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Failure Analysis of Pinion Gear Dump Truck

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***Abstract* - Dump truck is one of the vehicles that is often used to transport materials in an infrastructure. Failures often occur in dump truck components, one of which is the pinion gear component. Pinion gear is one of the components that functions to continue the engine rotation to the wheel shaft. In this study, an analysis of the causes of pinion gear failure was carried out on a dump truck with an engine capacity of 3,908 cc. The analysis is carried out to determine the causal factors in the failure. To find the cause of failure, the method uses several tests including, chemical composition testing, macroscopic and microscopic metallographic testing, vikers hardness testing, and fragtographic testing with Scanning Electron Microscope (SEM). Testing of chemical composition obtained non-standard results, where Ni and Mo elements have lower levels, while Cr elements are higher which can lead to increased hardenability. Martensitic phase is visible on the surface and center regions of failed components. The hardness of the material on the surface is higher than in this part which indicates that the material has received case hardening treatment. After analysis in the test, factors that cause failure in the pinion gear are found, including non-standard material composition and improper case hardening treatment. The failure mechanism begins with the occurrence of an initial crack in the pinion gear gear which gets a repeating load and then compresses to the core causing final failure in the opposite part to form fatigue failure.**

Keywords: fatigue failure, pinion gear, dump truck, failure analysis, AISI 8620.

I. INTRODUCTION

Dump truck is one of the vehicles that is often involved in infrastructure development. One of the functions of a dump truck is to transport materials such as stone, sand, soil, and other materials used for construction. A sturdy vehicle structure has an engine capacity of 3,908 cc, is easy to operate, able to operate in difficult terrain with a large load of 7.5 tons which is the advantage of dump trucks.

But in beside to its advantages, due to various factors such as high operating hours, excessive loads, and poor maintenance as well as various terrains traversed, not a few dump trucks experience problems during operation. Based on field surveys, some failures that often occur in dump trucks are broken axle shafts, broken wheels, and pinion gear failure on the drive axle.

Gears are engine components that function to transfer power or rotation and drive shafts to shafts that are driven by intermediate gears that press on other gears sequentially [1]. With a payload capacity of 7.5 tons (MAX G.V.W) and a maximum torque of 33/1600 kg.m/rpm, this is what makes the axle work system heavy, resulting in failing of the pinion gears. Previous research analyzed pinion gear with AISI 8620 material where failure occurs due to fatigue fracture in areas that have high stress concentrations, a combination of reversible flexural, torsional and axial stresses [2]. Other failures are also caused by pitting, spalling and fracture components occur due to eighment [3]. While failure also occurs in pinion gear with DIN 17CrNiMo6 material, components experience fatigue fractures that occur due to sliding rolling contact caused by inappropriate surface microstructure and alternating stress on the tooth surface due to misalignment or lubrication failure [4].

Failures in pinion gear do have various types, so they need to be analyzed in detail. This study aims to analyze in detail the failures that occur in the pinion gear dump truck with a capacity of 3,908 cc so that previous failures can be prevented.

II. RESEARCH MATERIALS AND METHODOLOGY

The material used in this study is the pinion gear on a 3,908 cc dump truck that has failed.

(a) (b)

Figure 1: (a) pinion gear (b) ring gear dan pinion gear

This research is a case study by making direct observations on dump truck that experienced failure in pinion

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gear operating in sand, stone, and soil mining. This dump truck specification has a maximum power (JIS) of 100/2,500 kW/rpm, maximum torque (JIS) of 420/1,500 Nm/rpm, and a final gear ratio of 6,666 [5].

Tests carried out in this study include testing chemical composition using the BRUKER Q2 Ion tool, macroscopic and microscopic metallographic testing, hardness testing using the Vikers hardness test method, and Scanning Electron Microscope (SEM) testing.

III. RESULTS AND DISCUSSIONS

Chemical Composition Test

The test sample is taken from the end of the pinion gear, which can be seen in Figure 2. The results of chemical composition testing and comparison to the standards are shown in Table 1.

Figure 2: Pinion gear area for chemical composition test

Table 1: Chemical Composition of Failed Pinion Gear and AISI 8620 Steel

Elements (%)	Pinion Gear	AISI 8620
% Fe	97.28	96.89 – 98.02
% C	0.191	0.18 – 0.23
% Si	0.248	0.20 – 0.35
% Mn	0.949	0.70 – 0.90
% Ni	0.007	0.40 – 0.70
% Cr	1.19	0.40 – 0.60
% MO	< 0.003	0.15 – 0.25
% S	< 0.001	≤ 0.040
% P	0.008	≤ 0.035

Table 1 shows the results of the chemical composition test of pinion gear components. Based on the above test data, the chemical composition of the components does not conform to AISI 8620 standard materials. The Mn element has a percentage of 0.949% which is higher than the AISI 8620 standard with a range of 0.70 – 0.90%. Ni and Mo elements have lower levels than material standards, while Cr elements are higher than AISI 8620 materials with a range of 0.40 – 0.60% which can result in increased hardenability, corrosion resistance, and also steel abrasion resistance because the addition of chromium is a carbide-forming element [6].

Metallographic Testing

Macroscopic Observation

Macro observations are carried out using a microscope and taking pictures using a smartphone camera on the broken pinion gear tooth.

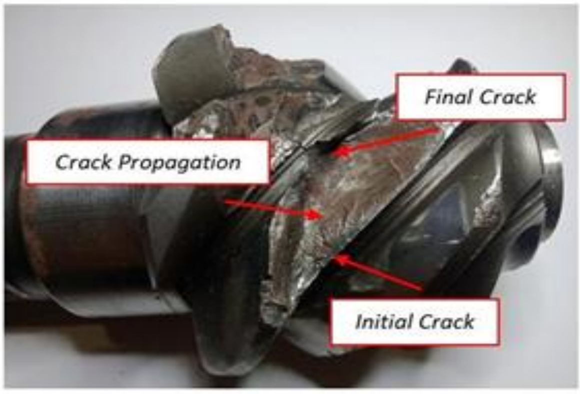

Figure 3: Macro photo of the failed pinion gear surface

Figure 3 indicates the surface of the pinion gear that has failed. It can be seen that the initial crack is on the surface of the tooth in contact with the ring gear, then the crack propagates to the inside of the pinion gear (crack propagation) and there is a final fracture or final crack on the opposite part of the pinion gear gear.

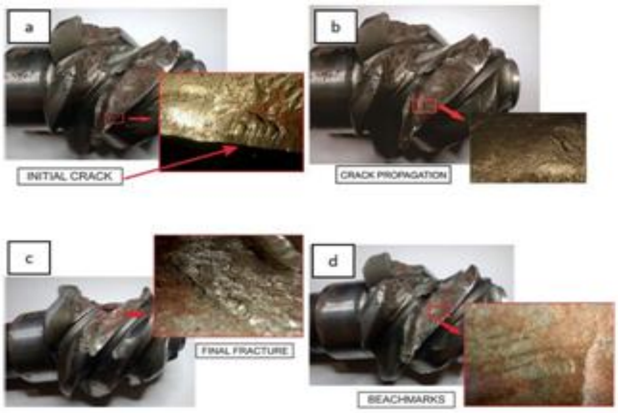

Figure 4: Stereomicroscope on fault area (a) initial crack; (b) crack propagation; (c) final crack; and (d) beachmarks

Figure 4 (a) shows the initial crack (crack initiation) in the pinion gear due to repeated tension-compression blocking. Then the direction of the crack spreads into the pinion gear. Crack propagation has a smoother surface compared to crack propagation. Figure 4 (b) shows crack propagation which then the direction of the crack spreads even more inward, namely to the part opposite to the initial crack. Figure 4(c) shows a final fracture characterized by the presence of coarse grains and the absence of macro-visible beachmarks, so it is very clear that this part is the final fracture area. Figure 4 (d) indicates the

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presence of beachmarks on the fracture surface of the pinion gear. Beachmarks indicate a tired fracture. Beachmarks profiles are the result of fluctuations in the load exerted on objects [7].

Judging from the results of macro observations using a stereomicroscope, it appears that fractures that occur on the surface of pinion gear teeth can be categorized as tired fractures. Fatigue fracture occurs through three stages, namely the initial crack stage (crack initiation), the crack propagation stage (crack propagation), and the static fracture stage (final crack). After the tired crack propagates far enough, then the working load will only be supported by the remaining cross-section that has not been cracked and finally the component will break (final failure stage) [8].

Microscopic Observation

This test is done using an optical microscope on the pinion gear tooth area close to the fracture. Tests are carried out on the surface area of the pinion gear and the core of the pinion gear. So that the phases and properties of the material can be observed.

Figure 5 shows the microstructure at a magnification of 500 times that of the pinion gear tooth surface area. While Figure 6 shows the results of the microstructure of the core region of the pinion gear.

Figure 5: Micro Test Results of pinion gear tooth surface parts

Figure 6: Micro Test Results of pinion gear tooth core parts

From the results of microscopic testing, the surface of the pinion gear teeth shows an even distribution of martensite, which can be seen in Figure 5. While the core of the pinion gear has a martensite phase that is less common than the surface area, it can be seen in Figure 6. These results, when viewed visually, appear to be visible black spots on each sample. The resulting martensite shape difference is the influence of heat treatment on components. The effect of holding time also affects the thickness of the case hardening process layer. Looking at the core of the pinion gear teeth that have entered the martensitic phase [9-10].

Vikers Hardness Testing

This hardness test is used to determine the hardness distribution of pinion gear teeth that are near failure (Figure 7 point a) and that are far from failure (Figure 7 point b). This test uses an indent of 5 points; the indent is carried out on the surface area up to the inside of the pinion gear with a loading of 100 kgf and an indentation time of 10 seconds. The division of the indented area can be seen in Figure 7.

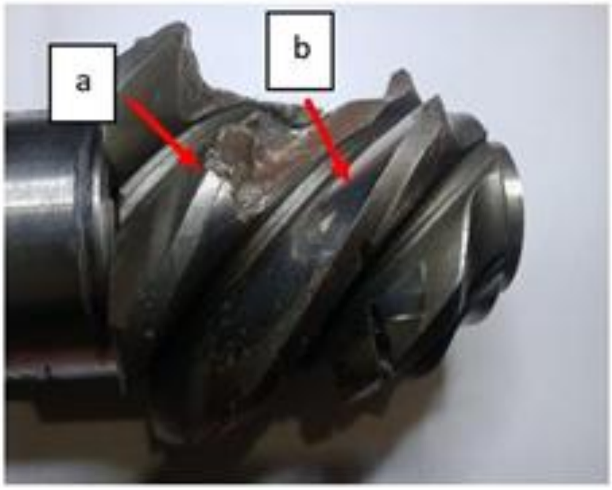

Figure 7: Hardness testing area

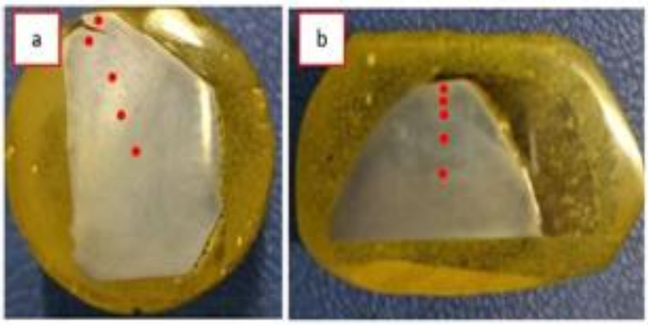

Figure 8: (a) Indentation of hardness test area close to a fracture (b) indent hardness test area far from the fracture

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Table 2: Vikers Hardness Test Results

Points (From Surface Area to Center)	The Hardness Value of Near Fracture Areas (HV)	The Hardness Value of Far Fracture Areas (HV)
Point 1	776	753
Point 2	712	699
Point 3	496	669
Point 4	458	490
Point 5	405	449

From Table 2 the hardness value of pinion gear teeth in areas close to faults has a higher surface hardness of 776 HV compared to areas far from faults of 753 HV. From this, this component has increased hardness in areas that experience faults when compared to those that are far from faults.

From the specimens, both also show where the middle of the pinion gear has a lower hardness than the surface. Where the more to the middle area the value of violence is visible. It can be known that the pinion gear gets surface hardening treatment.

Fractographic Testing

Fractography testing using the SEM (Scanning Electron Microscope) method is carried out on the surface of the failed pinion gear. The tested area was on the surface area of the initial crack and crack propagation. The results of the test can be seen in Figure 9 and Figure 10.

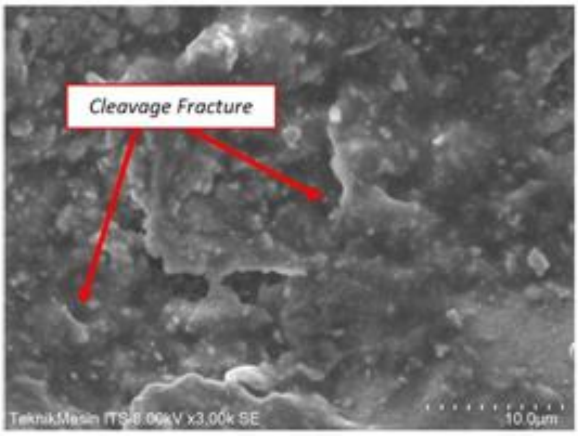

Figure 9: SEM Test Results in the initial crack area

The results of the SEM test in the initial crack area (Figure 9) with a magnification of 3000x can be observed that the fault surface has grains that tend to be smooth and form hollows, this indicates the characteristics of brittle fractures with the show of cleavage fracture [11]. The area has a high hardness resulting in brittle fractures on the surface of the pinion gear teeth.

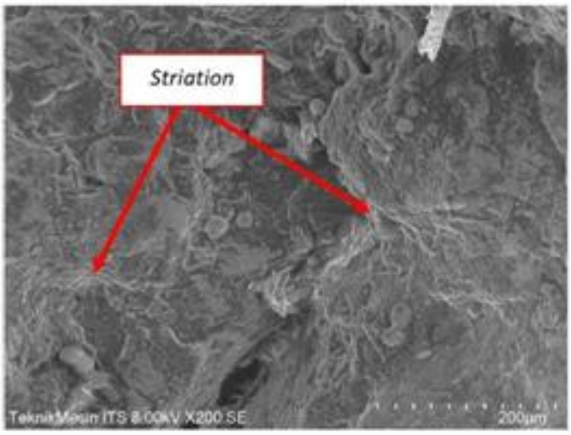

Figure 10: SEM Test Results in the crack propagation area

In the SEM test results, the crack propagation area (Figure 10) with a magnification of 200 x has a rougher structure than the initial crack. It can be seen from the test results that there is striation which indicates the propagation of cracks in the section [12]. Macroscopic testing also showed beachmarks on the fault surface.

IV. CONCLUSION

The research that has been done can be concluded as follows:

1) Chemical composition testing obtained non-standard results, where Ni and Mo elements have lower levels, while Cr elements are higher which can result in increased hardenability.
2) Macroscopic and microscopic metallographic test results indicate fracture fatigue. There are beachmarks on the fault surface. Microstructure testing shows the martensite phase on the surface and core of the pinion gear.
3) The material hardness test results on the surface of the pinion gear teeth are higher than on the core which shows that the material has received case hardening treatment.
4) SEM Test results show cleavage fractures in the initial crack area which indicates brittle fractures and striations in the crack propagation area which indicates crack propagation.

Factors that cause failure in pinion gear include non-standard material composition and improper case hardening treatment. The failure mechanism begins with the occurrence of an initial crack in the pinion gear which gets a repeating load and then compresses to the core causing final failure in the opposite part to form fatigue failure.

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