Comparative Analysis of Different Starter Driven Gear Materials Using Finite Element Method

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Abstract. Gear is an essential element in motor vehicles. Bending stress and gear surface strength are two factors contributing to a gear failure. Therefore, calculating precisely the bending stress and total deformation of the gear tooth is profoundly important for the development of modern gear design industry. This study aimed to investigate the strength, deformation, and crack in gears. The Finite Element Method (FEM) was used in the ANSYS simulation. The simulation was performed on three gear materials, i.e. alloy steel, structural steel, and carbon steel. The results showed that among the three materials, the highest strength with the equivalent stress of 921.63 MPa was structural steel, with the maximum principal stress of 407.33 MPa and maximum shear stress of 407.33 MPa.

Keywords: ANSYS, comparative study, FEM, gear, stress

1. Introduction
Motor vehicles run with various important components, one of them is gear. It serves to transmit power and rotation from one shaft to another [1-3]. A gear damage results in the electric starter failure. Bending stress and gear surface strength are two factors contributing to gear failure [4]. Therefore, calculating precisely the bending stress and gear tooth’s total deformation is profoundly important for the development of modern gear design industry. Therefore, estimating the total stress and deformation of a gear is very important and will be discussed below.

A suitable analytical method is required to generate useful information about bending stress and contact stress [5]. The use of ANSYS software is the most preferable because it can display specimens being analyzed or tested through simulation. The results which are close to the actual conditions can be obtained more quickly and easily [6]. The focus of the analysis was the starter driven gears of a motorcycle. Gears are generally made of alloy steel. 20MnCr5 case-hardening steel is used for production. It is a special alloy steel composed of 0.17 to 0.22% carbon [7].

Using alloy steel as a comparison, this study examined other types of gear materials, i.e. structural steel and carbon steel. Previous research has compared structural steel with other materials, aluminum and cast iron [8]. Carbon steel has also been studied closely by Shinde et.al [1] regarding the effect of its size on stress and deformation. Three materials were analyzed for various measures, i.e. equivalent stress, total deformation, maximum principal stress, maximum shear stress, and crack using ANSYS
software. This method aimed to reveal the differences between materials that are useful for motor vehicle production, particularly the manufacturing of starter driven gears.

2. Methods
Finite Element Method (FEM) was used in the ANSYS simulation. In this finite element analysis, the gears were divided into a number of elements [9]. This type of analysis is very easy to do for research with many parameters and can be done efficiently [10]. The division of the elements was intended to estimate the strength of gears under loading. Then, a comparative analysis was conducted to assess the performances of the three different gear materials.

2.1. Model construction
The starter driven gears in this research were designed using Autodesk Inventor. The properties of gear materials are presented in Table 1.

| Table 1. Material properties |
|-------------------------------|
| Properties                       | Structural Steel | Alloy Steel | Carbon Steel |
| Density (g cm⁻³)                | 7.85             | 7.85        | 7.87         |
| Poisson’s Ratio                 | 0.3              | 0.27        | 0.29         |
| Tensile Yield Strength (MPa)    | 250              | 415         | 370          |

2.2. Simulation
Strength simulation was done using ANSYS Workbench 18.1. Stress simulation was performed by involving various loading conditions such as giving a force 1000 N and using a mesh 1 mm in size. Deformation analysis was also conducted and the result of which became the basis for carrying out crack analysis.

3. Results and Discussion
Maximum equivalent stress often used to predict material tenacity. The maximum equivalent stress of the three starter driven gears is shown in Figure 1. The results showed that alloy steel had the equivalent stress, of 921.63 MPa, Structural steel had the equivalent stress of 925.62 MPa and Carbon steel had the equivalent stress of 933.23 MPa. The equivalent stress gear starter driven simulation showed that the largest maximum stress equivalent value is alloy steel, followed by carbon steel, and the lowest is structural steel. Maximum equivalent stress compared to metal yielding (Table 1) is a useful indicator to see the safety level of metals [11]. Maximum equivalent stress must be lower than the metal yielding [12]. From three materials tested, none of them met the safety criteria. However, to compare the three materials still can use other indicators through ANSYS simulations.
Figure 1. Maximum equivalent stress of (a) structural steel, (b) alloy steel, and (c) carbon steel.

Maximum Principal Stress which specifically shows the most tensed part indicated by red color. Figure 2, below shows the maximum principal stress of structural steel, alloy steel, and carbon steel. The results of Maximum principal stress showed that alloy steel had 407.33 MPa, Structural steel had 411.37 MPa and Carbon steel had 408.74 MPa. The principal stress coefficient plays an important role in increasing strength [13]. This causes consequences on research’s result, proven that structural steel has the highest strength because of the high value of principal stress.
Figure 2. Maximum principal stress of (a) structural steel, (b) alloy steel, and (c) carbon steel.

Maximum Shear obtained specifically for vertical stresses. Figure 3 shows maximum shear stress for three materials, which is structural steel 481.03 MPa, alloy steel 485.11 MPa and carbon steel 482.44 MPa. Shear stress only shows the hardening of the matrix [14]. The highest shear stress value shows high hardening, and this applies to alloy steel so, alloy steel’s strength is the lowest.
The analysis results showed that Structural steel had the equivalent stress, maximum principal stress and maximum shear stress of 921.63, 407.33, and 481.03 MPa. Alloy steel had equivalent stress, maximum principal stress and maximum shear stress of 925.62, 411.37, and 485.11 MPa. Carbon steel had the equivalent stress, maximum principal stress and maximum shear stress of 933.23, 408.74 and 482.44 MPa. Overall, among the other materials under study, alloy steel had a lower strength. A drop in stress indicates a higher strength [15]. In sum, structural steel is considered to have the highest strength among the three materials.

Figure 3. Maximum shear stress of (a) structural steel, (b) alloy steel, and (c) carbon steel.
Figure 4. Total deformation: structural steel (a), alloy steel (b) and carbon steel (c).

The simulation results of the total deformation of the three starter driven gears are shown in Figure 4. Maximum equivalent stress decreases as the deformation rate decreases [16]. This is an evident that alloy steel has the lowest deformation along with its stress. The crack occurring in each starter driven gear was examined based on the values of J-Integral and SIFS (K1). J-Integral value can be described as the strain energy release rate of a crack body per unit. Moreover, the SIFS (K1) value serves to determine the stress intensity factor (K) of a material with a certain geometry shape under elastic loading. The maximum J-Integral value was 0.0024292 mJ/mm², while the minimum J-Integral value was -0.001716 mJ/mm². The maximum value of SIFS (K1) was -21.353 MPa.mm⁰.⁵, while the minimum value was -22.739 MPa.mm⁰.⁵. The effective stress intensity factors found to increase the value of the crack speed [17].

4. Conclusion

The simulation analysis using ANSYS on the three types of materials suggested that the gear made of structural steel is the most favorable material. Among the three materials, structural steel had the lowest equivalent stress, maximum principal stress and maximum shear stress of 921.63, 407.33, and 407.33 MPa, respectively, and hence the highest strength. Highest strength indicated by low deformation and drop of stress. It can be a reference material for the manufacturing industry. Moreover, this finding is expected to provide useful information for future researchers to study other gear materials.

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