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Tooth Strength Analysis of Bevel Gear Using Solid Works Simulation Tool

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Abstract: In recent years, bevel gears have been exploited as power-transmitting gears due to their interesting features such as smoothness, huge load-supporting capability, higher working velocity, and smoother engagement of teeth. Thus, power can be transferred across non-parallel shafts with great efficiency; nevertheless, the gears in this case fail because the stress on the teeth exceeds the gears' maximum stress, as well as bending and surface stresses. The overarching idea of this work is to exploit the characteristics of an involute bevel gear system, mainly concentrating on bending stresses. In this paper, we attempted to model a bevel gear. The Finite Element Method (FEM) simulations are carried out using standard commercially available software such as the Solidworks tool. In contrast to traditional approaches, we step in to deal with challenges that modern gears confront, such as tooth stress exceeding the maximum limit, bending, and surface stress, with great efficiency and a low budget. We explored a bevel gear under changing loads and material conditions while considering the truck differential. When designing a gear, bear in mind the hub diameter, the number of teeth, the power used by the gear, and the pitch angle are important parameters. Conclusively, the changing loads and materials of bevel gear achieved high efficiency, high durability, and low cost of the material with the help of SOLIDWORKS software. In this regard, this work has huge potential and further experimental design is the future line of work.

Keywords: Bevel Gear; SOLIDWORKS; Stress; Equivalent Strain; Displacement.

1. Introduction

The bevel gears are one of the most basic types of gear that is used for transmitting the power at a constant velocity ratio between two shafts. Bevel gears are used for supplying power to non-parallel shafts and change the direction of rotation. The standards for the design, analysis, and manufacture of bevel gears are industrialized by the American Gear Manufacturing Association (AGMA). The best-known types of bevel gears have pitch angles less than 90° and thus are cone-shaped. They can be classified as, Straight gears, Spiral gears, Zero gears, and Hypoid gears [1] [2] [3]. The research focuses on gear tooth analysis. Bevel gears are commonly used in automobiles, aircraft, elevators, and heavy engineering machines [4]. Researchers found that gear teeth experience two types of stresses: root bending and tooth surface stresses. Root bending stress causes fatigue fracture, whereas surface stress results in pitting failure at the gear teeth's contact surface. Gear pair parameters such as torque, pressure angle, shaft angle, rim thickness, and face width are tuned to investigate their impact on the root stress distribution and the tooth's behavior at the root [5]. There were many discrepancies in the performance results, including the pitch cone angle value and the tooth profiles [6], which were uncovered due to the study conducted by LI Jun-wei and PAN Yu-tian. Furthermore, a study was done on the effectiveness of a micro-shape modification to the geometry of gear teeth in preventing fatigue-related surface wear, most gear failures are due to tooth bending fatigue [7] [8]. Gear design must consider the pressure imposed on each gear tooth. Increased repetitive contact stress may cause surface cracking and scratching [9]. The layer thickness and friction coefficient could be estimated using a mixed-lubrication model developed by Bahrami et al. (2014) for straight bevel gear. The Tred gold approximation is used to determine the transmit load and radius of curvature when a compound pair of spur gear teeth is used to replace a single pair of straight bevel gear teeth. Considering elastic, elastoplastic, and plastic deformation for cracks, this study of the gear system's influence on load, roughness, hardness, and rolling speed helps to define the concept of load sharing [10]. The root fillet stress can be reduced by using an optimization approach to change the tooth design criteria while still fulfilling functional limits [11]. SFEM study of bevel gear bending strength by Abhijeet.et al shows that bevel gears undergo tangential load, radial load, and axial load as a result of the combined effects of speed and torque [12]. Gear teeth were the focus of Rufang Li's 3D static and dynamic contract/impact research. The tooth load distribution and outcome are determined under static loading conditions. She does a stress analysis on the gear system under dynamic loading circumstances and simulates the stress on the gears under beginning speed and rapid load situations [13]. To measure the bending stresses in a straight bevel gear tooth, Nalluveettil and Muthuveerappan (1993) used finite element analysis (FEA), with an isoperimetric brick element employed for the work. The root of the tooth stress distribution data were compared with experimental results. The root behavior of teeth was evaluated by varying parameters such as pressure angle and rim thickness [14]. The results indicated that under low stress levels, speed has a minor impact on gear durability. Simon delivers a suitable tooth design for a spiral bevel gear that enhances the distribution of load and reduces maximum tooth contact pressure, whereas Yilmaz and Cenk researched fatigue behavior at gear tooth roots and hardness distribution throughout the tooth's radial direction [15] [16].

During the power transmission, the gears are always subjected to different load conditions that cause gear teeth failure or the gear itself. Therefore to avoid such failure in gear, the designers always emphasize the proper design of gear and selection of material so that the gear should be durable and reliable. Bevel gears have become a subject of research interest because of the dynamic load, attention to the noise level during operation, and the demand for lighter and smaller sizes. In such types of gears, there is a problem of failures at the root of the teeth because of inadequate bending strength and surface pitting. This can be avoided or minimized by proper method analysis and modification of the different gear parameters. The aim of this study involved conducting finite element analysis (FEA) to simulate the meshing of bevel gear under different load conditions. Through the FEA, the stresses and deformations of the gear were evaluated to assess their strength and durability. Furthermore, the material selection was based on a comprehensive analysis of properties such as hardness, fatigue strength, and wear resistance, ensuring the gear could withstand the expected loads—the design parameters adopted from the literature review for creating a reliable and efficient bevel gear system. Additionally, the analysis of tooth strength under varied load conditions enabled the identification of potential weak points and areas for improvement in the gear design.

2. Materials and Methods

2.1 3D Model Of Bevel Gear

The 3D model of the bevel gear as shown in Figure 1 was designed in SOLIDWORKS software as per the dimensions taken from a literature review. The details of the dimensions are given in Table 1.

Figure 1. 3D model of bevel gear

Table 1. Details of dimension

S/No:	Variable symbol	Description	Value	Units
1	Z	No. of Teeth	33	
2	M	Module	4	Mm
3	D	Pitch diameter	132	Mm
4	α	Pressure angle	20	degree
5	B	Face width	25	Mm
6	A	Addendum	0.027	Mm
7	B	Dedendum	2.16	Mm
8	$\theta\ p$	Pitch angle	62.74	Degree

2.2 Material Properties & Boundary Conditions

The selection of materials for the analysis and execution of results materials are to be applied on the bevel gear model are plain carbon steel and cast alloy steel. The properties of both materials are given in Table 2.

Table 2. Different material properties

Material	Yield strength (N/mm^2)	Mass density Kg/m^3	Poison's ratio	Tensile strength (N/mm^2)
Plain Carbon Steel	220.594	7800	0.28	399.826
Cast Alloy Steel	241.2752	7300	0.26	448.0825

The FEA is performed in the SolidWorks software to estimate the maximum stresses, strains, and displacement. The boundary conditions are essential in the calculation to identify the strength of the bevel gear.

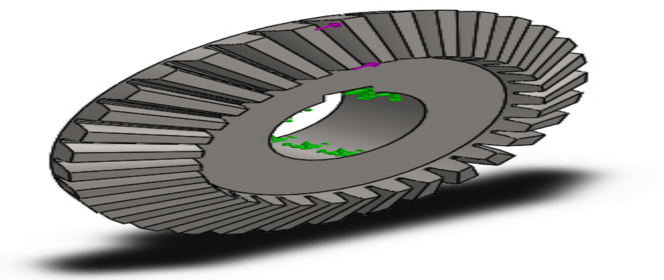
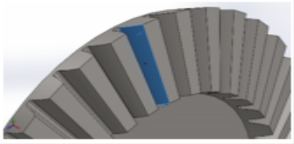
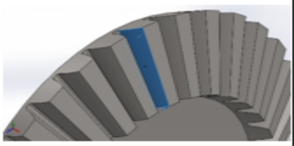


Figure 2. Forced and boundary conditions

2.3 Load Selections

For the analysis of the bevel Gear, static structure condition on the internal surface of the gear and selecting of the face where various load 500N, 750N, and 100N has to be applied on the gear tooth.

Load name	Load Image	Load Details
Force-1		Entities: 1 face(s) Type: Apply normal force Value: 500 N

Load name	Load Image	Load Details
Force-2		Entities: 1 face(s) Type: Apply normal force Value: 750 N

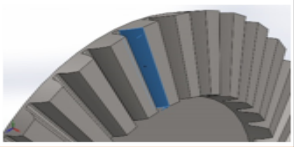
Load name	Load Image	Load Details
Force-3		Entities: 1 face(s) Type: Apply normal force Value: 1,000 N

Figure 3. Load and Fixture

2.4 Mesh Type

The mesh of the gear model has been generated using a solid mesh with a variety of 489437 components and various nodes of 711901 with increased mesh quality. The maximum size of the element used is 5.62552 mm. This mesh has been selected because it is excellent in quality and produces a small number of elements with suitable results, the computation time decreased. As shown in figure 4.

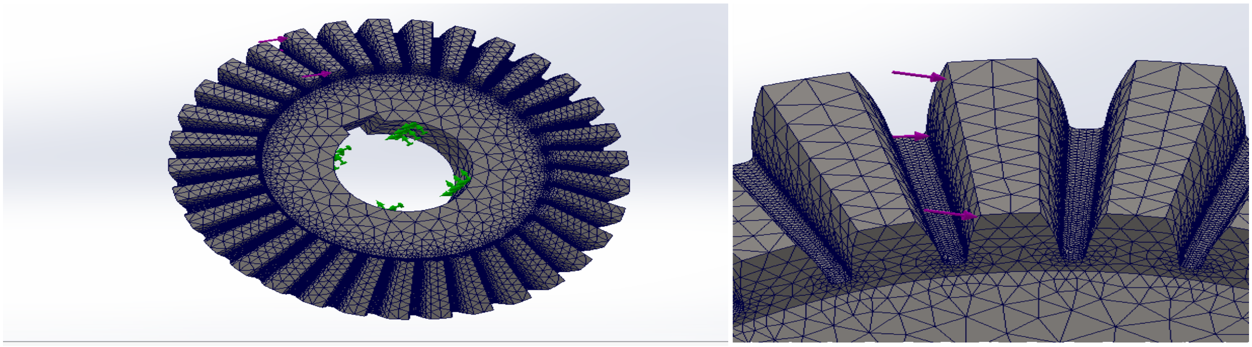


Figure 4. The meshing model of Bevel gear

3. Results and Discussion

The simulation of bevel gear of different materials on various load condition was carried out after the Simulation of the bevel Gear in SOLIDWORKS software on the principle of (FEA). Different results are obtained such as minimum and maximum deformation, stress (von Misses stresses), and strain. The results of maximum stress on maximum loads of different loads are to be compared to find suitable material for the design of efficient bevel gear.

The designed bevel gear was analyzed under the various static load conditions of 500N, 750N, and 1000N at the tooth of the gear. The behavior of the tooth subjected to be the load then simulated in the SOLIDWORKS FEA tool. The behavior of bevel gear was considered in von Misses stress, equivalent strain, and displacement or deformation.

3.1 Simulation of Plain Carbon Steel

In Figure 5, the results was analyzed under the various static load condition 500N, 750N, and 1000N. The behavior of the tooth subjected to the load was then simulated in the Solidworks FEA tool. The behavior of bevel gear was considered in von Misses stress, equivalent strain, and displacement.

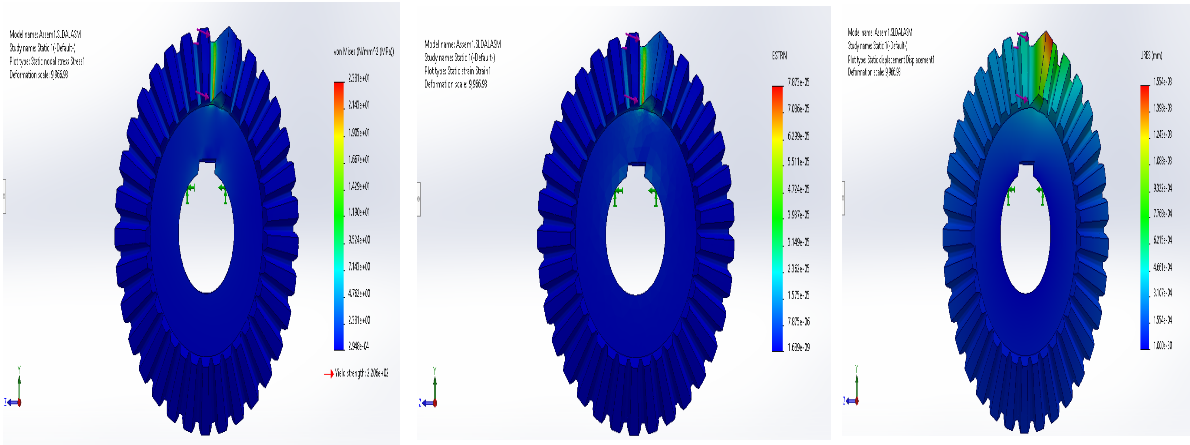


Figure 5. Simulation of model for Plain Carbon Steel

Table 3. Simulation result of Plain Carbon Steel

Load	500N	750N	1000N
Max: Von-misses Stress (MPa)	23.81	32.57	47.62
Min: Von-misses Stress (MPa)	2.948e-04	4.364e-04	5.895e-04
Max: Equivalent Strain	7.873e-05	1.076e-04	1.575e-04
Min: Equivalent Strain	1.689e-09	2.317e-09	3.378e-09
Max: Displacement (mm)	1.554e-03	2.314e-03	3.107e-03
Min: Displacement (mm)	0.0	0.0	0.0

In figure 6, shows the effect of loading conditions on the value of the von Misses stress. From this figure, it is clear that an increase in the value of loading will cause an increase in the value of the von Misses stress, this behavior can be attributed because the loading is directly related to the strength of the bevel gear.

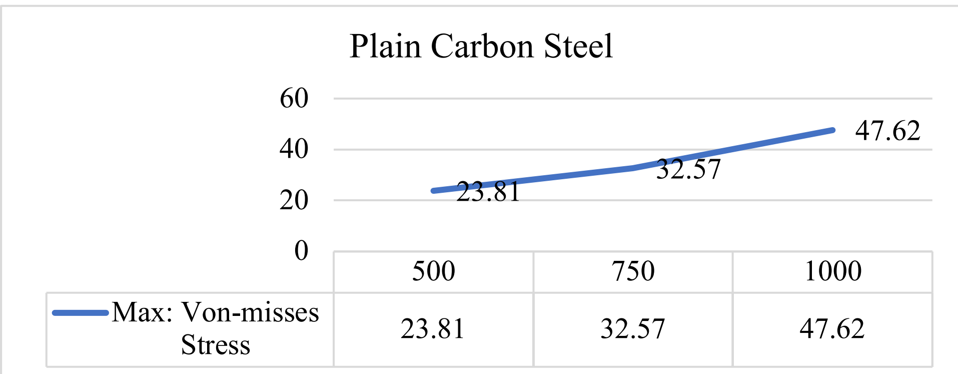


Figure 6. Plain Carbon Steel

3.2 Simulation of Cast Alloy Steel

In Figure 7, the results was analyzed under the various static load condition 500N, 750N, and 1000N. The behavior of tooth subjected to the load was then simulated in Solidworks FEA tool. The behavior of bevel gear was considered in von misses stress, equivalent strain and displacement.

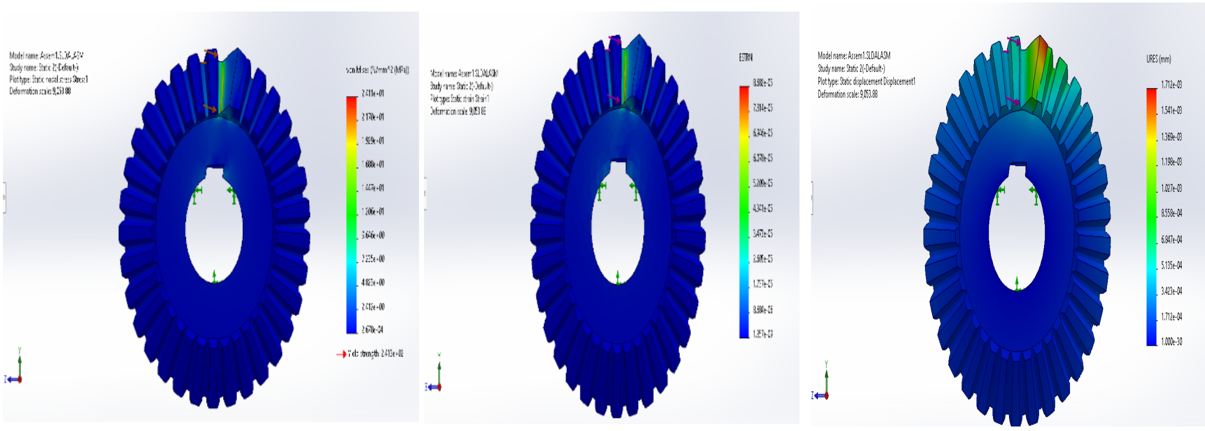


Figure 7. Simulation of model for Cast Alloy Steel

Table 4. Simulation result of Cast Alloy Steel

Load	500N	750N	1000N
Max: Von-misses Stress (MPa)	24.11	36.17	48.23
Min: Von-misses Stress (MPa)	2.678e-04	4.018e-04	5.357e-04
Max: Equivalent Strain	8.682e-05	1.302e-04	1.736e-04
Min: Equivalent Strain	1.857e-09	2.786e-09	3.715e-09
Max: Displacement (mm)	1.712e-03	2.568e-03	3.423e-03
Min: Displacement (mm)	0.0	0.0	0.0

Figure 8, shows the effect of loading conditions on the value of the von-misses stress. From this figure, it is clear that the increase in the value of loading will cause an increase in the value of the von Misses stress, this behavior can be attributed because the loading is directly related to the strength of the bevel gear.

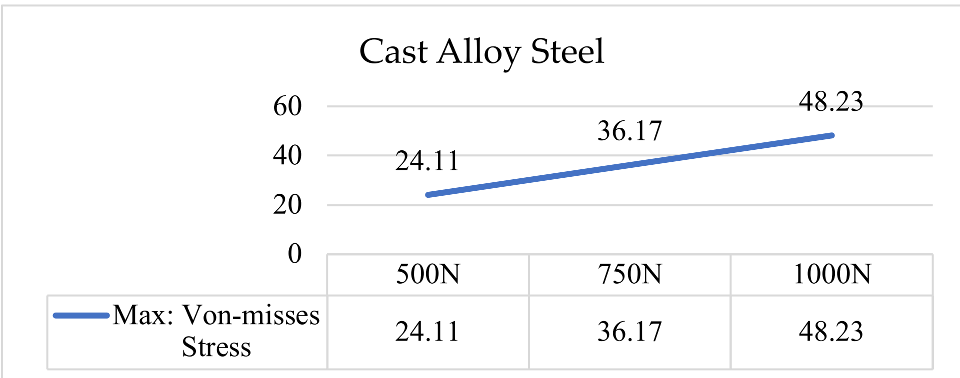


Figure 8. Cast Alloy Steel

Compare the maximum result of different materials on the maximum load condition (1000N) as shown in table 5.

Table 5. Compared result of plain carbon steel and cast alloy steel at max: load

Materials	Plain Carbon Steel	Cast Alloy Steel
Max: Von-misses Stress (MPa)	47.62	48.23
Max: Equivalent Strain	1.575e-04	1.736e-04
Max: Displacement (mm)	3.107e-03	3.423e-03

Figure 9, a comparative analysis of the results obtained for various materials under a maximum load of 1000N. The maximum von-misses stress values for plain carbon steel and cast alloy steel. The maximum von-misses stress for plain carbon steel is determined to be 47.62MPa. The maximum von Mises stress for cast alloy steel is slightly higher, measured at 48.23MPa. This observation suggests that, under the maximum load condition, cast alloy steel exhibits a marginally elevated stress level compared to plain carbon steel.

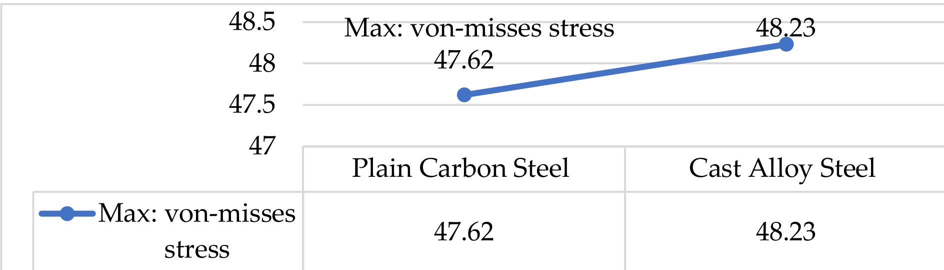


Figure 9. Graphical representation of results for different materials

4. Conclusions

In this study, the results show how the bevel gear can be a double-edged sword in mechanical rotating systems. Such capabilities can be achieved by following the proposed methodology, which uses current tools, such as SOLIDWORKS, to build the bevel gear. Based on the findings, it is surmised that the proposed system can achieve acceptable accuracies under a variety of load and material situations. Loads, stresses, strains, and deformation can be increased without compromising the performance of bevel gears at significant Cobe or von Misses stresses, which are responsible for the failure of the bevel gear tooth. Such stresses fall under the category of tensile stresses, which induce cracking, bending, and, eventually, gear tooth failure. If the stresses are high enough, the consequent strength of the tooth material translates into plastic deformation. As a result, cracks appear in the tooth's material. This is one of the most important causes of cracks on the tensile side. In light of the findings, it is concluded that the maximum deformation prevailing in plain carbon steel is smaller than that of the other gear materials. Still, the largest deformation occurs in Cast Alloy Steel.

Rapid advancements in bevel gears have enabled us to better understand the underlying principles of bevel gears. This has a large practical impact on engineering using conventional methods. Future work will broaden the scope of our research for bevel gear failures, particularly by using other material analysis to design bevel gear in tools other than plain carbon steel and cast alloy steel those we use. It is worthwhile to investigate the behavior of the bevel gear using various materials, such as ceramic and alloy. Extending to numerous loads (e.g., 1500N, 2000N, 2500N) to maximize bevel gear efficiency is another key focus of research.

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