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Fracture failure analysis on drive shaft component of diesel locomotive

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Abstract. Failure analysis is a systematic method of investigation to find the cause of the failure mechanism of a component or equipment. This research describes the fracture analysis of driveshaft components in a diesel locomotive. The drive shaft which is a connecting component around the compressor in the locomotive engine has failed. The methods used in this study include literature studies, visual observations, data collection, material characteristics through chemical composition tests, hardness tests, tensile tests, microstructure observations, fractographic observation, data processing, and analysis of test results. Based on the results of chemical composition testing and mechanical testing shows that the drive shaft is classified as plain carbon steel, specifically AISI 1025 steel. Visual observations and microstructure observations show that the driveshaft failure occurred at the connection part, which is the connection around the welded region. From the fractography results show a visible pattern of deformation plastic that showing the fracture occurred since the connection cannot bear the load given.

1. Introduction

Failure analysis is a systematic method of investigation to find the cause of the failure mechanism of a component / equipment. And it offers or recommends a solution to overcome the problems that arise. To analyze the failure of a component / equipment, a number of approaches are generally carried out, material identification, operational and environmental approaches. For the approach in terms of material, material composition, physical properties and mechanical properties will determine the resistance of a material in receiving a load so that it does not suffer damage prematurely. In terms of process, inappropriate operational conditions will cause premature damage to a component / equipment such as overload, operating temperature that exceeds the limit and schedule maintenance that does not follow procedures. In terms of the environment, in general damage due to corrosion occurs a lot if environmental conditions are not controlled so that premature damage can occur.

Failure or breakdown to a product often occurs because of incidents and not incidents [1]. Failures due to incidents generally occur due to loads that exceed the strength of components or structures, for example shock loads (shock) due to impact, overload (overload), and so forth. While non-incident failure is caused by operating life that has exceeded the design calculation.



A structure without stress concentration, fatigue fracture can occur at a voltage of less than one third of the static tensile strength. Whereas in structures with stress concentrations, fatigue will occur at much lower stresses [2]. Fracture due to exceeding tensile stress usually shows a ductile fracture, specifically the occurrence of considerable plastic deformation around the broken piece. Currently, we have entered the design phase of fail-safe design where cracking is permitted, but we must consider from time limit for the operation of a component to the condition where the component must be replaced.

Stress Corrosion Cracking (SCC) is the event of formation and propagation of cracks in metals that occur simultaneously between stresses acting on a material with a corrosive environment [3].

One form of failure is a failure in the drive shaft of the diesel engine locomotive. The locomotive is part of a series of trains where there are engines to drive trains. Usually, Locomotives are located at the front of the train circuit. The drive shaft is one of the mechanical components to transmit torque and rotation, usually used to connect other components of the drivetrain that cannot be connected directly because of the distance or the need to allow relative movement between them.

But what I will analyze in this case is in terms of material, what causes the drive shaft to experience the fracture. The drive shaft which is a connecting component in the diesel train locomotive engine is failure, precisely fracture in the area near the compressor.

Initial suspicion that the fracture area is a connection with the method welding because it looks on the inside looks as a result of machining while on the outside looks like a weld. More details about the results of metallurgical testing and fracture analysis will be explained further in the discussion chapter. To characterize the drive shaft material and identify the fractures, the following tests will be carried out:

- Visual observation
- Chemical composition testing
- Hardness testing
- Tensile testing
- Microstructure observation
- Observation of fractography with Scanning Electron Microscope (SEM)

2. Materials and methods

The research flow diagram can be seen in Figure 1, below.

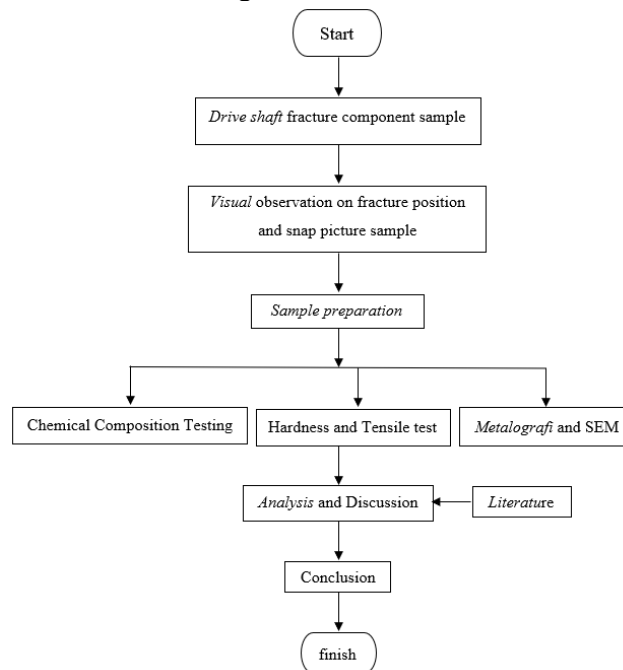


Figure 1. Research flowchart.

2.1. Visual observation

Visual observation aims to see an early indication of the cause of failure / fracture in the drive shaft component of diesel locomotive, such as the shape of the fracture and the fracture area.

2.2. Chemical composition testing

Chemical composition testing was carried out in accordance with ASTM E415 and A751 standards, using a Waslab foundry master machine, the purpose of which is to determine the chemical elements of the material.

2.3. Hardness test

This hardness test was carried out with reference to the ASTM E18 standard, using the hardness tester "Rocky", with the aim to determine the level of hardness of the material being tested.

2.4. Tensile test

This test refers to the ASTM E8 standard, using the Gotech AL-7000 LA 10 tensile testing machines, the aim is to determine the tensile strength value of the sample being tested and determine the mechanical behavior of the material and the fracture characteristics of the material.

2.5. Microstructure observation

Observation microstructure done by optical microscope according to ASTM E407-07 (metals and alloy) standard, with the aim of knowing the phases in the material / sample.

2.6. Observation of fractography with SEM

Observations using the Scanning Electron Microscope (SEM) are used to identify the type of fracture that occurs, by scanning it using high-energy electron rays, with magnification in microns.

3. Results and discussions

3.1. Visual observation results

The results of visual observations indicate that the failure area is the result of the joining process by welding method, specifically by the existence of differences in the inner and outer surfaces. The joining process was carried out by machining the outside of one side and then welding as shown in Figure 2.

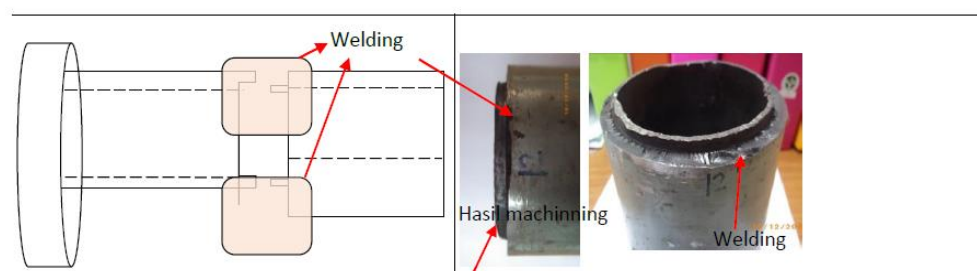


Figure 2. Illustration on the fracture area showing the fracture area is the result of joining welding.

3.2. Chemical composition testing analysis

Chemical composition analysis observed by optical emission spectrometer (OES) on the inside and outside drive shaft which refers to the ASTM E415 and A751 testing standards. Chemistry composition testing in both regions done to reconfirm that the drive shaft is a solid metal. The nominal chemistry composition results are tabulated Table 1. which indicates that the drive shaft does not contain Cr and Ni element, so can be categorized as plain carbon steel. Based on carbon elemental content, the composition of the drive shaft component can be categorized as AISI steel 1025. Steel AISI 1025 in general used as a machine component, construction components, frame as well tools and molds. AISI

1025 steel have good machinability but it is not suitable for components that must accept high loads. For high load applications, in general used HSLA steel (high strength low alloy).

% Elements	Fe	C	Si	Mn	P	S	Cr	Ni	Mo	Al	Co
Top Area	98,9	0.248	0.04	0.65	0.01	0.003	0.04	0.005	<0.005	0.0426	0.0018
Bottom Area	98,9	0.253	0.04	0.65	0.01	0.0038	0.04	0.006	<0.005	0.043	0.002

% Elements	Cu	Nb	Ti	V	W	Pb	Sn	B	Ca
Top Area	0.0184	<0.002	<0.002	<0.002	<0.015	<0.025	0.0076	<0.0004	>0.001
Bottom Area	0.0184	<0.002	<0.002	<0.002	<0.015	<0.025	0.0079	<0.0004	>0.001

% Elements	Zr	As	Bi
Top Area	<0.002	<0.005	<0.03
Bottom Area	<0.002	<0.005	<0.03

Table 1. Nominal composition of drive shaft.

% Element	C	Si	Mn	P	S	Cr	Ni
Inside	0.248	0.04	0.65	0.01	0.003	0.04	0.005
Outside	0.253	0.04	0.65	0.01	0.003	0.04	0.006
AISI 1025 (reference)	0.22-0.28	-	0.3-0.60	0.04 max	0.05 max	-	-

3.3. Hardness testing analysis

Hardness testing was done in accordance with ASTM standard E18 using the Rockwell B method. Hardness testing is carried out on the outside and inside of drive shaft for comparison. The results of testing shown in Table 2. The results hardness testing shows that there is no significant difference between deep and surface the outer surface of the drive shaft. The results also shows that the hardness of material in line to AISI 1025 standard.



Figure 3. Position of sample hardness testing.

Table 2. The test results of Rockwell hardness scale B.

Area	Indentation					Average
	1	2	3	4	5	
Outside	94.0	94.5	94.5	94.8	94.9	94.54
Inside	95.0	95.1	95.3	95.5	95.8	95.34
AISI 1025 (reference)	71 min					

3.4. Tensile testing analysis

Tensile testing is carried out with take a sample of 2 specimens with the direction of longitudinal. Tensile testing is performed according to standards ASTM E8 whose results are listed in the Table 3. Tensile test results show that the tensile strength of the drive shaft qualify AISI 1025 specifications. Tensile and yield strength value is approximately 60% above the minimum limit which shows that the material conditions are still very good, but for a little strain value below the minimum threshold considered insignificant affect mechanical properties.

Table 3. The result of tensile testing.

Sample		Tensile strength (MPa)	Pass limit (MPa)	Strain (%)
Drive shift	1	696	657	14.11
	2	706	666	14.08
	Average	701	662	14.10
AISI 1025 (reference)		440 min	370 min	15 min

3.5. Microstructures analysis

Microstructure observations was done of far areas from fracture and fracture area. On far area from fracture show that there is no difference microstructure on the top and parts below, the microstructure consists of ferrite-pearlite phases as shown in Figure 4. Pearlite phase is seen as an area black and elongated shape. The elongation shape is an effect of rolling process to get thickness which is desired. While the ferrite phase seen as a white area. Based on test results chemical composition, drive shaft material classified as low carbon steel should have a majority of ferrite phases. Microstructure observations shows that the ferrite phase is more dominant compared to the pearlite phase, its so confirm the results of chemistry composition testing (OES).

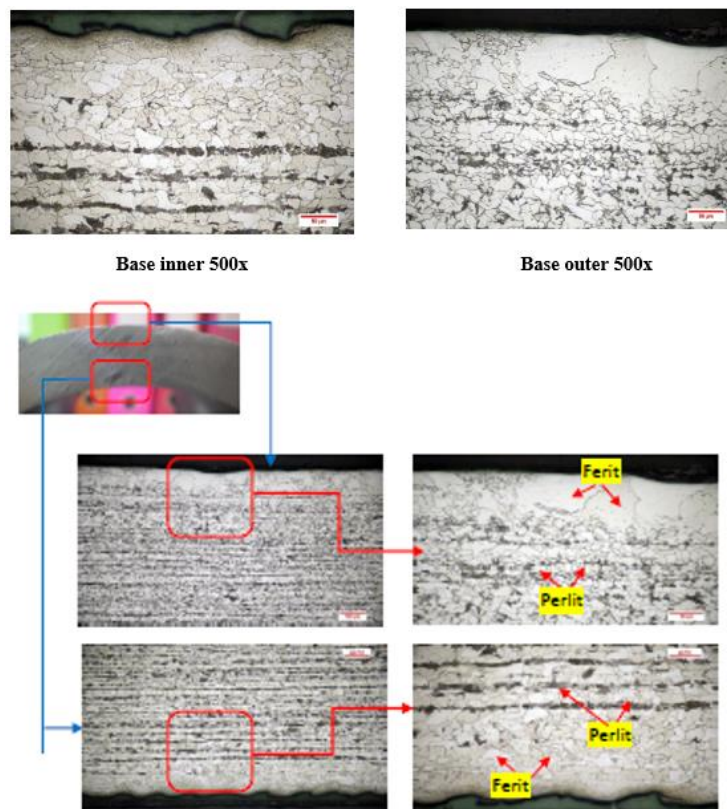


Figure 4. Microstructure on the far area from fracture.

The Observation of microstructure was done in the fracture area. The sampling position is in the 12 and 6 o'clock areas with transverse image taking directions. The results can be seen in Figure 4.4. The results of the microstructure observation re confirm that the fracture area is a welding joint, that is seen from the differences in grain size and the presence of weld metal. Microstructure observations also show that fracture on metal welds indicate that weld metal cannot withstand the load given.

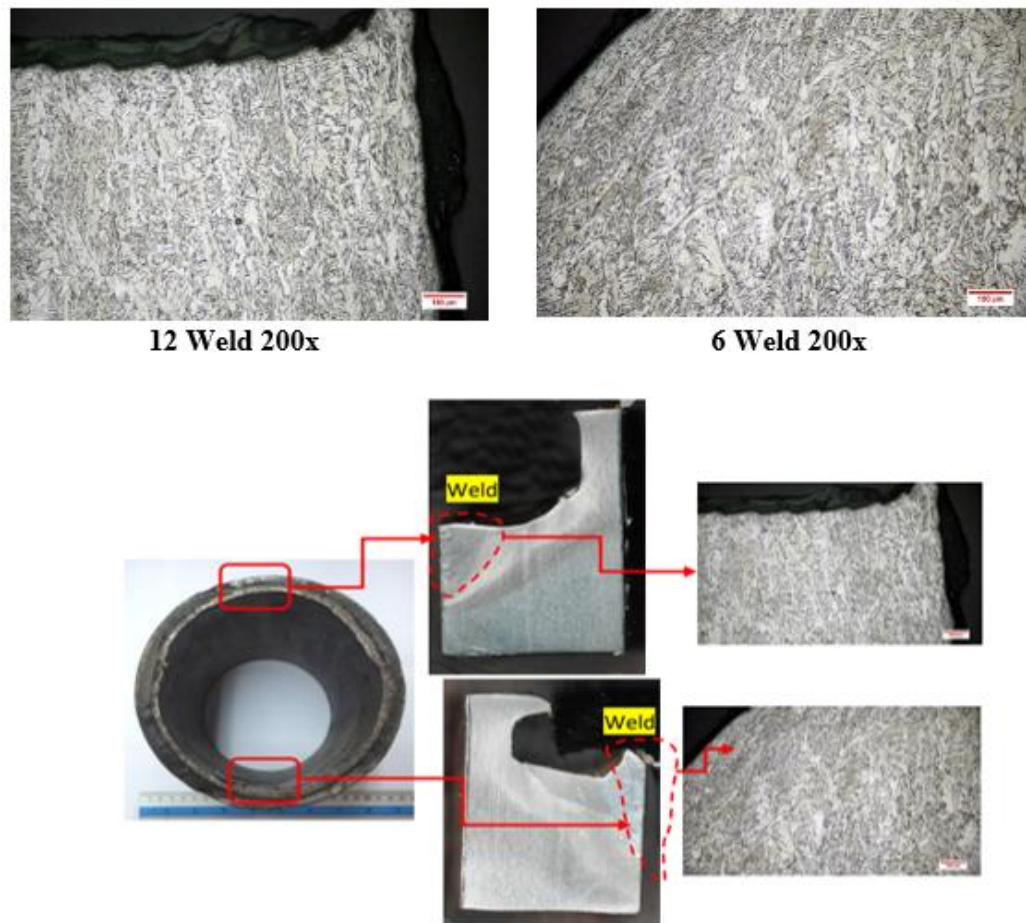


Figure 5. Microstructure on the fracture area.

3.6. Fracture surface observation analysis

Microstructure observation was done in the fracture area. The sampling position is at 12 and 6 o'clock areas using SEM that the results can be seen in Figure 4.5. The results of Observation on fracture surface shows that plastic deformation occurs characterized by the presence of structure dimple. Dimple is a combination microvoid at the time of plastic deformation. On elastic deformation, the distance between metal atoms can still stretch and return to original position if the load released, but at the time of deformation plastic, metal atoms cannot return to original position and at the time back load is increased then it will microvoid formed due to no metal can compensate for the increase volume due to strain formed. The presence of dimple on the fracture surface shows that welding joints cannot withstand the load given so that deformation occurs and finally broke up.

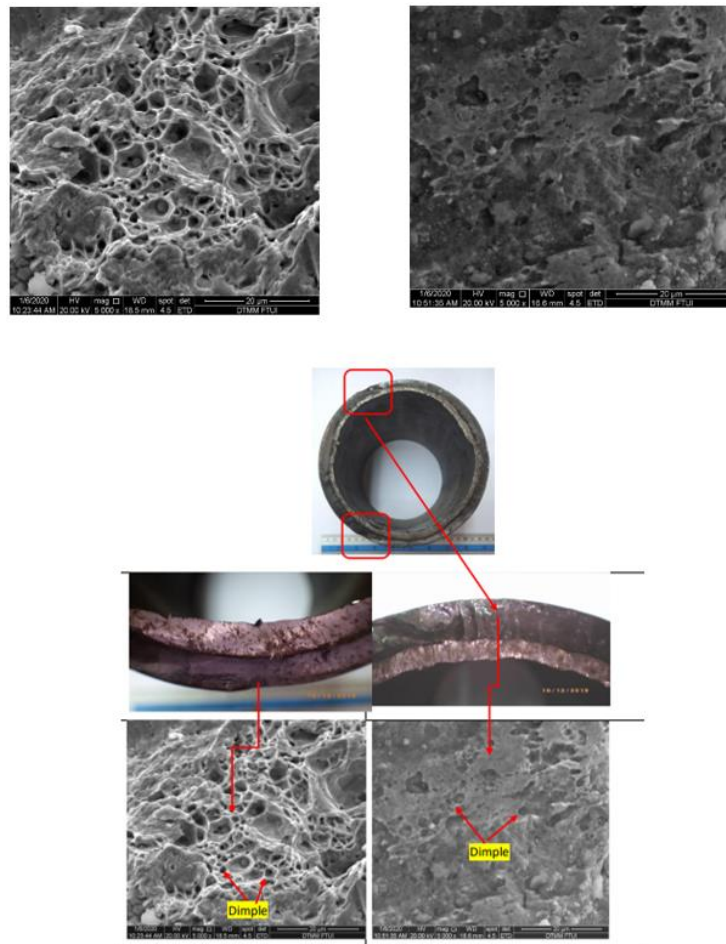


Figure 5. Fractography on the fracture area using SEM.

4. Conclusion

Based on results of chemical composition and mechanical testing show that:

Visual observations show that the drive shaft is fracture on the connection part that is the connection by welding method; Chemical composition testing results indicates that the drive shaft is AISI 1025 steel; The results of tensile and hardness test indicates that the mechanical properties of the drive shaft according to material standards AISI 1025; Microstructure observations confirm the results of observations visual that is drive shaft fracture occurs in the weld area. Microstructure the weld area consists of ferrite and pearlite phase, no hard phases such as brittle martensite are found; The results of fractography observations shown that fracture patterns due to plastic deformation which shows that the connection cannot withstand the load given so fracture can happen.

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