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Ansys Analysis on Fatigue Life Enhancement and Stress Relief Factors on Different Composite Spur Gear Combinations

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Abstract: Spur gears have become a subject of research interest because of the dynamic load attention of the noise level during operation and the demand for lighter and less significant. In such types of gears, there is a problem of failures at contact at meshing the teeth. This can be minimized or avoided by proper method analysis and modification of the various gear parameters. In this project characteristics of a Spur gear in dynamic condition containing contact stiffness and other stresses produce. The main objective of this thesis is by using a numerical approach to develop a theoretical model of the Spur gear and to find the effect of contact gear tooth stresses by taking material C-45. And later in the second phase after this study the laminate technology is introduced on forming of gear structure with layered composite materials and various case studies are involved in determining the better dynamic strength for load carrying capacity and improving the fatigue life of the gear. This work offering the chances of using the stress re-distribution methods by introducing the stress-relieving features in the stressed zone to the benefit of reduction of root fillet stress in spur gear. The application of laminates in the gear will prevent propagation and penetration of crack along the width of the gear. To evaluate the meshing stiffness, three-dimensional solid models for a different number of teeth are created by solid works and the numerical solution is done in ANSYS, which is a finite element analysis package. Fatigue analysis of the contacting points in gear tooth is also been carried out using ANSYS and are been compared against each other. In current days, engineering components made of composition materials find increasing applications ranging from spacecraft to small apparatuses. In this project, for a transmission system of Spur gear pair made of steel (EN-24) and for a composite laminate Spur gear pair (Al-SiC) / Steel (20Mn Cr5) and PEEK450G combinations, stress analysis is made under static load conditions using ANSYS and the results were compared.

Keywords: ANSYS, Spur gear, Fatigue, Composite spur gear, Stress

I. INTRODUCTION

Gears are defined as the toothed members that transmit power and motions from one shaft to another. They are the oldest devices and inventions of man. Spur gears are the simplest and the most common type of gears. The teeth are straight and parallel to the shaft axis and the gearing so formed is called spur gearing In recent days, spur gears made of steel (EN-24) are used in the field of machinery and automobiles. The gears made of steel have more weight and the life period is very short. So the main objective of this project is, to minimize the weight for a transmission system of spur gear pair, a composite spur gear has been introduced and comparative stress analysis has been done between spur gear pair (EN-24) and composite spur gear pair under static load condition using ANSYS. The designing of gear pair is very complex and it often wants the use of nonlinear functions, as well as discrete design variables. In almost all structures, it is extremely important to design machine elements in such a manner that the whole construction weight is minimal. In this project, the gear is divided into five layers each of the same thicknesses. Different material combinations are used by assigning certain selected materials to each of the five layers. Steel is been replaced using 20MnCr5 and two other materials AlSiC and PEEK450G.

II. LITERATURE SURVEY

A. *John.J. Coy & Erwin V. Zaretsky*, NASA, Washington DC Aug. 1975 have created a mathematical model for the surface fatigue life of spur gears. The derivation is based on the Lundberg-Palmgren theory, which has been accepted since 1950 as the best predictor of rolling-element bearing life. Besides, an equation for the dynamic capacity of a gear set was derived.
B. *DimitrovLubomir, IvaylorKovachev*, Technical University of Sofia, Bulgaria have presented a paper in which they have created a computer model, based on the fracture mechanics approach and on finite element analysis for the determination of spur gear teeth fatigue life, is demonstrated. The model allows following the growth of a net of micro-cracks and their mutual interaction. It is assumed, that the gear tooth contacting surface fails due to pitting when the size of pits increases by 40µm.

C. *NecatAltinkoket.al [2006]* predicted tensile strength of Al_2O_3/ SiC particle reinforced metal matrix composites. This composite is produced by the stir casting method. In the experiments, the Al_2O_3/SiC residue mix has been made by the reaction of an aqueous solution of aluminium sulphate, ammonium sulphate, and water containing SiC atoms at 1200°C. 10% vol. of this dual ceramic dust with dissimilar SiC atoms size ranges was added into liquid matrix alloy during mechanical stirring between solidus and liquids under inert conditions. The microstructure of the alloy is dependent on the cooling.

D. *Rohatgi[2006]* abridged attempts to incorporate fly ash into aluminium castings to reduce the energy content, material content, cost, and weight of certain industrial components, while also improving particular properties. It is exposed that fly ash can be integrated into an aluminium alloy matrix using stir casting and pressure infiltration methods.

III.METHODOLOGY

The sequences of works are represented in the form of a flow diagram as shown in Fig 1

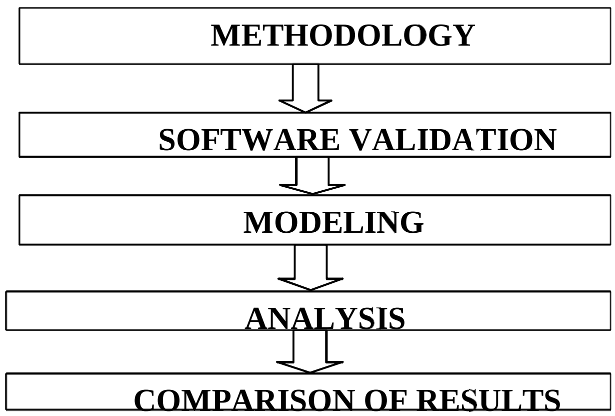

Fig. 1 Flow diagram of a methodology

A. Data collection and gear designing.
B. Designing the gear model (gear-pinion) for analyzing in solid works.
C. Exporting the model to ANSYS workbench 2019 in Para solid format.
D. Material Selection.
E. Assign composites properties in ANSYS in the mechanical section.

IV. SOFTWARE USED

ANSYS develops and markets finite element analysis software used to simulate engineering problems. The software generates simulated computer models of electronics, structures, or machine components to simulate toughness, strength, temperature distribution, elasticity, fluid flow, electromagnetism, and some features. ANSYS is mainly used to conclude how a product will perform with dissimilar specifications, without constructing a test product or organizing a crash test.

Most of the ANSYS simulations are accomplished by using the ANSYS Workbench software, which is one of the company's main products. Usually, ANSYS users break down larger structures into small components that are each modeled and tested individually. A user can start it by defining the measurements of an object, and then assign temperature, weight, pressure, and other physical properties. Lastly, the ANSYS software analyzes and simulates temperature distribution, movement, fluid flow, fractures, electromagnetic efficiency, fatigue, and other effects over time.

V. MODELING

In this project, for a transmission system of spur gear pair made of steel (en-24) and for a composite laminate spur gear pair (al-sic) / steel (20mn cr5) and peek450g combinations, stress analysis is to be made under static load conditions using Ansys and the results should be compared.

In this project, the gear is divided into 5 layers each of the same thickness. The thickness of each layer is 64mm. Different material combinations are used in each layer.

A. Meshing The Model

1) Gear pinion contact: frictional
2) Frictional coefficient: 0.3
3) Minimum contact thickness: 1.5mm

B. Combinations Used

The Gear tooth is being divided into 5 layer laminates(1,2,3,4,5), each of which are assigned with different material combinations as discussed below:

1) 20MnCr5 & PEEK450G Combination

TABLE I
Combination of 20MNCR5 & PEEK450G

Sl No:	20MnCr5	PEEK450G
1-a	1,3,5	2,4
1-b	2,4	1,3,5
1-c	1,5	2,3,4

2) ALSiC & PEEK450G Combination:

TABLE II
Combination of ALSIC & PEEK450G

Sl No:	AlSiC	PEEK450G
2-a	1,3,5	2,4
2-b	2,4	1,3,5
2-c	1,5	2,3,4

In all cases, the pinion material is being assigned as EN24 steel.

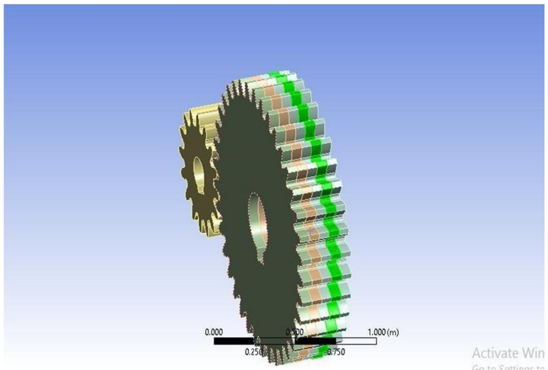

Fig. 2 Gear Laminates

VI. ANALYSIS

A. Geometry Modeling

Construction of Geometric Model mainly involves three methods:

1) *Modeling Of EN-24 Steel Gear*: The gear is drawn in solid work. The gear is having a face width of 320mm. The model thus obtained is inserted into the ANSYS workbench 19.0 in Parasolid format and then further analysis is done.
2) *Modeling Of Laminated Spur Gear*: The laminated spur gear is created on solid work by dividing the spur gear created before into five layers, each of thickness 64mm. The model thus obtained is inserted into the ANSYS workbench 19.0 in Parasolid format and then further analysis is done.

B. Finite Element Analysis (FEA)

The gear models created on solid works are introduced into the ANSYS workbench 19.0 in Para solid format. Material selection and material properties are assigned in ANSYS mechanical section.

Table III
Properties Of Materials

Material properties	EN-24 steel	20MnCr5	PEEK
Young's modulus MPa	2.1e+005	3.8e+005	3.8e+005
Poisson's ratio	0.29	0.38	0.38
Density Kg/mm^3	7.8e-006	1.31e-006	1.31e-006

Meshing is the process in which your geometry is spatially discredited into elements and nodes. This mesh along with material properties is used to mathematically represent the stiffness and mass distribution of the structure. The mesh has been generated automatically. The default element size is decided based on several factors including the overall model size, the proximity of other topologies, body curvature, and the complexity of the feature. In meshing, if the model, the gear pinion is taken as a frictional contact and the frictional coefficient is 0.3. The minimum contact pressure is taken as 1.5mm. The algorithm is solved by applying the boundary conditions. The boundary conditions are:

1) Cylindrical support
2) Radial movement: free
3) Tangential and axial movement arrested
4) Applying pinion moment

On solving, teeth stress and deformation is analyzed and then fatigue life is analyzed.

C. Comparison

Two types of material combination (20MnCr5 & PEEK450G and AlSiC & PEEK450G), each combination having three different arrangements are taken. The equivalent stress, deformation, and fatigue life of each combination are compared with that of EN-24 steel spur gear and the best combination is selected.

VII. RESULT AND DISCUSSION

Most of the gears commonly used are formed up of EN-24 steel. The main drawbacks of this gear are, it's much heavier and has a shorter life period. The life period of this type of gear is shorter because when a crack or wear occurs on the surface of the gear, it then propagates through the length of the material resulting in breaking or damage of the gear. So as to overcome these main drawbacks, the conventional gear is replaced by laminated composite spur gear. The studies show that crack propagation in gear can be reduced by using laminates. So the EN-24 steel gear is divided into five layers of equal thickness. Weight reduction can be obtained by using lighter materials (having higher strength and stiffness) instead of EN-24 steel.

In this project, steel is replaced by 20MnCr5, AlSiC, and PEEK 450G. Gears with different material combinations are analyzed in ANSYS 19.0 for equivalent stress, total deformation, fatigue damage and fatigue life of these material combinations are then compared with that of EN-24 steel. And the best combination that can be used to replace conventional gear is selected.

A. EN-24 Steel

1) The minimum deformation of EN-24 steel is 1.7005e^{-9}m and its maximum deformation is 6.104e^{-5}m.
2) The minimum equivalent stress is 118.19Pa and its maximum equivalent stress is7.2954e^{7}Pa.
3) The minimum fatigue life of EN-24 steel is 3.9802e^{5} cycles and its maximum fatigue life is 1e^{6} cycles.
4) The minimum fatigue damage of EN-24 steel is 1000 cycles and its maximum fatigue damage is 2512.4 cycles.

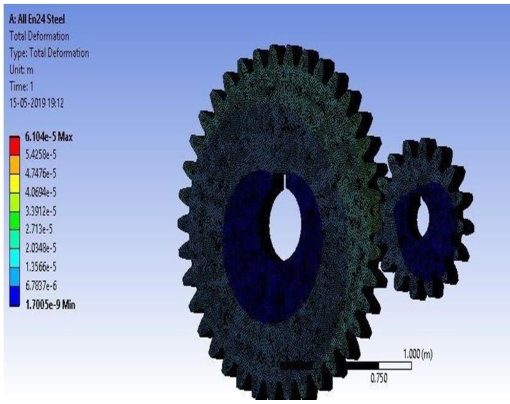

Fig. 3 Total Deformation of EN-24 Steel

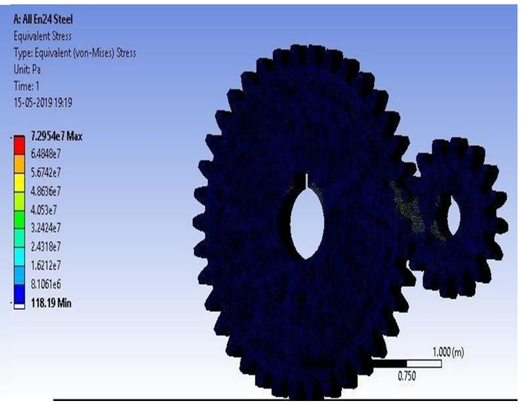

Fig. 4 Equivalent Stress of EN-24 Steel

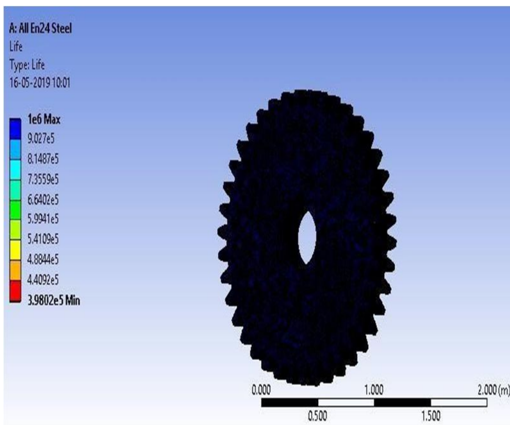

Fig. 5 Fatigue Life of EN-24 Steel

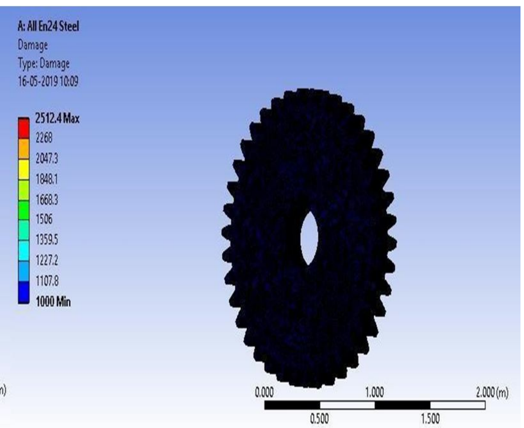

Fig. 6 Fatigue Damage of EN-24 Steel

B. 20MnCr5 & PEEK450G

1) Combination 1-a

a) The minimum deformation of Combination 1-a is $1.6751e^{-10}$m and its maximum deformation is $5.3081e^{-5}$m.

b) The minimum equivalent stress of combination 1-a is 101.07Pa and its maximum equivalent stress is $8.9412e^{7}$Pa.

c) The minimum fatigue life of combination 1-a is $1e^{6}$ cycles and its maximum fatigue life is $8.1e^{7}$cycles.

d) The minimum fatigue damage of combination 1-a is 12.346 cycles and its maximum fatigue damage is 1000 cycles.

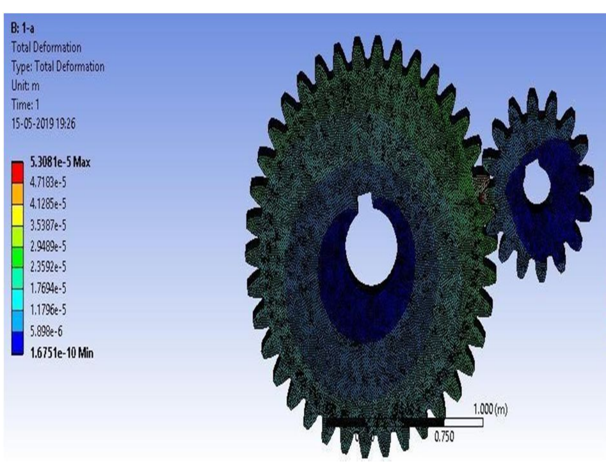

Fig. 7 Total Deformation of Combination 1-a

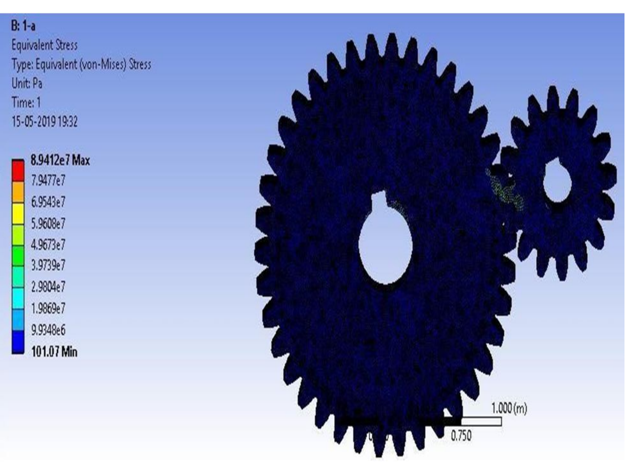

Fig. 8 Equivalent Stress of Combination 1-a

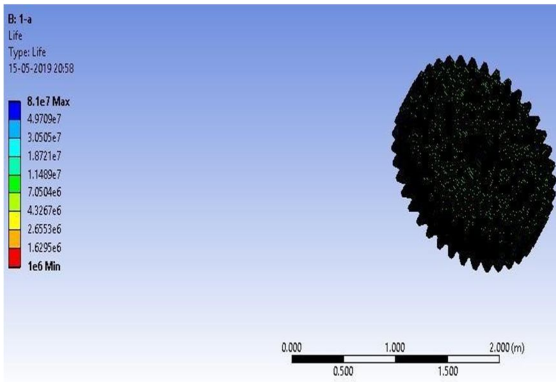

Fig. 9 Fatigue Life of Combination 1-a

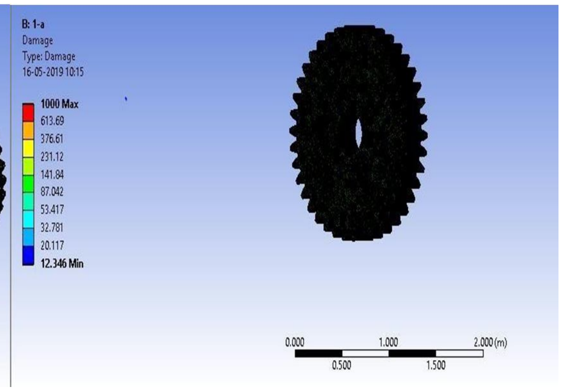

Fig. 10 Fatigue Damage of Combination 1-a

2) *Combination 1-b*

a) The minimum deformation of combination 1-b is $8.1915e^{-10}$m and its maximum deformation is $6.3789e^{-5}$m.

b) The minimum equivalent stress of combination 1-b is 5.0096Pa and its maximum equivalent stress is $1.0456e^{8}$Pa.

c) The minimum fatigue life of combination 1-b is $6.374e^{6}$ cycles and its maximum fatigue life is $8.1e^{7}$ cycles.

d) The minimum fatigue damage of combination 1-b is 12.346 cycles and its maximum fatigue damage is 156.89 cycles

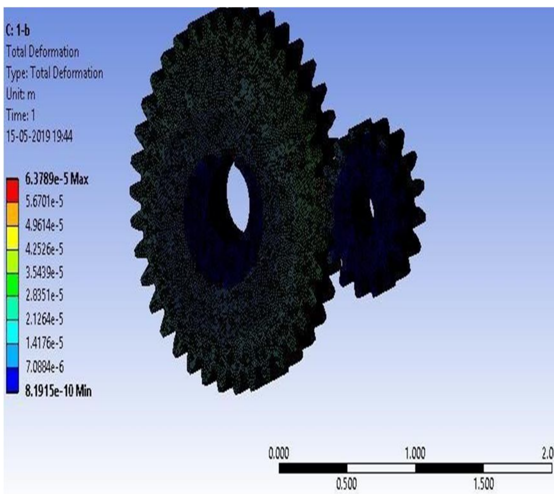

Fig. 11 Total Deformation of Combination 1-b

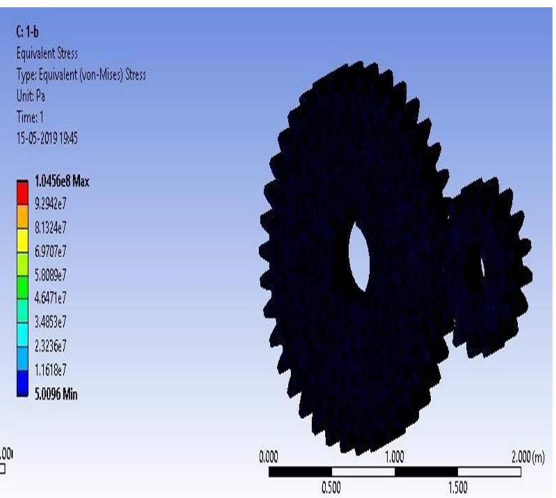

Fig. 12 Equivalent Stress of Combination 1-b

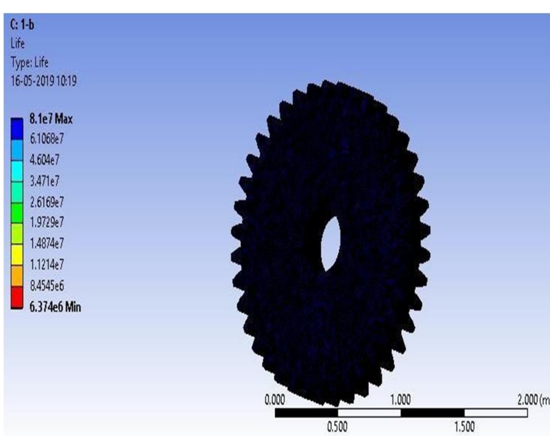

Fig. 13 Fatigue Life of Combination 1-b

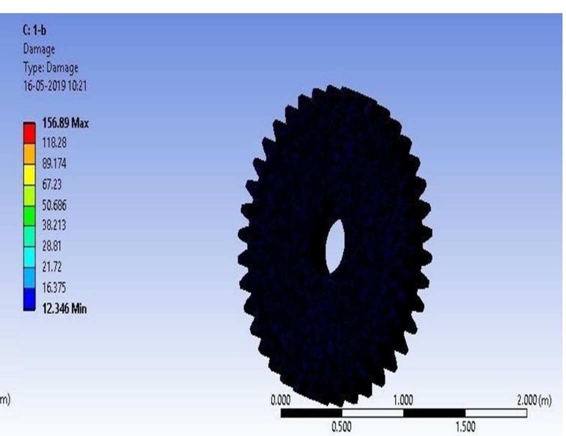

Fig. 14 Fatigue Damage of Combination 1-b

3) Combination 1-c

a) The minimum deformation of combination 1-c is $6.2472e^{-10}$m and its maximum deformation is $6.3773e^{-5}$m.

b) The minimum equivalent stress of combination 1-c is 23.562 Pa and its maximum equivalent stress is $1.0688e^{8}$ Pa.

c) The minimum fatigue life of combination 1-c is $6.3128e^{6}$ cycles and its maximum fatigue life is $8.1e^{7}$ cycles

d) The minimum fatigue damage of combination 1-c is 12.346 cycles and its maximum fatigue damage is 158.41 cycles.

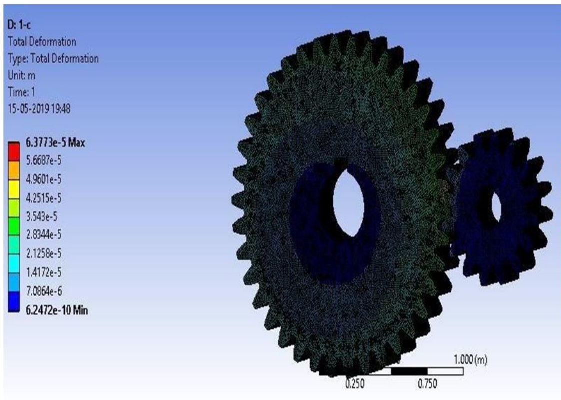

Fig. 15Total Deformation of Combination 1-c

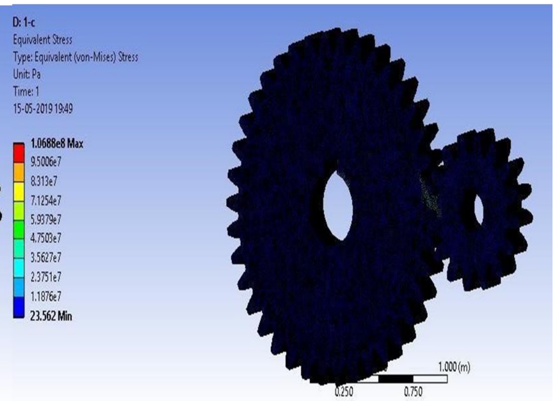

Fig. 16 Equivalent Stress of Combination 1-c

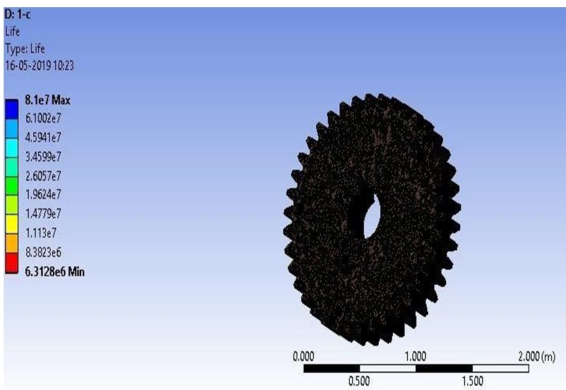

Fig. 17 Fatigue Life of Combination 1-c

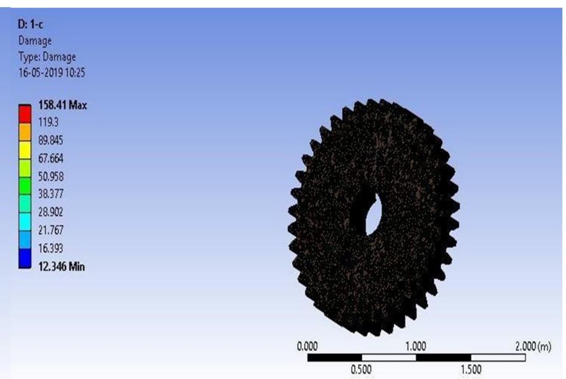

Fig. 18 Fatigue Damage of Combination

C. AlSiC & PEEK450G

1) Combination 2-a

a) The minimum deformation of combination 2-a is $2.4135e^{-10}$m and its maximum deformation is $5.5822e^{-5}$m.

b) The minimum equivalent stress of combination 2-a is 142.12 Pa and its maximum equivalent stress is $9.6647e^{7}$ Pa.

c) The minimum fatigue life of combination 2-a is $5.6179e^{5}$ cycles and its maximum fatigue life is $8.1e^{7}$ cycles.

d) The minimum fatigue damage of 2-a is 12.346 cycles and its maximum fatigue damage is 11780 cycles.

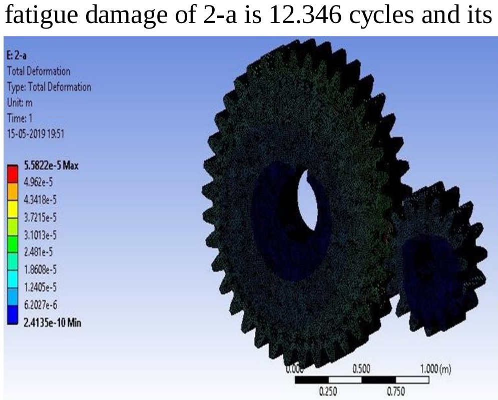

Fig. 19 Total Deformation of Combination 2-a

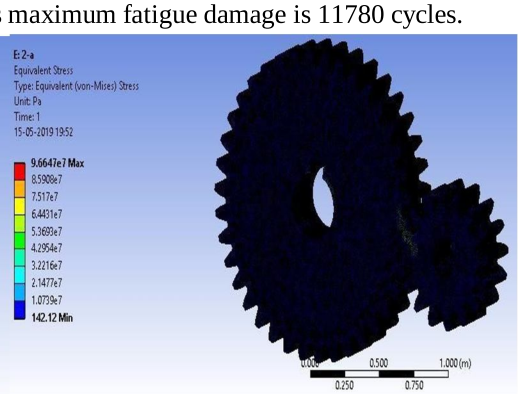

Fig. 20 Equivalent Stress of Combination 2-a

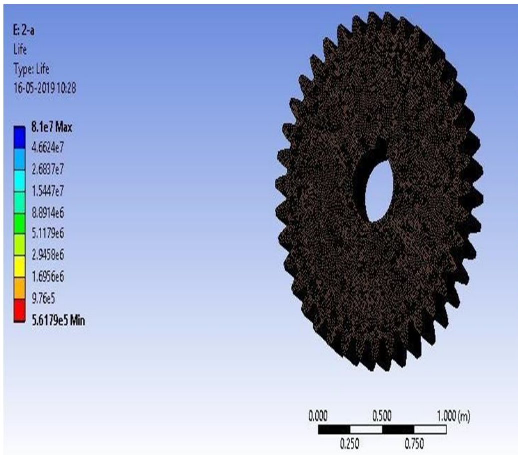

Fig. 21 Fatigue Life of Combination 2-a

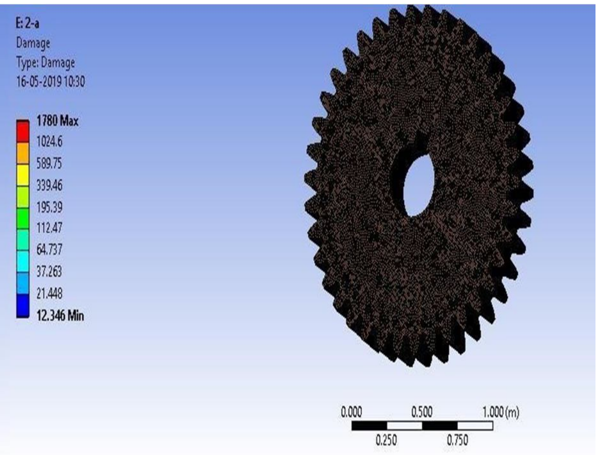

Fig. 22 Fatigue Damage of Combination 2-a

2) *Combination 2-b*

a) The minimum deformation of combination 2-b is 1.1116e^{-10}m and its maximum deformation is 6.2395e^{-5}m.
b) The minimum equivalent stress of combination 2-b is 7.9211 Pa and its maximum equivalent stress is 1.1394e^{8}Pa.
c) The minimum fatigue life of combination 2-b is 3.9346e^{5} cycles and its maximum fatigue life is 8.1e^{7} cycles.
d) The minimum fatigue damage of combination 2-b is 12.346 cycles and maximum fatigue damage is 2541.6 cycles

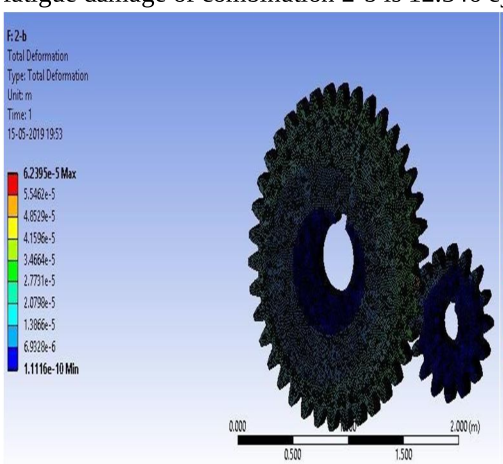

Fig. 23 Total Deformation of Combination 2-b

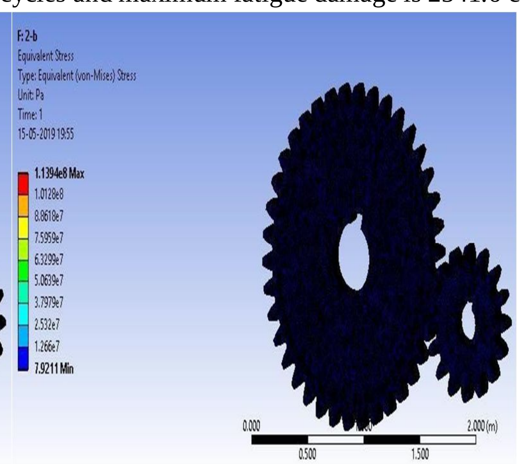

Fig. 24 Equivalent Stress of combination 2-b

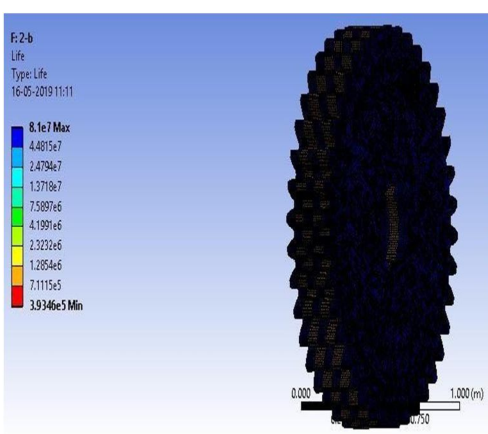

Fig. 25 Fatigue Life of Combination 2-b

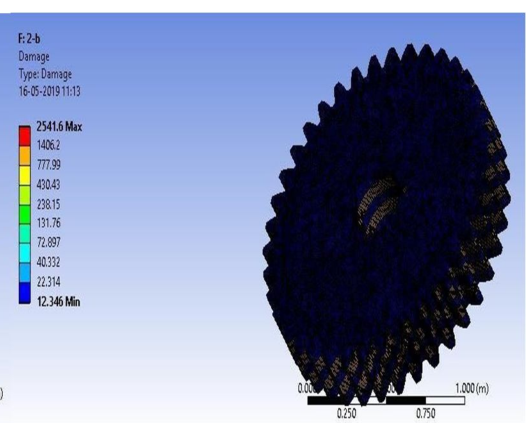

Fig. 26 Fatigue Damage of Combination 2-b

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3) Combination 2-c

a) The minimum deformation of combination 2-c is $1.9811e^{-9}$m and its maximum deformation is $6.2444e^{-5}$m.

b) The minimum equivalent stress of combination 2-c is 39.909 Pa and its maximum equivalent stress is $1.1648e^{8}$ Pa.

c) The minimum fatigue life of combination 2-c is $3.771e^{5}$ cycles and its maximum fatigue life is $8.1e^{7}$ cycles.

d) The minimum fatigue damage of combination 2-c is 12.346 cycles maximum fatigue damage is 2651.8 cycles.

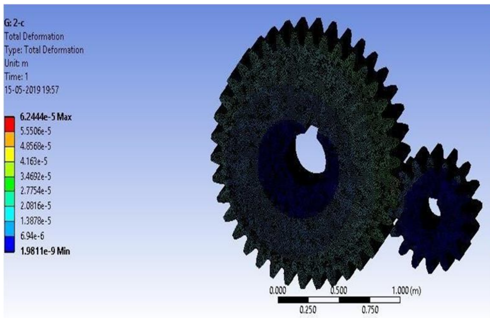

Fig. 27 Total Deformation of Combination 2-c

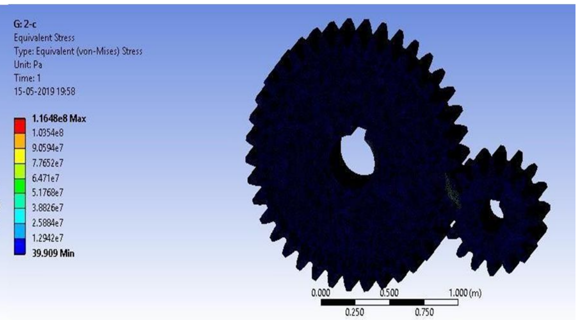

Fig. 28 Equivalent Stress of Combination 2-c

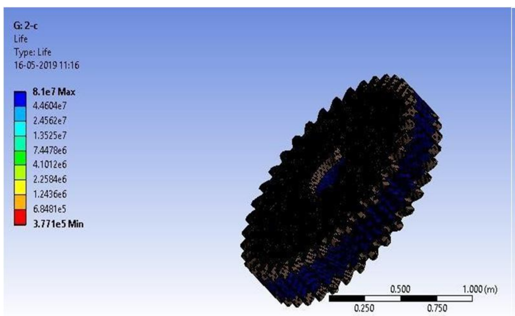

Fig. 29 Fatigue Life of Combination 2-c

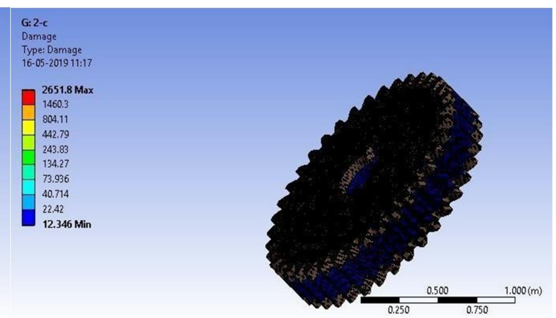

Fig. 30 Fatigue Damage of Combination 2-c

D. Comparison

TABLE IV
Comparison Of Result Of Steel With Different Combinations

Properties	Combination						
	Steel	1-a	1-b	1-c	2-a	2-b	2-c
Total Deformation (m)	$6.104e^{-5}$	$5.308e^{-5}$	$6.37e^{-5}$	$6.377e^{-5}$	$5.38e^{-5}$	$6.2e^{-5}$	$6.24e^{-5}$
Equivalent Stress (Pa)	$7.295e^{7}$	$8.94e^{7}$	$1.045e^{8}$	$1.06e^{8}$	$9.66e^{7}$	$1.13e^{8}$	$1.16e^{8}$
Weight (N)	5011.4	3571.3	2856.7	2856.7	1001.8	1143.7	1143.7
Fatigue Life (Cycles)	$3.980e^{5}$	$1e^{6}$	$6.374e^{6}$	$6.312e^{6}$	$5.617e^{5}$	$3.93e^{5}$	$3.77e^{5}$

VIII. CONCLUSIONS

A. The analysis is carried out using ANSYS 19.0 for the conventional existing spur gear with standard design as well as for composite spur gear combinations.

B. In 20MnCr5 and PEEK450G : On the basis of weight and fatigue life, 1-b and 1-c combinations are the best.

C. In AlSiC and PEEK450G: 2-a combination is the best when considered with the strength to weight ratio.

D. The average weight of the 20MnCr5 and PEEK450G combination is 38% less than that of EN24Steel gear.

E. The average weight of the PEEK 450G and AlSiC combination is 70% less than that of EN24steel gear.

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