

# Failure Analysis of Power Steering Gearbox Housing in 2500 CC Diesel Car

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**Abstract** - The power steering gearbox housing is one of the components in a car that functions as a coupling and directional force converter between the steering wheel and the front wheels of the car. This component experienced failure in the form of fracture. This study aims to determine the failure mechanism, material characteristics, and loading mechanism through failure analysis. The testing methods used were visual observation, chemical composition testing, metallographic testing, hardness testing, and Finite Element Method (FEM) simulation using SOLIDWORKS 2025 software. Visual observation results show that the failure that occurred led to the phenomenon of fatigue failure, which is characterized by crack initiation, final crack zone, and ratchet marks. Metallographic testing shows that the material has nodular graphite with a ferrite + pearlite matrix, indicating that the material is nodular cast iron. Hardness testing showed a value of 194-221 HV. Composition testing revealed the presence of nodulizer components, namely Mg and Ce. The FEM simulation results show that the peak stress for the 4-bolt model is 259.3 MPa and for the 3-bolt model is 288.2 MPa. The 3-bolt model is unsafe because the peak stress value is higher than the material fatigue margin.

**Keywords:** Failure analysis, fatigue failure, Finite Element Method, power steering gearbox housing, nodular cast iron.

## I. INTRODUCTION

Failure analysis is a systematic investigation method used to identify the causes and mechanisms of failure in a component, as well as to provide recommendations for overcoming the problems that arise [1]. The application of Failure Analysis is increasingly being used to solve various problems in operating systems in line with the development of science and technology, while also serving as a preventive maintenance measure to prevent further failures. One of the most common types of failure is fracture failure.

The gearbox housing is the main structural component in a vehicle's transmission system, designed to protect and support internal components such as gears, shafts, and

bearings. Its main functions are to provide protection against external contamination (such as dust and liquids), reduce noise and vibration, and ensure optimal lubrication of components [2].

Failures in gearbox housings can be divided into two main factors: static failures and dynamic failures. Static failures usually occur due to overloading, over-tightening, and the use of components that do not meet specifications. Meanwhile, dynamic failure is related to material fatigue that accumulates during use. This condition can be caused by suboptimal tightness of the connecting components between the gearbox housing and the mounting frame, as well as the possibility of self-loosening during use. Cracks will form and develop due to external and cyclic loads [3].

This study analyzes the failure of the power steering gearbox housing, which will be tested for the causes of failure to determine the failure mechanism factors, the causes, and provide recommendations for similar cases. This component functions as a cover for the power steering gearbox and as a support for the frame on Isuzu Panther cars.

## II. METHODOLOGY

In this study, experimental study and finite element method (FEM) is used. The failed power steering gearbox housing was inspected visually and macroscopically and then subjected to photo documentation, chemical analysis, optical microscopy and micro-hardness measurement both at the failure zone and away from the failure zone.

### 2.1 Power Steering Gearbox Housing for 2500 cc Diesel Cars

This study used test specimens of power steering gearbox housings from Isuzu Panther cars that had failed. Two test samples were taken from these specimens, namely the part near the fracture and the part far from the fracture. Both test samples underwent the same testing process. The power steering gearbox housing can be seen in Figure 1.



Figure 1: Power steering gearbox housing specimen

A small specimen of the power steering gearbox housing fracture was cut using an Electric Discharge Machining (EDM) wire cut machine into two parts, as shown in Figure 2. These were then mounted using resin. The mounted samples were then tested.



Figure 2: Results of cutting and specimen collection on small fractures in the gearbox housing using an EDM Wire Cutting Machine

## 2.2 Visual Observation

This test was conducted by analyzing the fracture area at low magnification to provide an initial overview of the investigation into the power steering gearbox housing. Through visual observation, it is hoped that early signs of failure that can be seen macroscopically from the components can be identified, such as crack initiation, crack propagation, final cracks, and others. The visual observation data was used as an initial overview of the investigation into the failure of the Isuzu Panther car's power steering gearbox housing. The test was conducted at the Engineering Materials Laboratory, Department of Mechanical Engineering, Diponegoro

University, using an optical microscope with 6.7x magnification.

## 2.3 Metallographic Testing

This test aims to observe the microstructure formed in the test specimen material. The test was conducted on two specimens, namely a specimen with a material cut near the fracture area and a specimen with a material cut in the component area far from the fracture.

Metallographic testing was carried out using an optical microscope at the Engineering Materials Laboratory, Department of Mechanical Engineering, Diponegoro University. Before testing, the test samples were sanded using 240 to 5000 grit sandpaper, then polished using a velvet cloth and autosol. After polishing, the test samples were etched using a mixture of 5 ml HNO<sub>3</sub> and 100 ml ethanol for approximately 3 seconds. Microstructural observations and image capture were performed using a 100x to 1000x magnification lenses.

## 2.4 Chemical Composition Testing

This test was conducted to determine the composition and chemical elements of the material. The results of the test were used to assess the quality of the material, in this case the power steering gearbox housing of the Isuzu Panther car. The test was carried out in accordance with the ASTM E415 standard using an Optical Emission Spectrometer (OES) at the Engineering Materials Laboratory, Department of Mechanical Engineering, Diponegoro University.

## 2.5 Hardness Testing

This test was conducted to determine the hardness value of the test specimens. The hardness testing method used was the Vickers hardness tester, referring to the ASTM E384 standard, with a load of 4.903 N (HV0.5) and a pressing time of 15 seconds. Indentations were made at 5 points with a distance of approximately 1 mm between points to obtain representative measurement results.

## 2.6 Finite Element Method Simulation

To support the test results, numerical simulations were performed on a 3D model of the power steering gearbox housing. The simulations were performed using SOLIDWORKS 2025 software.

The maximum force exerted on the tie rod of a Lincoln MKX vehicle at a speed of 15 km/h is 3000 Nm [4]. Using the vehicle weight ratio, it is possible to estimate the load on the tie rod of a Panther car. The Lincoln MKX has a gross weight

of 1910 kg, while the 2500 cc Panther has a gross weight of 2150 kg.

$$\frac{\text{Weight of the Panther car}}{\text{Weight of the Lincoln car}} = \frac{\text{Rack Force Panther}}{\text{Rack Force Lincoln}}$$

$$\frac{2150 \text{ kg}}{1910 \text{ kg}} = \frac{\text{Rack Force Panther}}{3000 \text{ N}}$$

$$\text{Rack Force Panther} = 3377 \text{ N}$$

The applied materials used consist of two materials, namely materials based on literature studies of the same type, namely nodular (ductile) cast iron grade 80-55-06, and materials resulting from micrographic and hardness testing of power steering gearbox housing materials with assumed mechanical properties. The mechanical properties of the materials for simulation are shown in Table 1.

Table 1: Mechanical properties of materials for simulation

Properties	Testing material	Material from the literature [5]
Tensile strength	654 MPa	696.37 MPa
Yield strength	414 MPa	427.475 MPa
Elastic modulus	120000 Mpa	120000 Mpa
Shear modulus	77000 MPa	77000 MPa
Poisson's Ratio	0.31	0.31
Density	7100 kg/m <sup>3</sup>	7100 kg/m <sup>3</sup>

### III. RESULT AND DISCUSSION

#### 3.1 Visual Observation

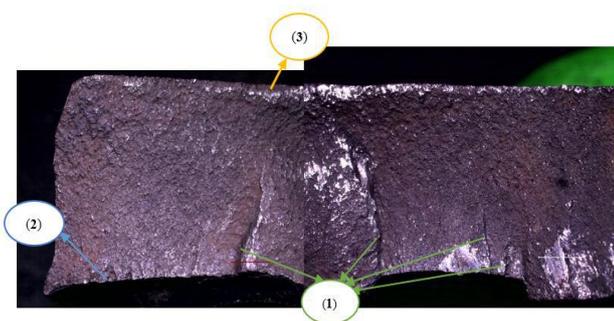


Figure 3: Observation using a 6.7x magnification macrographic microscope on the surface of the housing fracture, (1) Indication of ratchet marks, (2) Indication of crack initiation, (3) Final crack zone

Based on visual observations made on the surface of the power steering gearbox housing fracture, it can be seen that the fracture surface appears irregular, similar to gravel, with many small protrusions and holes as can be seen in Figure 3. There are indications of ratchet marks from several points on the fracture surface, indicating the presence of a fatigue mechanism with several initiation points. The crack started from the fillet on the inner side of the housing and spread to

the final crack zone on the surface of the housing that was in direct contact with the frame. On the other hand, material fatigue characteristics such as river marks, radial lines, chevrons, striations, and beach marks were not clearly visible in the fractography.

A comparison of the failure case with fatigue failure symptoms in nodular cast iron material is shown in Figure 4.

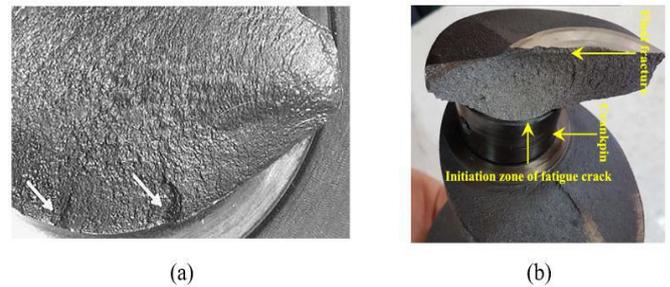


Figure 4: Cases of failure with symptoms of fatigue failure, (a) Indications of ratchet marks on the crankshaft due to fatigue failure [5], (b) Crack initiation and final crack zone on the truck crankshaft due to fatigue failure [6]

#### 3.2 Hardness Testing

The hardness test results show that the values in the area near the fracture (194–221 HV) and far from the fracture (196–215 HV) are within almost the same range without any significant differences. When converted to the Brinell scale, the hardness ranges from 205–225 HB, which corresponds to the typical hardness range for nodular cast iron based on various metal casting industries with metal production in accordance with ASTM A536 tensile material standards (179–255 HB). This indicates that there are no significant mechanical property differences between the areas near the fracture and those far from the fracture. From both measurements, the average hardness of the sample was 207 HV or 218 HB.

$$\sigma = 3 \times HB$$

$$\sigma = 3 \times 218 \text{ HB}$$

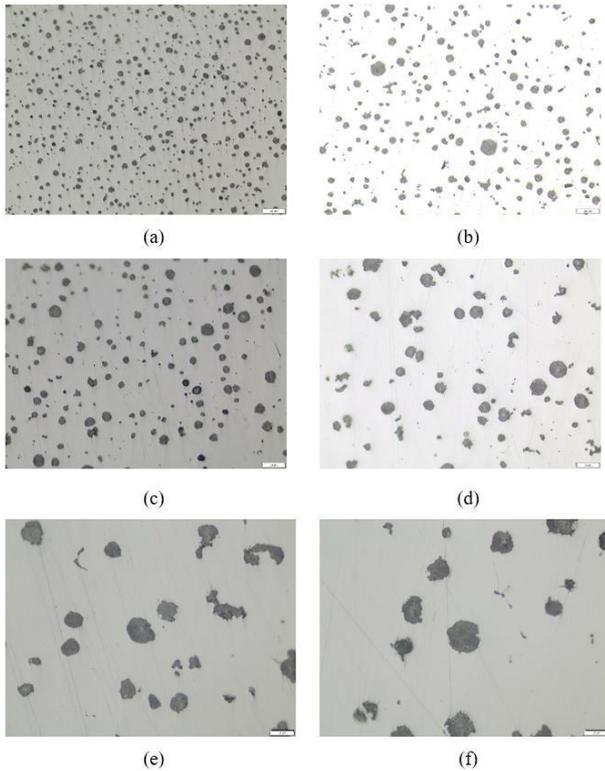
$$\sigma = 654 \text{ MPa}$$

The estimate for tensile strength ( $\sigma$ ) based on the material's hardness value is 3 times the Brinell Hardness value, as calculated above. Therefore, the estimated tensile strength value of the tested material is 654 MPa.

#### 3.3 Metallographic Testing

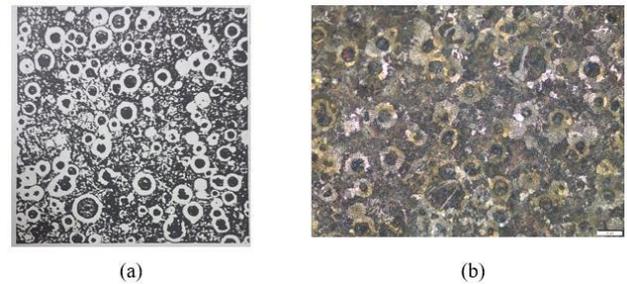
Metallographic testing results show that nodular graphite particles can be seen as dark, round particles with smooth edges scattered across the entire surface. Graphite nodules

have a spheroidal or circular shape, which is the main characteristic of nodular cast iron. In the far part of the fracture, the nodules are more evenly distributed and have a more rounded shape than in the part near the fracture, as can be seen in Figure 5.

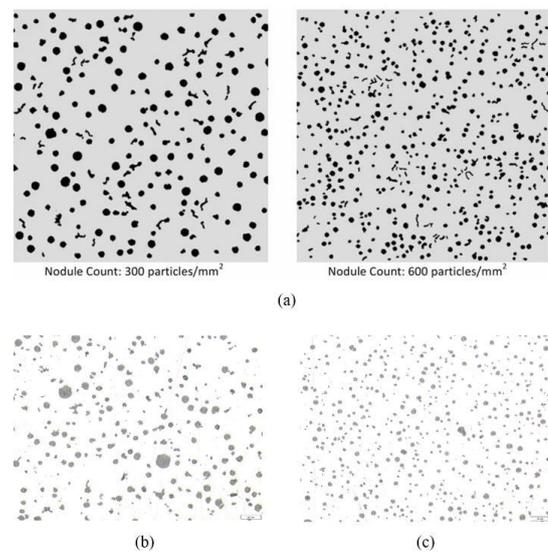


**Figure 5: Non-etched photo results, (a) Housing far from the fracture at 100x magnification, (b) Housing near the fracture at 100x magnification, (c) Housing far from the fracture at 200x magnification, (d) Housing near the fracture at 200x magnification, (e) Housing far from the fracture at 500x magnification, (f) Housing near the fracture at 500x magnification**

The nodules have a slightly rougher shape and are not as dense near the fracture, which can cause stress concentration during component use, resulting in component weakening in that area. This can increase the likelihood of fatigue crack initiation under cyclic loading conditions [7]. The metal matrix surrounding the graphite nodules consists of a combination of ferrite (light areas) and pearlite (dark areas) [8]. The presence of ferrite with a bull's-eye structure surrounding nodular graphite, both of which are also found in the pearlite matrix, indicates that the test material is grade 80-55-06 nodular cast iron. Figure 6 shows a comparison of the 200x magnification sample photo with a photo from the Microstructure Atlas of Grade 80-55-06 pearlitic ductile iron.



**Figure 6: Comparison of results with the Microstructure Atlas (a) NCI grade 80-55-06 Microstructure Atlas [9] (b) 200x magnification photo of housing results**



**Figure 7: Comparison of nodule density with ASTM A247, (a) Nodule density for 90% nodularity ductile iron at 100x magnification [10] (b) Housing near fracture at 100x magnification, (c) Housing far from fracture at 100x magnification**

Based on ASTM A247, the material for this power steering gearbox housing is classified as type 1 nodular graphite with 90% nodularity and a nodule density value of approximately 600 particles/mm<sup>2</sup> (class 7) for the far end of the fracture and 300 particles/mm<sup>2</sup> (class 6) for the near end of the fracture. A comparison of nodule density between specimens and ASTM A247 can be seen in Figure 7.

### 3.4 Chemical Composition Testing

Based on the results of chemical composition testing, the material shows a carbon content of more than 5% and the presence of nodulizer elements such as Mg and Ce. Although the measured carbon value is higher than the typical range for nodular cast iron, this difference is likely due to the limited accuracy of the test, which can increase the measured carbon value. Testing for cast iron materials requires test samples to be remelted and cast using the chill casting method, which is not possible due to the relatively small size of the samples. The presence of spheroidal or circular graphite in the

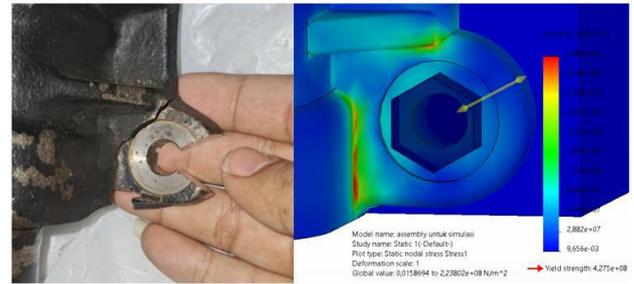
microstructure and a hardness value consistent with nodular cast iron indicates that this material is ductile (nodular) cast iron. The results of the chemical composition test of the power steering gearbox housing can be seen in Table 2.

**Table 2: Power steering gearbox housing chemical composition test results**

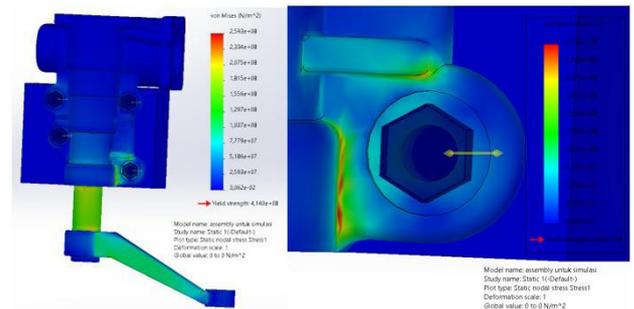
Element	Testing Sample	
	Gearbox Housing (%)	Standard Deviation
Fe	90.9	0.97
C	>5.00	0
Si	2.64	0.306
Mn	0.200	0.0107
P	0.0284	0.03531
S	0.130	0.0754
Cr	0.0643	0.02856
Mo	0.0781	0.05953
Ni	0.280	0.1951
Al	0.0797	0.04287
Co	0.0246	0.02018
Cu	0.0680	0.03904
Mg	0.125	0.0001
Nb	0.0597	0.04425
Ti	0.0401	0.02040
V	0.0363	0.02293
Pb	0.0393	0.02128
Sn	0.0176	0.00828
B	0.0024	0.00215
Ce	>0.0800	0
Zr	0.0229	0.01658
Zn	0.0044	0.00197
Bi	0.0116	0.00238
As	0.0023	0.00059
Se	<0.0040	0
Sb	0.0237	0.01299
La	0.00418	0.00869

### 3.5 Finite Element Method Simulation

From the simulation results with a load input of 3377 N in the pitman arm direction, the housing experienced a bending moment that caused stress concentration at two points (at the location of the fracture), which was indicated by a difference in color contour in that area. A comparison between the simulation results and the location of the specimen fracture can be seen in Figure 8.

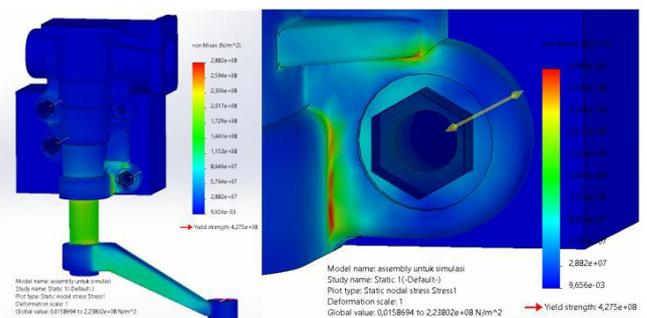


**Figure 8: Comparison of sample fracture locations with simulation results**



**Figure 9: Finite Element Methods simulation results for a 4-bolt gearbox housing with forces acting away from the frame**

Finite element simulation with 4 bolts and the force direction away from the frame shows that the peak Von Mises stress is 259.3 MPa, which is seen in the fillet area at the same location where the fracture on the specimen occurred, as shown in Figure 9. The estimated tensile strength value of the material based on the hardness test is 654 MPa. Meanwhile, the tensile strength value of the material from the literature is 696.37 MPa. The conservative industry estimate of the fatigue margin for ductile iron is 40% of the ultimate tensile strength value, which is 261.6 MPa for the tested material and 278.5 MPa for the material from the literature. This indicates that the model is still within the safe range because the peak stress has a lower value than the material fatigue margin.



**Figure 10: Finite Element Methods simulation results for a 3-bolt gearbox housing with forces acting away from the frame**

Figure 10 shows a simulation with three bolts and the direction of force away from the frame. The result is that the

Von Mises peak stress increases to 288.2 MPa. This indicates that this model is unsafe because the peak stress has a higher value than the fatigue margin of both the tested material (261.6 MPa) and the material from the literature (278.5 MPa). Higher stress significantly increases the risk of fatigue crack initiation and rapid propagation. This may explain why the component failed after a relatively long service life (23 years).

#### IV. CONCLUSION

Testing indicates that the power steering gearbox housing material is nodular cast iron with nodular graphite surrounded by ferrite and pearlite. The cast iron can be categorized as Nodular Cast Iron (NCI) grade 80-55-06 based on micrographic and hardness test results. There are defects found on the surface of the housing, namely a lack of nodular graphite caused by too rapid a decrease in temperature. This results in stress concentration on the surface.

The failure experienced by the power steering gearbox housing is a fatigue failure, characterized by perpendicular fractures and the presence of a crack initiation zone, final crack zone, and ratchet marks. The fractures that occur follow the ductile matrix category due to zig-zag cracks that connect the nearest graphite particles or the weakest parts of the largest graphite particles.

From the FEM simulation, it can be seen that the failure location of the power steering gearbox housing occurred precisely at the location of concentrated stress. The cause of crack initiation in the power steering gearbox housing was the maximum stress of 288.2 MPa, which exceeded the fatigue margin for ductile iron material. The failure was triggered by the loss of one of the bolts holding the housing to the vehicle frame, which caused an increase in the maximum stress value received by the housing.

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