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Development and Performance Analysis of Commercial Vehicle Axle Shaft

Ozan Seren[1,2], Gürbüz Güzey[2] and Emel Kuram[1*]

[1.] *Department of Mechanical Engineering, Gebze Technical University, Kocaeli, 41400, Turkey*
[2.] *Department of Engineering, Parsan Makine Parçaları Sanayii A.Ş, İstanbul, 34903, Turkey*

Research Article

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Contact
* Corresponding author
Emel Kuram
kuram@gtu.edu.tr
Address: Department of Mechanical Engineering, Gebze Technical University, Kocaeli, 41400, Turkey

Abstract

Axle shafts, which are an important part of the vehicle's powertrain system, transfer the torque to the wheels and enable the vehicle to move. In this respect, the design of the axle shaft to be used in a new vehicle is of great importance for vehicle manufacturers. When a cylindrical shaft is torsionally loaded, the shear stress is highest at the surface of component and zero at the center. Therefore, these axle shafts are exposed to an induction hardening process that enables only this superficial case to have its properties changed, remaining the core zone with its material original characteristics. Current study presents the results of a project aimed at developing and evaluating the fatigue life of axle shaft that belongs to a commercial vehicle. Developments were made on the existing axle and the results were examined using experimental tests and finite element analysis method. In line with the improvements made, the developed axle shaft has 331.7% more fatigue life than the existing axle, while the cost is 24% lower. According to these results, more attention must be paid to material selection, induction hardening process, stress concentration and surface condition of axle shaft in the design.

This study involves many disciplines such as design, manufacturing, analysis, testing, etc. It is very important to ensure communication between all these disciplines in the production of the product. The output obtained from one discipline becomes the input of another discipline. In the cumulative sum of all these inputs, the optimum level of parts is obtained. For this reason, this study, which processes all these disciplines together, is very valuable.

Keywords: Axle shaft; Cyclic; Fatigue; Induction hardening; Stress concentration; Surface condition

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Introduction

The design and analysis are of great importance in product development and improvement processes. It has incessantly upgraded and diversified its product offerings through development in technology and manufacturing processes. Developments in the automotive sector depend on the economy and security. Due to the advancement of technology, new systems or components are added to vehicles [1]. Hence, it is important to design and develop new components to meet rapidly expanding (and changing) Heavy and Medium Duty Vehicle markets.

The aim of part design is a required function as well as expected life to be performed. As long as these parameters are satisfied, optimization of the parts as regards shape, material and size can be thought. Yet, when there is problem i.e. failure before expected life or unsatisfied performance then various aspects such as material grade, hardness of material, hardening processes, manufacturing processes, heat treatments and operating conditions must be needed to investigate. If there is no variation in these, the details such as type of failure, nature of fracture and analysis of induced stress and arrive at a conclusion must be studied whether some modifications can do the job or total redesign of the part is required.

The movement of vehicles can be provided by transferring the torque produced by engines to tires after some modification. The transfer and modification system of vehicles is called as power transmission system and have different constructive features according to the vehicle’s driving type which can be front wheel drive, rear wheel drive or four-wheel drive. The elements of the system include clutch, transmission system, propeller shaft, joints, differential, drive shafts and tires. Each element has many different design and construction properties depending on the vehicles [2].

Axle shaft is rotating shaft usually employed to connect the wheels and differential to transmit wheel motion and drive force [3]. They transmit driving torque to the wheels and maintain the position of the wheels relative to each other and the vehicle body.

In most commercial vehicles, circular motion of the drive wheels is achieved through axle shafts that are an integral part of the rear axle. Shafts fit into the tire's wheel well near the differentials and run along the bottom of the vehicle. Shafts are often exposed to very large torque during operation because of heavy loads or sudden acceleration and are therefore manufactured from various grades of hardened steel [4]. These shafts pass through millions of cycles and are subjected to torsional stresses [3]. Because of fluctuating (cyclic) loading [5], axle shafts are prone to fatigue failure [3]. In extreme cases, cracks in the shafts while driving can cause the vehicle to overturn [4].

Rear axle shaft is the critical part of every vehicle because it receives torque from the engine. It is placed inside the housing [6]. Failure analysis is of great importance for the safe operation of mechanical component and the prevention of accidents. By determining failure modes and causes, effective measures can be recommended to extend the service life of shafts and eliminate possible accidents. Fatigue fracture is the most common failure mechanism for shafts because of the effect of cyclic (repeated) loads on shafts under normal operating conditions. It is cumulative damage rather than one-time load damage. Fatigue failure takes place at stress levels below yield or ultimate strength of material. Fatigue damage is dependent on several factors such as improper design, material and common defects [7]. Tawancy et al. [4] studied the failure of the rear axle shaft of an automobile. Researchers declared that the cause of failure could be improper heat treatment of the shaft, leading to poor ductility contributing to brittle fracture. Nanaware et al. [8] carried out the failure analysis of the rear axle shaft of 575 DI tractor. Researchers stated that the failure in the rear axle shaft was caused by inadequate spline root radius, leading to crack initiation and subsequent crack growth under cyclic loading. They indicated that the optimum value for the spline root radius of 1.5 mm (according to finite element analysis) should be employed in combination with shot peening of the spline region and the incorporation of boron to the material to improve the fatigue strength. Clark et al. [9] performed the failure analysis of induction hardened automobile axles. These researchers concluded that single overload failures usually occurred at the flange radii, while fatigue failures occurred at the axle journal surface at the outer edge of the roller bearing.

Many studies of the rear axle shafts were conducted. Chemical analyses, examinations of mechanical properties, microstructure and breaking surface (fractography), as well as EDX analyses were carried out as part of damage-analysis examinations. The failure or fracture of a rear axle shaft can cause death and injuries in transit and significant financial losses. An improper design or other metallurgical causes usually lead to a rear axle shaft fracture. Other researchers conducted some simulation studies to estimate the damage. The simulations allowed them to conclude that the damage and stress zones were similar [10].

Parsan Engineering Division, is facing one such case of failure of this type of rear axle shafts (Figure 1) of a commercial vehicle. The cyclic test results of the existing axle did not meet the sufficient acceptance criteria. The developed axle shaft contains changes in many aspects such as material grade, hardness distribution of material, manufacturing operations, heat treatments and surface conditions etc. As a result, more positive results were obtained with the developed axle shaft.

In this study, parameters such as surface roughness, stress concentration factor and hardness depth depending on the material, which affect torsional fatigue strength, were discussed. In line with these parameters, the axle shaft was developed with actions such as material change and process change. After this stage, the existing axle and the improved axle were compared with finite element analysis (FEA) programs. With the positive results of the analysis, the production of the axle shaft was carried out and laboratory tests were carried out with accelerated test data. With both verification methods, a more suitable axle shaft in terms of cost and durability was developed.

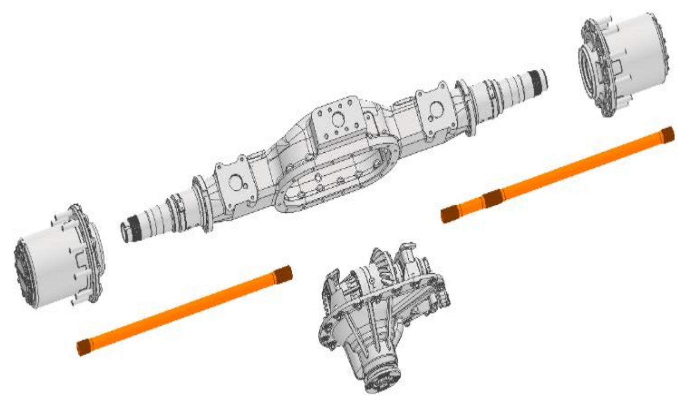

Fig. 1. Heavy duty commercial vehicle rear axle

2. Material and Method

In the commercial vehicle industry, forged steels are widely employed in drivetrain parts such as gears, axle beams, pistons or crankshafts. In order to increase fatigue resistance and minimize wear, these drivetrain components are usually surface-hardened components such as with induction hardening process, case-carburization process. Induction hardened shafts are appropriate for most torsional loading. Because induction hardening process increases the hardness the surface where it is most needed and it leaves the surface in compression stress, which improves fatigue resistance. Thus, the service life of the part is increased. Because, crack starts from surface. When torsional loading was applied to a shaft, the shear stress is maximum at the surface of shaft and zero at the center of shaft. In the absence of a stress concentrators, stress decreases linearly from the surface to the center. Therefore, only the surface layer needs to be induction hardened to a depth to adequately exceed the applied stress. When the outer layer is hardened, martensitic phase transformation causes it to expand, leaving the outer layer in compression stress.

When compared in terms of mechanical properties, the material of the developed axle has lower strength. (Figure 2). However, with the depth of hardness, an axle shaft that is more resistant to fatigue resistance is obtained. For this reason, the hardening process is an important criterion for fatigue strength.

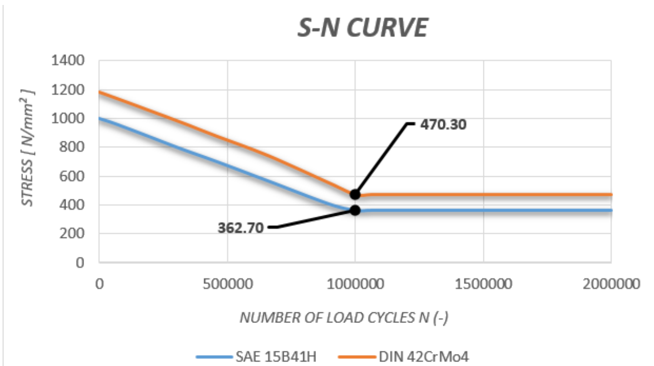

Fig. 2. SN curves of shaft materials before hardening process

2.1. Current Axle Shaft Material & Induction Hardening

DIN 42CrMo4 (AISI 4140) medium-carbon steel is widely employed in automotive industry. This material is appropriate for induction hardened powertrain parts. The chemical composition and mechanical properties were measured at Parsan Material Laboratory and are tabulated in Table 1 and Table 2. Results for induction hardening of DIN 42CrMo4 axle shaft are presented in Figure 3.

Table 1. Chemical composition for DIN 42CrMo4

Element	C	Si	Mn	Cr	Mo	Ni	Al	Cu
Weight (%)	0.40	0.30	0.83	1.15	0.23	0.15	0.026	0.14

Table 2. Material properties of DIN 42CrMo4

Young's modulus (GPa)	210
Poisson's ratio	0.3
Yield Strength (MPa)	928
Ultimate Tensile Strength (MPa)	1045

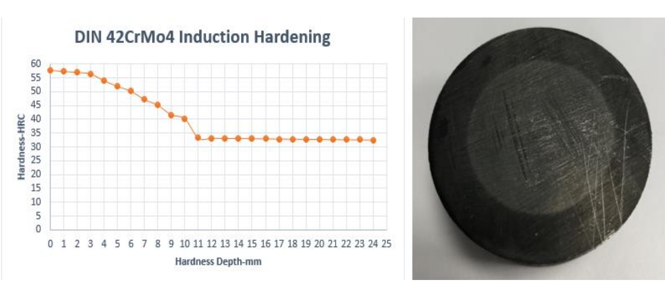

Fig. 3. DIN 42CrMo4 induction hardening

2.2. Developed Axle Shaft Material & Induction Hardening

Detailed view of developed axle and current axle are shown in Figure 4. From figure, the solid axle shaft was made in the form of a block and its cross-section was circular. Transition fillets were seen in several positions of the shaft, acting as stress concentrators. Also surface condition factor is so important for axle shaft fatigue life. SAE 15B41H is suitable for induction hardened components. Gradient-distributed hardness is provided with this material grade and this brings many advantages. Investigations have validated that surface-hardened axles can achieve excellent fatigue resistance and lightweight design which can be attributed to their gradient microstructure and mechanical properties. It is well known that fatigue damage mainly depends on local microstructural features, including the grain dimension and morphology, together with the grain orientation and loading boundary [11]. Material utilized for manufacturing the axle was SAE 15B41H and chemical composition and mechanical properties of the axle shaft were measured at Parsan Material Laboratory and are tabulated in Table 3 and Table 4. Results for induction hardening of SAE 15B41H axle shaft are presented in Figure 5.

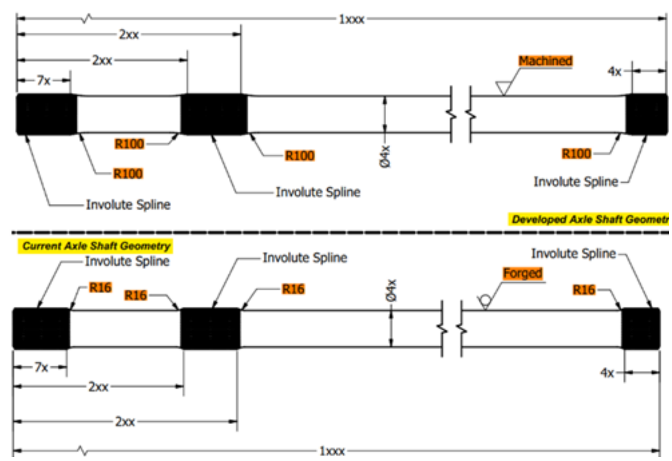

Fig. 4. Geometry of Developed & Current axle shaft

Table 3. Chemical composition for SAE 15B41H

Element	C	Si	Mn	Cr	Mo	B	Al	Cu
Weight (%)	0.39	0.23	1.59	0.15	0.02	0.0014	0.026	0.13

Table 4. Material properties of SAE 15B41H

Young's modulus (GPa)	210
Poisson's ratio	0.3
Yield Strength (MPa)	638
Ultimate Tensile Strength (MPa)	806

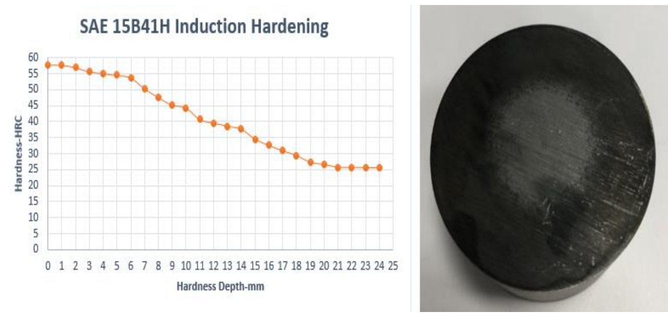

Fig. 5. SAE 15B41H induction hardening

3. Effects of Surface Conditions

It is well established practically that the fatigue process is very sensitive to surface state. Fatigue life is strongly influenced by the surface finish and surface treatment. The reason why fatigue is a surface-sensitive process lies in the fact that fatigue cracks always nucleate from free surfaces of cyclically loaded metals [12].

Surface roughness condition is a highly significant parameter affecting fatigue resistance, as fatigue failures start from the surface. Surface finish factors must be evaluated to justify the fatigue analysis outputs. Surface finish correction factor k_s used to represent the surface roughness of the component. It is presented on figures that classify finish by means of manufacturing types such as polished, rolled, forged or machined [13]. The surface roughness measurement results of the current and developed axle are shown in Figure 6.

Fig. 6. Comparison of axle shaft surface condition

4. Effects of Stress Concentration Factor

The stress concentrators are geometrical irregularities that cause an increase in the average effort that should be present in regions near these discontinuities, the relationship between the maximum stress that occurs and the average effort that should occurs is defined as stress concentration factor; which is determined by experimental or analytical methods and presented in graphical form for ease interpretation [14].

All mechanical parts are structures include some form of stress concentrators which can cause cracks to form. The parameters such as stress analysis and stress concentration factor are connected with only the ratio of the geometric dimensions to the loads. These parameters are independent of size. Transition radii, stress concentration factors resulting from these radii, and FEA results are presented in Figures 6 and 7. The radius values in the transition zone on the axle shafts and the stress concentration factors resulting from these radius values are determined as 1.18 for R16 and 1.04 for R100. In a construction design, lower stress concentration factors should be preferred as much as possible (Figure 7).

Static linear analyzes of axle shafts under 8800 Nm torsional load were carried out, and the results of the transition zones were examined and compared. In this examination, it was observed that higher stress occurred in the R16 transition zone. The resulting high stress caused lower fatigue life in the axle shaft (Figure 8).

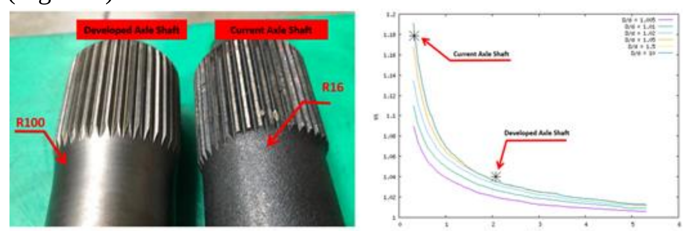

Fig. 7. Comparison of axle shaft transition radius & Kt factors

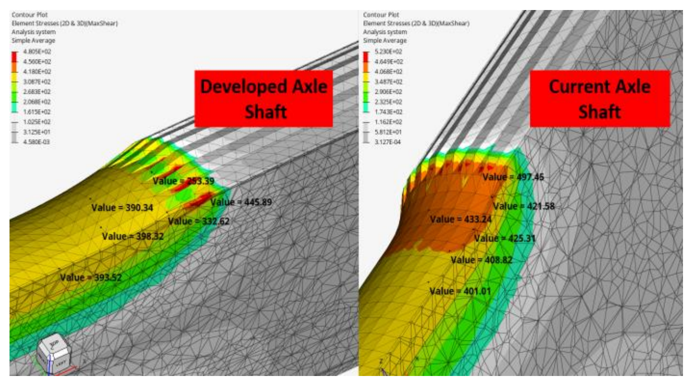

Fig. 8. Shear stresses at transition zone

5. Laboratory Test and FEA Analysis

Fatigue is the progressive and localized structural failure that occurs when a material is exposed to repeated loading. Fatigue is the most important failure mode for mechanical parts under repeated loading. It is important to recognize that fatigue failure is a probabilistic event, and that a proper design against fatigue should involve analyses, synthesis and testing. In order to increase confidence in the results, the finite element analysis (FEA) and laboratory tests should simulate the real situation.

Fully reversed torsional loading was applied for both axles. Torque, shear stress and twist angle diagrams for this loading are shown in Figure 9.

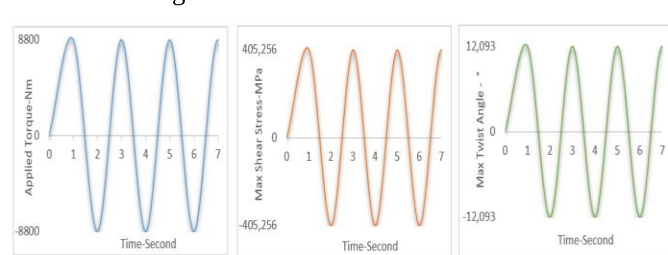

Fig. 9. Torque, shear stress and twist angle diagrams

5.1. Laboratory test

To meet certain reliability levels in the automotive industry, vehicles must be designed and tested using loading conditions based on realistic customer usage. Today, different test acceleration methods have been developed in order to perform vehicle durability tests in shorter periods of time and for different road conditions.

At automotive sector, in the new product design or improvement of existing products, companies create a virtual model of the product firstly and analyze them in computer environment. Then there is a necessity to validity these analyses with real life test applications on prototypes of new products. In that very competitive sector, test cost and time are the most important among the parameters. When we consider the cost of the test applications especially in structural parts, accelerated vehicle tests puts itself one step forward (Figure 10).

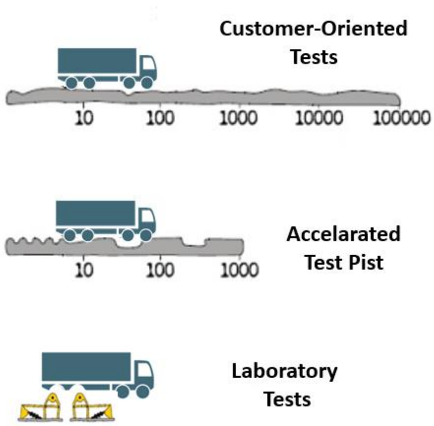

Fig. 10. Accelerated durability test methods

Torsional cyclic loading tests of the axle shafts were conducted in Parsan Engineering Division. Fatigue test was performed on torsional fatigue testing machine (Figure 11).

For heavy vehicle types, the maximum conditions for axle shafts are approximately 23kNm. For fully reversed dynamic loading, the torque is 36-40% of failure torque [15]. Torque was applied to the axles in the range of +8800 Nm / -8800 Nm and at 0.5 hertz.

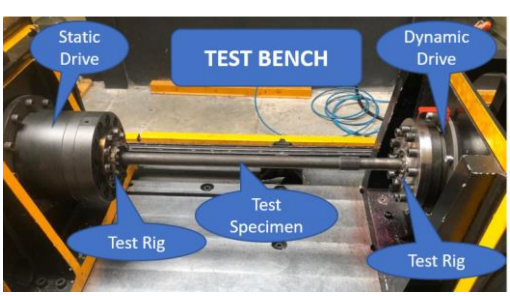

Fig. 11. Laboratory test bench

6. Fatigue FEA Analysis

Fatigue analysis is a significant part of finite element analysis. Subjecting a material or structure to cyclic loading and measuring the fatigue damage and determining fatigue region are conducted by Fatigue FEA analysis. Designating the material and structural fatigue properties and behavior is so important for component service life assessment and fracture mechanics analysis in design stage. In order to properly forecast the fatigue life of a component, the expected minimum stress, mean stress, maximum stress, stress amplitudes, stress ranges, and correlations are needed to know firstly. This is where analysis, specifically FEA structural analysis, can help (Figure 12).

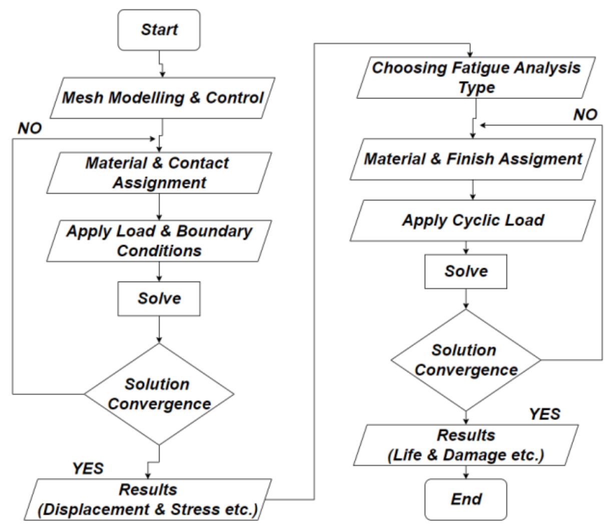

Fig. 12. Fatigue FEA analysis flow chart

Torsional load creates stress at the maximum outer diameter of the part. It is also known that the fatigue phenomenon starts from the outer surface. For these reasons, different induction hardening profiles are available for both axle shafts. The induction hardening process provides an increase in hardness on the outer surface of the part, and thus the yield and tensile strengths of the material increase. Material Assignment is an important step of FEA analysis. In order for the convergence to be correct, the mechanical properties of all layers must be introduced separately.

Samples taken from axle shafts were scanned for hardness at Parsan Material Laboratory. Then, yield and tensile strength values were obtained with the empirical formulas. Depth-based hardness distributions and the yield and tensile strength values corresponding to these hardness values were determined from the samples taken from the axle shafts and are presented in Tables 5, 6. Meshing was performed in FEA analyzes depending on the layers in the distribution. (Figures 13, 14). In the fatigue analysis of axle shafts, average yield and tensile strength values were assigned while defining the material of these layers. To evaluate fatigue behavior for the axle shaft, first, a 3D model was established in accordance with its geometry. Model is depicted in Figure 4.

The model was meshed, boundary conditions and torsional loading were applied, and cyclic loading was conducted via Altair HyperWorks and HyperLife software. TET 10 / 2.5 mm solid mesh used for mesh modelling. A total number of 1094352 elements were utilized in the developed axle shaft model. A total number of 944104 elements were utilized in the current axle shaft model. A great number of elements were employed for fillets zones due to presence of stress concentrations and high stress [16]. Cyclic Loading and Surface Condition factor was carried out through the Hyperlife.

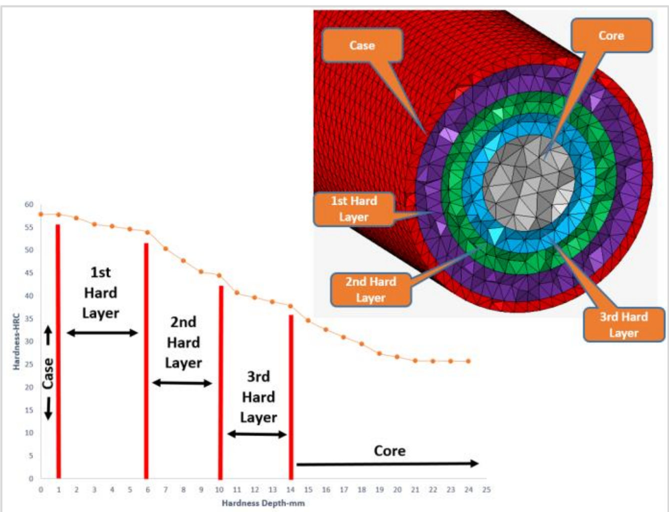

Fig. 13. SAE 15B41H hardened shaft FE model

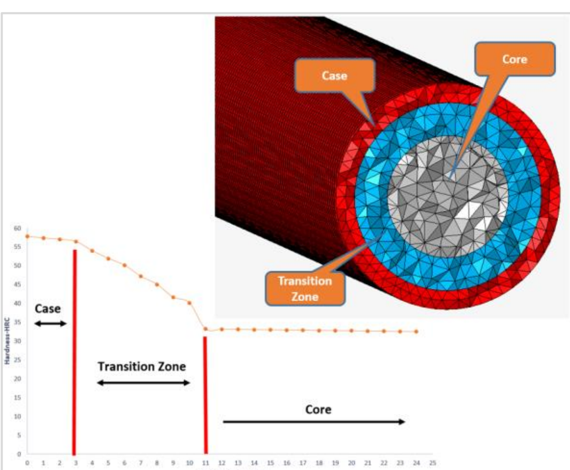

Fig. 14. DIN 42CrMo4 hardened shaft FE model

Table 5. SAE 15B41H hardened shaft mechanical properties

Distance From Surface (mm)	Hardness (HRc)	Yield Stress (MPa)	Tensile Stress (MPa)	Mean Yield Stress (MPa)	Mean Tensile Stress (MPa)	Layer
0	57.76	1845.0	2037.9	1844.4	2037.3	Case
1	57.74	1843.8	2036.8			
2	56.99	1788.0	1986.8	1666.5	1877.7	1st. Hard Layer
3	55.64	1692.7	1901.3			
4	55.15	1660.3	1872.1			
5	54.51	1618.5	1834.5			
6	53.79	1573.3	1793.7			
7	50.31	1376.5	1614.7	1219.6	1468.4	2nd. Hard Layer
8	47.62	1246.8	1494.6			
9	45.21	1144.3	1398.2			
10	44.35	1110.7	1366.2			
11	40.67	981.1	1240.6	934.3	1194.1	3rd. Hard Layer
12	39.60	947.5	1207.4			
13	38.62	918.1	1178.1			
14	37.66	890.5	1150.3			
15	34.54	808.8	1066.7	680.7	929.6	Core
16	32.56	762.3	1018.1			
17	30.92	726.8	980.3			
18	29.39	695.7	946.9			
19	27.34	657.2	904.7			
20	26.58	643.6	889.6			
21	25.76	629.3	873.7			
22	25.71	628.5	872.8			
23	25.66	627.7	871.9			
24	25.61	626.9	871.0			

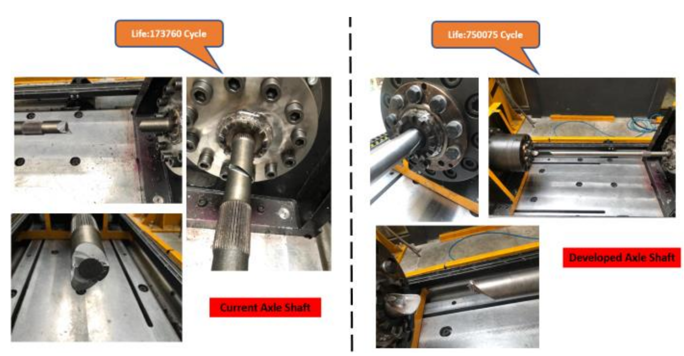

Fig. 15. Current & Developed axle laboratory test life results

Table 6. DIN 42CrMo4 hardened shaft mechanical properties

Distance From Surface (mm)	Hardness (HRc)	Yield Stress (MPa)	Tensile Stress (MPa)	Mean Yield Stress (MPa)	Mean Tensile Stress (MPa)	Layer
0	57.79	1847.8	2040.4	1800.3	1997.8	Case
1	57.36	1815.5	2011.5			
2	57.02	1790.4	1989.0			
3	56.43	1747.5	1950.5			
4	53.99	1585.3	1804.6	1251.8	1496.2	Transition Zone
5	51.94	1464.0	1694.6			
6	50.15	1368.4	1607.2			
7	47.20	1228.0	1477.1			
8	45.07	1138.9	1393.1			
9	41.64	1012.9	1271.8			
10	40.17	965.2	1224.9			
11	33.24	777.8	1034.3	769.4	1025.6	Core
12	33.18	776.5	1033.0			
13	33.12	775.2	1031.6			
14	33.07	773.9	1030.3			
15	33.01	772.5	1028.8			
16	32.95	771.3	1027.5			
17	32.89	769.9	1026.0			
18	32.84	768.6	1024.7			
19	32.78	767.4	1023.4			
20	32.73	766.2	1022.1			
21	32.68	765.0	1020.9			
22	32.63	763.9	1019.7			
23	32.57	762.6	1018.4			
24	32.52	761.4	1017.1			

7. Results

In this study, the material and manufacturing process of the axle shaft were changed. Depending on the material, the induction hardening depth and profile varied. Depending on the manufacturing process, the surface roughness of the shaft and the transition zone where stress concentrations were high were developed. As a result of the tests carried out in the laboratory environment, the current axle shaft failed at 173760 cycles. The developed axle shaft failed at 750075 cycles. These cycle values were indicated on the interface screen of the testing machine. Fatigue life analyzes of 2 different axle shafts were carried out using the finite element method. In line with FEA, the current axle shaft had a minimum fatigue life of 248600 cycles and the developed axle shaft had a minimum fatigue life of 598500 cycles. FEA results and laboratory test results of current and developed axle shafts are presented comparatively in Table 7.

Table 7. Comparison of axle shaft life results

Axle Shaft	Laboratory Test Results	FEA Fatigue Life Results
Current Axle Shaft	173760 Cycle	248600 Cycle
Developed Axle Shaft	750075 Cycle	598500 Cycle

Based on laboratory tests, the current axle failed at 173760 cycles. The developed axle failed at 750075 cycles. A 331.7% fatigue life increase was achieved with the developed axle shaft. Both axle shafts failed in the transition zones, as expected. The strain change due to loading was higher at each end of the axle shaft than in the middle of shaft (Figure 15).

In torsional loading, the crack starts from the outer of the part and progresses towards the inner of the part. When the failure type of the current axle shaft was examined, it could be seen that there were multiple crack origin points and the crack started from these points and created an overload zone in the center of the shaft. It can be interpreted that the reasons for there being more than one crack starting point are the surface conditions and stress concentration of the axle shaft. In addition, since the hardness depth was less than the developed axle shaft, the crack progressed faster in the core part (Not Hardened Zone) and the axle shaft failed (Figure 16).

When the failure type of the developed axle shaft was examined, it could be seen that there was a single crack starting point and the crack started from this point and created an overload zone on the other side of the shaft cross-section. Due to better surface conditions and less stress concentration factor, the axle shaft had a failure as seen in Figure 16. In addition, since the hardness depth was greater than the current axle shaft, the crack propagation distance was longer. Ductile fracture could be seen more clearly in the developed axle shaft due to the lower hardness of the core zone [17].

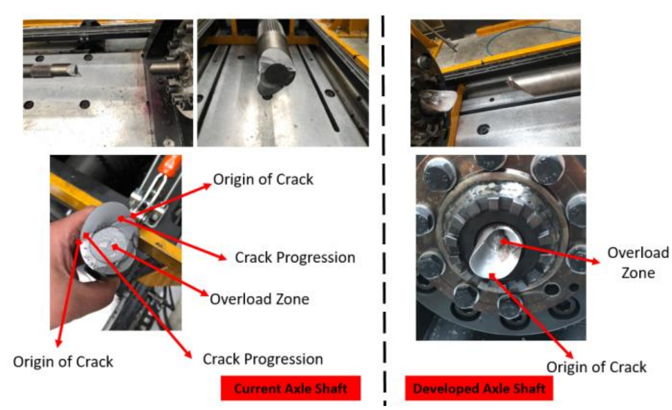

Fig. 16. Current and Developed axle shaft failure analysis

Before examining FEA, it is necessary to know the loading type and fatigue analysis approach. There are three different approaches: Strain-life approach (ε−N), Stress-life approach (S−N) and Fatigue crack growth approach. This study proceeded through Stress-life approach (S–N).

Material testing was performed by some researchers to establish fatigue damage behavior in 1999. These tests were based on the exhaustion of material ductility and estimated the instantaneous damage in material for a given stress amplitude or range [18].

The stress amplitude and mean stress calculation formulas that occur in line with fully reverse loading are shown in Figure 17 [19]. Mean stress and stress amplitude values are significant factors affecting the fatigue life of the part. In torsional loading, the mean stress value being close to zero means higher fatigue life.

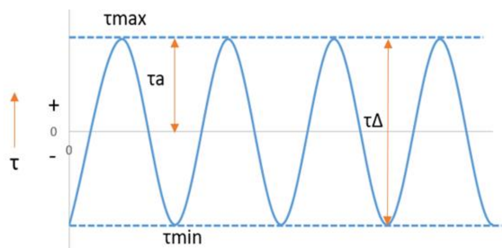

Fig. 17. Fully reversed loading type

Eq. (1) was used to calculate cyclic stress range:

$$\tau\Delta = \tau max - \tau min \quad (1)$$

Eq. (2) was used to calculate cyclic stress amplitude:

$$\tau a = \frac{(\tau \max - \tau \min)}{2} \quad (2)$$

Eq. (3) was used to calculate mean stress:

$$\tau m = \frac{(\tau \max + \tau \min)}{2} \quad (3)$$

Eq. (4) was used to calculate stress ratio:

$$R = \frac{\tau \min}{\tau \max} \quad (4)$$

As a result of FEA, it was predicted that the current axle shaft would failure after 248600 cycles and the failure zone would be in the spline transition zone (Figure 18). Although the failure zone is similar, considering the FEA results, the developed axle shaft will failure after 598500 cycles. (Figure 19).

Fully reverse loading was applied to the examined axle shafts. Since it is a fully reverse loading, the mean stress value is 0 and the stress amplitude is equal to the [Max Stress-Min Stress] value. The stress here was the maximum shear stress value. The mean stress value of the current axle shaft is 0 MPa and the stress amplitude value is 901.3 MPa (Figure 18). For the developed axle shaft. The mean stress value is 0 MPa and the stress amplitude value is 823.5 MPa (Figure 19).

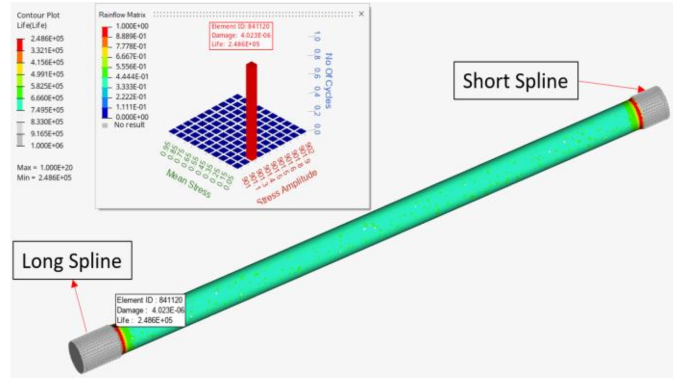

Fig. 18. Current axle FEA cyclic life results

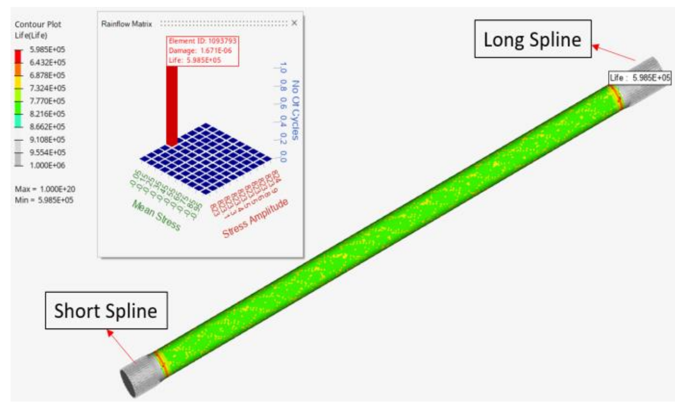

Fig. 19. Developed axle FEA cyclic life results

Transition between spline and shaft is provided with R16 radius for the current axle shaft. Providing these transitions with R16 radius caused higher stress concentration factor. Higher stress concentration factor means lower fatigue resistance. Transition zones were also obtained by the forging process. The fiber structure, which positively affects the fatigue life resulting from the forging process, was ineffective due to the high stress concentration factor (Figure 20).

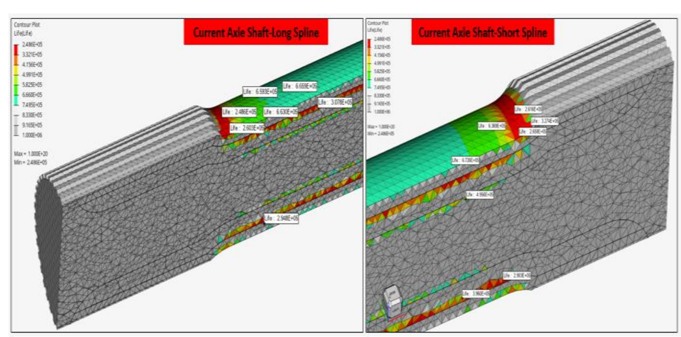

Fig. 20. Current axle shaft transition zone FEA cyclic life results

The R100 radius in the spline transition zone of the developed axle shaft was obtained by the machining process. In the machining process, there was no fiber structure that comes from the forging process and will positively affect the fatigue life. Despite this situation, the smooth transition zone created less stress concentration factor. This caused the shaft to have a longer fatigue life (Figure 21).

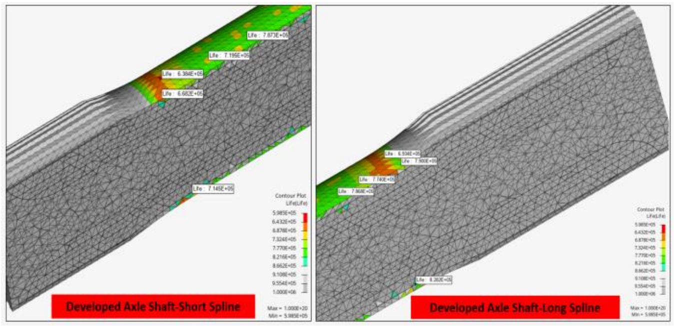

Fig. 21. Developed axle shaft transition zone FEA cyclic life results

8. Conclusions

With the development of the automobile industry, automobile reliability has received more and more attention. Automobile reliability is a complex comprehensive performance, which refers to the ability of the automobile to complete the specified functions within the specified time and under the specified service conditions. Broadly speaking, it includes fatigue reliability, maintainability, and preservation. Among the indexes of automobile reliability, fatigue reliability is the top priority [20].

When evaluated within this framework, the study is a good example for fatigue life. The axle shaft was developed by taking into account the parameters affecting fatigue strength. FEA of both axle shafts were performed and the results were examined. Then, these parameters were reflected on the developed axle shaft and its manufacturing was ensured. Accelerated tests of the current and developed axle shafts were carried out in a laboratory environment and the results were observed. In today's conditions, the cost and fatigue life of a part are of great importance. This development study carried out in this direction is very valuable. According to laboratory test results; with the axle shaft developed by reverse engineering, a 331.7% increase in fatigue life was achieved. According to FEA results, a 140.7 % increase in fatigue life was achieved with the developed axle shaft.

In many markets, firms compete over time by expending resources with the purpose of reducing their costs. Sometimes the cost reducing investments operate directly on costs. In many instances, they take the form of developing new products that deliver what customers need more cheaply. Therefore, product development can have the same ultimate effect as direct cost reduction [21].

When evaluated within this framework, the study is a good example for cost reduction. The current axle shaft, the material of which is DIN 42CrMo4, is roughly produced by upset forging, turning (Only Spline Diameters), spline cold rolling and hardening manufacturing processes. The developed axle shaft, unlike the current axle shaft, is produced from SAE 15B41H material and no forging process was applied. Considering the material cost and manufacturing costs, a 24% lower cost axle shaft was produced.

The ever-rising demand for increased fuel efficiency and a reduction in the harmful emission of greenhouse gases associated with energy generation and transportation has led, in recent years, to a resurgence of interest in light materials and new lightweight design strategies. In the automotive industry, the need to reduce vehicle weight has given rise to extensive research efforts to develop lighweighted components for vehicle driveline system parts.

Lightweight construction is a key factor to success mainly in the transportation sector but also in general engineering, machine tools, and architecture. Design, materials, and manufacturing processes have to be considered in an integrated manner. Based on these and similar studies, lightweighting studies can be carried out.

In this study, the role of FEA and tests performed with accelerated test parameters in part design and improvement was also emphasized. In addition, this study serves as a reference for the design and improvement of other parts of the vehicle.

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Conflict of Interest Statement

The authors declare that there is no conflict of interest in the study.

CRediT Author Statement

Gürbüz Güzey: Conceptualization, Supervision,
Ozan Seren: Conceptualization, Writing-original draft, Validation, Formal analysis, Investigation
Emel Kuram: Data curation, Project administration

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