section of the gear tooth (Fig. 10). The area immediately above or below the pitch line is very susceptible to pitting. Not only is the rolling pressure great at this point but sliding is now a real factor [1].

Spalling regions and fatigue cracks initiation sites from spalling region at the pitch line of the failed helical gear tooth can be seen clearly, as shown in Fig. 10. In addition, Fig. 10(a) shows top view of developing spalls in the vicinity of the pitch line.

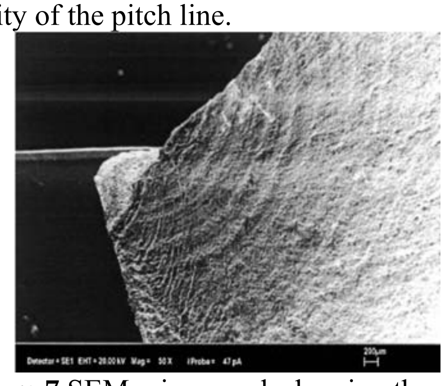


Figure 7.SEM micrograph showing the crack initiation and propagation region.

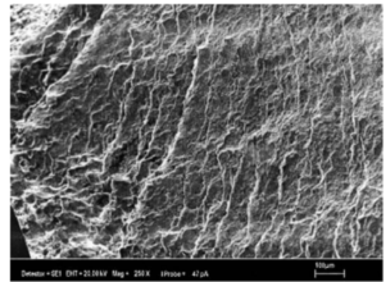


Figure 8.SEM micrograph showing typical brittle fracture observed in the crack propagation region.

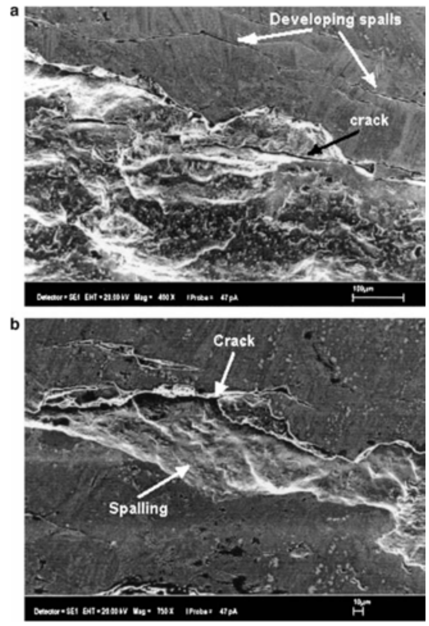


Figure 9. SEM micrograph showing two damaged area at the pitch line at the different magnification.

The composition, microstructure, hardness were found to be satisfactory and within the specification. Microscopic features indicated that fatigue was the main cause of failure of the gear. On the fracture surface of the teeth, the crack initiation region and beach marks could be seen clearly with naked eye. It was observed that the fatigue crack originated from destructive pitting and spalling areas in the vicinity of tooth pitch line and propagated toward tooth region of tooth. Failure analysis results indicate that a part of tooth fatigue failure in this case was, therefore, as a result of an incorrect load distribution on the gear teeth.

5 CONCLUSIONS

In this work, a pair of gear teeth was characterized by SEM, X-ray diffraction allowing the evaluation of material mechanical properties and residual stress. These mechanical properties and four residual stress levels were analyzed and shows following conclusions:

- Failure analysis results indicate that a part of tooth fatigue failure in this case was, therefore, as a result of an incorrect load distribution on the gear teeth.
- By observing the crack surface specified that the gear tooth failed due to a fatigue crack.
- It was concluded from SEM examination of the gear crack surface that the crumble of gear tooth resulted from fatigue due to heavy loading.
- Formation of the destructive pitting at one end of tooth, and all the fatigue crack initiation sites that were close to one end of the gear teeth supported this hypothesis.
- As per results as the additives and coating increases the life time and avoids fatigue failure of gear tooth.

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