REAR AXLE FAILURE ANALYSIS OF THE DUMP TRUCK

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Abstract. The dump truck rear axle has failed while operating. The shaft transmits torque from the differential gear to the rear wheels through a planetary gear arrangement. Axle parts that fail to be investigated to determine the cause of failure. Field scanning is done using scanning electron microscopy (SEM). The hardness profile along the cross section is evaluated by measurement of micro hardness. Chemical analysis shows that the shaft is made of american iron steel institude (AISI) 4140 steel. The shaft carbon content is 0.52%, higher than AISI 4140 standard where the maximum carbon content is 0.45%. Manganese (Mn), sulfur (S), phosphorus (P), silicon (Si), and chromium (Cr) content have met standards. Microstructure analysis and profile hardness testing revealed that the edge profile was more fragile, different from the more resilient core. This phenomenon is related to the discovery of microstructure on the edge of the profile found in a martensitic structure which reveals that the manufacturing of the shaft undergoes a surface hardening process to harden the shaft surface. The analysis shows that the fracture starts from the edge of the profile where there is a fragile martensitic structure due to improper heat treatment (high hardness).

Keywords: rear axle, AISI 4140, failure analysis, fatigue

Introduction

One form of failure of an automotive component occurs in a rear axle shaft of a dump truck vehicle. This condition occurs because the wheel shaft stem fails early (premature fracture). Some common reasons for failure can be manufacturing and design errors, maintenance errors, raw material errors and errors originating from use **[1]**. The dump truck rear wheel shaft used to transmit power to rotating components generally experiences torsional loads. Therefore the material characterization of the axle shaft is carried out to determine the mechanical properties, workmanship and chemical composition of the axle shaft**[2]**.

Axle shafts on the vehicle are divided by two type, front axle shaft and rear axle shaft. Power is obtained from a declining force and the resultant torque or torque moment is connected to an axle shaft (Differential gear), in other words that the shaft is used to produce torque and bending moments. The rear axle generally carry heavier loads than the front axle, so that the construction of rear axle shaft is also relatively stronger. Carbon steel classified into three parts according to the carbon content, there are low carbon steel with carbon content of less than 0.25%, medium carbon steel containing 0.25 - 0.6% carbon, and high carbon steel containing 0.6 - 1.4% carbon **[3].** The rear axle shaft uses a medium carbon steel type. Figure 1 (a) and figure 1 (b) are examples of rear wheel shafts that are still good and which have been damaged.

Figure 1. The broken of the axle shaft whos connected with a differential gear

Experimental Procedure

Broken rear axle are collected from the workshop for investigation. Samples were cleaned with acetone to clean from impurities for visual inspection before preparation for metallographic samples. Transverse and elongated specimens were made from the crack tip of the sample which failed to undergo optical microscopic examination. The polished sample was etched in a 3% Nital solution (3 mL HNO in 97 mL ethyl alcohol), then examined using an optical microscope. Micro hardness from several points was tested using a Vickers Hardness Testing Machine by pressing the sample using a diamond pyramid-shaped press that is essentially a square. The magnitude of the diamond pyramid 136º identifier peak angle. The amount of violence is calculated based on equations (ASM, 1992). In the Vickers test the force is given slowly without collision, and is held for 12 seconds. In accordance with ASTM E384, the force applied was 0.3 Kgf. Hardness testing is carried out by crossing 16 points along the diameter (Figure 7) and circular along the axis of the shaft by 40 points (Figure 8). The composition test is used to check the mechanical properties of failed shaft types compared to the AISI 4140 / DIN 42CrMo4 standard. Scanning Electron Microscopy (SEM) test is performed to determine the phase formed.

Result and Discussion

1. Visual observation

From the results of the macroscopic analysis it is seen that the crack initiation on the shaft starts from the edge of the shaft towards the center of the shaft as evidenced by the shape of the spiral in the center of the shaft that has failed. In the figure 2. there is a beach mark that is evenly distributed from the edge to the center of the shaft and the combination of slow crack propagation (dull and fibrous areas) and rapid crack propagation (areas that are shiny and slippery) indicates the shaft accepts dynamic loads.

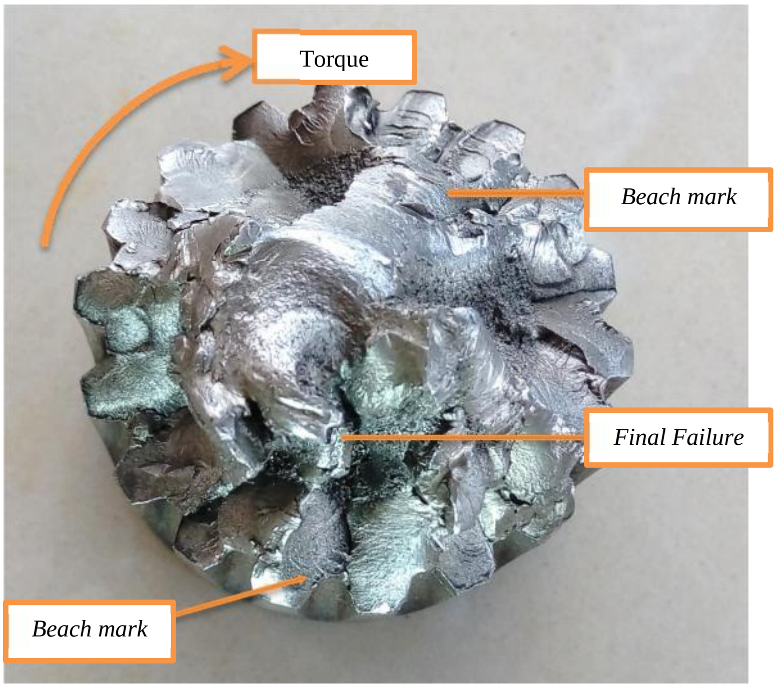

Figure 2. cross section of broken shaft

The crack initial is indicated by striation and beach mark in the area around the crack initiation at the fault edge and appears to be rougher, while the beach mark is indicated by fine semi-circular lines in the initial crack area to final failure. Beach marks also called to be crack propagation stages. The area between the crack propagation stage and the final stage can quantitatively show the magnitude of the stress acting. If the area of the crack propagation area is greater than the area of the final fracture, the working stressing is relatively low, and vice versa if the area of the crack propagation is smaller than the area of the final fracture, the working of the stressing is relatively higher. Phase one occurs metal fatigue, which is the initial stage of crack formation, is easier to occur in metals that are soft and resilient but will be more difficult in the crack propagation stage (Phase two), meaning that ductile metals will be more resistant to crack propagation. Likewise, the hard and brittle metal will withstand the initial formation of the crack but is less resistant to crack propagation. The stages of initial crack formation and crack propagation in the metal fatigue mechanism require time so that the fatigue life of the component or metal is determined from the two stages. The crack grows small to the surface and angle, finally, curves causing the release of material debris and leaving the crater. Fatigue cracks can occur either on the surface or at a small depth below the surface, where the shear stress is high enough to initiate propagation from defects or inclusions **[4]**. The failure in the rear axle shaft hardening process can occur due to the temperature of the heat treatment process from the surface of the rear axle shaft has not reached the austenizing temperature **[5]**. So that the final result of the heat treatment process on the surface of the rear axle shaft which is expected to be fully martensite (full martensite) phase does not occur because the grain boundary in the form of ferrite is still left in the micro structure (martensite phase).

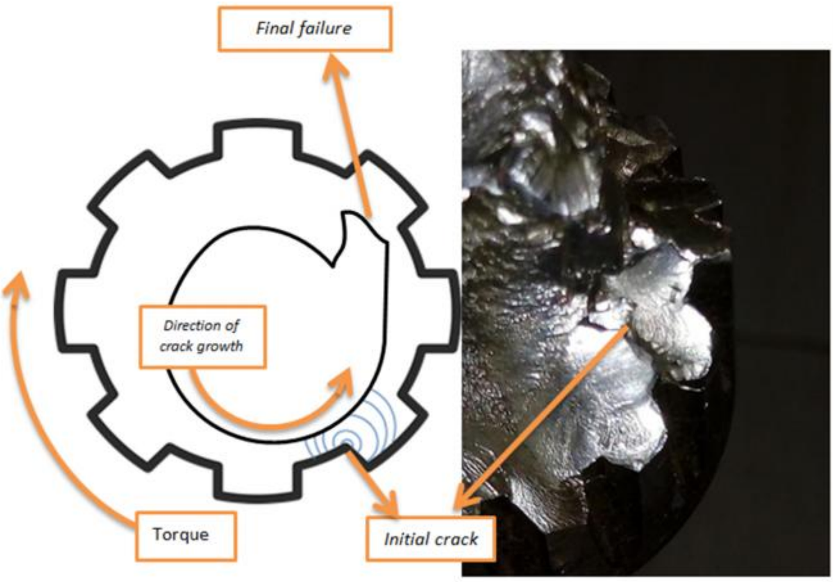

Figure 3. Initial Crack and Direction of Crack Growth

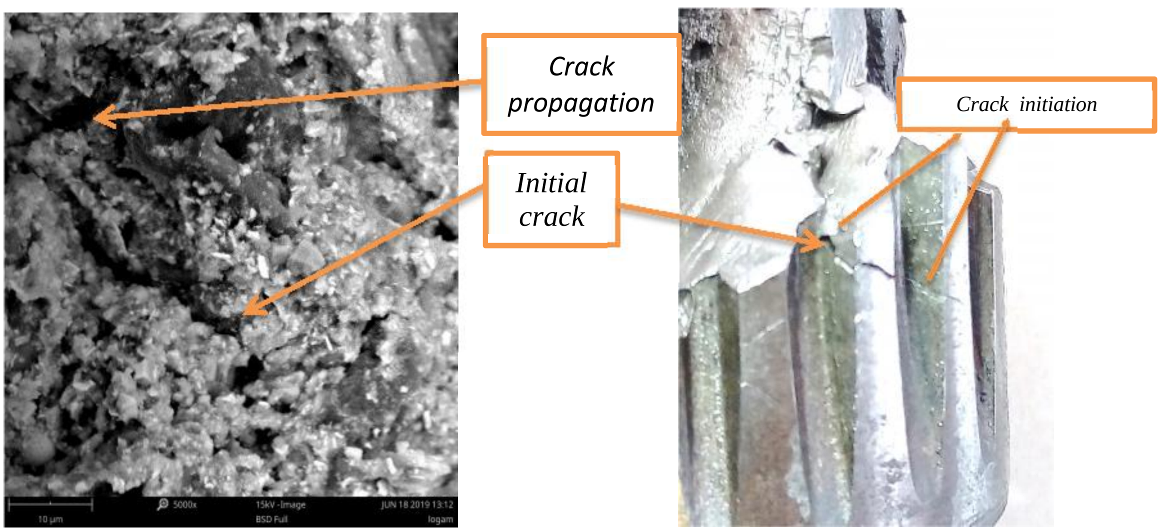

Figure 4. Crack Initiation and Crack Propagation

2. Chemical analysis

The analysis of chemical composition, it appears that the broken shaft carbon content is higher than the AISI 4140 standard which should be a maximum of 0.45%, which is

0.52%. Impact on increased shaft hardness, on the other hand an increase in the amount of carbon reduces toughness and increases fragility.

Table 1. Chemical Composition of AISI 4140 and Failed Part

item %	**Standard AISI 4140**	***Failed Part***
C	0,37-0,45	0,52
Si	0,17-0,37	0,24
Mn	0,75-1,00	0,66
P	< 0,036	0,02
S	< 0,05	0,02
Cr	0,80-1,10	1,02
Ni	-	0,03
Al	-	0,01
Co	-	0,02
Cu	-	0,01
Nb	-	0,00
Mo	0,15-0,25	0,23
Pb	-	0,01
Fe	-	97,1

3. Fractography

Fractography on the surface of the shaft can be seen as a V-shaped cleavage on the surface fracture, certainly broken because on brittle mode. While the fracture on the core of the shaft shows the shape of the dimples on the fault. Ascertained is an elastic type of fault. The fracture surface assessment identified several characteristics of fatigue failure characteristics: (i) a beach mark sign that is a sign of development of fatigue front cracks and (ii) a rachet mark which is a sign of crack initiation due to high stress concentration. The exact mechanism of fatigue is always consistent with unidirectional bending **[6]**.

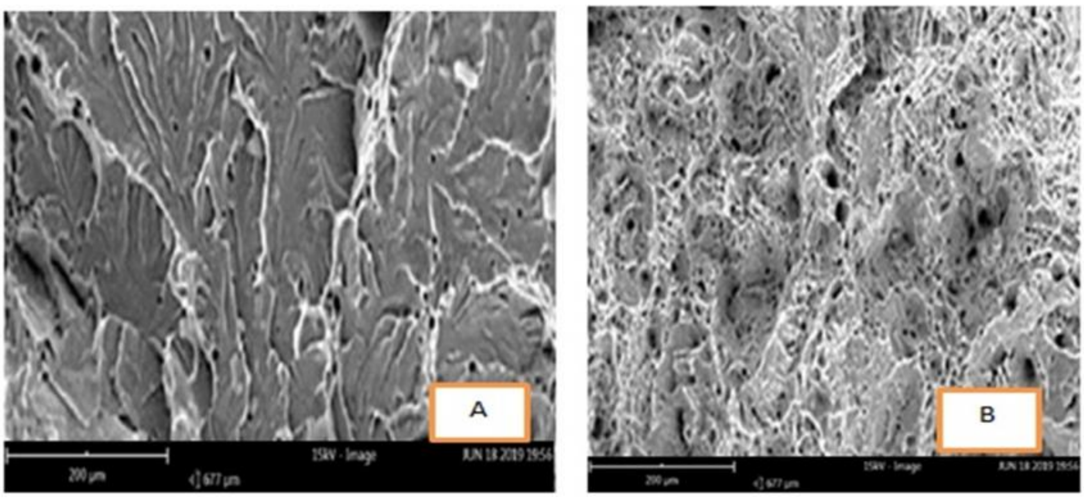

Figure 5.1 (A) Fractography analysis of the edge of the failed component; (B) fractography analysis of the core of the failed component.

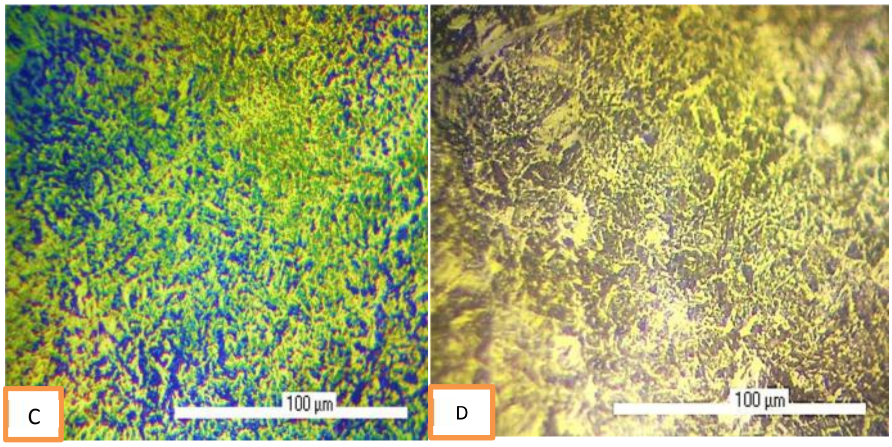

Figure 5.2 (C). Microstructure of the edge of the component 600x, (D). Microstructure of the core of the component 600x

4. Microstruktural analysis

Microscopic analysis on the shaft surface, figure 39. and figure 43. show that the martensite phase is uneven tends to be grouped. There is a ferrite-pearlite phase on the sidelines of a martensite group, indicating the temperature at the surface hardening process is unstable. The matrix area shows that the dominant martensite phase is rough and sharp so that it can be concluded that tempering is carried out at high temperatures and quite a long time and is quenched quickly. This grouped and uneven martensite phase results in uneven surface hardness of the shaft.

Analysis of the core of the shaft, shows the dominant ferrite and pearlite phases. It was concluded that the core of the shaft was more resilient than the surface of the shaft which was dominated by the hard bainite and martensite phases.

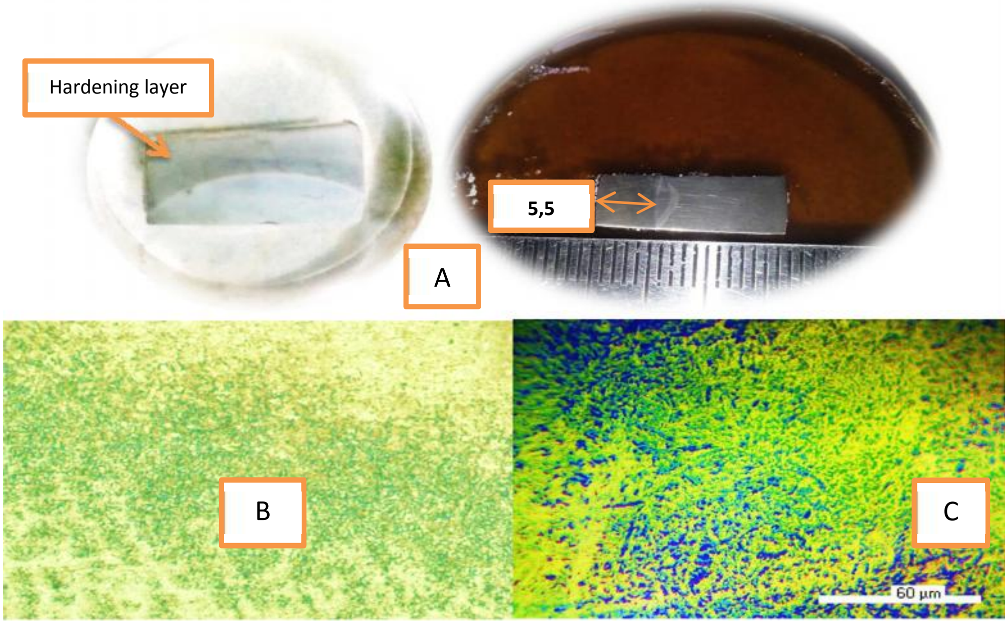

Figure 6. (A). Macrostructure of the cross section of the failed shaft, (B). Microstructure of the edge of the component 50x, (C). Microstructure of the edge of the component 600x

5. Hardness profile

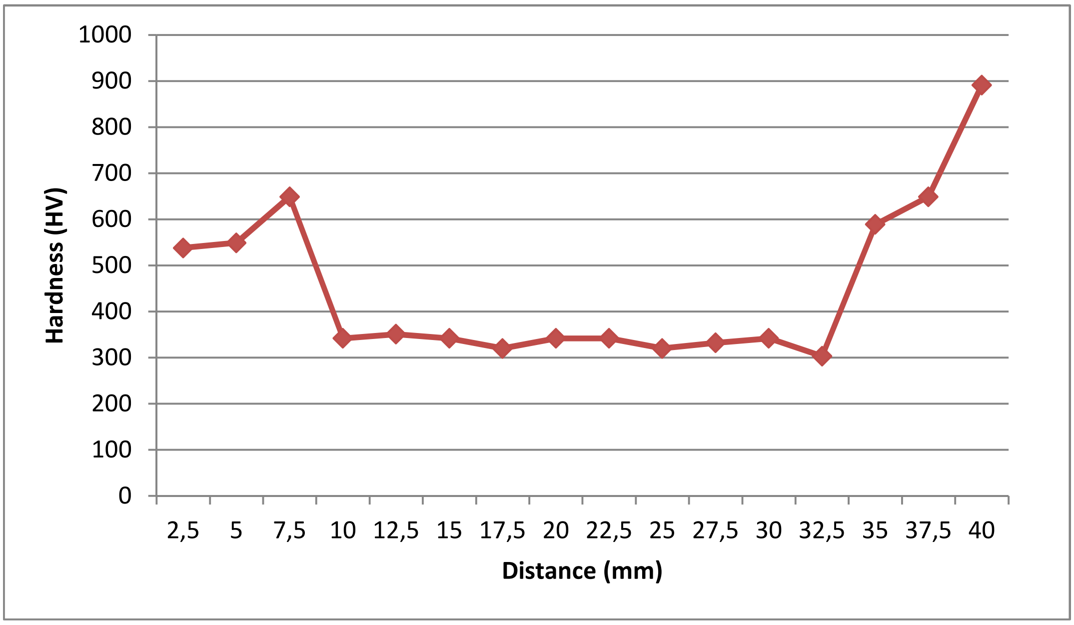

Figure 7. Rear Axle hardness distribution A

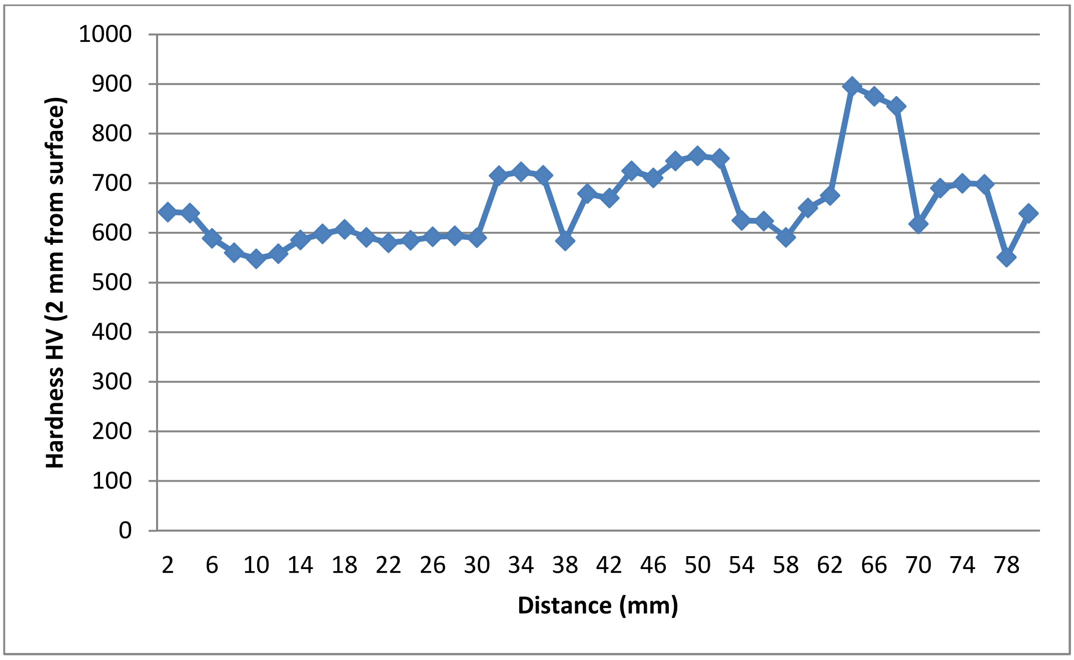

Figure 8. Rear Axle hardness distribution B

The distribution of the hardness values observed in Figure 7 does not look uniform. Surface hardness on different left and right sides is different, namely 538 HV and 891 HV indicating that surface hardening is not evenly distributed on the shaft.

The distribution of the hardness value observed in Figure 8 There is a fluctuation in the value of hardness which is tested 2 mm from the edge (surface) by 40 circular points using a Vickers hardness tester. The highest hardness value is 885 HV and the lowest is 548 HV.

Discussion

On the surface of the shaft, the martensite phase tends to be grouped and uneven. There is a ferrite phase around it, indicating an uneven surface hardening process. This indication is reinforced by a hardness test where the hardness distribution on the edge of the shaft is different between one edge and the other edge namely 438 HV and 891 HV. On the edge area test the highest hardness value was 885 HV and the lowest value was 548 HV. The deviation of the value of violence that is not reasonable, reinforces the indication that the beginning of crack initiation occurred at the edge area with the discovery of cracks on the shaft surface and there were beach mark / coastline and striation patterns near the initial crack.

At the boundary of the surface with the center area of the shaft, the buildup of the bainite and martensite phases as well as a bit of cementite evenly surrounds the shaft. An indication that the boundary area between the edge and center of this shaft is hard evenly than the shaft edge area. In the hardness test found in the boundary area the value of the hardness is stable and evenly that is an average of 549 HV.

In the middle part the dominant phase shaft is ferrite and pearlite. The middle part has uniform hardness with an average hardness value of 350 HV, lower than the edge and shaft boundary which is an average of 589 HV.

The shape of the shaft fracture surface on the outer diameter and inner diameter shows differences in fracture characteristics from the SEM test analysis, where the broken surface area of the outer diameter is relatively flat with beach mark lines and V shape and there is cleavage on the shaft indicating the tough outer shaft but brittle / brittle and the fault diameter area of the dimples pattern has plastic deformation indicating the inner diameter of the shaft is more resilient.

Chemical composition test between standard AISI 4140 and failed part, found higher carbon composition than standard AISI 4140 0.045% which is 0.52%. The effect of a higher carbon content than the AISI 4140 standard is to increase resistance to wear but reduce toughness and increase brittleness.

Conclussion

Based on visual investigation, material hardness test, material composition test, and microstructure test and SEM test concluded that shaft failure is a manufacturing factor during the heat treatment process and is categorized as fatigue failure due to dynamic repetitive stresses.

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