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Effect of Normalizing on Semi Float Axle Shaft Performance - Case Study

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Abstract

The primary function of axle shaft in semi float rear axle is to transmit the power to wheels. These shafts would experience the torsional load along with bending load as well. Hence shaft metallurgical structure at case & core would become very important. The objective of this study is to understand the importance of normalizing heat treatment process carried out at post forging treatment. Bench test Performance study conducted by comparing the normalized shaft Vs non-normalized shaft. Ultimate torsion test, torsional impact test & shaft side impact test conducted on both the shafts. The ultimate torsion test result shows JAEL of normalized shaft is 5106Nm & non normalized shaft is 4718Nm. The drop is 7.6%. The torsional impact test shows peak torque of normalizing shaft is 9384Nm & non normalizing shaft is 8386Nm. The drop is 10.6%. The side impact test shows impact energy of normalized shaft is 2903 Jouls & non normalized shaft is 2321Joule. The drop is 20%. The fractography shows ductile fracture in normalized shafts & non-normalized shaft shows brittle. This is evident by complete fracture (breakage) in non- normalized shaft & bend in (not broken) normalized shaft. Micro structural comparison shows the grain size in normalized shaft is finer but non- normalized shafts are coarser. During the impact test, the fracture occurs by sudden heavy load applied on part surface, causes the tremendous shock load in the shaft. As a result microcracks generates at multiple points & propagates through the grain boundary. This phenomenon reduces fracture toughness characteristics & hastens the dislocation move-ments. Normalized shaft having finer grain size, shows sufficient ductility before final fracture but non normalized shaft do shows brittle nature due to coarser grain size. Relatively non normalized shaft shows lesser ability to absorb impact energy, JAEL torque & peak torque. The coarser grain size is easing the fracture in non- normalized shaft.

Introduction

Semi float rear axle shaft would experience both torsional load & bending load in their service. Many times impact load will come on these members suddenly during running of vehicles in the field & could lead to failure if the shaft quality is inferior particularly the metallurgical micro structure & grain size. Medium carbon steel SAE 1541 material grade with axle shaft diameter 35mm are considered for this study. This study is conducted to understand the importance of normalizing heat treatment which is done after forging. The purpose of normalizing treatment is to homogenize the micro structure & grain size across the shaft section. As this shaft will undergo surface hardening treatment later ,the normalizing defines the core structure of the shaft . Also the surface hardening takes place at the body of the shaft, the flange region where the impact load is applied remains same as normalized structure. Normalized shaft 3 number & non normalized shaft 3 number are processed & bench validated for ultimate torsion test to understand the JAEL (Johnson Apparent Yield Limit) behavior, torsional Impact test to understand the peak torque & shaft side impact test to understand the impact energy absorbed by the shaft. The bench validation test results are compared for all these 6 samples. Correlation is established between the grain size & performance of the shaft. Axle shafts assembly is shown in figure-1.

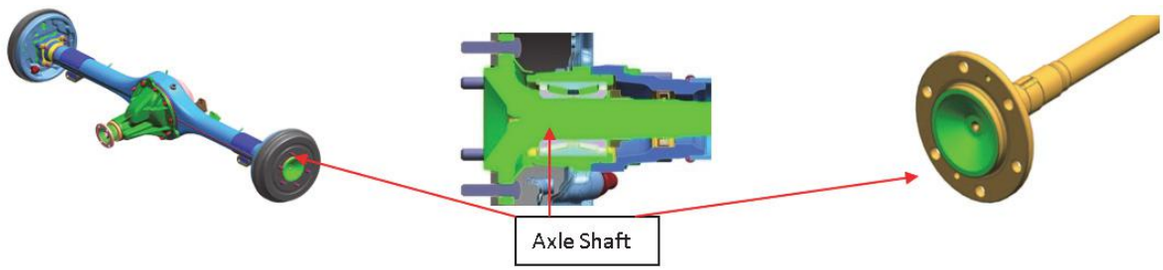


Figure 1 Axle Shaft Assembly & Cross Section View.

ABBREVIATIONS: JAFL – Jhonson Apparent Elastic Limit

Manufacturing of Axle Shaft

Typical process flow diagram for axle shaft is as below,

Raw Material→Hot Forging→Normalizing Heat Treatment→Machining-→Induction Hardening & Tempering→Machining & Grinding-→Final Inspection

Heat treatment is carried out after forging to homogenize the material microstructure & grain size [1]. Normalizing heat treatment cycle is shown in figure-2, The normalizing is not conducted in inert atmosphere as there will be machining all over the surface of the shaft later. Normalizing results in reducing the forging heterogeneity & particularly the uniform phase & fine grain size which is one of the prime responsible factor to absorb the impact energy [2].

Normalizing Heat Treatment Process Cycle for Axle Shaft

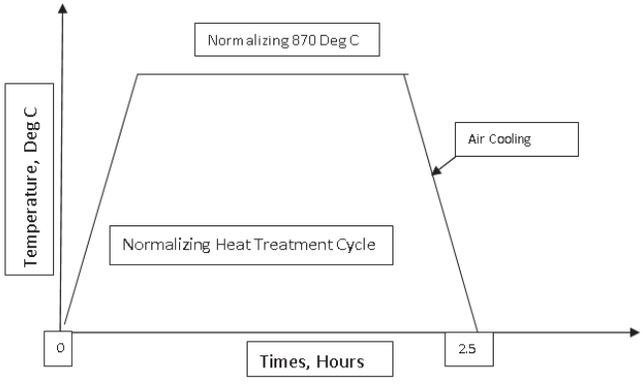


Figure 2 Normalizing Heat treatment Cycle.

Bench Test Validation

Bench validation is conducted for both normalized samples & non normalized samples particularly side impact test, ultimate torsion test & torsional impact tests. Three samples SN1, SN2, SN3 of normalized & three samples SN1, SN2, SN3 of non normalized shafts are validated for bench tests. The average test results of these shaft samples are taken for the study & ease of interpretation.

The side impact bench validation set up is shown in figure-3. In this case the axle shaft is hold vertically using fixture facing the flange portion upward, load is applied from the top on the flange surface as shown in the figure-3. The impact energy absorbed by the shaft is noted. 2903 Joules for normalized shaft & 2321 Joules for non normalized Shaft observed indicate that normalized shaft has better impact energy absorption ability than the non normalized shaft.

In ultimate torsion test load is applied gradually on the shaft at forward direction. Test set up is shown in figure 5. Monitor the applied torque & degree of rotation of shaft until fracture occurs.

In ultimate torsion test, the JAEL (Johnson Apparent Elastic Limit) [3] is plotted from the graph as shown in figure-4. Since it is difficult to determine the true elastic limit accurately, especially in hardened steel which does not show sharp yield point, the late Prof. J. B. Johnson proposed another point which he called the "apparent elastic limit." JAEL is point at which the rate of change of strain is 50 % greater than the initial rate of change of strain. It is that point on the curve at which the slope of the tangent from the vertical is 50 percent greater than that of the straight line part of the curve.

In figure 4, the best straight line possible through straight line portion of curve is drawn. Measured distance ob where curve departs from straight line drawn. Multiply ob dimension by 1.5 and lay it off along same oc dimension. Draw a line through origin and point described in oc. Draw a line parallel to this line and tangent to the curve. The torque value to the tangent point is the JAEL yield torque.

In this case, JAEL torque obtained for the normalized shaft & non normalized shafts are 5106 Nm & 4501 Nm respectively. The results indicates that the normalized shaft has better JAEL torque than the non normalized shaft. Normalizing treatment increases the elastic limits due to finer grain size.

In torsional impact test, peak torque is determined. The load is applied on the shaft at forward direction; the peak torque is noted prior to the fracture of the shaft. The test set up is as shown in figure 6. The normalizing shaft has peak torque

9384 Nm & non normalized shaft 8386Nm indicates normalized shaft has better peak torque than non- normalized shaft.

Since this side impact bench validation is more significant test in deciding the effect of normalizing heat treatment, this test is discussed more than other two bench validation tests.

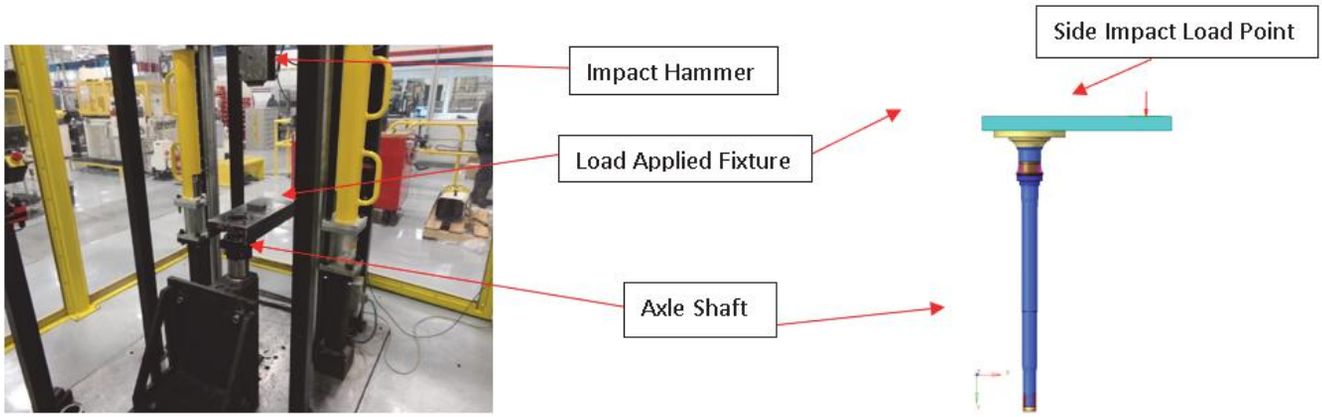


Figure 3 Side Impact Test bench Set up (Right), Loading of Shaft shown (Left).

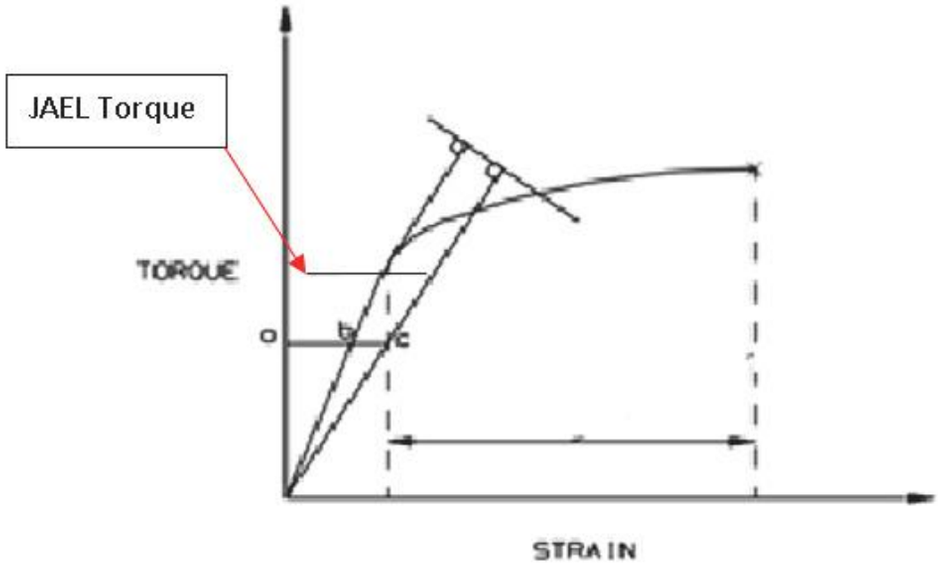


Figure 4 Ultimate Torsion Test- Johnson's Apparent Elastic Limit showing the JAEL torque.

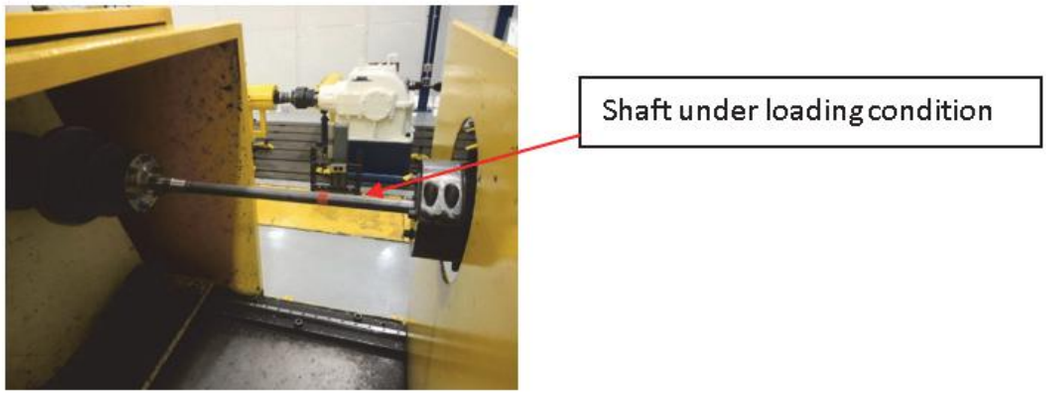


Figure 5 Ultimate Torsion Test Set up.

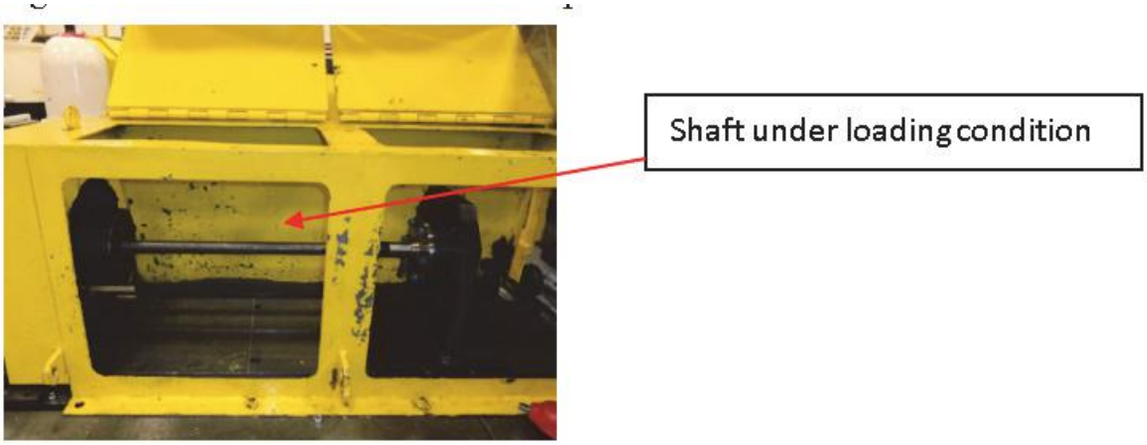


Figure 6 Torsional Impact Test Set up

Performance Comparison

The bench validation performance for normalized shaft & non normalized shafts are compared for side impact test, ultimate torsion & torsional impact tests in table-1. The average value of SN1, SN2, SN3 samples have been taken for all these test results, for ease of interpretations. The bench validation test results show that the normalized shafts are better in performance than the non-normalized shaft. The drop in JAEL torque in ultimate torsion test is 7.6%, In torsional impact test the drop in the peak torque is 10.6% and in the side impact test the drop in the impact energy absorbed is 20%. These results are plotted in graphs as shown in figure-5. The significant drop is observed in side impact energy test indicates that normalizing treatment contributes more for Impact Loading condition. This is due the fine grain size produced by the normalizing structure. Also it is observed that part to part variation of JAEL torque, peak torque & impact energy in normalized shafts samples are lesser than that of non normalized Shafts samples, This tells us the homogeneity of microstructure & grain size in a batch of normalizing treatment.

Table 1

Bench Validation Test Results Comparison

Bench Tests	**Normalized**	**Non-Normalized**
Ultimate Torsion	JAEL, Nm	JAEL, Nm
SN1	5604	5595
SN2	5215	4501
SN3	4501	4059
Average Value	5106.67	4718.33
Drop in JAEL Torque, Nm	388.33	
JAEL % Drop	7.60	
Torsional Impact	Torque Peek, Nm	Torque Peek, Nm
SN1	10109	9697
SN2	9050	8027
SN3	8995	7435
Average Value	9384.67	8386.33
Drop in Torsional Impact Torque, Nm	998.33	
Torsional Impact Torque % Drop	10.64	
Side Impact Test	Energy, Joules	Energy, Joules
SN1	2087	3468
SN2	2705	2218
SN3	3919	1279
Average Value	2903.67	2321.67
Drop in Side Impact Energy, Joule	582.00	
Impact Energy Value % Drop	20.04	

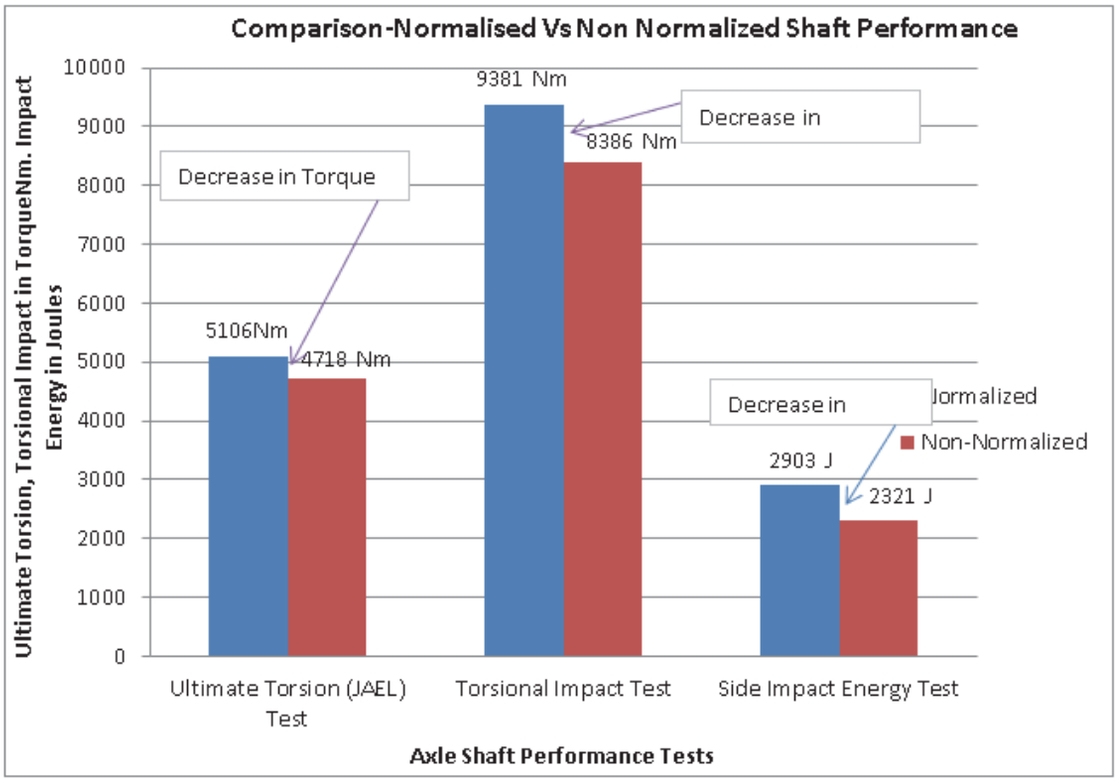


Figure 7 Bench Validation Test Results Comparison showing Drop in Characteristics.

Fracture Analysis & Metallurgical Evaluation

All the bench validated shafts are analyzed for fracture analysis to understand the fractography [4]. The fracture location of normalized & non normalized shaft are same near the flange area as shown in figure-6C. The fracture mode is bending type in both the shafts initiated at the case & propagated towards the core. Generally, crack initiation chance at core region is very remote because the stress level is highest at the case than the core in the Shaft. Hence typical breakage of the shaft happens at the case only. The normalized shafts are not completely broken but bending happened near the flange region as shown in figure-6A. The fracture surface broken intentionally after the test to study. Non normalized shaft completely broken to two pieces as shown in Figure-8A. The fracture surface of normalized shaft is ductile in nature with dull appearance where as that of non normalized shafts are brittle in nature with bright appearance. The metallurgical evaluation of induction harden characteristics do not show any differences between normalized & non normalized shaft particularly for case depth, hardness & micro-structure. The core grain size show significant difference between the normalized & non normalized shaft. [5]. The normalized shaft show grain size 6 or finer at the core as shown in figure-7 but non normalized shaft shows zero grain size as shown in figure-9. Grain size evaluation performed in accordance with ASTM E112.

Result Discussion [6],[7]

The reason for the difference in behavior of shaft performance is the poor quality of non normalized shaft. In such fracture mechanism, the fracture toughness plays a vital role because in both the shafts crack initiated at the surface but not propagated in normalized shaft but propagated quickly in non normalized shaft. This is evidenced by normalized shaft bends & non normalized shaft broken to two pieces. This indicates normalizing heat treatment increases the fracture toughness when there is impact load applied on the part. Also

the fracture is ductile in nature in normalized shaft where as brittle in nature in non normalized shafts. The phenomenon is when sudden impact load applied on the shaft, the tremendous shock waves generates exceeding the material ultimate strength at the grain boundary & grains region. Due to this action the dislocations pile ups at the grain boundaries & dislocations movement takes place when the applied stress exceeds the material ultimate strength causing the micro cracks at the grain boundaries. These cracks propagate based on the resultant force acting on the region of fracture. The non normalized shaft having coarser grain size, the grain boundary per area is less (ref figure 10). Due to this crack reaches its final destination faster than the normalized shaft, Hence its bench validation test results shows lesser torque carrying ability & lesser impact energy absorption ability. In case of normalized shaft, due to the finer grain, the grain boundary per area would be more (ref figure 11). Due to this the crack travel time increases & crack will take longer time to cause its final fracture. In this case, the cracks do not propagate to final fracture as applied stress weakens & becomes lesser in magnitude than the material strength during its journey. Hence in this case study, the normalized shaft show bend, not the fully fracture. So with this case study it is evident that the coarser grain size lowers the grain boundary per area & number of grains per area & fracture toughness characteristics where as fine grain increases the grain boundary per area & number of grains per area & fracture toughness characteristics.

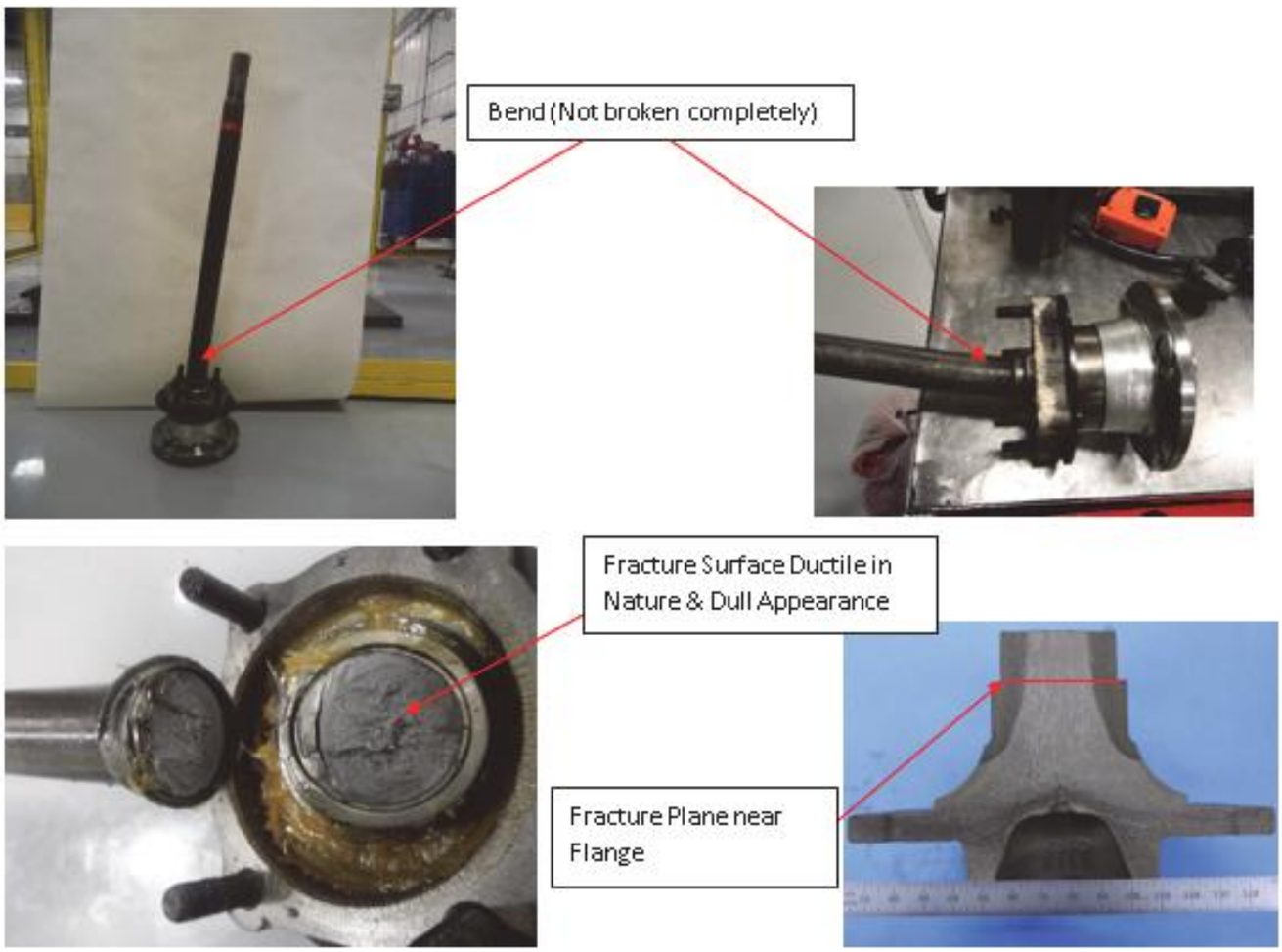


Figure 8 Side Impact Test Normalized Shaft showing Bend near the Flange (Not Full Broken), Shaft Showing Fracture Surface & Location Plane.

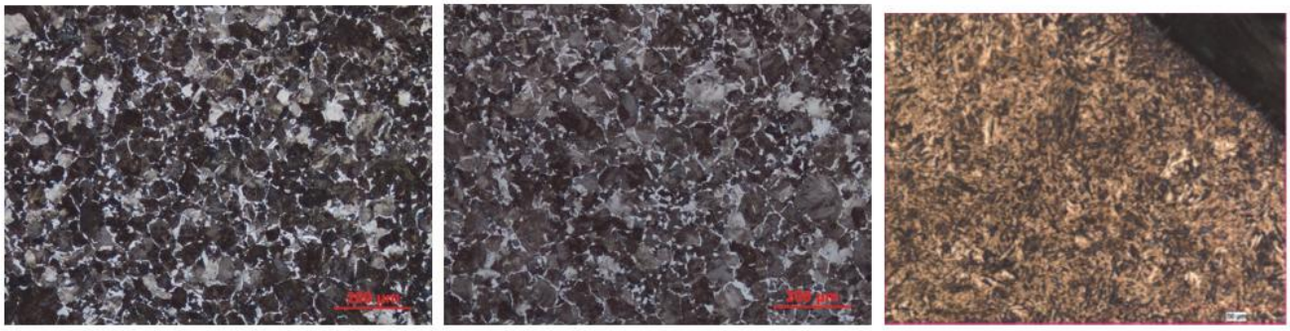


Figure 9 Side Impact Test Normalized Shaft showing Grain Size Finer ASTM No. 6 at Core (Left), Case-Martensite (Right).

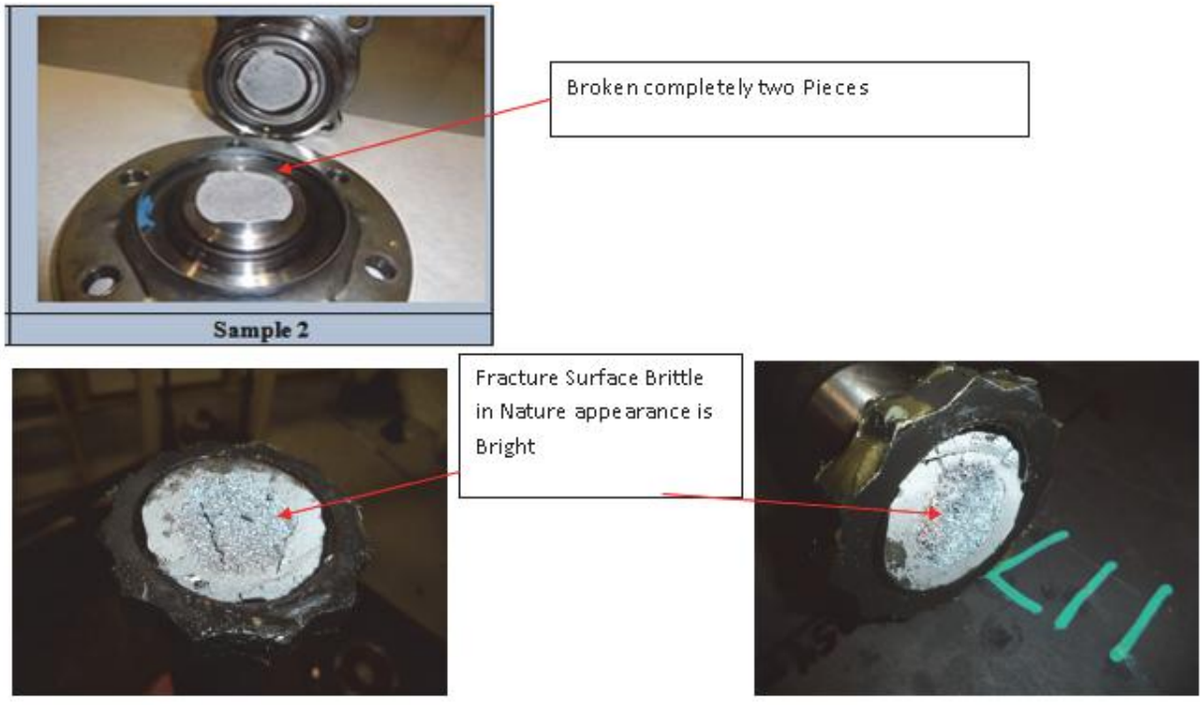


Figure 10 Side Impact Test Non Normalized Shafts broken completely two Pieces, Shaft Showing Fracture Surface.

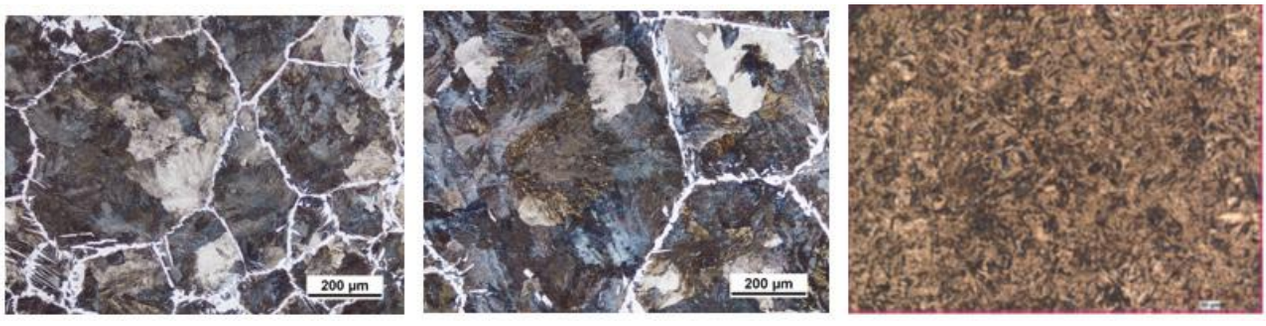


Figure 11 Side Impact Test Non-Normalized Shaft showing Grain Size ASTM Number Zero at Core (Left), Martensite at Case (Right).

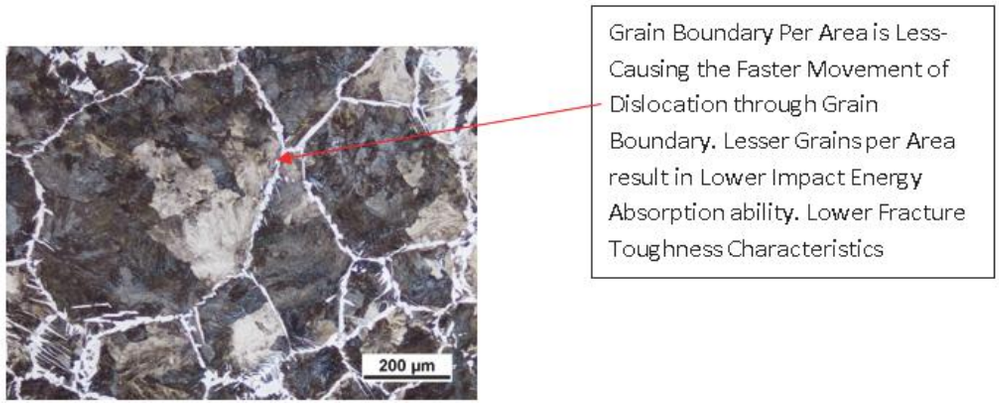


Figure 12 Non Normalised Shafts Coarser Grain show Lesser Grain Boundary & Grains per Area

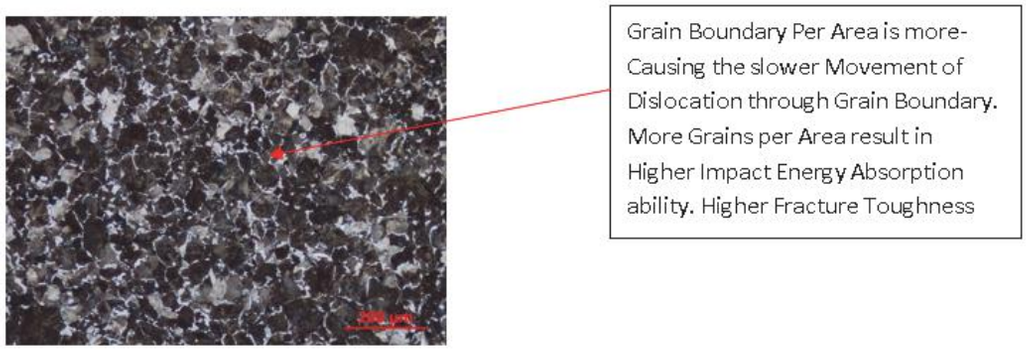


Figure 13 Normalised Shafts Finer Grain show More Grain Boundary & Grains per Area.

Summary & Conclusion

The effect of normalizing heat treatment on axle shaft performance is studied. The normalizing heat treatment after forging is the key treatment in deciding the quality of the shaft Core. The bench test is conducted for both normalized shaft & non normalized shaft for ultimate torsion to understand the JAEL behavior, Torsional impact to understand the peak torque holding capability & side impact test to understand the impact energy absorption behavior of the shafts. The fracture analysis is compared & understood that normalized shaft show finer grain size where as non normalized shaft show coarser grain size. Mechanism is understood by discussing the fracture toughness factors, grain size, grain boundary per area, number of grains per area and dislocation movements. The shaft bench performance comparison shows normalized shafts performed better than non normalized particularly when impact load is applied. This case study can be used while deciding the Heat treatment for post forged components.

References

[1] ASM International, ASM Hand Book Vol 4- Heat Treatment

[2] ASM International, ASM Hand Book Vol 20- Material selection & Design

[3] Thomas Neumann, Kenneth Pickett, Rapid Tempering of Automotive Axle Shafts, Heat treating Progress, March/April 2006

[4] ASM International, ASM Hand Book Vol12- Fractography

[5] ASM Hand book Vol 9- Metallography & Microstructure

[6] C. Kendall Clarke Æ Don Halimunanda, Failure Analysis of Induction Hardened Automotive Axles, DOI 10.1007/s11668-008-9148-3, metalconsult.com

[7] Yeild Strength- Stength of (Mechanics) of Materials, Materials Science, https://www.engineersedge.com