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Optimization of Plastic Spur Gear of Gear Box in a Single Stage

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Abstract. The most common failure in plastic spur gear is the less strength in the operation condition. This study aims to optimize the plastic spur gear in a single stage to improve the strength of spur gear. In this study, finite element analysis (FEA) is performed on gears under cyclic loading. The greatest stresses are sustained in each step of cyclic loading, and crucial spots are determined. The modeling of the gears is done in Solidworks software, while the FEA (Ansys Static Structural) is used for the analysis. Ansys Static Structural is used in this research to model the stresses and load impact on the gear. Shape optimization is done in this study to find the best couple from increasing fillet root radius and face width. The simulation results show that based on the optimization of plastic spur gear, an increase in the strength by 12,673% with increasing fillet radius of the root and an increase in the strength by 32.43% with the optimized shape design (by increasing fillet radius and face width) are obtained.

INTRODUCTION

Robotics, electronic power steering, and motor starters are just a few of the applications where plastic gears are now widely used. There is a lack of understanding of how plastic gears behave under load, which has led to problems with their use in certain applications [1]. This gear transmission system is designed to operate at high speeds and under high loads for extended periods. As a result of interactions between fatigue loads, overloads, overheating, and other factors, gears can be easily damaged. When a gear fails, it has a direct impact on the transmission system's performance, and it can even result in serious workplace accidents and large property losses [2].

Plastic gears have several advantages over metal gears, including lightweight and low inertia. In this case, plastic gears reduce the weight of the entire gearbox and eliminate the need for additional parts to balance the inertia. [3]. Another important factor is gear lubrication, which ensures lighter and smoother gear operation. However, in toy production, computer printers, and other machines, this is not desired, so plastic gears are used for transmission. Furthermore, plastic gears are quiet to operate and can be produced in large quantities at a low cost, which are key factors in increasing the use of plastic gears in the industry [4].

When it comes to small gears, there are three main failure modes to look out for: wear, cavity formation on the surface of the teeth, and static or root fatigue fracture [5-7]. The role of tooth fracture is crucial because it causes the entire system to become inoperable. The failure rate of gears in a typical industrial system has been estimated to be around 60%, with root cracks being the most common failure mode in plastic gears [8]. Y. Shektman, A. Kapelevich [9] The root geometry of the gear teeth, which affects load capacity and crack initiation, is one of the most important parameters of plastic gears. Proper optimization reduces the concentration of flexural stresses dramatically, resulting in a variety of benefits and cost savings. Optimization costs are less than the total cost of launching a new product. Working with plastic has several potential advantages. Under flexural and contact stresses, a working pair of spur

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gear teeth will usually fail. V.B Bhandari [10] concluded that flexural stresses are developed at the tooth roots, while contact stresses develop at the tooth surfaces of the gear teeth.

The stress will be highest at the two points where the force is applied, as well as at the tooth root. Many studies have been conducted on this gearing technology to reduce failures by improving the material, geometric parameters, and manufacturing process. Finite Element Analysis (FEA) can analyze components with complex shapes under complex loading conditions that are as close to real-world conditions as possible, predicting fatigue life and saving time and money in the manufacturing process. Finite Element Analysis with stress analysis has become a key research area in the prevention or reduction of catastrophic tooth decay, as the optimal gear design to use in the recommendation for production.

In this study, the maximum stress points were investigated using finite element analysis to determine where gear teeth can fail. The locations that caused the most stress were then identified, and it was found that they frequently occur at critical points on the teeth. From the design of plastic spur gear, the maximum stress points were investigated using finite element analysis to determine where gear teeth can fail. The locations that caused the most stress were then identified, and it was found that they frequently occur at critical points on the teeth.

MATERIALS AND METHODS

Stresses in Spur Gear

During the load applied to the gear when the transmission process is running between the mesh gear teeth, they are subjected to several strains or stresses. Root bending stress and surface contact stress both create stress on the teeth of spinning gears. The contact load on the tooth can cause the spur gear to fail. When a heavy load is done to gear tooth at a certain point, it can wear down quickly, and bending stress occurs, causing the tooth to flex and start to be a fatigue failure. The maximum surface contact stress influences gear tooth surface fatigue (pitting and wear). The goal of stress analysis is to find out where there is a higher concentration of stress, which can lead to failure or fracture. Due to repetitive bending stress generated by power transmission, a fatigue fracture occurs on the surface of the root fillet and typically extends to the root fillet surface. The area of the tooth gear is vulnerable to failure as a result of cyclic load.

Modeling and Meshing

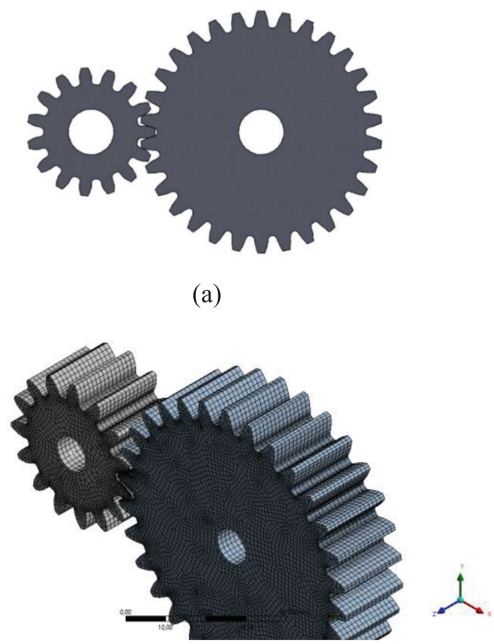
In this study, we designed spur gear in Solidworks 18.1 modeling software and Table 1 shows the parameter of plastic gear design. Figure 1 shows the 3D model and mesh model. When these models were imported, ANSYS Workbench was used to analyze total deformation and the Maximum value of Von-Misses equivalent stresses. In the meshing process, we used element size 1,4 mm and a contact mesh size of 0.25 mm to increase the quality of the mesh, because the accuracy of the mesh is dependent on the sizing of the elements, a reduction value when sizing element will produce the better results, as shown in Table 1.

Materials

Depending on the application, spur gears are made from a variety of materials. Ferrous and nonferrous metals, composite materials, and a variety of other materials are available for gear. As detailed in the introduction section, the present study use 30% Glass Filled Nylon 66 for carrying out structural analysis. The materials property for the gear in this study was chosen from the literature. Nylon may be utilized as the matrix material in composite materials with reinforcing fibers such as glass or carbon fiber since it has a higher density than pure nylon. These thermoplastic composites are often used in automotive components near the engine, such as intake manifolds, because of their great heat resistance, which makes them a feasible metal alternative [15]. Material 30% Glass-Filled Nylon 66 is used as the material of the gear and the properties of the material as shown in Table 2. The use of Nylon results in a lighter assembly, as it is less expensive than titanium and carbon fiber and is simple to machine

Table 1. Parameter of gear design and mesh quality

Properties	Pinion	Gear
Number of Teeth	15	30
Module (mm)	2.5	2.5
Pressure Angle	20	20
Pitch Circle (mm)	37.5	75
Face Width (mm)	20	20
Fillet Radius Root (mm)	0.9	
Addendum	1 module	
Dedendum	1.25 module	
Max Skewness	0.797	
Min Orthogonal	0.332	



(a)

(b)

FIGURE 1. Gear design (a) Spur gear assembly, (b) Meshing of gears

TABLE 2. Properties of material

Properties	Units	30% Glass Filled Nylon 66
Specific Gravity	g/cm^3	1,36
Tensile Strength	Mpa	160-175
Compression Test	Mpa	60-77
Flexure Strength	Gpa	9,4
Modulus of Elasticity	Mpa	5000-10000
Poisons Ratio	-	0,4
Rockwell Hardness	-	M76

Numerical Method

Numerical methods such as Finite Element Analysis (FEA) are essential for correctly tackling computational mechanics and current engineering issues. Numerous methods are commonly used to solve a wide range of problems. Each method has its own set of benefits and drawbacks. The finite element method is a numerical method that employs differential equations to solve a wide range of problems in civil, mechanical, and aerospace engineering. The behavior of gears, particularly the gear tooth meshing, will be explored in this study, which will use FEA to assess the meshing of two spur gears (traction gear).

Finite Element Analysis Ansys with Static Structural Analysis is carried out to model a 3D spur gear model imported in STEP format from Solidworks. For the meshing process, the 3D model, whole body sizing method, and contact area sizing method are used. Modeling irregularly shaped components like spur gears is a breeze with this higher-order 3D element with quadratic displacement behavior. These aspects make us produce more realistic results. The mesh model of spur gear with different element sizes at various locations is shown in Fig 1.

The machine configuration determines the boundary conditions in the spur gear model. The pinion gear is provided with frictionless support and fixed support as given to the spur gear, and the contact between the pinion and the spur gear is bounded. In the anticlockwise motion, an 800 N/mm2 moment is given to the pinion. Figure 2 depicts the gear analysis and step-by-step boundary condition. The Von Mises stresses are calculated in every reversible cyclic loading, when stresses surpass the allowed limit, crucial spots are detected. The FEA is performed at various points on the spur gear.

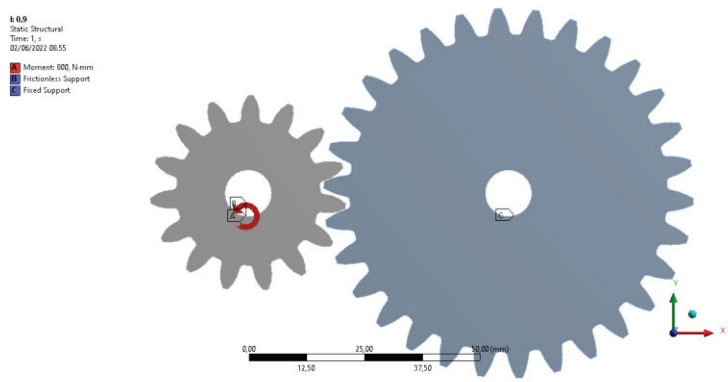


FIGURE 2. Boundary condition

Shape Optimization of Plastic Spur Gear

Because the component's size, material construction, manufacturing method, and other aspects impact its cost, this step of the optimization process necessitates knowledge of these parameters. Weight, noise, and cost may all be reduced by switching to plastic gears. Lubricity, chemical resistance, and stress resistance are all advantages. These are strong motivators. To stay out of difficulties, you must be aware of property disparities. It's important to strike a good balance between material qualities and the requisite duty cycle. The major goal of this research is to improve the design of spur gear so that it can resist large loads. In this form optimization strategy, just the size of the spur gear is changed within the permitted limit, rather than all of its dimensions. In shape optimization, geometrical characteristics parameters are employed as design variables. This procedure alters design elements such as the fillet radius at the root of the teeth and the spur gear's face width. The number of teeth, Addendum circle radius, Dedendum circle radius, Pitch circle diameter, Pressure angle, and Face width of spur gear are all specified during the form optimization process. Table 1 shows that the dimension will remain constant throughout the investigation. The flowchart for spur gear shape optimization is shown in Figure 3. Geometry changes are made within the permitted limit during the optimization process to reduce the maximum stress at the crucial area for spur gear.

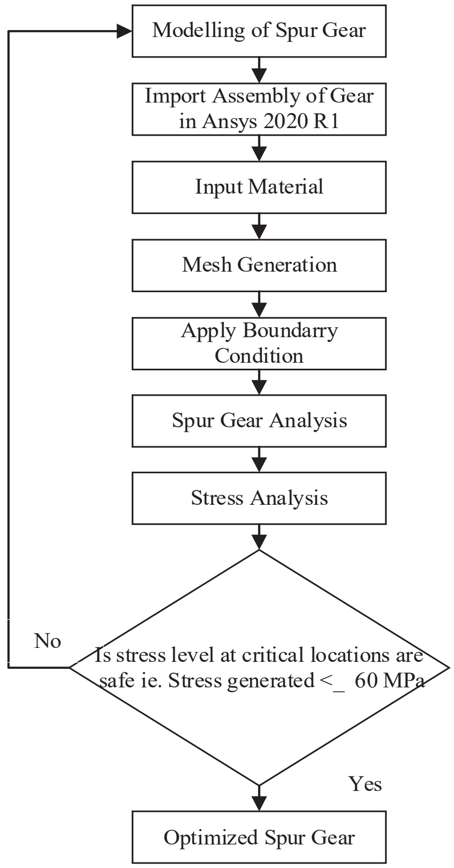


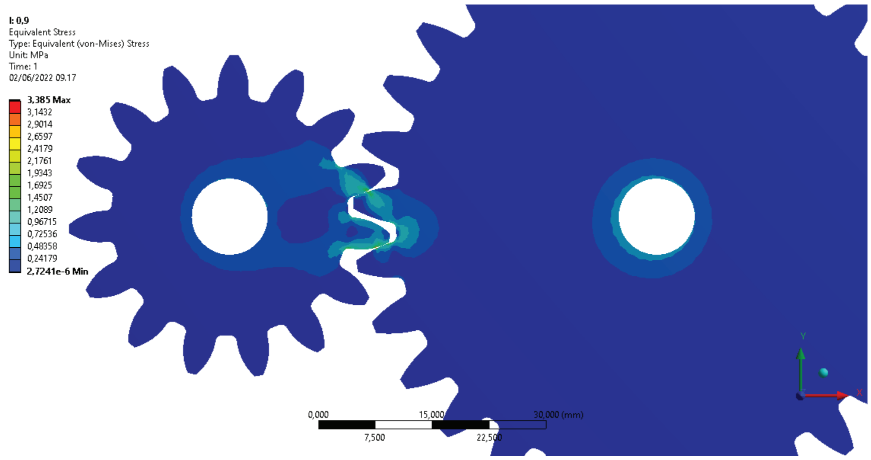
FIGURE 3. Flowchart of shape optimization plastic gear

RESULTS AND DISCUSSION

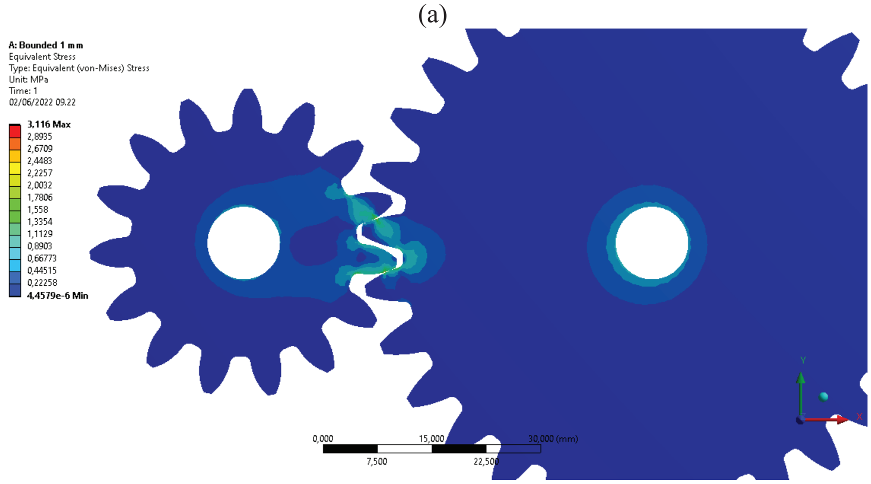
The effects of critical dimensions on maximum stresses generated at the critical point under loading, such as fillet radius at the root of teeth and face width of spur gear, are studied using finite element analysis. The key specifications of the original spur gear are fillet radius at the root of tooth = 0.9 mm and face width = 20 mm. The influence of design factors on Von Mises stress at crucial places was investigated using spur gear masses.

Effect of Fillet Radius

The overall reduction in stresses induced by increasing the fillet radius is attributable to a reduction in stress concentration near the root of the tooth fillet, which may be favored. According to the FEA results, a greater fillet radius of 1.3 mm may be regarded as ideal at the optimum level. When compared to the original type of spur gear, increasing the fillet radius from 0.9 mm to 1.3 mm reduces the stresses generated on the critical point by 12.673 percent. The level of tension created during the modification of the fillet radius at the root of the spur gear tooth is shown in Table 3. Figure 4 illustrates the improved spur gear model with a 1.3 mm fillet radius.


I: 0,9
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
02/06/2022 09.17
3,385 Max
3,1432
2,9014
2,6597
2,4179
2,1761
1,9343
1,6925
1,4507
1,2089
0,96715
0,72536
0,48358
0,24179
2,7241e-6 Min
0,000
15,000
30,000 (mm)
7,500
22,500
Y
X

(a)


A: Bounded 1 mm
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
02/06/2022 09.22
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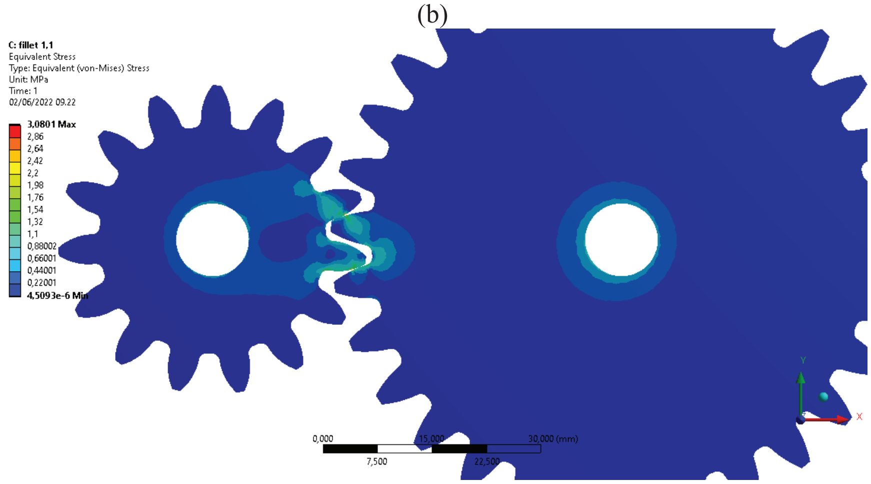
2,6709
2,4483
2,2257
2,0032
1,7806
1,558
1,3354
1,1129
0,8903
0,66773
0,44515
0,22258
4,4579e-6 Min
0,000
15,000
30,000 (mm)
7,500
22,500
Y
X

(b)


C: fillet 1,1
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
02/06/2022 09.22
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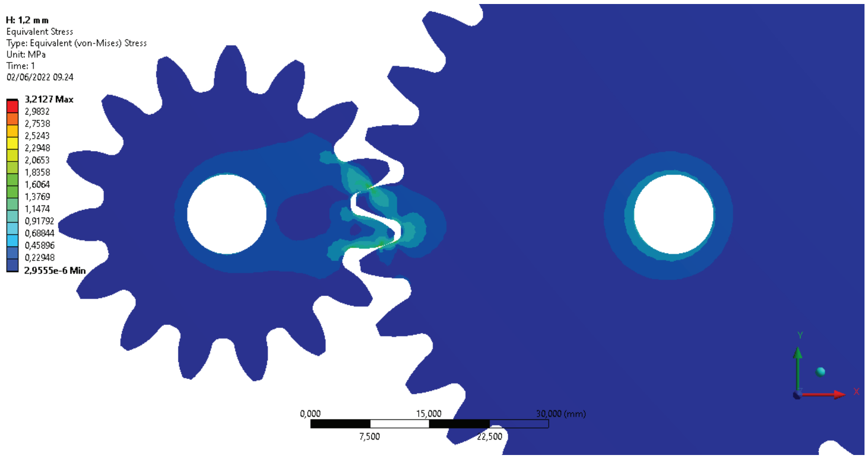
2,64
2,42
2,2
1,98
1,76
1,54
1,32
1,1
0,88002
0,66001
0,44001
0,22001
4,5093e-6 Min
0,000
15,000
30,000 (mm)
7,500
22,500
Y
X

(c)



(d)

(e)

FIGURE 4. Stress generated on various fillet radius spur gear (a) 0,9 mm; (b) 1 mm; (c) 1.1 mm; (d) 1.2 mm; (e) 1.3 mm

TABLE 3. Maximum stress generated at the gear with a variation on fillet radius

Fillet Radius (mm)	Max Equivalent Stress (MPa)
0.9	3.385
1	3.116
1.1	3.08
1.2	3.212
1.3	2.956

Effect of Face Width

Another phase in gear optimization does not necessitate any complicated adjustments in the geometry, which is a spur gear's face width. The stresses at the crucial position are calculated using the consideration of deformation and mass for all spur gear design specifications. The corresponding (maximum) stress at crucial places for each face width decreases as the face width is increased. Table 4 shows the influence of face width on maximum stresses generated at the critical zone for plastic spur gear. In addition, Figure 5 depicts the optimum model for generating the amount of stress on a spur gear with a face width of 25 mm. As a result, this might be regarded a safe loading value. As a result, a face width of 25 mm may be preferable for spur gear optimization. Furthermore, the stress level at the critical area is lowered by 28,7% as a result of stresses generated during the 25 mm face width modification. Table 4 shows the effect of face width gear on the stress generated and max deformation of gear.

TABLE 4. Effect of face width gear

Face Width (mm)	Mass (gr)	Max Deformation (mm)	Max Equivalent Stress (MPa)
17.5	124.6	0.00492	3.82
20	142.4	0.00435	3.212
22.5	160.2	0.00386	2.609
25	178	0.00341	2.287

Comparison Optimized Spur Gear to Original Spur Gear

Using the results of the dynamic load and stress analysis as a foundation, local geometry improvements are made separately for each section of the spur gear. Table 5 shows the comparison of optimized gear's design parameters to the original spur gear's design parameters derived by lowering maximum stresses at the crucial point. The first local improvement is to increase the value of radius from 0.9 mm to 1.3 mm on the fillet root tooth, followed by a face width increase from 17,5 mm to 25 mm, because the stresses in the fillet area are greater owing to increased stress concentration. As a consequence of this shape optimization, the maximum stresses are lowered from 3.385 MPa to 2.287 MPa. The improved spur gear model is shown in Figure 5. This spur gear model will be more long-lasting.

TABLE 5. Comparison optimized spur gear to original spur gear

Parameter	Original Spur Gear (MPa)	Optimized Spur Gear (MPa)	Percentage Reduction Stresses (%)
Fillet Radius (mm)	0.9	1.3	-
Face Width (mm)	20	25	-
Max Equivalent Stress (Mpa)	3.385	2.287	32.43722304

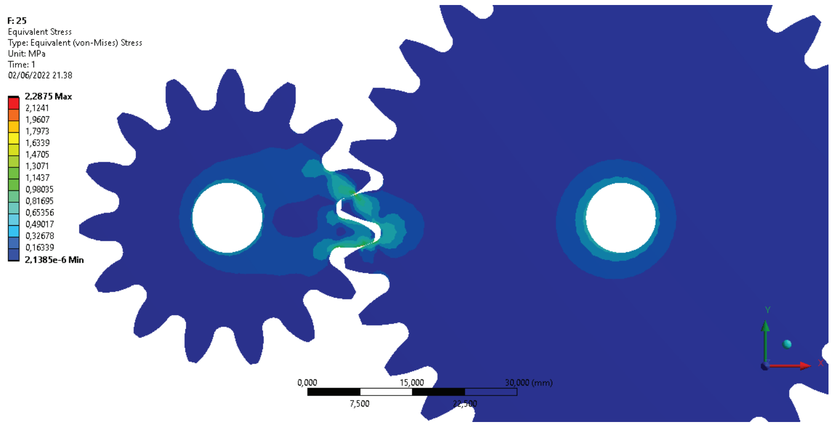


FIGURE 5. Von Misses Contour of the Optimized Plastic Gear.

CONCLUSIONS

The paper presented a plastic spur gear optimization for reducing the stresses generated at the crucial point. The following is the conclusion of this gear shape optimization analysis:

1. The crucial point that will be the first to fail is the area surrounding the root of the tooth of the fillet radius because it gets the maximum stress, which results in the highest stress concentration than other areas
2. After increasing the value of fillet radius on the spur gear, the maximum stresses generated decrease due to a reduced concentration of stress around the critical point. The 1.3 mm fillet radius is preferred because it decreases stress by 12.673 percent compared to the original spur gear type.
3. After the shape optimization, the variations of fillet radius and face width are applied to optimize the spur gear. The maximum stress reduces from 3.385 MPa to 2.287 MPa when compared to the original spur gear model to the optimized gear model (25 mm face width and 1.3 mm fillet radius).

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