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RESEARCH ARTICLE

Computer aided numerical damage analysis of the axle shaft

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Abstract: Axle shafts are one of the most important components used in power transmission. These components, which are used in many different places, can cause great costs in case of failure or fracture. Among the main reasons for these undesirable situations are wrong axle shaft selections and inappropriate metallurgical properties. In order to prevent such unfavourable situations and to investigate the causes of damages, numerical analyses offer cost-effective solutions. In this study, the mechanical damage analysis of the axle shaft and the characteristic changes in steel materials as a result of static loading were investigated numerically. In order to observe the mechanical behaviour of the axle shaft under various loading conditions, mechanical tests should be supported by numerical analysis. Because the physical causes of damage development can be understood through numerical analysis. The aim of our study is to reach the most suitable values in the design of the axle shaft made of AISI 1035 steel. Values were obtained by performing numerical analyses of the axle shaft designed with Solidworks program. As a result of the analysis, it was observed that deformation occurred at the ends of the axle.

Keywords: Static load, design, numerical analysis, axle.

1. Introduction

Today, while transportation is constantly moving forward, costs are increasing. The aim is to obtain light structures that are suitable in terms of weight, sufficient in strength, and to save materials and energy. Axles are not only used in transport vehicles but also in buses, automobiles, and forklifts. Axles must be of a reliable structure due to their place of use. The external effects that the axles are generally exposed to are the applied loads. Damage is the inability of a structure, machine, or its parts to perform their functions [1]. Damages usually occur as a result of forcing parts by mechanical or chemical effects [2]. Damages in structural elements or machine parts occur due to mistakes made in any of the stages such as design, production, and assembly [3]. Axles are very important in vehicles. Axles are steel shafts that transmit the rotational movement from the differential to the wheels in motor vehicles. It is the part that transfers the power and torque from the engine to the wheels. It carries the entire load in vehicles, including passengers [4]. Öndürücü and Kanbir emphasized that the material used in damaged machine parts is very important in their studies. As a result, they tried to determine the cause and mode of damage by evaluating the data obtained by mechanical experiments and metallographic examinations. They found that the part was damaged due to excessive stress [5]. In this study, Mercan focused on the causes of damage by examining the damage mechanisms of welded metal materials and aimed to create a systematic approach to use in damage analysis [6]. In this study, Dursun and Özbay performed damage analysis using a graded failure model to determine the tensile strength of bolted composite materials. The damage model was prepared with Ansys APDL software. Finite element analyses were performed using the Hashin damage criterion. Comparing the results with experimental studies, they reached similar results [7]. In this study, Turan and Kaman experimentally and numerically investigated the damage analysis of single-lap adhesive bonds obtained with adhesive in order to join composite boards. They performed the numerical work in the ANSYS program, which coordinates with the Finite Element Method. While the damage analysis, they used Hashin damage theory for composites and maximum principal stress damage theory for adhesive material. As a result, they observed that the changes in the adhesion surface areas were effective in the damage loads [8].

Yalçın et al. aimed to determine the causes of damage in 1.2367 hot work tool steel injection runner bushings, which cracked due to repeated mechanical and thermal loads, by using finite element analysis and optical research methods. They have made changes in the design of the runner bush in order to prevent crack damage. As a re-

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sult, by making improvements in the design phase, they observed a reduction in the stresses formed in the injection runner bushings and achieved improvements in the face of mechanical loads [9]. In this study, Parnas et al. applied crack propagation tests to determine the mechanical properties of composite materials. A Finite Element model was created to investigate hollow composite materials. They developed a progressive damage analysis to perform a realistic simulation. They discussed the results obtained from the simulations in detail by choosing the most accurate model [10]. In this study, Şen and Pakdil experimentally investigated the damage analysis of laminated composite materials connected with a single bolt under moment loads. As a result, they observed that the lowest damage loads occurred in composite specimens without preloading torque [11].

In our study, numerical damage analysis of the axle shaft was performed. The investigated axle shaft is made of AISI 1035 steel. These shafts, which are used as machine elements in various places, are frequently preferred in load-carrying. As stated in the above-mentioned studies on various machine elements, each damage has its unique situation. The damage analysis study carried out here will bring along solutions for the prevention of damage to the axle shafts.

2. Material and Method

Axle shafts are one of the important parts of powertrains. In order to be able to move a vehicle, transmission organs are needed to increase the torque produced in the engine by the required amount and transmit it to the wheels and to give the vehicle traction as much as its structure allows [12]. Axle shaft damage constitutes 26% of the damages that occur in a vehicle [13]. Although the axles produced from composite materials are extremely light, the most used material in axle manufacturing is steel [14]. Tempered steels are unalloyed and alloyed machine-building steels that are suitable for hardening, especially in terms of carbon content, and show high toughness at a certain tensile strength at the end of the curing process [15].

Mechanical damage analysis has become an important engineering field with scientific methods [5].

Damage is the failure of a structure or structural element to perform its expected functions under service conditions. The causes of industrial faults that because damage are shown in Figure 1 [16].

After the damage occurs, necessary inspection activities are carried out at the location of the damaged system. The main stages to be followed in the damage analysis are shown in Figure 2 [16]. The damage analysis report is prepared as a result of the investigations. All data obtained should be recorded in the damage analysis report.

The distribution of the damages that are frequently encountered in the industry in terms of percentiles according to their causes is given in Figure 3 [16]. As seen in Figure 3, it has been determined that the highest factor that creates damage is "wrong material selection". Wrong material selection is followed by manufacturing and heat treatment errors.

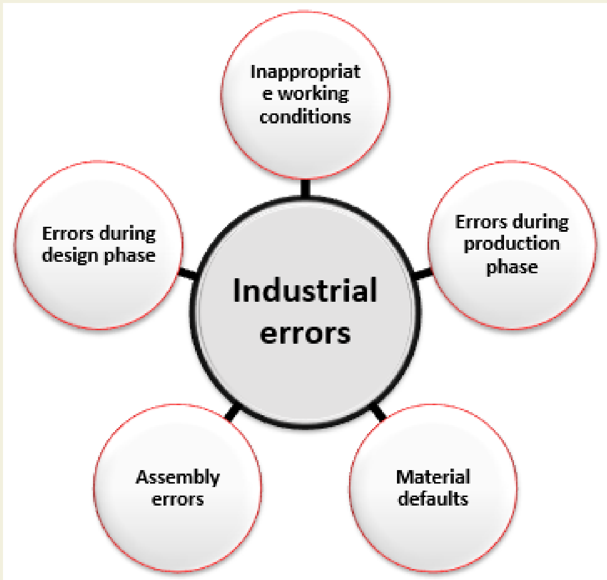

Figure 1. Industrial faults causing damage [16]

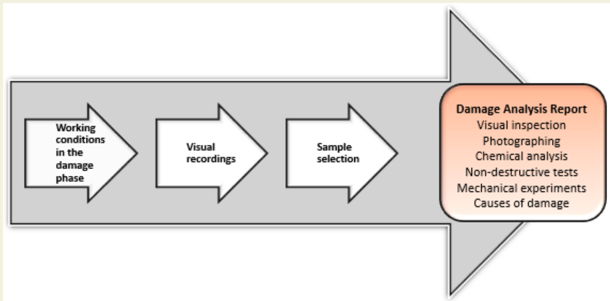

Figure 2. The main stages to be followed in the damage analysis [16]

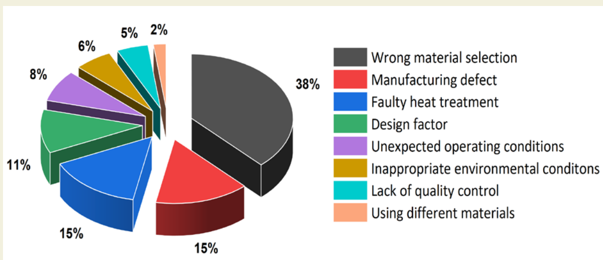

Figure 3. Causes of damage frequently encountered in industry [16].

Major damage mechanisms in axle shafts can be listed as bearing deterioration, overload, seal deformation, impact, and deterioration.

Axles are used in vehicles to transmit the movement from the differential to the wheels. Axle shafts are parts that work during vehicle movement. Axle shafts, which are

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one of the powertrains of vehicles, are exposed to different loads and therefore, some damage and malfunctions may occur in the axle shafts. Axles are subjected to both torsional and bending stresses. Materials used to manufacture axle shafts must be tough to lean the pressure and loads caused by heavy weights [17]. A tough material must be produced to resist the varied stresses, resist spline wear and provide great strength to fatigue. Medium carbon alloy steel having such elements as molybdenum, chromium, and nickel is a common selection [18]. Since axles conduct the force that rotates the wheels, each vehicle requires axle shafts in order to operate properly [19]. Axles are principally responsible to transfer the rotational force and power to move the vehicle [20].

In this study, the axle shaft manufactured by utilizing AISI 1035 steel was investigated. Static analysis investigations were started after the fracture occurred in the shafts after a certain working period. The mechanical damage analysis of the axle shaft and the characteristic changes in steel materials as a result of static loading were investigated numerically. In order to observe the mechanical behaviour of the axle shaft under various loading conditions, mechanical tests were supported by numerical analysis. AISI 1035 sheets of steel are utilized in the construction of machine parts such as bolts, bearer mechanisms, axle shafts, and gear wheels. AISI 1035 sheets of steel can be hardened by induction or flame [21]. Chemical compositions, hardness values obtained from the material surface, and the hardening depth of the steel material have major importance in the selection of steel materials to be heat treated [22].

The chemical composition of AISI 1035 steel is given in Table 1.

Table 1. Chemical composition of AISI 1035 steel

Chemical composition of AISI 1035 steel				
Material	Elements			
AISI 1035	C	Si	Mn	Fe
Min. (wt.%)	0.32	0.15	0.50	99.03
Max. (wt.%)	0.39	0.35	0.80	89.46

In addition to its superior hardening properties, high load bearing capacity and toughness are sought in tempered steels. In order to obtain high hardening values for tempered steels, carbon is added at a higher rate than other steel types. While the machine elements perform the functions expected from them, the surfaces of the parts are exposed to higher stress and higher abrasive forces compared to their inner parts. When these stresses and forces exceed the surface strength limit of the material, cracks begin on the material surface. However, the increase in the load of the vehicle and the pressures it will be exposed to in potholes and bumps should also be considered [23]. Mechanical properties of AISI 1035 steel are given in Table 2.

Table 2. Mechanical properties of AISI 1035 steel

Mechanical properties of AISI 1035 steel			
AISI 1035	Diameter (mm)	Yield Strength(N/mm^2)	Tensile Strength (N/mm^2)
Min.	100	275	490
Max.	160	-	635

The damaged axle shaft manufactured by utilizing AISI 1035 steel is given in Figure 4. It was observed that the damages occurred at the tip of the shaft.

Figure 4. Damaged axle shaft

The model and applied loads of the axle shaft which are given in Figure 5 were determined by using the Solidworks program.

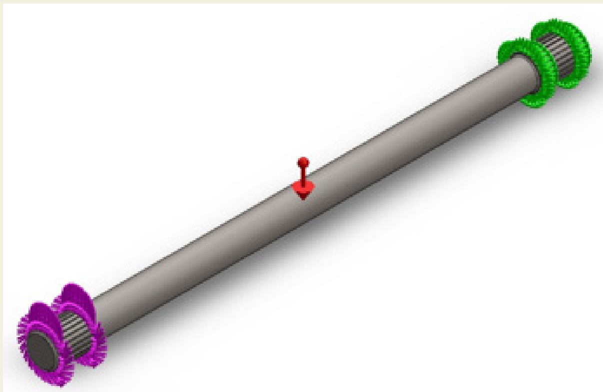

Figure 5. Axle shaft modelled in Solidworks

The volumetric and mass properties of the axle shaft are given in Table 3.

Table 3. Volumetric and mass properties of the axle shaft

Volumetric and mass properties of the axle shaft		
Mass	Volume	Density
20,0878 kg	0,00255896 m^3	7.850 kg/m^3

After the geometric model of the axis was created, static analyses were made using the determined mechanical properties of the material.

3. Results and Discussion

Static analyses are analyses to examine mechanical properties such as compression, tensile, and torque. In our study, the results of static analysis using various loads and various support points were examined. Solidworks program was used in the analysis. The head of the axle shaft is fixed and subjected to bending with a force of 250 N from its middle part. After the forces were determined, the part was meshed to be divided into finite elements.

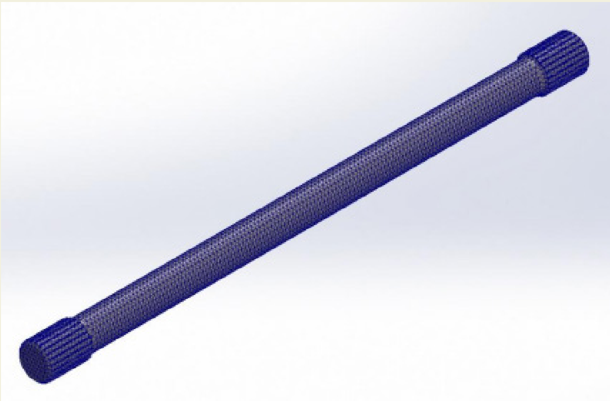

Figure 6. Mesh structure of axle shaft

The mesh structure of the axle shaft is given in Figure 6. There are 92.767 mesh elements and 60.928 nodes in the mesh structure of the axle shaft.

The mechanical properties of the axle shaft are given in Table 4.

Table 4. Mechanical properties of the axle shaft

Mechanical properties of the axle shaft	
Material	AISI 1035
Yield Strength	2.82685e+08 N/m^2
Tensile Strength	5.85e+08 N/m^2
Poisson Ratio	0.29
Mass Density	7.850 kg/m^3
Shear Module	8e+10 N/m^2
Thermal Expansion Coefficient	1,1e-05 /Kelvin

The forces applied to the axle shaft and the reaction forces applied in the direction of the x, y, and z axes are given in Table 5.

Stress analyses of the axle shaft made of AISI 1035 steel were carried out by the Finite Element Method. Von-Mises stress criterion was used as the equivalent stress criterion in the finite element analysis of the axis. Von-Mises criterion for damage analysis is among the widely used and advanced criteria for damage analysis of steel materials. The Finite Element model of the axle shaft is a three-dimensional, tetrahedral SOLID 92 element type with 10 nodes and 30 degrees of freedom in the mesh structure.

Table 5. Axle shaft reaction forces

Axle shaft reaction forces				
	X	Y	Z	Result
Reaction Force (N)	-189,65	-1.641,96	0,678664	1.652,87
Reaction Moment (Nm)	0	0	0	0

The maximum and minimum Von-Mises values obtained at the end of the mesh process are shown in Figure 7, the maximum and minimum displacement values are shown in Figure 8, and the maximum and minimum equivalent strain values are shown in Figure 9.

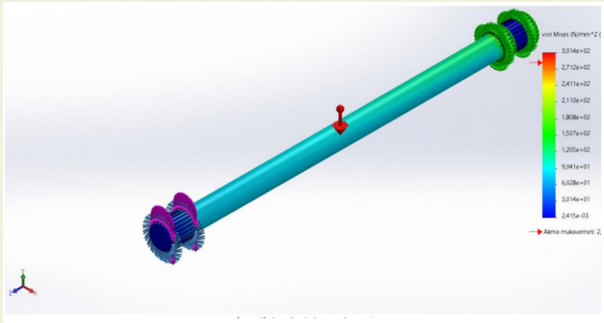

Figure 7. Maximum-minimum Von-Mises strength values

As shown in Figure 7, the maximum stress on the axle shaft was obtained as 3.014x10^2 N/mm^2. The minimum stress on the axle shaft was found to be 2.415x10^3 N/mm^2. The maximum stresses that occur as a result of the constant load applied from the middle part of the axle shaft were observed at the ends of the axle shaft. No damage is expected in the middle parts of the axle shaft and takes place in the safe zone.

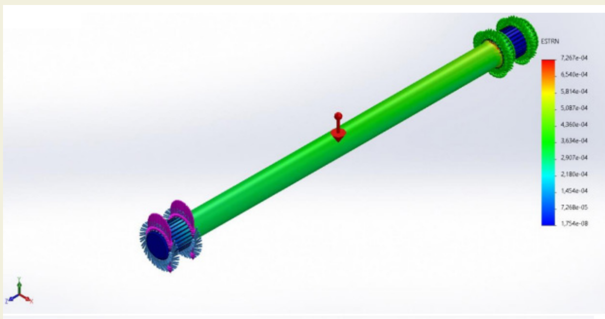

Figure 8. Maximum-minimum equivalent stresses

As shown in Figure 8, the maximum equivalent stress on the axle shaft was measured as 7.267x10^2 N/mm^2. The minimum equivalent stress on the axle shaft was measured as 1.754x10^3 N/mm^2. The maximum equivalent stress values formed as a result of the constant load applied from the middle part of the axle shaft were observed at the ends of the axle shaft. The shaft is considered to be in the safe zone since no damage has occurred in the middle parts of the axle shaft.

In this study, numerical analyses of axles used in heavy-duty vehicles were carried out in Solidworks environment under load, and the following results were obtained.

According to the analysis results, it was observed that the axles were deformed at the ends. It was determined that stress concentration occurred in the damaged parts of the axle. It has been determined that there is no deformation that may pose a danger at the midpoints of the axle shaft.

According to the numerical analysis results, the cause of the damage in the axles; is thought to be caused by the usage error of the vehicle. Sudden loads should be avoided while driving, attention should be paid to the unfavourable road conditions, and attention should be paid to the driver having adequate driving training.

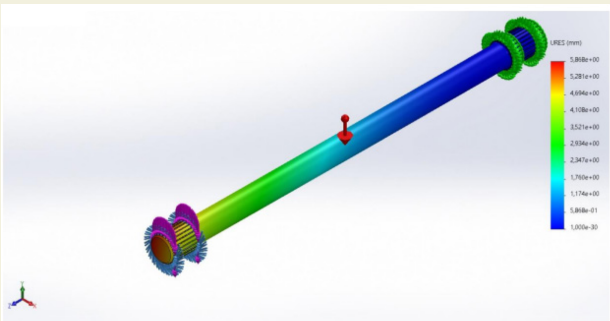

Figure 9. Maximum-minimum displacement values

As shown in Figure 9, the maximum displacement of the axle shaft was measured as 5,868 mm. The minimum displacement on the axle shaft was measured as $1x10^{-3}$ mm. It has been observed that the maximum displacements that occur as a result of the constant load applied from the middle part of the axle shaft are at the end of the axle shaft. It has been determined that the deformations that may occur in the middle parts of the axle shaft will not reach dangerous dimensions. In addition, deformations that occur in the middle parts of the axle shaft do not pose a danger, since the material does not show rigidity.

4. Conclusions

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