Numerical Analysis of Damaged Helical Gear Wheel

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ABSTRACT

In the present day, gear wheels are used to transmit mechanical power in land, sea and air vehicles. Damages can sometimes occur in these gear wheels used in machines. In order to prevent these damages, the use and importance of numerical programs increase with the developing technology. Damages that may occur can be determined in advance through these programs. Thus, material selection can be made with cost-effective analysis. In this study, a damaged helical gear, which is frequently used in car engines, was analyzed numerically. In the study, the damaged helical gear was first modeled with the help of Solidworks program and then static stress analysis was performed with the ANSYS Workbench Finite Elements Package program. In the analysis, the properties of the helical gear made of structural steel were used. As a result of the study, it was determined that the helical gear was broken due to exceeding the safety stress limit.

Keywords: Damage, Helical Gear, Finite Element Analysis, Ansys

Hasarlı Helis Dişli Çarkın Nümerik Analizi

ÖZ

Günümüzde, kara, deniz ve hava araçlarındaki mekanik gücü iletmek için dişli çarklar kullanılmaktadır. Makinelerde kullanılan bu dişli çarklarda bazen hasar meydana gelebilmektedir. Bu hasarların önlenmesi amacıyla gelişen teknolojiyle birlikte nümerik programların kullanımı ve önemi de artmaktadır. Oluşabilecek hasarlar önceden bu programlar aracılığıyla belirlenebilmektedir. Böylece uygun maliyetli analizlerle malzeme seçimi yapılabilmektedir. Bu çalışmada, araba motorlarında sıklıkla kullanılan hasarlı bir helis dişli nümerik olarak analiz edilmiştir. Çalışmada, hasarlı helisel dişli önce Solidworks programı yardımıyla modellenmiş, ardından ANSYS Workbench Finite Elements Paketi programı ile statik gerilme analizi yapılmıştır. Analizde yapısal çelikten yapılmış helis dişlinin özellikleri kullanılmıştır. Çalışma sonucunda emniyet gerilme sınırının aşılması nedeniyle helis dişlinin kırıldığı tespit edilmiştir.

Anahtar Kelimeler: Hasar, Helis Dişli, Sonlu Eleman Analizi, Ansys

1. Introduction

Gear wheels are widely used in various applications of engineering sciences, especially in power transmission. They appear as elements that transmit force and motion in different applications such as clock mechanisms, automobiles, machine tools, aircraft and space technologies (Çaydaş and Seçgin, 2003; Karpat et al., 2002). It is important to understand the causes of damage due to the wide range of uses. Numerically, the gear wheel sizing process requires extensive knowledge, experience and intensive engineering work in various fields (Karpat et al., 2002).

Wilcox and Coleman applied the finite element method (FEM) to the gear wheel to analyze the gear tooth stresses. As a result of their analysis, they calculated the root stresses for symmetrical and non-symmetrical tooth shape (Wilcox and Coleman, 1973). Flodin et al. studied the simulation of wear behavior in helical gears. As a result of their work, they calculated the pressure distribution in each element of the model that they meshed with the finite element method using the Hertz theory (Flodin and Andersson, 2000). Kramberger et al. in their research, developed a numerical model for bending fatigue in gears. In their work, they numerically modeled the formation and propagation of cracks as a result of bending fatigue at the bottom of the tooth (Kramberger et al., 2004). Chen et al. investigated the contact zone stress and torsional stress in helical gears using the finite element method. In their analysis, they found that the gear exhibits bearing contacts due to double crowning on the tooth surfaces (Chen and Tsay, 2002). Rao et al. conducted a study on three-dimensional finite element modeling and stress analysis in helical gears. As a result of their studies, they found the maximum root stresses by analyzing the load distribution and stress for different positions of the contact line in helical gears (Rao and Muthuveerappan, 1993). Mohanraj et al. indicated that the long-term availability of a helical gear depends on the tooth load as well as the sliding speed and the friction coefficient (Mohanraj et al., 2020). Wei Li et al. examined the temperature field generated in the gear according to the errors that occurred during the helical gear manufacturing. They applied numerical analysis with the finite element method and experimental work for verification. As a result of their studies, they observed that the production error increased the temperature fluctuation on the tooth surface and the average contact tension (Li et al., 2018). Lisle et al., Using the finite element method and the strain gauge technique experimentally to determine the effect of bending, concluded that the stress affecting the gear tooth is affected by the tooth geometry (Lisle et al., 2017). Peng et al. developed a model for evaluating the load distribution of helical gears, taking into account tooth changes and misalignments. They verified the data obtained from the model with the help of finite elements analysis. The results indicated that due to the increasing magnitude of profile crowning size, the input torque decreased, the contact pattern became smaller, and as a result, sudden load transitions occurred (Peng et al., 2018). Hwang et al. compared the contact stress generated when a pair of spurs and helical gears rotated, relative to the contact position. They stated that found the highest stress value at the lowest point of the gear in contact with finite element analysis (Hwang et al., 2013). Patil et al. studied the helix angles in helical gears and the contact stress in gears caused by the effect of friction. As a result of their investigation, they found that the contact stress is affected by the friction coefficient and helix angle (Patil et al., 2014). Osman A. investigated tooth breakage at one end of the tooth in his study, where he examined the failure conditions of the AISI 8620 steel helical gear. As a result of his work, he concluded that tooth fracture was due to misalignment of gears (Asi, 2006). Jing Wei thought that the reason for the instability in the helical gears was the transmission failure. To analyze this situation, he modeled a helical gear and studied the effect of gears contact ratio, bearing supporting stiffness, mesh damping, backlash, transmission faults, and vibration stability (Wei et al., 2014). Lin et al. used the Gauss-Newton method with a different approach to analyze the contact stress of a pair of helical gears by numerical modeling (Lin and He, 2017).

As stated in the aforementioned studies on helical gears, each damage situation has its own unique situation. Therefore, the abundance of studies on this subject will bring about easy solutions to prevent damages.

2. Gear Wheel Damages

Gear failures and damages are numerous according to their usage areas. Most of these damages usually occur in the teeth and may occur in the body, even if a little. In Fig. 1, all tooth damages that generally occur on gears are presented (Chalabi, 2020; Khurmi and Gupta, 2005).

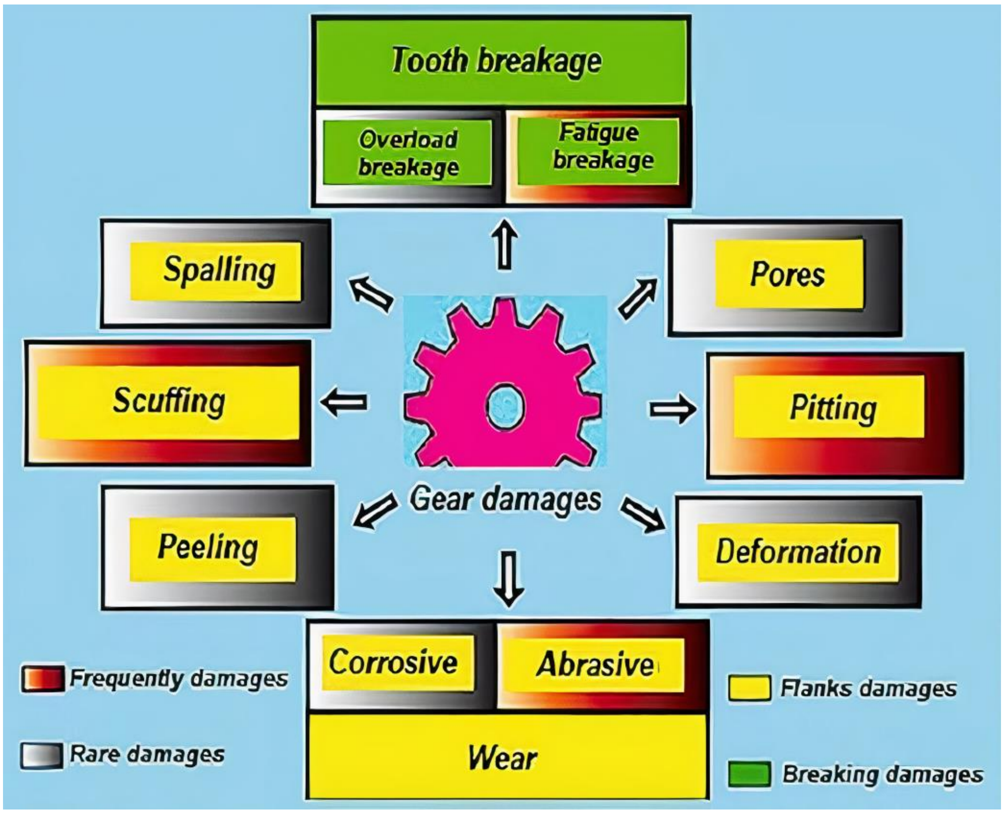

Figure 1. Gear damages (Chalabi, 2020).

As indicated in Fig. 1, the damage such as abrasive wear, pitting, tooth fatigue breakage and scuffing are often expected damages. Tooth damage as a result of deformation, flaking, corrosion, peeling, pores, and overload fracture are usually rare and accidentally occurs during operation (Chalabi, 2020).

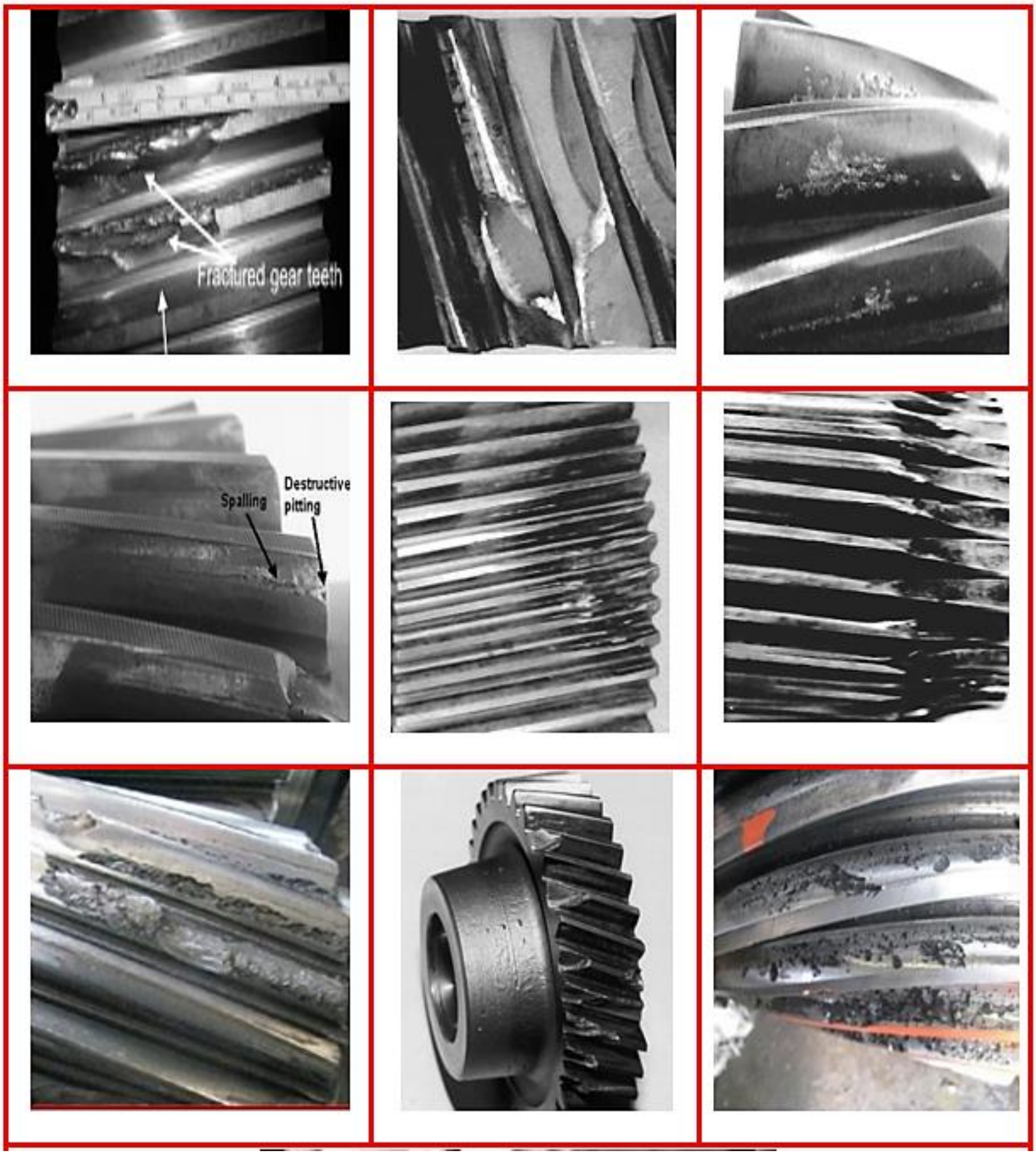

Figure 2. Examples of gear wheel damage (Alban, 1985; Asi, 2006; Netpu et al., 2010; Vasić et al., 2020).

The damages of gears are different according to their usage areas. Some of these damages can be seen in Fig. 2 (Alban, 1985; Asi,2006; Netpu et al., 2010; Vasić et al., 2020). Gear wheel fractures occur as a result of plastic deformation, tooth slippage, overloading or material fatigue (Basan et al., 2010).

2.1. Helical Gearing Theoretical Calculations

In Fig. 3, there is a three-dimensional view of the forces acting on a helical gear tooth. The point of application of the forces is in the center of the gear face and in the pitch plane. The analysis of the force occurring in helical gears is as in Fig. 3 (Nisbett and Budynas, 2014).

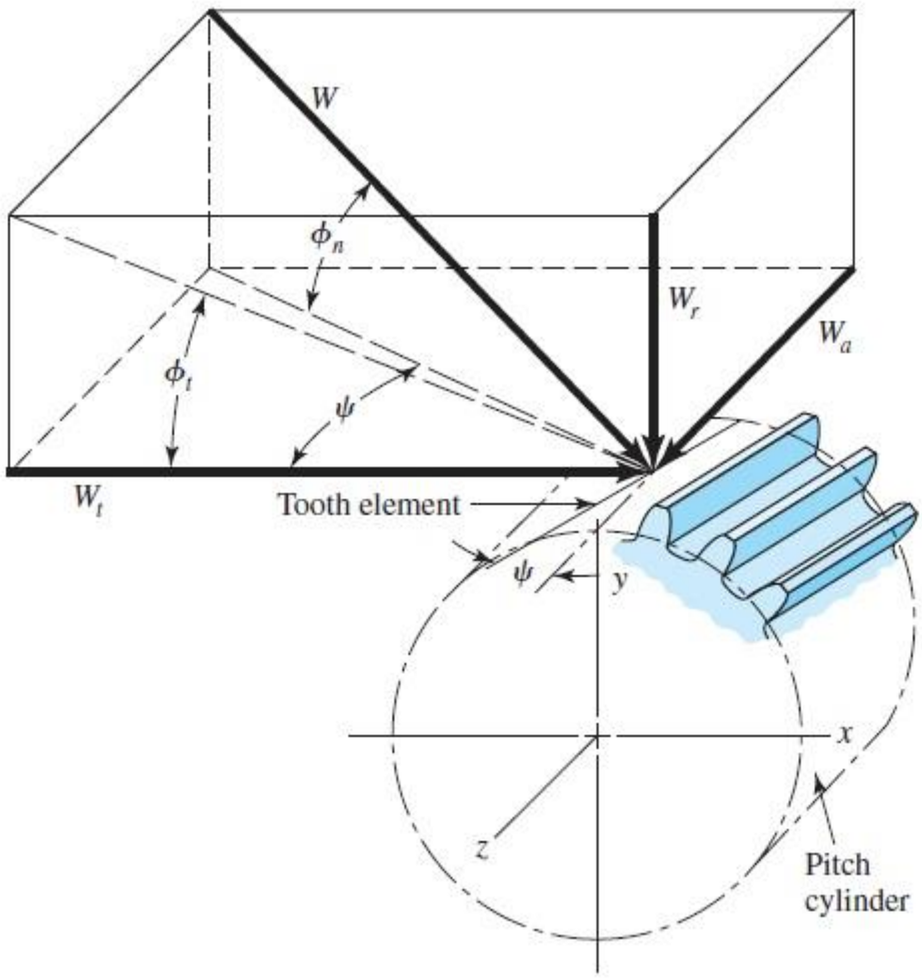

Figure 3. Force states in helical gears (Nisbett and Budynas, 2014).

From the geometry of the Fig.3, the three components of the total (normal) tooth force W are

$$W_r = W \sin \emptyset_n \tag{1}$$

$$W_t = W \cos \emptyset_n \cos \psi \tag{2}$$

$$W_a = W \cos \emptyset_n \sin \psi \tag{3}$$

where $W = Total\ force,$

$W_r = Radial\ component,$

$W_t = Tangential\ component, also\ called\ the\ transmitted\ load,$

$W_a = Axial\ component, also\ called\ the\ thrust\ load.$

3. Material and Method

In this study, a damaged helical gear, which is frequently used in car engines, static stress analysis was performed with the ANSYS Workbench Finite Elements Package program. The drawings of the helical gear wheel were made in the Solidworks program (Solidworks, 2021). In the analysis, the properties of the helical gear made of structural steel were used. A picture of the damaged helical gear wheel is given in Fig. 4.

Figure 4. The damaged helical gear wheel.

In analysis, mechanical properties of the damaged helical gear (Table 1) were introduced to the system respectively, and mesh operation was performed by selecting the mesh structure. The mechanical properties of the damaged helical gear wheel made of structural steel are given in Table 1.

Table 1. Mechanical properties of the damaged helical gear.

Material	Structural steel
Elasticity Module	250 Gpa
Poisson's ratio	0.3
Tearing Module	75 Gpa
Mass density	7.7 gr/cm^3

Tensile Strength	517 Mpa
Yield Strength	250 Mpa
Thermal Expansion	1.2e-05 1/°C
Thermal Conductivity	0.0605 W/mm.°C
Specific Heat	460 J/kg.K

The input parameters used in the Solidworks program for the drawing of the helical gear wheel are given in Table 2.

Table 2. The input parameters of the helical gear wheel.

Input parameters of helical gear wheel	
Module (m)	2.5 mm
Helix angle (β)	30º
Number of teeth (z)	24
Outside diameter (d_a)	74.282 mm
Pitch diameter (d)	69.282 mm
Base diameter (d_b)	63.447 mm

4. Results

In numeric study, the selected design parameters and detailed pictures of the helical gear wheel to be designed have been created with the help of the Solidworks program design library. In three-dimensional solid modeling, when the cylindrical helical gear is selected from the toolbox menu of the Solidworks program and the input parameters are selected, the program has made the drawing automatically. The helical gear wheel drawn in the Solidworks program has been transferred to the ANSYS Workbench Finite Elements Package program. It is divided into finite elements after meshing in ANSYS program (ANSYS, 2021; Lee, 2020). The helical gear wheel with mesh can be seen in Fig. 5.

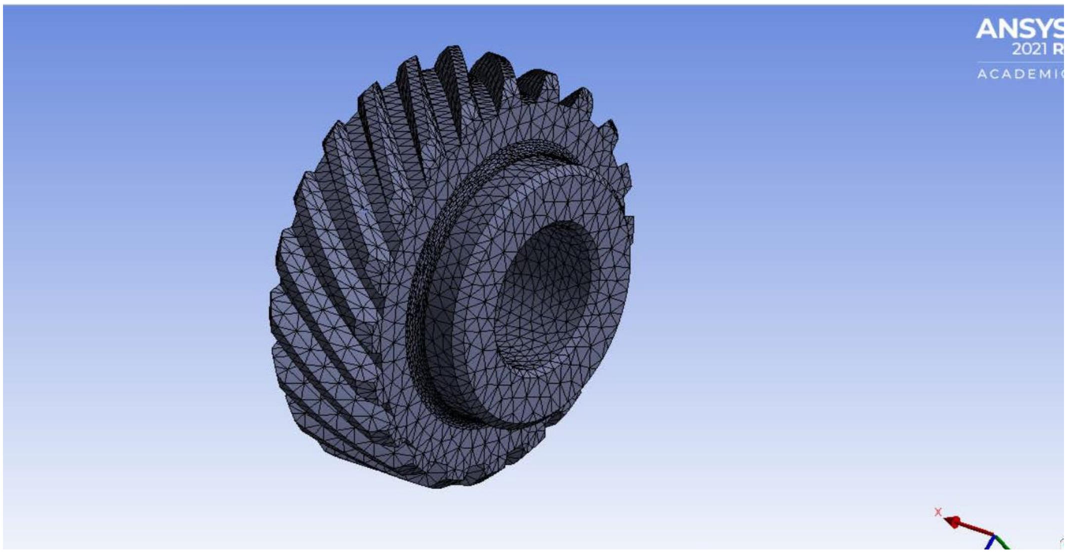

Figure 5. The gear wheel with mesh.

At the end of the meshing process applied, the number of nodes and elements were 112554 and 53131, respectively. Here, the element size is 148.33 mm and the tolerance is 0.272 mm. The number of nodes and elements of the analyzed helical gear wheel are given in Table 3.

Table 3. Number of the nodes and elements of the helical gear wheel.

Element size (mm)	Tolerance (mm)	Number of nodes	Number of elements
148.33	0.272	112554	53131

The reaction forces of the gear after the forces applied on the teeth of the helical gear are given in Table 4.

Table 4. The reaction forces of the gear.

Reaction forces (N)	X	Y	Z	Result
	1.0626e-006	-1.1162e-006	26080	26080

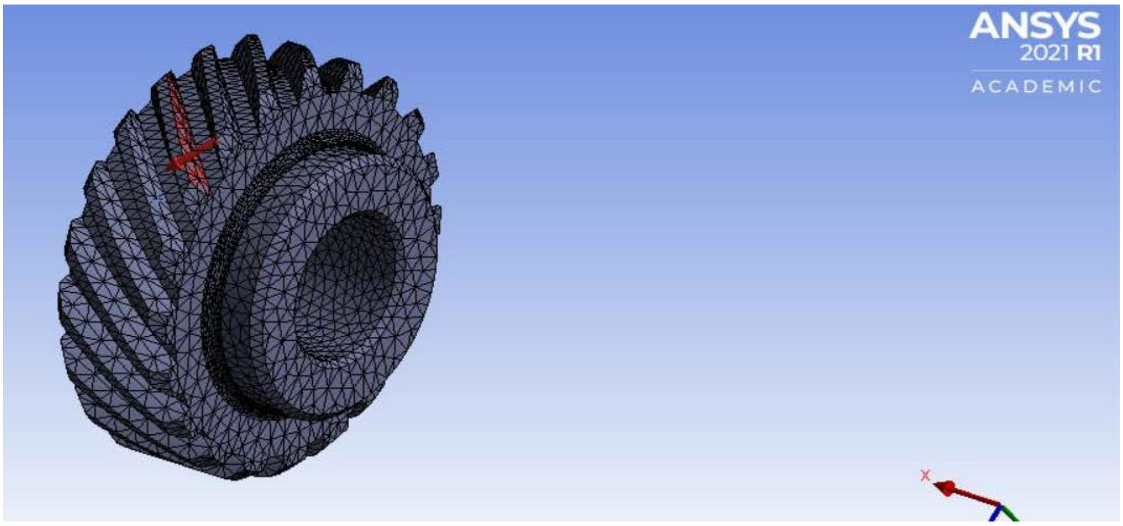

Figure 6. The force applied to the tooth of the gear wheel.

The Von-Misses stresses is generally expressed as the average of the stresses and shear stresses on the part. It is used when force is applied on the materials. It has also been used in our damaged helical gear wheel. The equivalent Von-Mises stress is given in Fig. 7. Maximum Von-Mises stresses and mesh values of the region are given in Table 5. And, the results of the von-Mises stresses are given in Table 6.

Table 5. Maximum Von-Mises stresses and mesh values of the region.

Mesh size (mm)	Number of elements	Number of nodes	Von-Misses (Mpa)
1	53133	112554	460.5 (max.)

Table 6. The results of the Von-Misses stresses.

Von-Misses Stresses		Number of nodes
Minimum	7.469e-008 Pa	112554
Maximum	2.9462e-003 Pa	112554

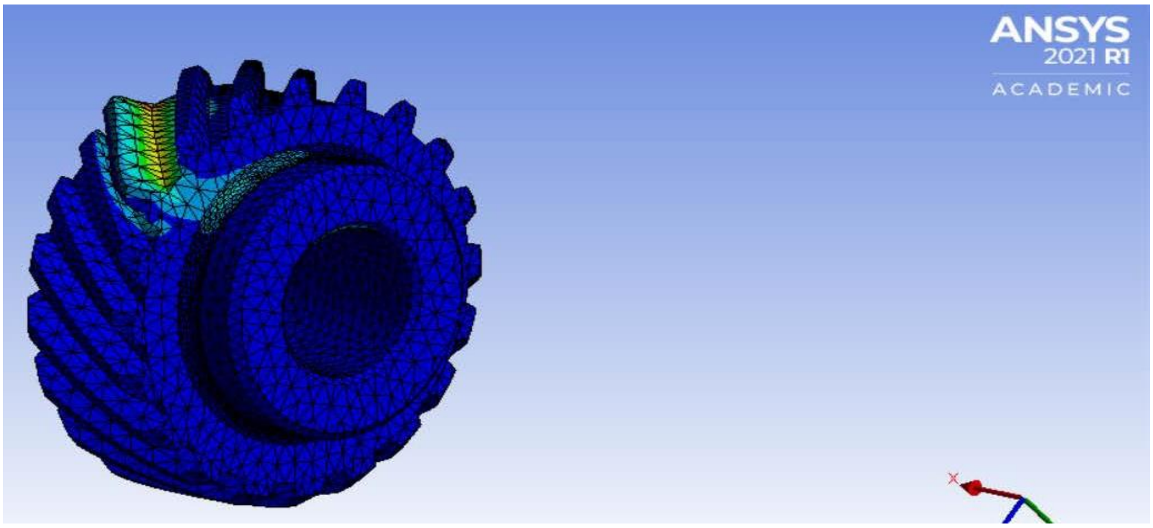

Figure 7. The equivalent Von-Mises stress.

The highest equivalent stress was found to be 460.5 MPa. The equivalent Von-Mises stress occurring in the gear wheel is given in Table 7.

Table 7. The results of the equivalent Von-Misses stresses.

Time (s)	Minimum (MPa)	Maximum (MPa)	Average (MPa)
1	6.3604e-003	460.5	15.15

Total deformations are minimum 3.7099e-002 mm, maximum 3.7099e-002 and average 2.7512e-003 mm. The total deformation values occurring in the gear wheel are given in Table 8.

Table 8. The total deformation values.

Time (s)	Minimum (mm)	Maximum (mm)	Average (mm)
1	0	3,7099e-002	2,7512e-003

In Fig. 8, the maximum and minimum total deformation values of the stress applied to the part are shown in color. In this coloring, the red color defines the maximum, and the blue color defines the minimum deformation values.

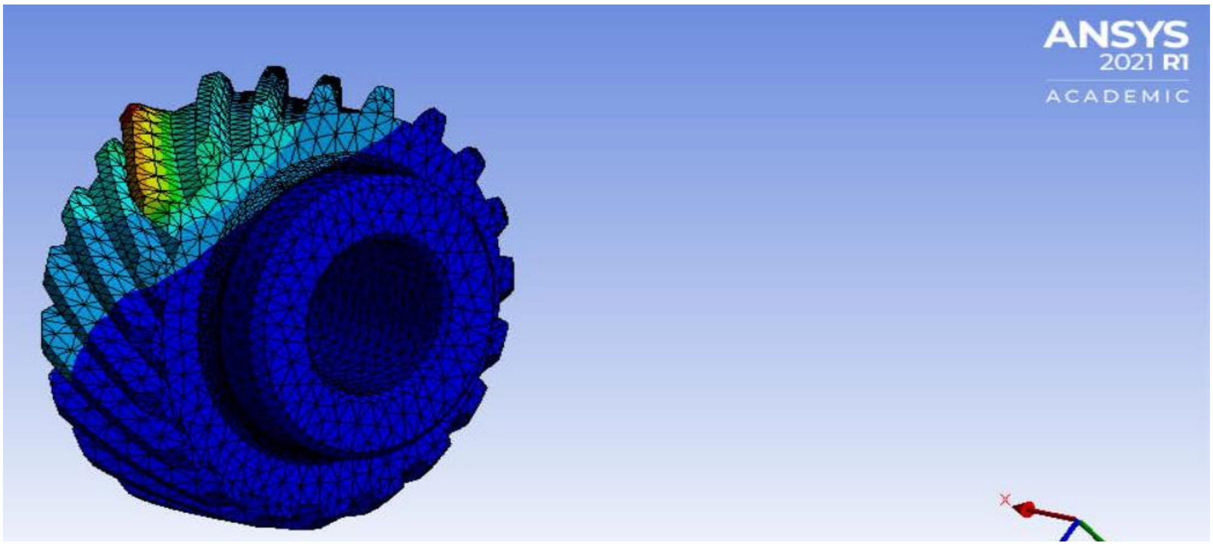

Figure 8. Deformations in helical gear wheels.

It was known that the damaged helical gear whose numerical analysis was made was a ductile material. Due to this material structure, it was observed that the damage starting area was broken at an angle of 45 degrees.

5. Conclusion and recommendations

In the study, the damaged helical gear was first modeled with the help of Solidworks program and then static stress analysis was performed with the ANSYS Workbench Finite Elements Package program. In the analysis, the properties of the helical gear made of structural steel were used. The following results and recommendations are presented as a result of the numerical analysis of the helical gear.

- It is understood that the damaged helical gear wheel can be modeled in the ANSYS finite element program and used to observe in detail the distribution of stresses that cause gear damage.
- With the help of numerical analysis, it will be possible to prevent the wrong material selection, which is the biggest cause of damage.
- It was determined that the helical gear was broken due to exceeding the safety stress limit. The safety stress limit of 26000 N has been exceeded as shown in Table 4.
- The helical gears are made of steel material. With the use of low carbon ratio, the fracture rate in steel materials can be reduced. In particular, studies can be carried out on this subject and more durable helical gears can be produced.
- Additionally, in order to prevent fractures in the helical gear, sudden gear changes and excessive skidding should not be made.

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