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An Investigation on the Premature Failure of Spur Gear in Coal Stacker Reclaimer: Mechanical Properties and Microstructure Analysis

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Abstract

In this paper, the premature failure of the spur gear on the coal stacker reclaimer system is reported. Fault failure that occurs in the driving spur gear which is made from AISI 4340 steel with respect to the composition of nickel, carbon, chromium, mangan and molybdenum. The spur gear has been operating for about three years when several teeth failed. A tooth in the driving gear is failed where a part of a tooth is separated and torn from its main gear body. An integrity evaluation of this driving spur gear including visual examination, photo documentation, chemical analysis, hardness measurement, metallographic examination and also a tensile strength test. The failure zone is examined by an electron microscope equipped with EDX facilities. Premature failure is associated with porosities present inside the gear bodies which propagate and torn a gear tooth. The hardness around the failed tooth also increase based on the Rockwell Hardness Test. The gear actually able to receive the designed load on the coal stacker and reclaimer based on the yield strength which around 834.73 MPa and the maximum tensile strength is around 921.39 MPa.

Keywords: Spur Gear; Premature Failure; AISI 4340; Stacker and Reclaimer.

1. Introduction

In the world of machinery that the occurrence of failure occurs on a machine and its components. One of the machine components which fails frequently is gear. There are two common forms of gear failure namely fatigue failure and impact failure. Fatigue failure occurs because the gear has reached the age of failure.

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There are a number of studies that investigate the failure of the gear fatigue by various researchers. Neptu and Srichandr [1] investigated premature failure of a helical gear in a damper gearbox used in a continuous hot rolling steel bar in Thailand. Ren [2] investigated fatigue fractures of planetary teeth at 825 kW wind turbine gearboxes, which have been running for more than 5 years. Guangliano and his colleagues [3] investigated contact fatigue failure analysis of shot-peened gears. Chen and his colleagues [4] analized gear box failures carried out by SEM, metallographic examination, mechanical properties testing and calculations. It was found that failure was a fatigue fracture caused by fretting wear. Moolwan and Netpu [5] at their paper reported the results of failure analysis of an idle gear shaft of a gearbox in a hot re-rolling steel mill in Thailand. The shaft failed prematurely after only about 6,000 hours of service which was very much lower than the expected working life of 40,000-50,000 hours. The results showed that the shaft failed by fatigue fracture.

The other researchers reported the impact failure which is caused by the sudden heavy load in gear pair system. Yang [6] reported the phenomenon of tooth decay in the process of running a car gear. Damage occured because of the concentration of stress that occurs on the surface of the tooth, which resulted in local damage and cracks on the surface of the tooth. Goher and his colleagues [7] investigated tooth failure occurred in the sugar industry. The failure occurred in 1 month of a continuous operation. The gears were driven by a 315 kW motor at 1450 rpm. Flores-Márquez and his colleagues [8] investigated the critical parameters that had the most impact on the micro gear motor structural capacity, namely: motor configuration, torque output, and speed. Goher [9] analyzed the failure of high-speed gears in the process of making starch. The gears have failed within 3 weeks of the first operation. A visual investigation had been carried out and a series of photos had been taken. The teeth of the gear had undergone a bending deflection accompanied with surface wear.

In addition to the two causes of gear failure, there are factors that cause easier gear failure, namely the existence of defects in gear material. There are number of studies that investigate gear failure because of the defect in gear material by various researchers. Boonmag and his colleagues [10] investigated micro cracks in gear transmissions which failed to adjust the engine with an increased horsepower. The results showed that the fracture characteristic of the helical gear's surface was expected to beach marks and break away. Jiang and his colleagues [11] investigated the cause of failure of an 845 mm external diameter gear that operated during 30 months in a petrochemical plant. The failure analysis procedure included material characterization (microstructure, chemical composition and microhardness), fracture surface evaluation, and stress distribution by finite elements on critical regions of the gear.

In this paper, the premature failure of the spur gear on the coal stacker reclaimer system is reported. Fault failure that occurs in the driving spur gear (see Figure 1). The failure is located in one of the teeth at the upper side of the root and propagates until the upper part of the gear is broke. The fault occurs when the stacker reclaims work in service, causing material transportation to stop. The constraints of this research are the specimens in the form of spur gear, not discussing the vibration aspect, the test material is the specimen of fracture the spur gear from the slewing gearbox on the stacker reclaimer. The driving gear position is shown in Figure 1 and the failure occurred at the driving gear. Configuration of the pinion spur gear as a driving gear shown on Figure 2 while the dimensions of the spur gears are shown in Figure 3.

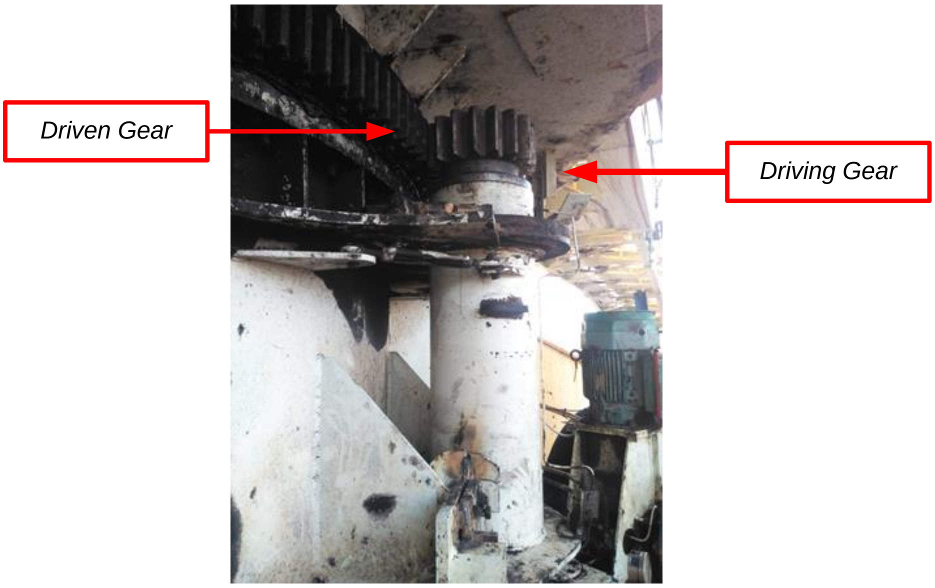

Figure 1: The position of driven and driving gear on stacker reclaimer

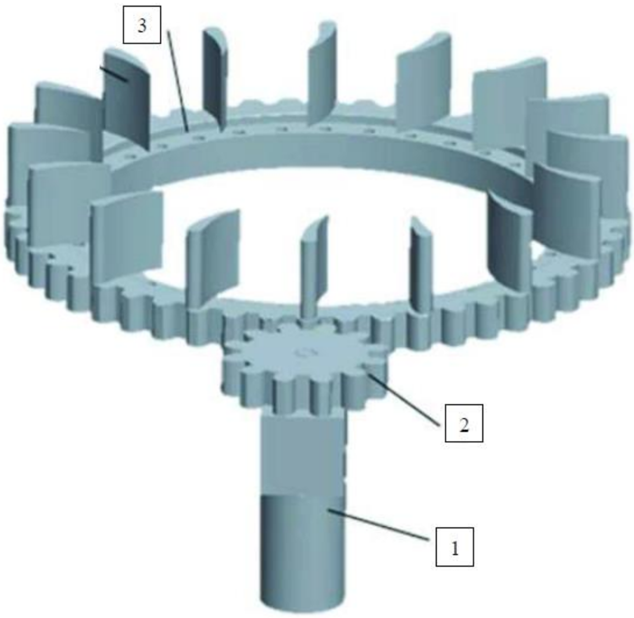

Figure 2: The configuration of: 1) Driving shaft, 2) Driving gear and 3) Driven gear

2. Experiment Methods

Figure 2 shows the configuration of driving and the driven gear whereas the precise dimensions of the driving gear is depicted in Figure 3 and Table 1. Based on the pinion gear motion in Figure 2, the force diagram acts on the driving gear relataed to the direction of the applied load is presented in Figure 4 which can be predicted as the initial/origin of crack propagation which resulted in gear failure.

The driving gear was failed around 5 month of its initial replacement in the coal stacker and reclaimer for an electric generation company in Jepara, Central Java, Indonesia. The driving gear is the replacement component for the previous part which failed after 3 years of working time. This failure increased big question related to the short failure of the driving gear in the coal stacker and reclaimer system. In order to answer the curiousity related to the failure, some initial investigations and testing are conducted.

In this paper several tests are conducted to study the failure of the gear, namely: (i) chemical property tets, mechanical properties test and microstructure analysis The chemical composition of spur gear material will be tested using spectrometer chemical analysis. The microstructure will be analyzed using an optical microscope and SEM. Mechanical properties i.e. strength and ductility are tested by standard ASTM E 8M-04. Hardness test is carried out on tooth fractures in the surface area and crack surface area using Rockwell Hardness Test (HRC).

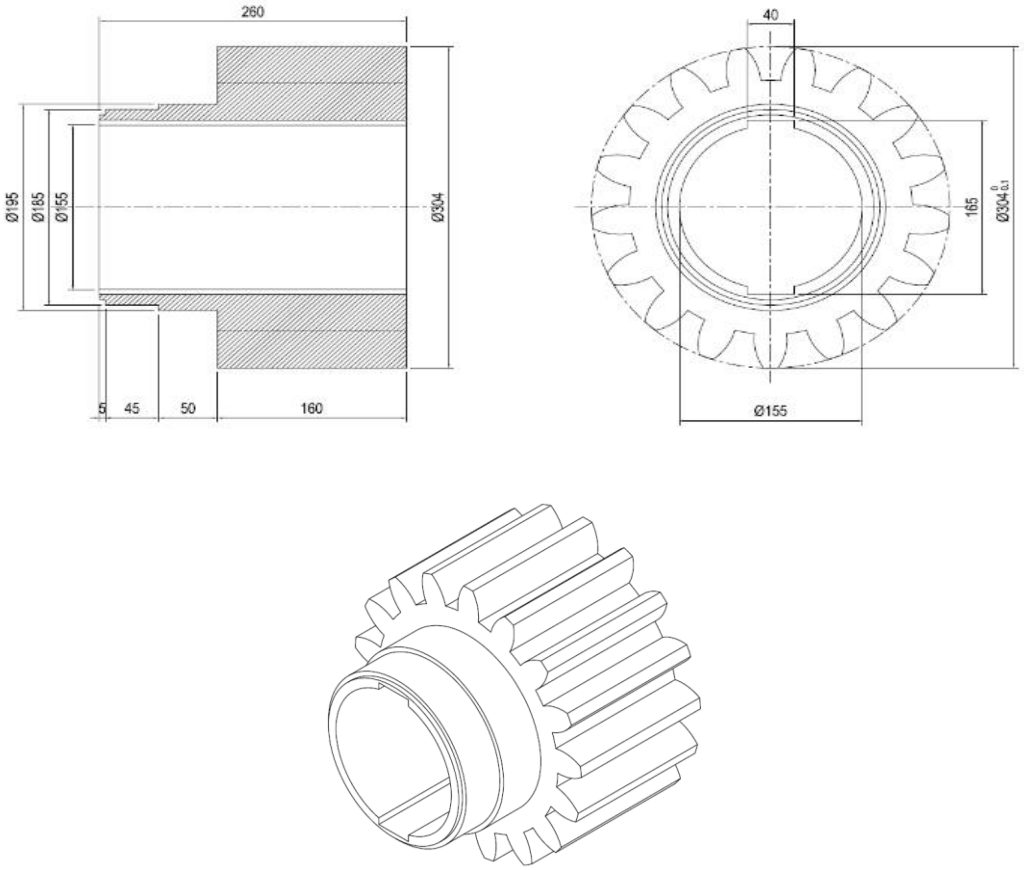

Figure 3: Drawing spur gear dimensions

Table 1: Spur gear specification

Modul	20
OD	304 mm
ID	156 mm
L	260 mm
Number of Teeth	17

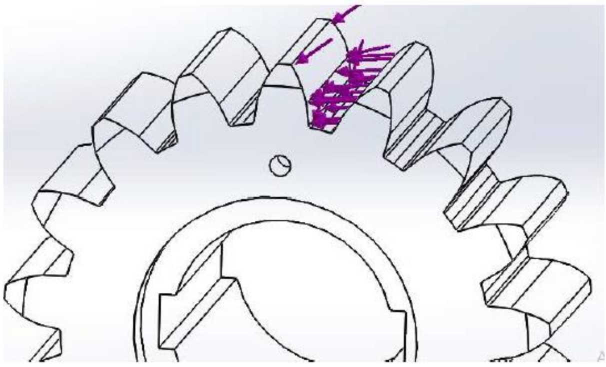

Figure 4: Force diagram in 3D model

3. Test Result

3.1. Visual Inspection

Based on the visual inspection, the driving gear recieved a heavy load which concluded based on the shape of the failure in Figure 5. The direction of the failure starts from the a gear surface, propagates to the center, then failed with a brittle pattern which push a part of a gear tooth seperated form the main gear body. The falied part is depicted in Figure 5. The gear get palstic deformation before the failure occurs. According to Dieter [12], brittle fracture is indicated by the direction of origin of the crack and the crack propagation path. The direction of the failed component and the shape of the fault surface are shown in Figure 6-7.

Figure 5: Fault spur gear (left) and Fracture surface of fault spur gear (right)

3.2. Chemical Composition Snalysis

The chemical composistion of the failed spur gear are shown in Table 2 which achived form the spectrometer test. The results show that the gear material can be classified into low alloy steel material where the main alloy compositions are nickel (1.31%), carbon (0.58%), chromium (0.51%), mangan (0.43%) and Mo (0.15%). This type of material composistion is well known for the gear material and already been used by some company to manufacture the gear.

The present material is identified as AISI 4340 with respect to the composition of nickel, carbon, chromium, mangan and molybdenum.

Table 2: The chemical composition of the spur gear speciment*

C	Si	S	P	Mn	Ni	Cr	Mo	Cu	Fe
0.58	0.23	0.042	0.0187	0.431	1.314	0.513	0.149	0.2	Balance

*The number of non-carbon elements is <5%, so this alloy steel is classified as low alloy steel [13].

3.3. Microstructure Observation

The martensitic structure in the spur gear tooth specimen is shown in Figure 6-7. The image shows that the microstructure of the gear corresponds to the martensitic phase. At a depth of 10 mm, as shown in Figure 7 below the surface of the specimen, the martensitic structure begins to decrease and some fields consist of ferrite-pearlite structures.

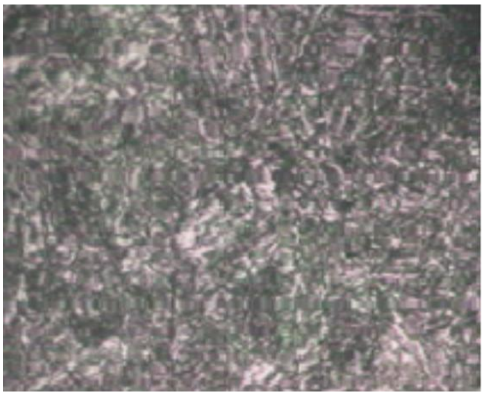

Figure 6: Microstructure on the surface of the specimen which get the contact during the gear works, with 500X magnification

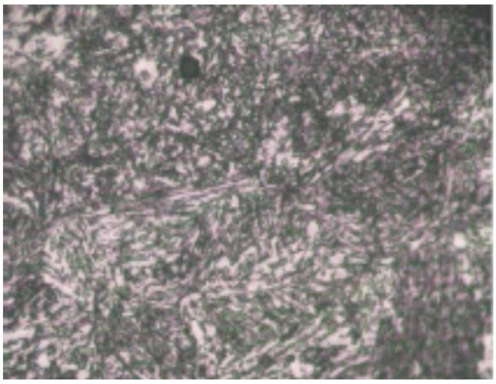

Figure 7: Microstructure of the inside of the specimen which located below the loading surface, with 500X magnification

In addition to the martensitic structure, a ferrite-pearlite structure is formed in some of the fields shown in Figure 8. This shows the difference in hardness and structural inequality which can cause an indication of the cause of cracks or faults. Hardness in the fault area will be carried out in the next test.

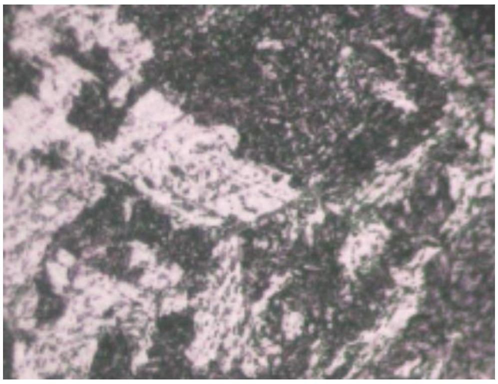

Figure 8: Microstructure of the failed gear using 500X magnification which show a ferrite-pearlite microstruature.

Observation with SEM on the surface of the spur gear fracture specimen is shown in Figure 9. The image shows some porosity pointed with red marks and grain size disparities that can cause dislocation to form. According to Dieter [12], grain boundary irregularities can lead to the emergence of dislocations.

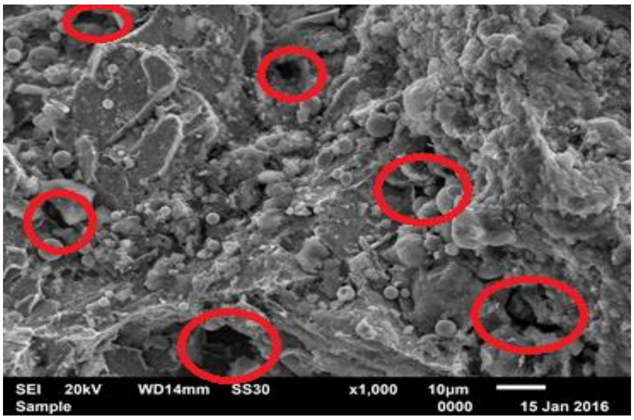

Figure 9: SEM on the surface of the spur gear fault

Figure 10 shows the part which failed and separated form the main body of the driving gear. This part is then observed on the microstructure which resulted in Figure 6-8 and the SEM image on Figure 9. From this area, the microstructure on good surface to the inside and fractured surface can be observed.

Figure 10: Observation area of microstructure and SEM image marked with a red dotted line

3.4. Hardness Test (HRC)

Hardness test is carried out on the surface of the specimen that is still intact and on the surface of the fault. The location of hardness testing is shown in Figure 11 while the results of the hardness test in Rockwell scale are shown in Table 3.

Based on Table 3, the failed surface has a high level of hardness. The increase of the hardness may be an indication of the decreasing ductility of material in this area, and also may be a strenghtening mechanims. The decreasing ductility of material results in the lower load carrying ability of the material. From the visual surface of the spur gear fracture, it can be seen that the failure initially start with high deformation.

Table 3: Hardness test results

Location	Good Surface (HRC)	Demaged Surface (HRC)
1	63	53
2	60	57
3	57	64

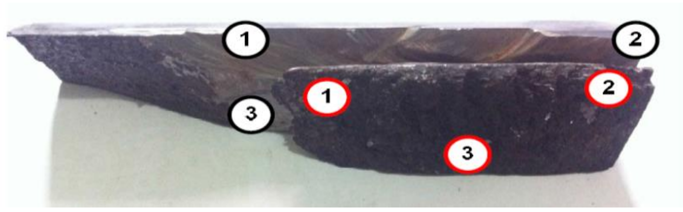

Figure 11: Hardness testing area

3.5. Tensile Test (ASTM E 8M-04)

From the tensile test results in Tabel 4, it can be analyzed that the material properties (strength and ductility) of the material show the high yield strength and maximum strength, namely 843.73 MPa and 921.39 MPa, respectively. The value of elongation 55.06 % indicates that the specimen has good ductility. The results of the yield strength, the maximum strength and the elongation indicates that the material has a good mechanical properties and able to recieve the full load in the coal stacker and reclaimer .

Table 4: Tensile test results of the driving spur gear specimens

Yield Strenght (MPa)	Max. Strenght (MPa)	Elongation (%)
834.73	921.39	55.06

4. Failure Analysis

Based on the previous test, the failure which occur in the spur gear may be caused by defects found inside the gear. This defect is proven by observations with an optical microscope, SEM and hardness test. The appearance of several porosities and grain uniformity causes the formation of dislocations at the grain boundary, with a large amount of dislocation inside the gear will perform a failure.

The high value of hardness on the failed surface is more convincing that the finding of defects in the area causes the spur gear to be unable to withstand high loads and stress. Along with the increase in the value of hardness, the ductile nature of the material will decrease.

Defects in the inside of the gear spur can be caused by several things, there are the parameters of the hardening process on spur gear or defects during the material production process or operational spur gear. Defects formed in solid materials such as pores, cracks and foreign inclusions are normally formed during the fabrication process [14].

If the defect is caused by the parameters of the hardening process or operational spur gear, it can be ascertained that the defect occurs due to stress during the heat treatment process or heat generated when the spur gear is operating according Toten [13], when steel is heated, there will be a temperature difference between the outside and inside so that residual stress is formed.

5. Conclusion

The driving spur gear has been designed with a force that matches its function. This analysis is obtained by comparing the calculation of the stress value applied to the driving spur gear and the value of the tensile test results in accordance with ASTM E 8M-04 standards. The driving pacemaker has a yield stress value of up to 834.73 MPa, while the stress received from the max load of the reclaimer stacker arm is 48.27 MPa.The fracture that occurs in the driving spur gear is caused by a defect on the inside of the drive gear spur gear. One factor that determines defects is porosity. The more porosity, then the material will be easily deformed. Deformation of the drive gear occurs when the drive gear is activated, so the heavy load applied causes pressure on the material.

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