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Failure Analysis of Rear Axle Shaft Dump Truck Capacity 7.5 Ton

[1]Angwar Mukhojin, [2]*Sri Nugroho, [3]Ismoyo Haryanto

[1,2,3]Mechanical Engineering Department, Diponegoro University, Semarang, Indonesia
*Corresponding Author's E-mail: srinugroho2004@yahoo.com

***Abstract* - The rear axle shaft is a component of the dump truck that functioned to forward the engine's rotation to each tire. The rear axle shaft is a shaft that is connected to the axle directly and serves as a power or rotation forwarder. This study conducted an investigation of the reasons for failure in the rear axle shaft dump truck of 7,5 Ton, with the goal of determining the case and process of the happened of failure. The study is to examine the causes and mechanisms of failure in the rear axle shaft with Fractrography testing, both macroscopically or microscopically, hardness testing and tensile testing. Then, the mechanical characteristics test revealed yield strengths of 655 MPa, and tensile strengths of 795 MPa. The value is beyond the standard of AISI 4140, that is yield strength 690 MPa and tensile strength 810 MPa. The layer thickness is 9 mm (the standard is 2-3 mm) and the hardness value obtained by 48 HRC that is the upper of the standard case hardening material, the composition test results are as the standard. The hardness value obtained is not equally distributed around the rear axle shaft, and the composition test results are within the acceptable range of standard. After the research was done, it clarified that the failure of the rear axle shaft dump truck at 7.5 tons was caused by a heat treatment error on the rear axle shaft. An initial crack at the axle shaft's edge initiates the failure mechanism, which then propagates to the core area owing to repeated loads and strains, leading to a final fracture at the rear axle shaft's core, becoming a fatigue failure.**

Keywords: fatigue failure, rear axle, dump truck, failure analysis, AISI 4140.

I. INTRODUCTION

A dump truck is a transportation of goods that is quite superior in the field of mining; both small minings to large mining choose dump trucks as tools in work. The large power, the large load capacity, and efficiency in the loading and unloading process are one of the reasons dump trucks were chosen, sales reached 1.1 million units in 2015 [1]. However, the operation carried out in the generally steep and muddy terrain resulted in several components being damaged such as broken rear axle shafts, broken final drive gears, broken axle housings, and broken leaf springs. The rear axle is a component that often suffers damage, fractures in the rear axle cannot be predicted by the driver, and in some cases, it occurs in mining areas with flat but muddy road conditions. The rear axle shaft has very important function in supporting the main performance of the dump truck, namely bypassing the engine rotation connected through the propeller shaft to the differential and forwarded to each axle shaft, thus the condition of the rear axle shaft must be maintained, and remain excellent.

At the time of dump truck operation, the rear axle shaft receives a moment of torque and bending along the axle shaft cross-section. The moment of torque received from the engine rotation and passed to the propeller shaft and the differential or axle. Inside the axle, the rotation is passed to the wheels by each axle shaft, then the torque moment corresponds to the engine speed. The bending moment received from the load (Max 5 tons) provides repeated pressure (cyclic) due to operation. In general, the axle shaft fails when the dump truck starts running after charging is complete.

In previous studies, the failure that occurred in the rear axle forklift was caused by the hardening of surface unevenly, that is 735 HV on the outside and 210 HV on the core [2-3], while other studies mentioned axle failure due to differences in hardness during the welding process, in the HAZ area it had lower hardness and initiation cracking began in the HAZ area [4]. On the surface of the edges form a brittle fracture (martensite) and on the surface of the core form a ductile fracture (ferrite and perlite) [5-8]. In the SEM test results, cleavage fracture accompanied by fatigue striations at the edges and dimple at the core [9-15], macroscopic examination results showed initial crack, crack propagation (beachmark), and final rupture [16-17]. The cyclic loads occur in the entire cross-section of the rear axle shaft, resulting in a faster initiation crack propagating in the axle shaft cross-section and resulting in fatigue failure [18-21], macro-wise in the shape of a filamentous fault and forming a 45° angle [22-23]. Von misses the value of 64.51 MPa, principal stress of 70.59 Mpa, Von misses with a twisting moment of 3441 MPa is much smaller than the material elasticity limit of 689 MPa [24-25]. Another factor caused by corrosion of the axle shaft is

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evidenced in the tensile test results of 235 MPa (standard 320 MPa), there is an inclusion of C silicate and type D (globular oxide) resulting in initiation cracks [26], when viewed from the chemical composition, the material in the rear axle shaft component is included in the 42CrMo4 or AISI 4140 steel classification. [27-29].

The failure of the rear axle shaft cannot be predicted in detail and certainty, thus making it difficult for the driver to overcome and anticipate the problem. The aims of the study is to determine the exact cause of rear axle shaft failure and analyze the failure mechanism that occurs so as to minimize the risk of failure or fracture of the rear axle shaft in a 7.5 Ton dump truck.

II. RESEARCH MATERIALS AND METHODOLOGY

The material used in this research process is a rear axle shaft dump truck with a capacity of 7.5 tons which has failed. The use of samples in the form of a rear axle shaft that has failed in the hope that the cause of the failure can be known for sure.

Figure 1: Rear axle shaft

This research is a case study and made direct observations on a 7.5-ton dump truck that experienced a rear axle shaft failure operating in the sand, soil and stone mining with a capacity of 5 tons. The specifications of the dump truck with a capacity of 7.5 tons (MAX G.V.W) have a 3,908 cc engine, with a maximum power of 125/2900 PS/rpm equipped with a hydraulic system, a rear-drive engine with a full floating type rear axle type (diameter 40 mm and length 830 mm), the data is by the specifications issued by the dump truck manufacturing company.

Tests carried out to support this research include fractography testing carried out macro (using Fujifilm Finepix HS 5S EXR camera) and micro testing using the SEM method (SEM-EDX JOL JSM-6510LA) and microstructure test. Composition Testing (BRUKER Q2 ION), Rockwell C Hardness Testing (affri 206 RT) and Tensile Testing (Shimadzu UH 1000 kNI).

III. RESULTS AND DISCUSSIONS

After conducting the observation and testing process, the following results were obtained:

3.1 Fractrography testing

On macroscopic examination, there is an initial crack, crack propagation (beachmark), and final failure. The initial crack is located at the edge and is characterized by a shinier surface and there are fine lines that show the beginning of the crack. The second part is crack propagation characterized by a rougher circular line (beachmark) with a darker color. This shows the rapid propagation of cracks from the edge that is experiencing case hardening to the core area. At the end it forms an angle of about 45° with a very rough and dark fault surface, indicating the final fracture shown in figure 2. The beachmark is visible on the edge area to the core area and a fault groove is obtained in the direction of the beachmark until the final fracture [24, 25]. The final shape of the fault is filamentous and has an angle of 45° [2].

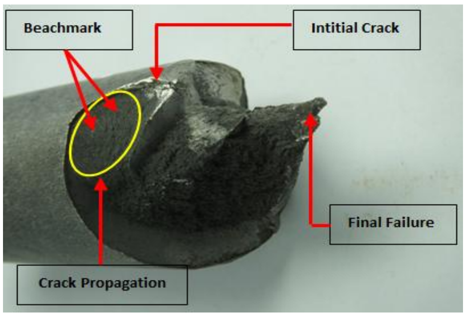

Figure 2: Macroscopic examination

Crack propagation occurs at the edges because it has a higher hardness value as a result of the case hardening process, this results in brittle properties in the axle shaft, while the core part has a lower hardness value, but has tenacious properties so that the fault surface tends to be rough, filamentous and forms a 45° angle. So macroscopically the fracture that occurs is a fatigue fracture shown in figure 3. In other studies, the fault surface forms a 45° angle and is dark in color, and tends to be filamentous [2].

Figure 3: The fault surface is filamentous and forms a 45°

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After macroscopic observations are made, microscopic observation steps are done by using metallurgical microscopes (microstructure tests) and SEM. As the results of microstructure testing there are phase differences formed in the axle shaft, in the core area there is a ferrite-pearlite phase and at the edges shows the martensite phase. The shows is the presence of case hardening that is carried out on the axle shaft, the thickness of the hardening case reaches 9 mm and exceeds the specified standard of 2-3 mm shown in figures 4 and 5. Other studies have shown that in the core there is a ferrite-pearlite phase and at the edges, dominated by the martensite phase [2,4,5,11,31].

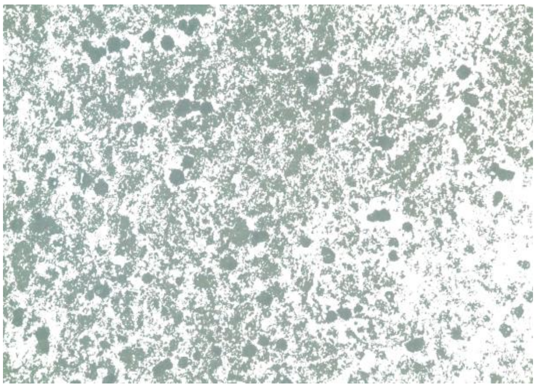

Figure 4: Microstructure test results on the core area

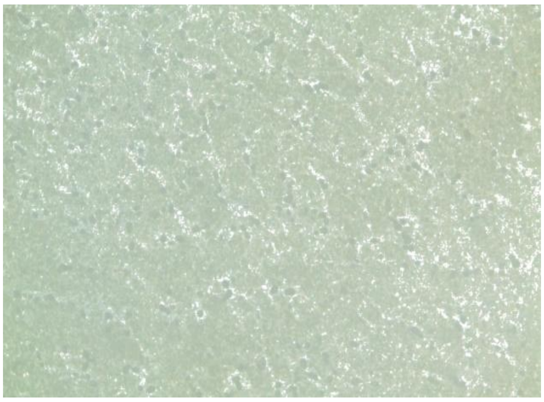

Figure 5: Microstructure test results on the edge

Figure 6: Case hardening thickness

The results of the SEM test show that the edge has a cleavage fracture with a smooth surface and a brightness color, when viewed from the mechanism of the fracture cleavage fracture showing brittle properties, this is in line with the results of macroscopic observations that show an initial crack in the edge area, in terms of these results leading to case hardening carried out on the rear axle shaft to increase the hardness value and result in brittle properties in the edge area. In other studies Cleavage, Fracture, and river type were also seen at the edges which showed brittle properties in the area [2,9,30]. While the core area shows the presence of striation, that is smooth lines that are circular throughout the cross-sectional area of the rear axle shaft, a further dimple is found near the striation. The results of observations on the core area are in line with macroscopic examinations that show the propagation of cracks (beachmark) and final fracture in the core area. Another study found dimples in the core area, accompanied by fatigue striation [2,9,30]. The fault angle that makes up 45° indicates tenacity in the core region. These results can be seen in figure 7 and 8.

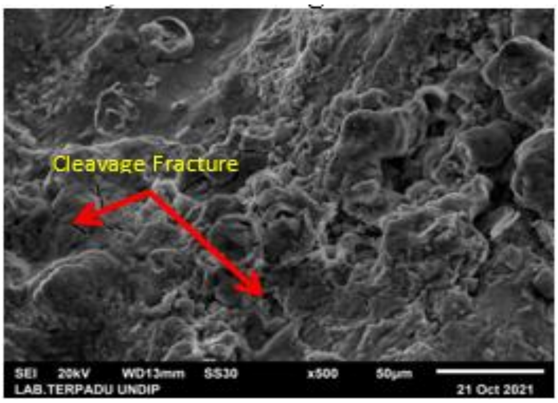

Figure 7: SEM test results edge parts

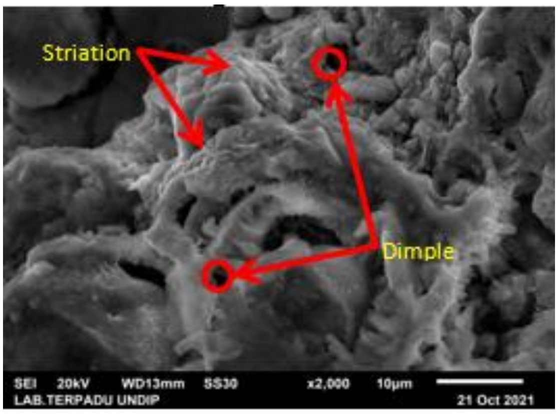

Figure 8: SEM test results core parts

3.2 Chemical composition testing

In testing the chemical composition of two-axle shaft samples that experienced failure as follows:

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Table 1: Chemical composition test

Elements	Result (%)
C	0,429
Si	0,343
Mn	0,665
P	<0,0030
S	0,014
Cr	1,115
Mo	0,252
Ni	0,089
Cu	0,053
Fe	*Balance*

The test results are by the standard used as a reference, namely ASTM-A29 on the composition of AISI 4140 or 42CrMo4. The steel used in the axle shaft dump truck is a type of low alloy steel with a case hardening process to strengthen the surface. Thus the chemical composition contained in the axle shaft is according to standards.

3.3 Hardness testing

Hardness testing uses the Rockwell method (HRC) to obtain a more accurate hardness value.

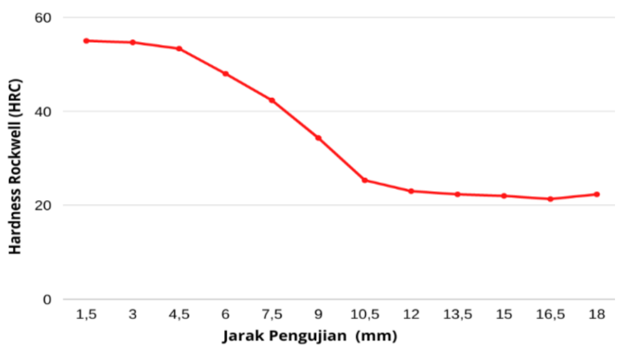

Figure 9: Hardness test result graph (HRC)

From this data, a hardness value of 45.7 HRC was obtained in areas that received case hardening (peripheral areas). Meanwhile, areas that do not get case hardening (core areas) have a hardness value of 22.5 HRC. The hardness value obtained above the specified standard is 36-42 HRC in areas that get case hardening and in areas that do not get case hardening 13 HRC. The core hardness value is obtained at a distance of 10.5 mm from the edge area, indicating that the layer thickness exceeds the specified standard limit (2-3mm). The improper heat treatment process may be the cause of the increase in hardness value above the specified standard and layer thickness. In previous studies, the hardness values obtained along the rear axle were uneven [2-3], and the phase formed in the edge area (martensite) and the core area (ferrite-perlite) [5-8]. Layer thickness is affected by temperature and holding time in the case hardening process [32-33].

3.4 Tensile testing

In the tensile test results, the results were below the standard value set for materials that received case hardening, a yield strength value of 655 Mpa and a tensile strength value of 795 Mpa were obtained. The results of the research that is below the standard values refer to the heat treatment process that is carried out incorrectly, this is in line with the results of hardness testing that get the value and thickness of the layer above the standard, resulting in the strength obtained not as expected. Another study found substandard strenght and ultimate tensile strenght yield values [25].

Table 2: Rear axle shaft tensile test results

No	Sample	Diameter (mm)	*Yield Strength (MPa)*	*Tensile Strength (MPa)*	% EL	% RA
1	*Axle shaft*	12,58	655	795	22,65	63,20

IV. CONCLUSION

From a series of tests that have been carried out, it can be concluded:

1) Based on the results of fractography testing both macroscopically and microscopically, it gets the characteristics of fatigue fractures. Macroscopic observations get the beachmark along the cross-section, the final fracture area forming a 45° angle. On microscopic observations, there are striations and dimples in the cross-sectional area of the rear axle shaft.
2) The results of microstructure testing show the ferrite-pearlite phase at the core and the martensite phase at the edges, this is by the criteria of the material undergoing case hardening. The thickness of the hardening case is obtained by 9 mm, higher than the specified standard limit (2-3mm).
3) The results of chemical composition testing are by the standard reference used, namely ASTM-A29.
4) The results of hardness testing using the Rockwell C method get the hardness and thickness values of the layer above the standard specification values, both on the edge area (getting case hardening) and the core area (not getting case hardening).
5) Tensile testing obtains substandard values, both strength yield values, and ultimate tensile strength. This is possible due to improper heat treatment process factors.
6) The factor that causes failure in the rear axle shaft dump truck is the improper heat treatment process, it has an impact on mechanical properties that become incompatible. One of them is the sensitivity value that exceeds over the standard and the thickness of the layer

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or case hardening layer reaches 9 mm (standard 2-3mm), the yield strength and tensile strength below the determined standard value before. This makes the rear axle shaft components brittle and the faulting mechanism that occurs is a fatigue fracture.

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AUTHORS BIOGRAPHY

Angwar Mukhojin, S.Pd,
Mechanical Engineering Department, Diponegoro University, Semarang, Indonesia.

Sri Nugroho, ST., MT., PhD,
Mechanical Engineering Department, Diponegoro University, Semarang, Indonesia.

Dr.-Ing. Ir. Ismoyo Haryanto, MT,
Mechanical Engineering Department, Diponegoro University, Semarang, Indonesia.

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