DESIGN AND ANALYSIS OF HIGH ENTROPY ALLOY SPUR GEAR

Kamalesh.S[1], Satishkumar.J[2], Dinesh Kumar.R[3]

[1,2,3] *Student, Dept. of Mechanical Engineering, Kumaraguru College of Technology, Tamilnadu, India*

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Abstract – *Gear and gearbox arrangement play a vital role in the power transmission system of any vehicle. Several types of gear were available. Some of them are Bevel gear, Worm gear, Spur gear, and Helical gear. Of which spur gear is involved in the majority of vehicles and locomotives. The problem with the conventional gear is that the weight of the gear contributes majorly toward the total weight of the vehicle and machine. Design and analysis of spur gear are done with the help of the designing software Catia V5 and analysis software Ansys. Kinematic analysis of designed gear was done theoretically by applying a gear ratio of 1:2. A comparison study of Structural steel gear and High entropy alloy gear was done on the aspects of structural parameters like Stress, Strain, Strain energy, and Deformation. The effect of one of the structural parameters on the other was studied with the help of a graph, and Hooke's law of stress and strain was verified.*

Key Words: **High entropy alloy, Weight reduction, Material science, Ansys, Static structural**

1. INTRODUCTION

Carbon steel is one of the majorly used materials in the field of mechanical engineering. The main properties of carbon steel were high tensile strength, high load carrying capacity, and low deformation. Even though it has good mechanical properties, the main problem of carbon steel was its poor corrosion resistance and greater weight. To replace these issues, one of the recent advancements in the material science field is the development of High entropy alloys. These high entropy alloys have similar tensile and load-carrying capacity but have good corrosion and less weight. A study on CrMnFeCoNi high entropy alloy shows good fatigue strength and has a more excellent fracture point [1]. Another study on high entropy alloys $Nb_{25}Mo_{25}Ta_{25}W_{25}$ and $V_{20}Nb_{20}Mo_{20}Ta_{20}W_{20}$ reveals that at room temperature yield stress of both the material drops to 30-40% while at the range of 600°C to 1600°C the material behaves efficiently in terms of yield strength and refractive property [2]. $CoCrFeNiTiAl_x$ alloy were studied at different molar concentrations of Aluminium, and it reveals that the value of compressive stress and tensile stress reaches the maximum value of 2.28GPa [3]. Properties of AlNbTiV high entropy alloy were studied at different temperatures, and it was found to be that the value of tensile strength gradually decreases from 1020MPa to 158Mpa when the temperature of the material is increased from 800°C to 1000°C [4]. MoNbHfZrTi microstructure and mechanical properties study reveal that the value of tensile strength at room temperature is found to lie between 1719Mpa and 1575Mpa [5]. AlCoCrFeNi high entropy alloy surface coated with a nitride layer by the nitriding process exhibits good wear and hardness property. The study achieves a Vickers hardness value of 720HV and a wear rate of 2.8×10^{-5} mm^3/Nm [6]. A spur gear taken from a machine is designed and analysed with the help of CATIA V5 and Ansys software. Graphs required for the comparative analysis were plotted, and data analysis was done in Microsoft excel.

1.1 Selected Materials and Their Properties

Materials selected for the study are characterized by three critical mechanical properties yield strength, density, elastic modulus and Poisson ratio. Materials selected for the study and their properties are given in Table-1[7].

Table-1: Materials and their Properties

Material	**Density (g/cm^3)**	**Yield Strength (MPa)**	**Elastic Modulus (GPa)**	**Poisson Ratio**
EN8 Steel	7.85	280	190	0.3
$Al_{80}Li_5Mg_5Zn_5Cu$	2.9	488	69	0.3
$AlCrFeNiMo_{0.5}$	6.8	1749	205	0.34
Ti-6Al-4V	4.43	883	110	0.31
Al7075-T6	2.81	505	70	0.32

1.2 Specifications of the spur Gear

Important specifications that need to be considered before designing the spur gear are Outside Diameter (OD), Pitch Circle Diameter (PCD), Module (m), Addendum (A), Dedendum (D), Clearance (C), Circular Pitch (CP), Tooth Thickness, Face Width, Number of Teeth (T), Internal Hole Diameter/Shaft Diameter (d), Angle Between Two Successive Teeth, Total Depth (TD), Working Depth (WD), Depth of The Gear Tooth. Figure-1 represents the image of the gear taken from the simple six-speed gearbox.

Fig-1: Gear taken from gear box

1.3. Formulas Used to Calculate Spur Gear Parameters.

Specifications measured directly with the help of a vernier calliper, screw gauge and gear tooth vernier were Outside Diameter, Tooth Thickness, Face Width, Number of Teeth, Internal Hole Diameter/Shaft Diameter, and Depth of The Gear Tooth. Other parameters required to design the spur gear were calculated from the formulae given in Table-2,

Table -2: Formulae to be used.

Pitch Circle Diameter	[T×OD/T+2]
Module	PCD/T
Circular Pitch	π×m
Addendum	1×m
Clearance	0.157×m (OR) 0.25×m
Dedendum	Addendum + Clearance
Addendum circle diameter	PCD+Addendum
Dedendum circle diameter	PCD-Dedendum
Angle between successive teeth	360/T
Total depth	Addendum + Dedendum
Working depth	Addendum + Dedendum-Clearance
Clearance circle diameter	DCD+Clearance

2.Designed Spur Gears Parameters

A pair of spur gears were designed in which the larger gear (Wheel) is the one which is taken from the gearbox while the smaller one (pinion) is designed entirely based on the gear ratio. A standard gear ratio of 1:2 is maintained to design the pinion. The gear ratio of 1:2 represents that the pinion rotated twice for one revolution of the wheel. An assumption is made to design the pinion, i.e., the wheel is taken as the input gear while the pinion is taken as the output gear. Expression for the calculating the number of teeth on the pinion is given below,

$$\frac{N1}{N2} = \frac{T2}{T1}$$

N1 is the speed of the input gear in RPM.

N2 is the speed of the output gear in RPM.

T1 is the number of teeth in input gear.

T2 is the number of teeth in output gear.

For a pair of gears to mesh, the module of both the gears must be the same. All other design parameters required were calculated by keeping the module the same and calculating the number of teeth in the pinion. Table-3 and Table-4 give the gear wheel and pinion dimensions, respectively.

Table-3: Dimensions of gear wheel

Particulars	Dimension (mm)
Outside Diameter	120
Tooth Thickness	6.12
Face Width	20
Number of teeth	22
Internal hole diameter	24
Depth of gear tooth	7.14
Pitch circle diameter	110
Module	5
Addendum	5
Dedendum	6.25
Clearance	1.25
Circular Pitch	15.71
Angle between successive teeth (degrees)	16.364

Table-4: Dimension of Gear Pinion

Particulars	Dimension (mm)
Outside Diameter	60
Tooth Thickness	3.06
Face Width	20
Number of teeth	11
Internal hole diameter	12
Depth of gear tooth	2.45
Pitch circle diameter	55
Module	5
Addendum	5
Dedendum	6.25
Clearance	1.25
Circular Pitch	15.71
Angle between successive teeth (degrees)	32.727

2.1. Modelled Wheel and Pinion

The data obtained from the calculation and table-3 and table-4 gear wheel and pinion were designed with the help of modelling and drafting software CATIA V5. Figure-2 and Figure-3 represent the 3-Dimensional part models of the Gear wheel and pinion. Figure-4 and Figure-5 represent the assembly models of gear and pinion together, showing the teeth are in mesh. In Figure 5, a rectangular block is provided, which makes it similar to a gearbox arrangement where the shafts are enclosed in the common box-like structure.

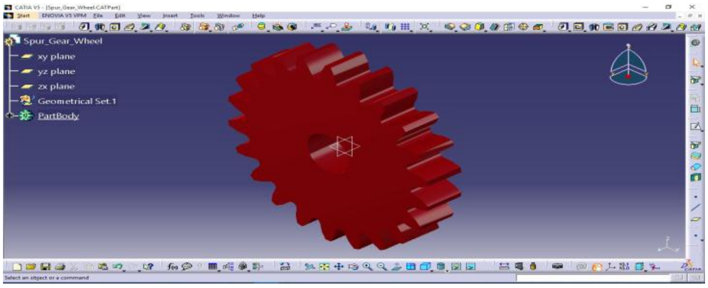

Fig-2: Designed Wheel Part

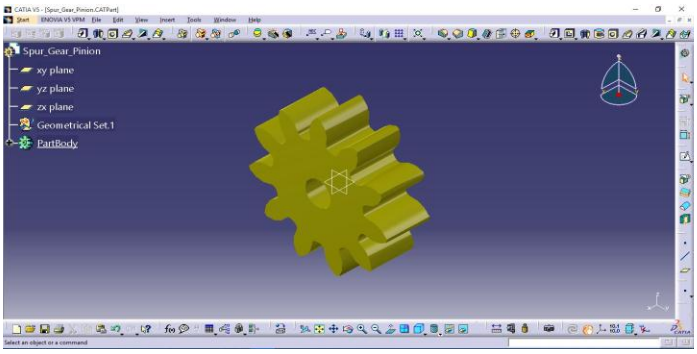

Fig-3: Designed Pinion Part

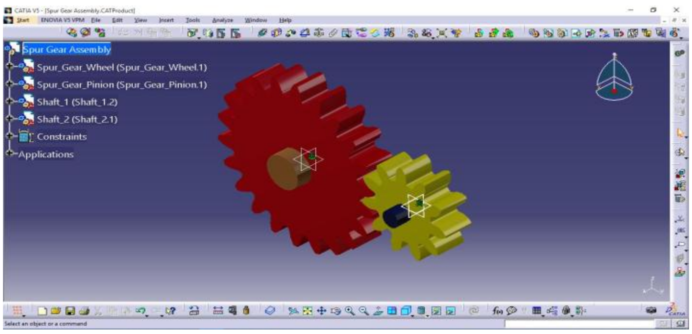

Fig-4: Meshing of Gear wheel and Pinion

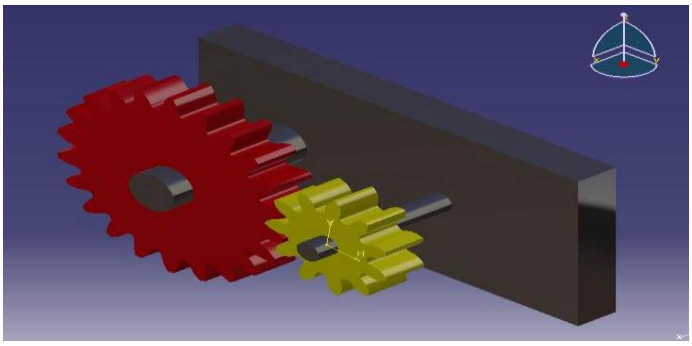

Fig-5: Meshing of Gear Wheel and Pinion Sharing Common Rectangular Base

3. Static Structural Analysis of Spur Gears

Static structural analysis is one of the most commonly used methods in which the entire model is converted into small elements of finite size. In those small elements, loads and support reactions are applied, and results are calculated. After calculating all the elements' results, they are added together to get the required result. Here, static structural analysis of carbon steel was done for ten different loads starting from 50N-mm to 1000N-mm, and their corresponding stress, strain, strain energy, deformation, and volume change effect was studied. For a single load of 100N-mm, all other High entropy alloy gears were analysed and compared with the value of the same amount of load that is applied in the structural steel. Analytically all these load reaction analyses were done on the analysis software Ansys. All the readings were tabulated and presented as a line plot using excel. In both, the analysis standard number of 2106 mesh elements were found. A global coordinate system is maintained throughout the process. Figure 6 represents the number of nodes formed on the model.

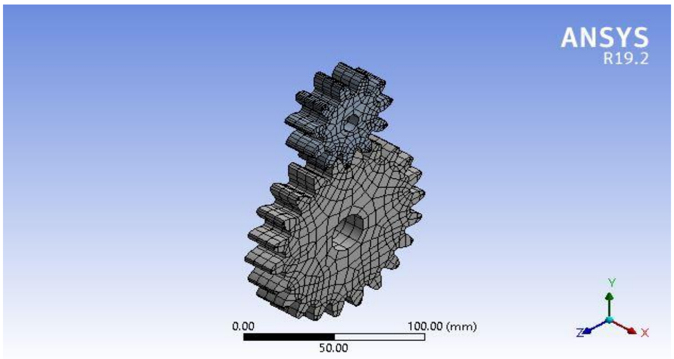

Fig-6: Nodal Elements formed on the Assembly Model

3.1. Boundary Conditions for the Structural Analysis.

1. Apply fixed support to the smaller gear or pinion.
2. Apply frictionless support to the larger gear or wheel.

3. Apply clockwise (or) anticlockwise moment to the larger gear.
4. Apply ten different moments and measure all the values, i.e., Stress, Strain, Strain energy, Deformation.

Figure 7 represents the boundary conditions applied for the analysis.

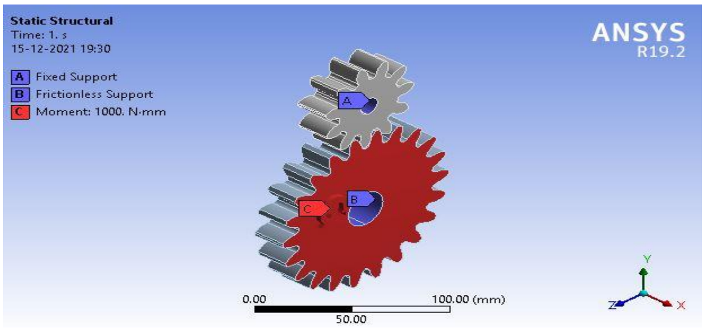

Fig-7: Boundary Condition for Wheel and Pinion

4. Results and Discussion

4.1. Structural Analysis of Carbon Steel

Loading is given as a moment, and the corresponding results are noted and tabulated. Loading starts by applying a moment of 50N-mm and loads progress by adding 50N-mm until the value 1000N-mm is attained. Strain, Strain Energy, Deformation, and Stress are the main parameters noted. Tables 5 and 6 give the data of applied load or moment and its corresponding analysis values regarding static structure. Figure-8,9,10,11 represents the stress, deformation, strain energy, and strain distribution contour when the moment is applied on the larger gear wheel.

Table-5: Load vs Stress vs Deformation

Load (N-mm)	Stress (MPa)	Deformation (E-5)
50	0.010459	0.15887
100	0.020919	0.31774
150	0.031378	0.4766
200	0.041837	0.63547
250	0.052297	0.79434
300	0.062756	0.95321
350	0.073215	1.1121
400	0.083675	1.2709
450	0.094134	1.4298
500	0.104590	1.5887
1000	0.209190	3.1774

Table-6: Load vs Strain vs Strain Energy

Load (N-mm)	Strain Energy (10^{-7} mJ)	Strain (10^{-7} mm/mm)
50	0.17217	0.71585
100	0.68867	1.4317
150	1.5495	2.1475
200	2.7547	2.8634
250	4.3042	3.5792
300	6.1981	4.2951
350	8.4362	5.0109
400	11.019	5.7268
450	13.946	6.4426
500	17.217	7.1585
1000	68.867	14.317

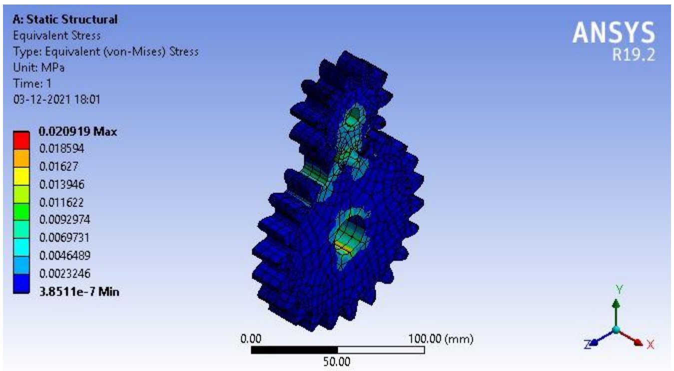

Fig-8: Equivalent Stress Contour

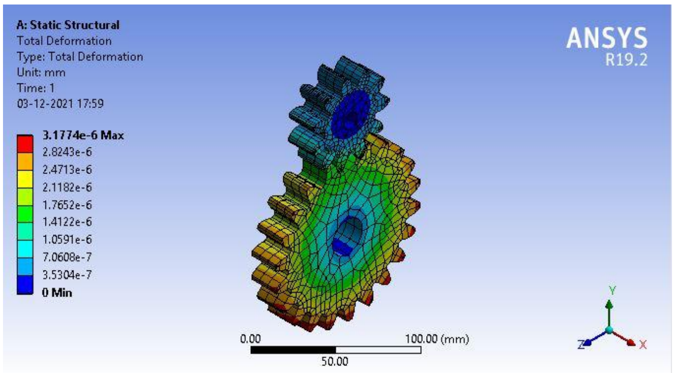

Fig-9: Equivalent deformation contour

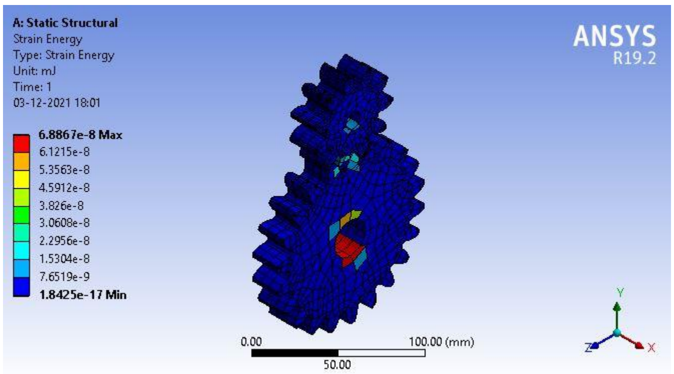

Fig-10: Equivalent Strain Energy Contour

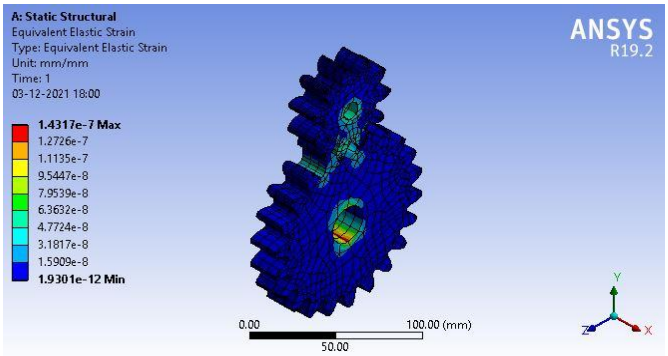

Fig-11: Equivalent Strain Contour

Chart-1 and Chart-2 represent the graphical format of Table-4 and Table-5, in which chart-1 establishes the relationship of the moment with stress and deformation. In contrast, the chart-r establishes the relationship of the moment with strain energy and strain. The charts show that the value of stress, strain, strain energy, and deformation is directly proportional to the value of the applied moment. Therefore, given material obeys Hooke's law which states that stress is directly proportional to the strain within the given elastic limits. Since ANSYS does not give the fracture result of the analysis maximum of 1000N-mm can be applied to the given pair of spur gears as the elastic point, and beyond this value, plastic deformation occurs.

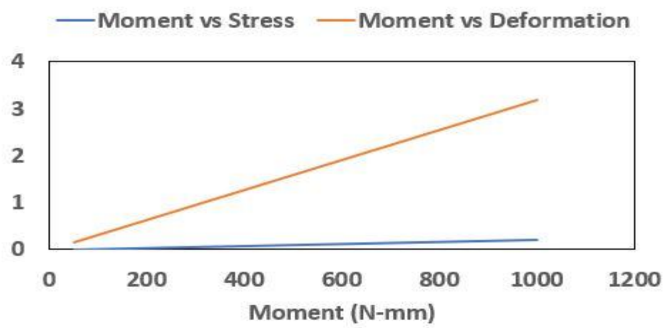

Chart-1: Moment vs Stress and Moment vs Deformation

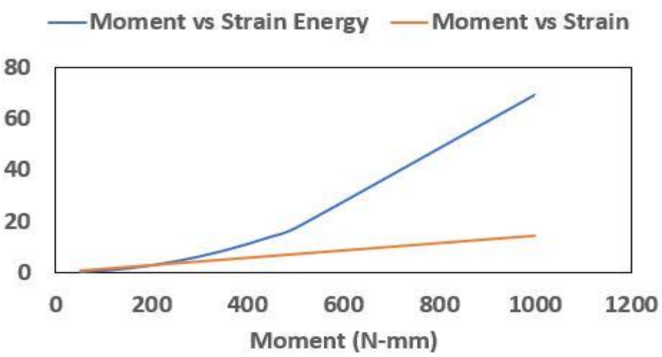

Chart-2: Moment vs Strain energy and Moment vs Strain

4.2. Comparison with High Entropy Alloy Gears

The maximum load that the designed spur gear assembly withstand is 1000N-mm. Therefore, for the maximum load of 1000N-mm, High entropy alloys selected for the study are applied to the given spur gear assembly by simply changing the material's properties in the Ansys workbench. The required calculated values are noted and presented in Table 7 and Table 8. A comparison of those data was made, and relevant results were drawn.

Table-7: Material, Mass, Deformation, Strain Comparison

Materials	Mass (Kg)	Deformation (10^{-5} mm)	Strain (10^{-6})
Structured Steel (or) EN8 Steel	1.7314	3.177	1.4317
$Al_{80}Li_5Mg_5Zn_5Cu$	6.3962 E-4	9.2098	4.1498
$AlCrFeNiMo_{0.5}$	1.4998	3.106	1.3543
Ti-6Al-4V	0.61977	9.091	4.0294
Al7075-T6	0.97707	5.7819	2.5838

Table-8: Material, Stress, Strain Energy Comparison

Materials	Stress (MPa)	Strain Energy (10^{-5} mJ)
Structured Steel (or) EN8 Steel	0.20919	0.68867
$Al_{80}Li_5Mg_5Zn_5Cu$	0.20919	1.9962
$AlCrFeNiMo_{0.5}$	0.21012	0.67104
Ti-6Al-4V	0.20967	1.9664
Al7075-T6	0.20943	1.2518

From the Table-7 and Table-8, the following results were derived,

1. It is inferred that the material "Al-Cr-Fe-Ni-$Mo_{0.5}$" replaces the conventional steel alloy most likely because it reduces the weight of the gear by "13.37%" and it has the nearly identical value of stress, strain, strain energy and deformation.

2. The second most material that can replace conventional steel is "Ti-Al-V" because it reduces the weight of the gear by "43.56%". However, the strain, strain energy and strain increase by a considerable amount while the stress remains nearly equal value.

3. The remaining two materials, "Ti-Al-V" and "Al-T6", are not practically feasible ones.

5. CONCLUSION

A spur gear is taken from the gearbox, and it is designed with the help of designing software Catia V5. Its static structural analysis was done on the analysis software Ansys. Various structural parameters like Stress, Strain, Strain energy, and deformation were studied elaborately for carbon steel, and their data were presented in the form of charts and tables. After finding the maximum load value for carbon steel gear, the high entropy alloy gear was analysed for that particular maximum load. Results of high entropy alloy and carbon steel were compared, and it was found to be that "Al-Cr-Fe-Ni-Mo0.5" and "Ti-Al-V" replaced the conventional carbon steel by reducing its weight to 13.37% and 43.56%, respectively without significant variations in other structural parameters.

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