International Journal of Electrical Engineering & Emerging Technology, Vol. 05, No. 02, DEC 2022, pp 1-5

Investigation of Spur Gear Pair under Contact Load for Different Materials by using FEA Approach

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[**Received on:** 03/08/22 **Accepted on**: 05/10/2022 **Published on:** 11/12/22**]**

***Abstract* - The spur gear is the most basic and is used in essentially all mechanical systems. There are numerous reasons why two pairs of gears can break, which leads to the failure of the gears. One of the primary forms of failure is caused by contact stresses generated during gear operation at high speeds. In this research, two pairs of spur gear are subjected to an analytical and finite element analysis with a focus on the stresses and deformation analysis for the two materials. 3D CAD model of spur gear pairs was modeled using ANSYS Design Modular, and then FEA analysis with different materials is conducted using ANSYS Workbench 16.0 and Analytical analysis is done by using Hertz Theory of contact stress. The results show that the maximum contact stresses calculated using the Hertz equation differ from those obtained using Finite Element Analysis by a very tiny, tolerable amount.. Contact stress for aluminum alloy by applying the same loading condition was recorded as 865.48 MPa while for gray cast iron it is 1034.6 MPa. Grey cast iron and aluminum alloy gears only slightly differ in overall deformation. It is concluded that aluminum alloy materials show better performance in overall operation as compared with gray cast iron hence it would be better for manufacturing.**

***Index Terms*— ANSYS, Deformation, Contact Stress, FEA, Spur Gear.**

I. INTRODUCTION

ONE of the most effective ways to transmit power and rotary motion from a source to an application without necessarily changing speed or direction is through gear. [1]. A gear is a rotating machine part with cut teeth, also known as cogs that mesh with another toothed part to transmit torque. The application of gear is found almost all kind of modern engineering system such as from tinny wristwatches to huge machinery [2]. In addition to successfully transmitting motion and huge power, gears are also capable of doing so with remarkably uniform motion. It is the most effective and practical way to transmit this motion [3]. Pitting and scoring are surface defects that are mostly caused by contact fatigue, due to the high contact stresses present when teeth are mated, it is a phenomenon whereby tiny particles are removed from the tooth's surface [4]. Stress analysis for gear teeth is considered a design constraint. Understanding the areas of concentration of stress where failure or fracture may occur is the main goal of stress analysis [5].

The automobile industry, which is the biggest producer of gears, needs gears with higher dependability and lower weight as the market for lighter cars continues to expand. Additionally, engine success with less noise drives the development of quieter gear pairs for even greater noise reduction. When designing severely loaded spur gears for robust and silent power transmission systems, the finite element method can be used [6].

To determine the maximum contact stress in the gear teeth, a stress analysis of mating spur gear teeth was performed. The FEA results were compared to the Hertzian equation predicted values. Steel and Grey cast iron are the materials used to make the spur gears for this study. The findings of the study revealed that the maximum contact stresses determined using the Hertz equation and the finite element method are extremely similar and acceptable [7]. Rao and Vamsi (2016) conducted a research and design of the contact stresses of a spur gear carried out using a variety of software tools, such as pro-e and ANSYS. The contact stress is investigated in mechanical ANSYS multi-physics using the ANSYS design for developing the spur gear. [8]. the normal or resultant force acts along the pressure line at the pitch point in a horizontal and vertical plane to balance both tangential and vertical components. The torque and power of a spur gear are calculated using the tangential force component. Contact stress and bending stress are created on the gear as a result of the tangential force acting on it. When the contact stress on the gear exceeds the wear strengths of the gear material, the gear wears out or fails due to pitting. [9]. Bharat Gupta 2012 presented a paper to suggested that careful investigation of the contact stress that forms between various matting gears is crucial for gear design. They used Hertz equations, an analytical technique originally developed for determining gear contact stresses between two cylinders. To calculate contact stresses using ANSYS and compare the findings to Hertz's theory, they constructed and identified relevant models of contact elements. Conclusions indicate that contact stresses for a pair of spur gears decrease as the module increases [10]. Using a spur gear pair, Patil et al. (2014) performed a finite element analysis to examine how the coefficient of friction affects the line-of-action gear contact stresses. Theoretical calculations were used to validate the FE model, and the FE findings revealed that contact stresses increased as the

coefficient of friction increased. Additionally, they have identified the variation in contact stresses throughout the spur gear pair's line of contact [11].
The primary goals of this work are to investigate the contact stresses and deformations for various materials using FEA analysis and to theoretically validate the FEA results.

II. MATERIALS AND METHODS

A. *Research Methodology*

The initial part of the research involved a thorough literature review, and to accomplish the desired goals, the second step of the research involved performing theoretical calculations based on the mathematical calculations for contact stresses. For the analysis of contact stress, the Hertzian equation is employed. Utilizing ANSYS Design Modeler, the third stage of our task entails creating a 3D CAD model for spur gear. Since it is the most user-friendly and precise method for stress analysis, the finite element analysis is carried out using the ANSYS 16.0 finite element software. The FEA result will be compared with theoretical findings in step 4 of the process. Fig. 1 shows the proposed methodology flowchart.

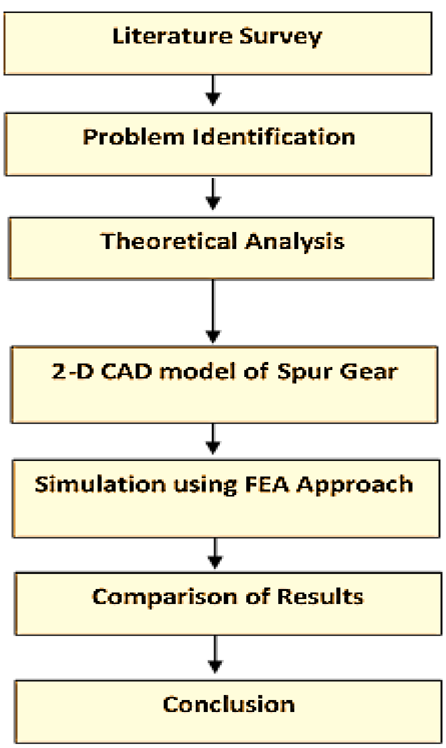

Fig. 1. Research Methodology Flow Chart

B. *Theoretical Analysis (Hertz Contact Theorem)*

Hertz's equations, which were initially created for the contact between two cylinders, are typically used in current methods of calculating gear contact stress. In Fig.2, the contact stresses between two cylinders were depicted. An ellipsoidal-prism pressure distribution is generated between the two contact points.

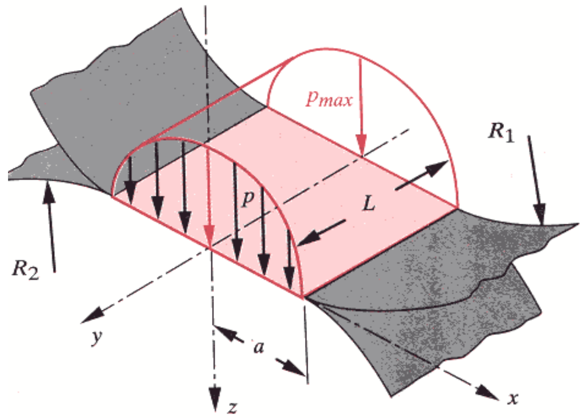

Fig. 2. Ellipsoidal-prism pressure distribution

Fig. 2 depicts the contact zone width as 2a. The relationship between F and p(x) can be seen in the following formula if the total contact force is F and the contact pressure is p(x):

$$F = 2L\int_0^a P(x)dx \tag{1}$$

Contact width

$$a = \sqrt{\frac{\frac{2F(1-v_1^2)}{E1}+\frac{1-v_2^2}{E2}}{\pi L \quad \frac{1}{d1}+\frac{1}{d2}}} \tag{2}$$

The Maximum Contact stress

$$Pmax = \frac{2F}{\pi a L} \tag{3}$$

The pinion and gear pitch diameters are represented by d1 and d2.

The maximum surface (Hertz) stress:

$$Pmax = \sigma H = 0.564\sqrt{\frac{F(\frac{1}{R1}+\frac{1}{R2})}{\frac{1-v_1^2}{E1}+\frac{1-v_2^2}{E2}}} \tag{4}$$

The maximum allowable stress is determined by,

$$\sigma_a = {}^{\sigma_c}\!/_{FOS} \tag{5}$$

C. 3D CAD Modeling of Spur Gear Set

TABLE I: Specification of spur gear set

Teeth Geometry	Values
Pitch Circle Diameter	63.5 mm
Number of Teeth	20
Pressure Angle	20°
Addendum	3.175 mm
Dedendum	3.683 mm

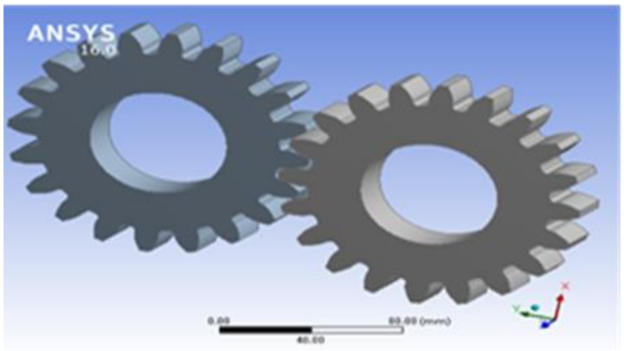

Fig. 3. Spur Gear 3D CAD Model in ANSYS

D. The meshing of spur gear

Researchers can use mesh technology to optimize various requirements and find the best mesh for each simulation. The results are not guaranteed to be accurate if the default settings are used. Tetrahedral elements are used in the current assembly. The total No of Node is 6228 and the total no of Elements is 1764.

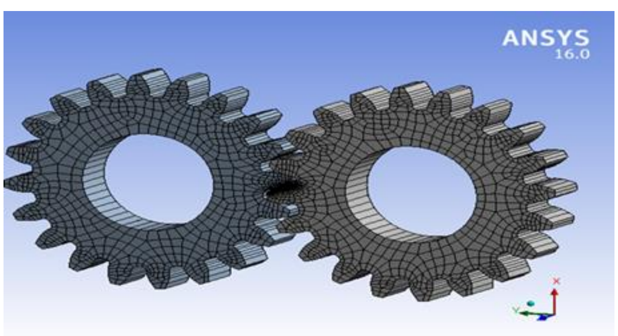

Fig. 4. Meshing of Spur Gear

E. Loading Conditions of Spur Gear Set

Figure 5 depicts the boundary conditions for the FEA study of the two different materials made gears. A fixed contact is fastened to the inner lower gear rim. The inner rim of the higher gear provides frictionless support, allowing tangential rotation but limiting radial translation.

The maximum moment of 1694.7725 N-m was applied at top gear's inner rim [12].

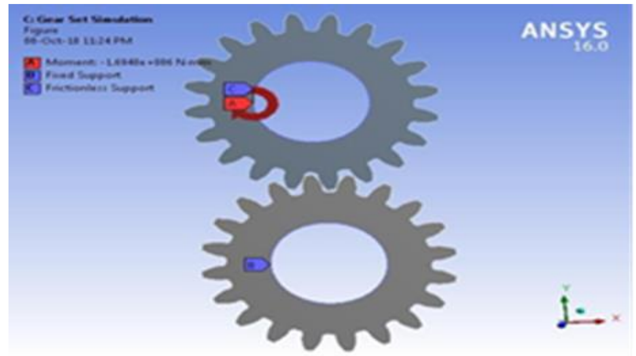

Fig. 5. Applied loads and support for Spur Gear

III. RESULTS AND DISCUSSION

This section of the study compares the stress distribution over the flank of grey cast iron spur gear and aluminum alloy spur gear. By applying the maximum moment of 1694.7725 N-m at the top of inner rim of spur gear the maximum contact stress for aluminum alloy spur pinion and gear was 865.48 MPa, and maximum contact stress for grey cast iron spur pinion and gear was 1034.6 MPa. From a deformation point of view, the total deformation for aluminum alloy gear was found to be 0.3036 mm and for gray cast iron gear, it is 0.160 mm.

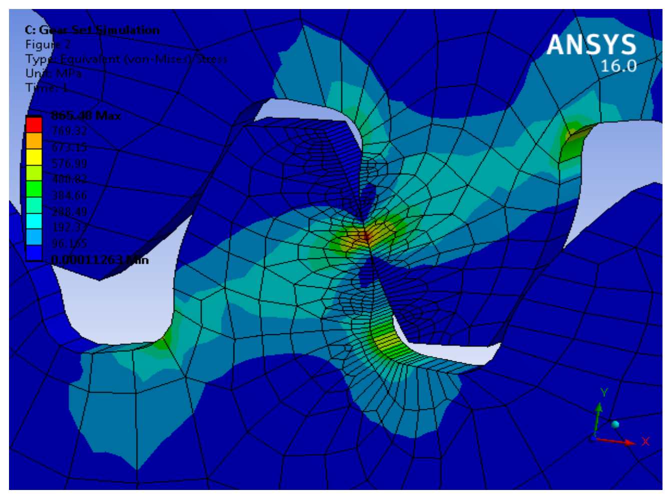

Fig. 6. Three dimension Von Mises contact stress for Aluminum Alloy

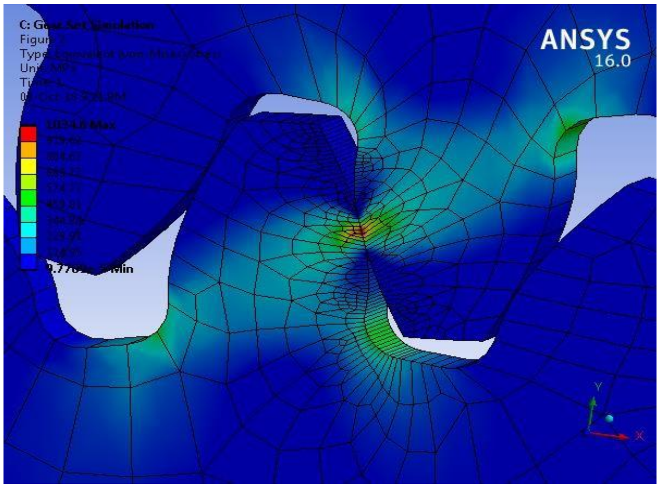

Fig. 7. Three dimension Von Mises contact stress for Grey Cast iron

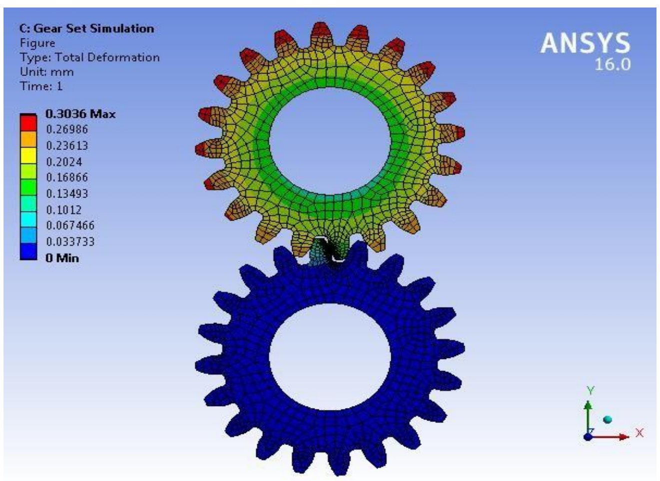

Fig. 8. Deformation pattern for Aluminum Alloy

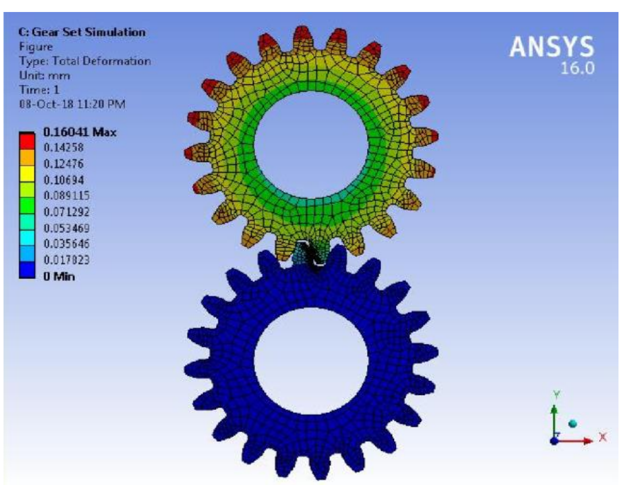

Fig. 9. Deformation pattern for gray cast iron

A. Validations of FE results with HERTZ contact theorem

The FEA contact stresses generated can be validated by comparing them with the HERTZ contact stress theorem.

TABLE II: Validations of theoretical and FE contact Stress analysis

Properties of Materials	Theoretical	FEA	% Error
Grey Cast Iron	1012.47 MPa	1034.60 MPa	2.18
Aluminum Alloy	854.64 MPa	865.48 MPa	1.26

The results of the theoretical and FEA approaches are compared in Table 2. It was found that both methods exhibit strong agreement and small percentage error.

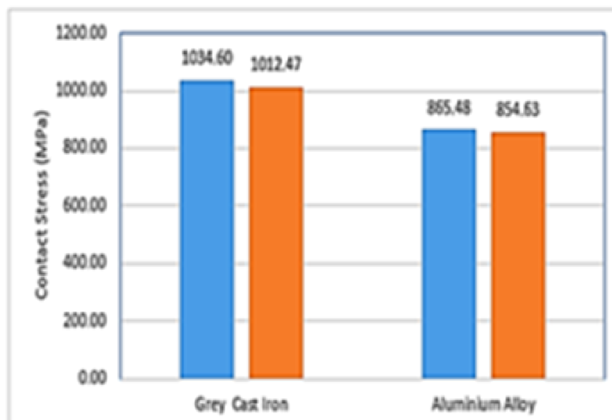

Fig. 10. Graphical representation of FEA and theoretical results of contact stress

Figure 10 shows the comparison of theoretical and FE approach analysis of contact stress both results were found to be in good accord, it was decided. While grey cast iron displays more stress than aluminum alloy.

IV. CONCLUSION

- The maximum theoretical contact stress is calculated using Hertz contact theorem.
- The maximum contact stress and deformations of the spur gear are investigated using ANSYS 16.
- For the same applied loading conditions the maximum contact stress for aluminum alloy was

found less as compared with the gray cast iron spur gear.

- Due to the material density and other features, it was determined that aluminum alloy gear exhibits greater deformation than grey cast iron from a deformation perspective.
- The validations of Hertz and FEA results was acceptable. These both result shows very less difference.
- It is concluded from this research that aluminum alloy material can also be suitable for manufacturing the spur gear for future applications

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