Industrial Engineering Letters
ISSN 2224-6096 (Paper) ISSN 2225-0581 (online)
Vol.3, No.6, 2013

Investigations on the Material Efficacy of Failed Helical Gears in a Gear Train

O. O. Joseph,* O. A. Abidakun, A. O. Aniyikaye, O. O. Folorunsho
Department of Mechanical Engineering, Covenant University, P.M.B.1023, Ota, Nigeria
* E-mail of the corresponding author: funmi.joseph@covenantuniversity.edu.ng, Tel: +2348035172086

Abstract

An investigation on the material efficacy of failed helical gears in the gearbox of an automobile has been carried out. Two helical gear samples taken as representatives of the whole of six in the gearbox were denoted as samples A and B. Methods employed in the failure investigation include visual examination with the unaided eye and fractography; compositional analysis; hardness measurements and microstructural analysis. The results obtained showed that Gear sample A failed by oxidative wear essentially caused by insufficient lubrication. On the other hand, Sample B exhibited no outward sign of failure. Processes culminating in the formation of a wear particle were however noticed few micrometers below the surface of Gear Sample B. Furthermore, in the absence of sufficient lubrication, numerous carbide precipitates formed in both samples contributed to wear of the gear material. It was concluded that the premature service failures of the gears was caused by inadequate lubrication and not inadequate material selection.

Keywords: material efficacy; helical gear; wear; lubrication

1. Introduction

The fundamental requirement of effective power transmission in various machines, automobiles, elevators and generators, has created an increasing demand for more accurate analysis of the characteristics of gear systems (Norton, 1996). Gear transmissions are vital machine parts, and their reliable operation is required to prolong machine damage and fracture. Helical gears are being widely used due to the advantages of silent operation, increased operating speed and increased load carrying capacity. However, gear tooth failures of different kinds occur in service, altering the operating characteristics of transmission and eventually leading to the failure of the whole mechanical assembly with built-in gear. Great care is therefore paid to analysis of different tooth failure types in order to prevent or at least prolong the process of their initiation and propagation (Nanija et al., 2011). Furthermore, gear failures not only result in replacement cost but also in process downtime (Samroeng and Panya, 2010). For the case being investigated, the downtime was approximately 14 days and income generation was practically impossible during this period. Moreover, large amount of energy and material loses also occur simultaneously on virtually every mechanical device in operation experiencing gear failures.

Gear failures could be as a result of application errors, design issues and manufacturing errors. Application errors include improper mounting and installation, poor cooling, deficient lubrication, and inadequate maintenance. Design errors include wrong material selection, improper material geometry and poor material quality among others (Samroeng and Panya, 2010). Manufacturing errors could be as a result of poor machining and faulty heat treatments. The most common mode of gear failure encountered in practice is that of surface contact fatigue. This mode of failure leads to crack initiation at or near the contact surface, and subsequently damage ranging from microscopic pitting to severe spalling. These pits acts as stress raisers which lead to other modes of gear failure e.g. tooth bending fatigue (Fernandes and McDuling, 2006). Pitting originates from small, surface or subsurface initial cracks, which grow under repeated contact loading. It is a three-dimensional phenomenon and strongly depends on contact surface finish, material microstructure and operating conditions, such as type of contact, loading, misalignment, lubrication problems, temperature, etc. Spalling, in general, is not considered an initial mode of failure but rather a continuation or propagation of pitting and rolling contact fatigue. Although pitting appears as shallow craters at contact surfaces, spalling appears as deeper cavities at contact surfaces (Osman, 2006). It is worth noting that material for rolling contacts must be of very high quality since any imperfection present can act as initiation sites for developing cracks. Also, the presence of a lubricant can have a significant effect on contact fatigue by preventing true contact between the rolling bodies (Stachowiak and Batchelor). For the purpose of this study, failure analysis methods were used for a preliminary investigation (with respect to material performance and efficacy) on the root cause of failure of helical gears in the gearbox of a passenger car which if avoided will prevent similar failures in the future.

1.1 Background

The passenger car, whose gear was employed for this study, was taken to an automobile repair shop for replacement of its gears which failed in service after being used for two years. The gear box was reported to have excessive vibration and loud noise before it eventually could not function any more. The complete gear train was received from the technician in charge for failure analysis. The gear train had six helical gears; of which one showed several worn teeth and seven fractured teeth (indicated by the red curve) and the remaining five had no visible sign of failure. The appearance of the gear train is as shown in Fig. 1. The helical gear is a five speed manual transmission gear. The passenger car has 202horse power and 6000revolution per minute (rpm) engine power. For the purpose of analysis, two helical gears were randomly chosen as representative samples of the six. The gear showing visible signs of fractures and wear was taken and denoted as Sample A, and another showing no visible sign of failure was chosen as Sample B. Basic data of the representative samples of the failed helical gears is presented in Table 1 and relevant layouts of the gears are shown in Fig. 2.

2. Methodology

The gear train was disassembled and gear samples A and B were randomly chosen as representatives of the whole for analysis. Both gears were examined visually with the unaided eye and by fractography. Brinell hardness measurements were taken for both samples as well as chemical composition analysis via an atomic absorption spectrometer and Energy Dispersive Spectroscopy (EDS). The investigation was crowned with microstructural examination of both samples. Fractographic and microstructural analysis was carried out using a focus ion beam Scanning Electron Microscope (SEM) equipped with EDS.

3. Results and Discussion

3.1 Visual Examination

The purpose of which is to ascertain the mode of failure, observation of sample A with the unaided eye revealed surface wear (blue arrow) on nearly all tooth surfaces and tooth fracture (red curve) of seven out of a total number of 28 teeth (Fig. 3). The fractures occurred as a result of wear induced fatigue on the gear teeth. Hence, the failure mode of sample A can be classified as wear failure. This is further confirmed by Fractographic studies which showed cracks propagating from a point on the surface of the metal (which is the origin of crack initiation indicated by the red arrow), upward and downwards along slip planes (Fig. 4).

It was observed from the fractograph of sample A that the frictional heat (due to insufficient lubrication) between the rolling gear parts caused re-austenization of pearlite on its surface (lower left), producing as-quenched martensite (upper right) upon cooling, which led to crack initiation in the material. After initiation, repeated rolling contact caused crack growth which eventually led to surface contact damage (spalling). In the case of sample B, visual examination with the unaided eye (Fig. 5) revealed that there was no visible sign of failure. Nevertheless, sample B was subjected to Fractographic examination (Fig. 6). Curiously, developing spalls were observed on the gear tooth of sample B.

3.2 Hardness Measurement

The microhardness distribution of both gears, across the gear tooth was measured using a digital Vickers hardness tester (HVD501 model) with 500kgf load. The results are shown in Figures 7 and 8. The decreasing hardness values from the case of both materials to the core are an indication that the material has been case hardened by carburization which is a normal operation for gear heat treatment.

3.3 Compositional Analysis

This was carried out in order to identify the gear material and to ascertain its conformity with the standard requirement for helical gear use in automobiles. From the results shown in Table 2, sample A's composition was found to correspond with that of AISI 5130 chromium steel. According to Matweb material property data (eFunda Inc., 2012), AISI 5130 chromium steel contains 0.80% -1.10% Cr which must be second highest to the composition of iron in the material. In addition, its carbon content is low (0.2% - 0.3%). This requirement was met by sample A. On the other hand, sample B's composition (Table 3) corresponds with that of AISI 5060 chromium steel which has a higher carbon content (0.55% 0.65%) and a lower chromium content (0.27% - - 0.65%).

Hence, compositional analysis revealed that the two helical gear samples from the same gear train were made from chromium steel of different grades. According to KarlHeinrich and Erik (2009), applications involving high core and case hardness such as automotive gears, universal joints, piston rings and others require high carburizing steel. This signifies that AISI 5060 chromium steel is suitable for automotive gears due to its high carbon content. AISI 5130 chromium steel is also a good material for automotive gears, moreover the strength of the gears have been improved by carburizing. Thus, for both samples A and B, there were no deviations from standards as regarding chemical composition. Nevertheless, it was deemed necessary to further analyze the composition of the samples using EDS in order to detect the presence of contaminants which may have contributed to spalling as revealed by fractography.

The X-ray spectrum that was generated from a point on sample A and another on sample B are shown in Figs. 9 and 10. EDS of sample A shows high proportions of boron, carbon and oxygen. Boron had reacted with carbon to yield boron carbide which is extremely hard, improving the material's property. On the other hand, it can be asserted that in the absence of sufficient lubrication, the steel being rich in carbide particles, exhibited a low coefficient of friction which resulted in a high wear rate. Iron oxide, a contaminant, weakened the gear teeth in the presence of frictional heat generated from improper lubrication. The oxide contaminant in sample A was a major contributor to its failure. In the absence of lubrication, wear of the gear metal proceeded by cyclic disintegration of oxide films and subsequent reformation of these films. In other words, oxidative wear occurred. The EDS view of sample B showed the presence of iron, carbon, copper and chromium in the material. There was no indication of contaminants. It is worth noting however, that there is no wear on sample B which is also reflected by its EDS view. These results were further confirmed by microstructural examination.

3.3 Microstructural Examination

The gear samples were metallographically prepared and observed with a scanning electron microscope under etched conditions. The views obtained are shown in Figs. 11 and 12. Analysis of sample A showed severe sub-surface spalling of the gear sample. Subsurface spalls are characterized by oxide inclusions and initiation of contact fatigue cracks (Qiong, 2008). This confirms that actually, there were oxide contaminants in the sample. Spalling of the gear material is a form of subsurface damage which led to crack initiation, crack growth and ultimately, fracture. Carbide precipitates could be seen on the micrograph as well. The unavoidable presence of these carbides contributed to the wear of the material. Hence, the failure mechanism of sample A as seen by the micrograph was by subsurface crack initiated spalling.

Spalling was observed in sample B. Both modes of spalling (surface and subsurface) were observed. Surface spalling is indicated with the red curve and subsurface spalling with the yellow curve. However, it is noticeable that the surface of sample B remained smooth and lacking in obvious damage, while a few micrometers below the surface, processes culminating in the formation of a wear particle were taking place.

4. Conclusion

Investigations on the material performance of failed helical gears in a gearbox have been carried out. Gear sample A failed by oxidative wear essentially caused by insufficient lubrication. On the other hand, sample B exhibited no outward signs of failure whereas; processes culminating in the formation of a wear particle were already taking place some few micrometers below the surface. It was further deduced that numerous carbide precipitates formed in Sample A also contributed to its wear. It is therefore, recommended that adequate lubrication should be ensured for materials used in rolling contact applications in order to prevent premature failures. Suggested future works include stress analysis of the failed gears.

Acknowledgments

The authors thank Mr. Gbolahan for providing useful information about the history of the failed gears. Also, Mr. Fayomi, Engr. Tech. Makun and Mr. Makinde for assisting in the laboratory work.

References

eFunda, Inc., Alloy Steel: AISI 5130, (2012), http://www.efunda.com/glossary/materials/alloys/materialsalloys-steelalloy_steelaisi_5130.cfm. Accessed June 7, 2012.

Fernandes P.J.L. and McDuling C. (2006), "Surface contact Fatigue Failures in Gears", Advanced Engineering and Testing Services, CSIR, Auckland Park, South Africa.

KarlHeinrich G., Erik K.A. (2009), Springer Handbook of Mechanical Engineering 10, 172.

Nañija H, Andreas D, Samir L (2011), "Analysis of gear damage causes using Microhardness and Metallographic testing", University of Zenica, Bosnia.

Norton R.L. (1996), Machine Design: An Integrated Approach, New Jersey: prentice Hall Inc.

Osman A. (2006), "Fatigue failure of a helical gear in a gearbox", Eng Fail Anal 13, 1116-1125.

Samroeng N., Panya S. (2010), "Failure Analysis of a Helical Gear", The First TSME International Conference on Mechanical Engineering, Ubon Ratchathani, Thailand, 36.

Stachowiak G.W., Batchelor A.W. (2005), Engineering Tribology, 3rdedn. ButterworthHeinemann, Oxford

Qiong W. (2008), "Analysis of surface and subsurface initiated spalling of forged cold work rolls", Eng Fail Anal 14, 795–800.

Figures

Figure 1 Appearance of the gear train.

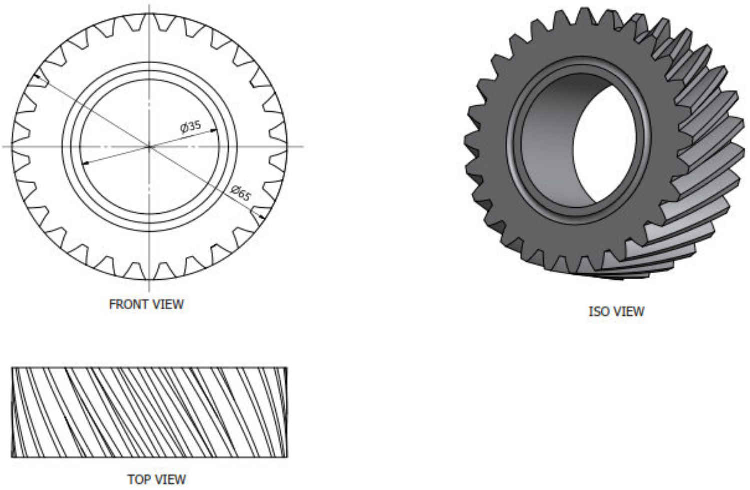

Figure 2a Schematic of gear sample A.

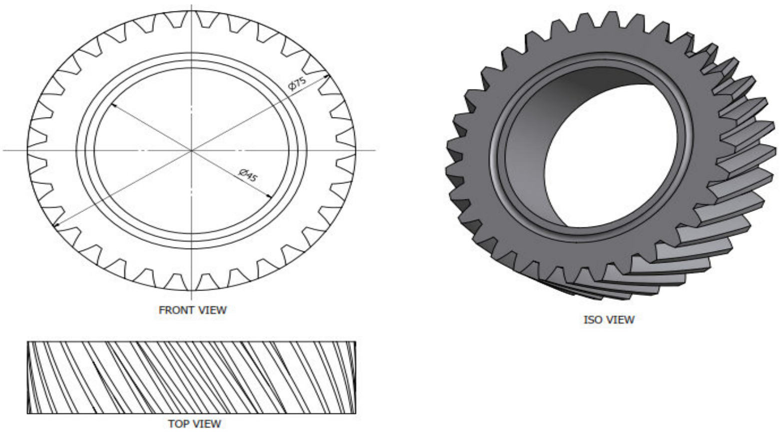

Figure 2b Schematic of gear sample B.

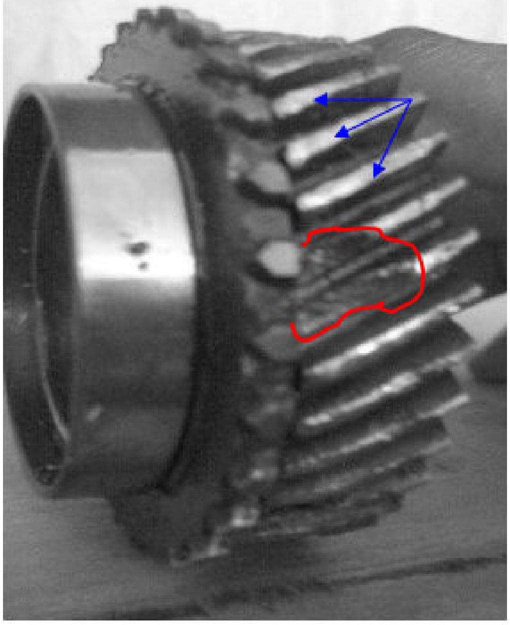

Figure 3 Unaided view of gear sample A .

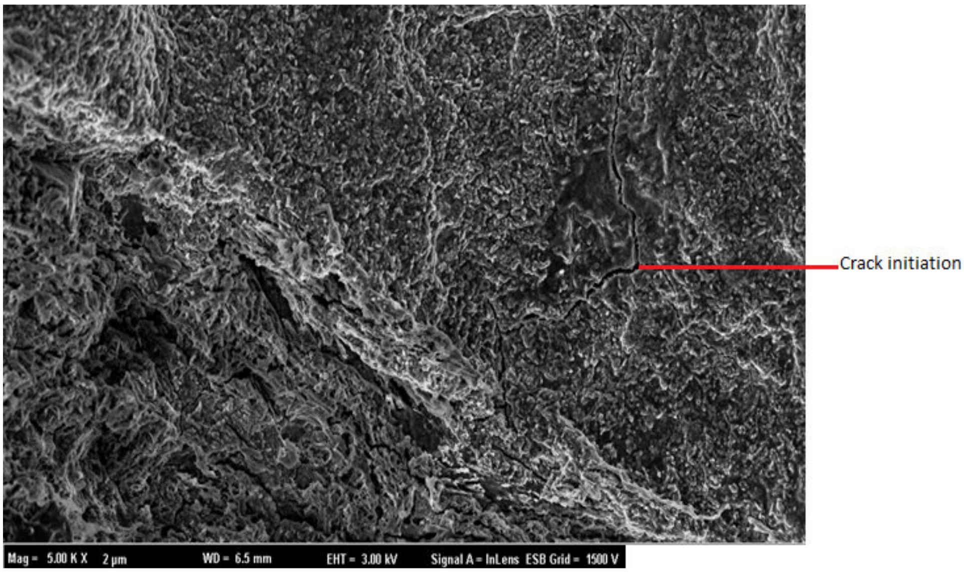

Figure 4 Fractograph of gear sample A.

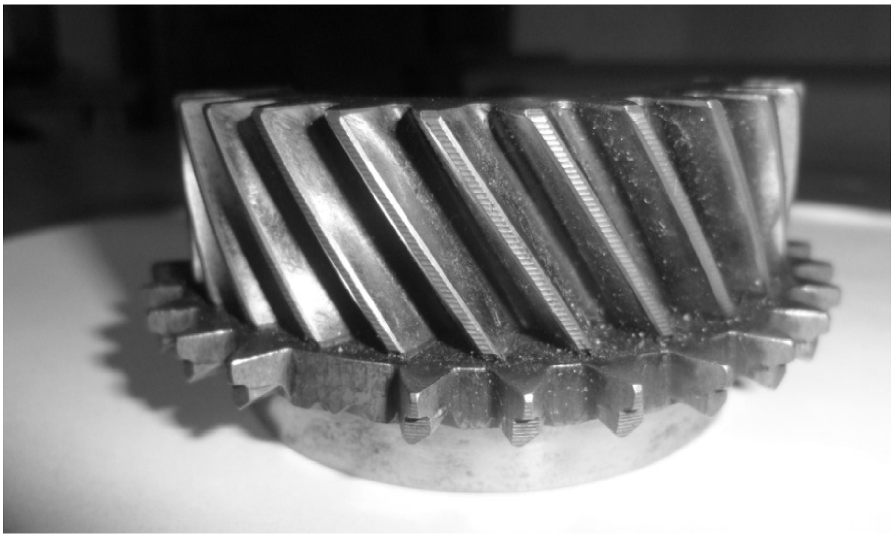

Figure 5 Fractograph of gear sample A.

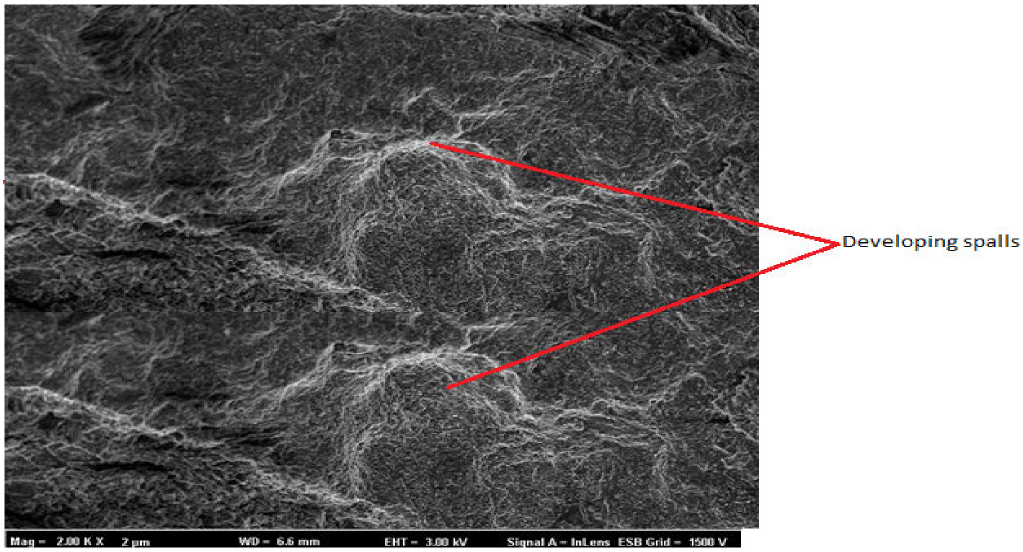

Figure 6 Fractograph of gear sample B.

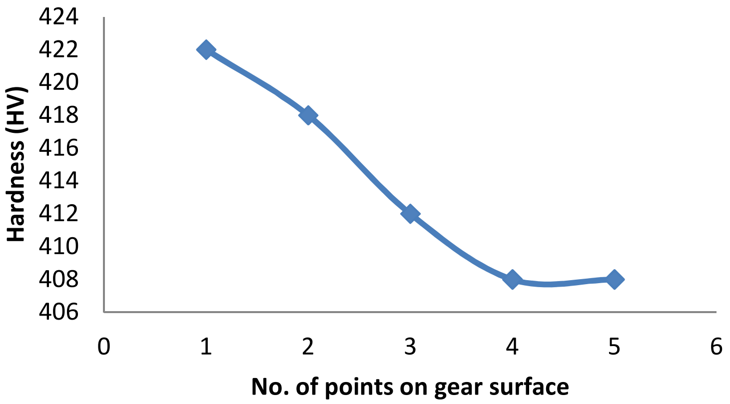

Figure 7 Hardness distribution of gear sample A.

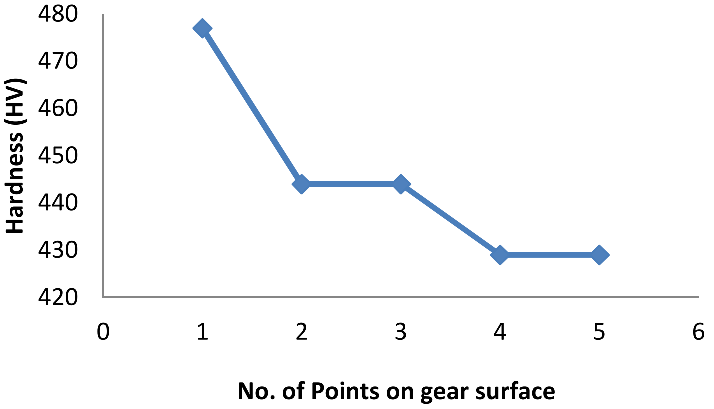

Figure 8 Hardness distribution of gear sample B

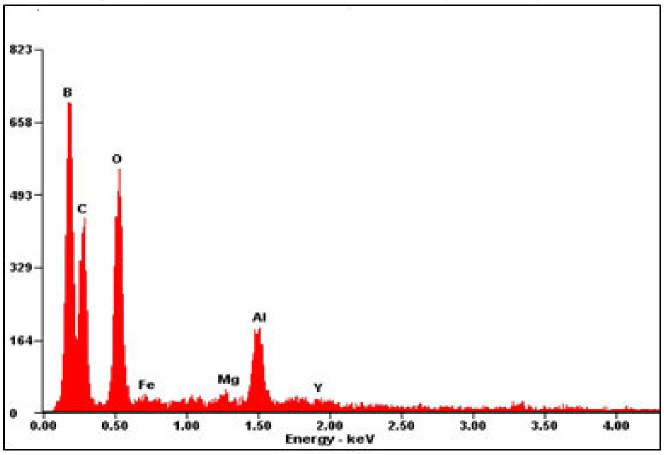

Figure 9 EDS view of gear sample A.

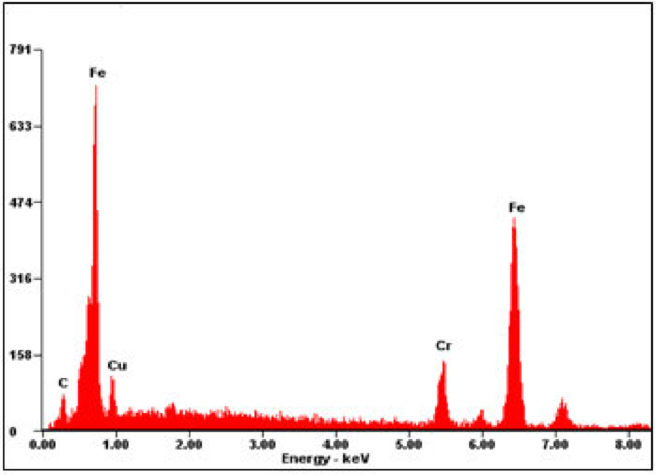

Figure 10 EDS view of gear sample B.

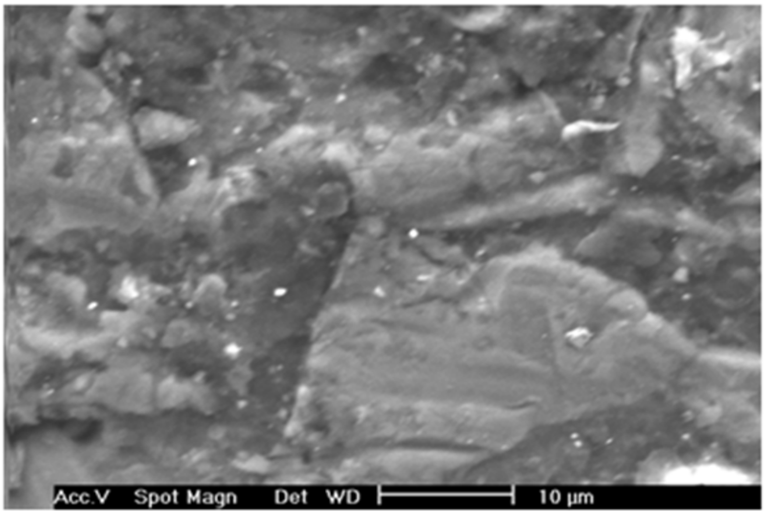

Figure 11 SEM view of sample A.

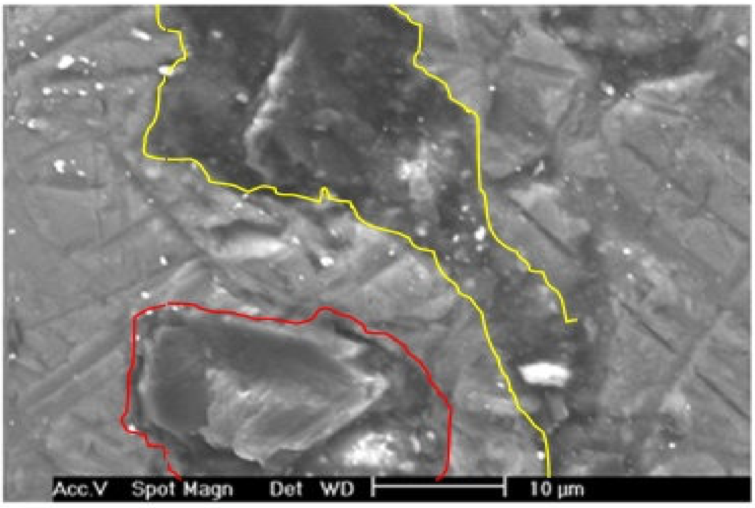

Figure 12 SEM view of sample B.

Tables

Table 1: Basic Data of Representative Gear Samples

Parameter	**Sample A**	**Sample B**
Number of teeth	28	32
Helix angle	30	30
Inside diameter (mm)	35	45
Outside diameter	65	75
Number of failed teeth	7	0

Table 2: Composition of Gear Sample A (wt %)

Element	Composition	AISI 5130
C	0.24	0.20-0.30
Si	0.18	0.15-0.30
S	0.01	0.04 maximum
P	0.01	0.035 maximum
Mn	0.78	0.70-0.80
Ni	0.07	0.05-0.20
Cr	1.1	0.80-1.10
Mo	0.02	0.3 maximum

Table 3: Composition of Gear Sample B (wt %)

Element	Composition	AISI 5060
C	0.61	0.55-0.65
Si	0.19	0.15-0.30
S	0.03	0.04 maximum
P	0.02	0.035 maximum
Mn	0.84	0.75-1.00
Ni	0.03	0.01-0.10
Cr	0.45	0.27-0.65
Mo	0.41	0.1-0.50

This academic article was published by The International Institute for Science, Technology and Education (IISTE). The IISTE is a pioneer in the Open Access Publishing service based in the U.S. and Europe. The aim of the institute is Accelerating Global Knowledge Sharing.

More information about the publisher can be found in the IISTE's homepage:
http://www.iiste.org

CALL FOR PAPERS

The IISTE is currently hosting more than 30 peer-reviewed academic journals and collaborating with academic institutions around the world. There's no deadline for submission. **Prospective authors of IISTE journals can find the submission instruction on the following page:** http://www.iiste.org/Journals/

The IISTE editorial team promises to the review and publish all the qualified submissions in a **fast** manner. All the journals articles are available online to the readers all over the world without financial, legal, or technical barriers other than those inseparable from gaining access to the internet itself. Printed version of the journals is also available upon request of readers and authors.

IISTE Knowledge Sharing Partners

EBSCO, Index Copernicus, Ulrich's Periodicals Directory, JournalTOCS, PKP Open Archives Harvester, Bielefeld Academic Search Engine, Elektronische Zeitschriftenbibliothek EZB, Open J-Gate, OCLC WorldCat, Universe Digtial Library , NewJour, Google Scholar