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Design Optimization And Material Analysis Of Reused Plastic Composite Spur Gear

Mr.D.Manivannan ME. [*1], Mr.S.Suriya[*2], Mr.V.Anandha[*3],Mr.S.Arunprakash[*4]

*1 Head of the Department of Mechanical Engineering, MRK Institute of Technology, Kattumanarkoil, Tamil Nadu
*2 UG student of Mechanical Engineering, MRK Institute of Technology, Kattumanarkoil, Tamil Nadu
*3 UG student of Mechanical Engineering, MRK Institute of Technology, Kattumanarkoil, Tamil Nadu
*4UG student of Mechanical Engineering, MRK Institute of Technology, Kattumanarkoil, Tamil Nadu

ABSTRACT :

To design the spur gear, study the weight reduction and stress distribution for cast steel and composite materials. Gearing is one of the most critical components in a mechanical power transmission system and in most industrial rotating machinery. It is possible that gears will predominate as the most effective means of transmitting power in future machines due to their high degree of reliability and compactness. In addition, the rapid shift in the industry from heavy industries such as shipbuilding to industries such as automobile manufacture and office automation tools will necessitate a refined application of gear technology. To design the spur gear model using design software. To study the impact analysis for carbon and composite materials. To study the torque loading for carbon and composite materials. Finally, comparing and analyzing the composite gear with existing cast steel gear is to be done.

Keywords: Design optimization, Material analysis, Reused plastic composite, Spur gear, Sustainability, Testing.

1. INTRODUCTION

The integration of reused plastic composites in engineering applications presents an opportunity to address both performance requirements and sustainability concerns. This introduction will discuss the design optimization and material analysis of a reused plastic composite spur gear, a critical component in many mechanical systems. With a growing emphasis on environmental responsibility and resource efficiency, the reuse of plastics offers a compelling solution to mitigate waste while meeting functional demands. However, ensuring the viability of such materials requires a thorough understanding of their mechanical properties, durability, and compatibility with operating conditions. Design optimization plays a pivotal role in maximizing the performance of spur gears while minimizing material usage and environmental impact. Material analysis is equally crucial, involving the selection of recycled plastics based on mechanical strength, thermal stability, and chemical resistance. By combining these aspects, this study aims to develop a sustainable spur gear design that balances performance, durability, and environmental stewardship.

2. OBJECTIVES

- Investigate the feasibility of integrating reused plastic composites in the design of spur gears.
- Optimize the design parameters of spur gears to maximize performance and efficiency while minimizing material usage.
- Conduct a comprehensive material analysis to evaluate the mechanical properties, thermal stability, and chemical resistance of reused plastic composites.
- Assess the environmental impact of the spur gear design throughout its lifecycle, including material production, manufacturing, use, and disposal.
- Validate the performance of the optimized spur gear design through testing under simulated operating conditions.
- Develop documentation and reporting detailing the design process, material selection criteria, testing procedures, and environmental analysis results.

3. METHDOLOGY

3.1 MIXING SOLUTION

- Carbon

- Epoxy resin
- Reused plastic material
- Hardener

SI NO	MIXING COMPONENTS	QUANTITY
1	Carbon	300g
2	Epoxy resin	1kg
3	Reused plastic material	500 g
4	Hardener	800g

Table 2: mixing components

3.2 WORK FLOW

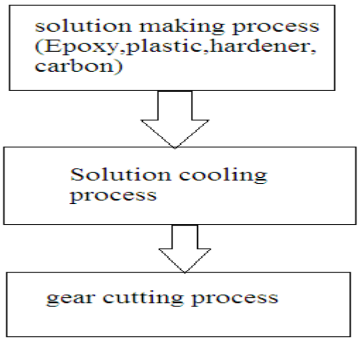


Fig 1: work flow

4. DESCRIPTION OF COMPONENTS

4.1 EPOXY

Epoxy resin serves as a potential material component for the project due to its compatibility with reused plastic composites. Its adhesive properties facilitate bonding between composite layers or with other materials, enhancing structural integrity. Epoxy can reinforce the composite's strength and stiffness, crucial for load-bearing components like spur gears. Additionally, its resistance to chemicals and environmental factors ensures durability in various operating conditions. By incorporating epoxy into the composite formulation or as an adhesive agent during assembly, the project can optimize the performance and longevity of the reused plastic composite spur gears, contributing to sustainable engineering practices.

Fig 2: Epoxy

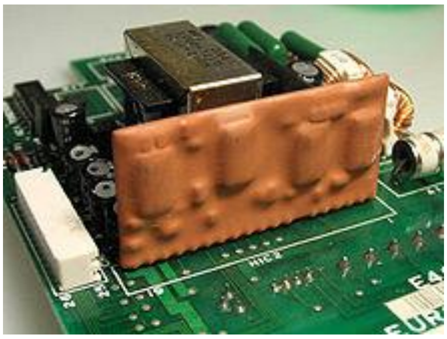


Fig 3: An epoxy encapsulated hybrid circuit on a printed circuit board.

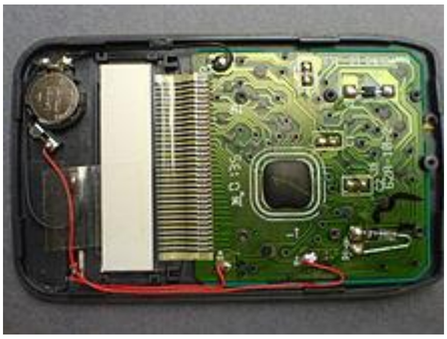


Fig 4: The interior of a pocket calculator

4.2 RECYCLED PLASTIC

Recycled plastic, a key material component, offers environmental and functional advantages for the project. Derived from post-consumer or post-industrial sources, recycled plastic contributes to waste reduction and resource conservation. By reprocessing plastics like polyethylene (PE) or polypropylene (PP), recycled materials can exhibit comparable mechanical properties to virgin plastics. These recycled plastics can be blended or reinforced to create composite materials suitable for spur gear applications. Their versatility, cost-effectiveness, and sustainability make recycled plastics an ideal choice for the project, aligning with eco-friendly initiatives while maintaining performance standards in gear functionality and durability.

Plastic identification code	Type of plastic polymer	Properties	Common packaging applications	**Melting**- (°C) and **glass transition**temperatures	Young's modulus (GPa)
01 PET	Polyethylene terephthalate(PET, PETE)	Clarity, strength, toughness, barrier to gas and moisture.	Soft drink, water and salad dressing bottles; peanut butter and jam jars; small consumer electronics	Tm = 250;[43] Tg = 76[43]	2–2.7[44]
02 PE-HD	High-density polyethylene(HDPE)	Stiffness, strength, toughness, resistance to moisture, permeability to gas	Water pipes, hula hoop rings, five gallon buckets, milk, juice and water bottles; grocery bags, some shampoo/toiletry bottles	Tm = 130;[45] Tg = -125[46]	0.8[44]
03 PVC	Polyvinyl chloride(PVC)	Versatility, ease of blending, strength, toughness.	Blister packaging for non-food items; cling films for non-food use. May be used for food packaging with the addition of the plasticisers needed to make natively rigid PVC flexible. Non-packaging uses are electrical cable insulation; rigid piping; vinyl records.	Tm = 240;[47] Tg = 85[47]	2.4-4.1[48]
04 PE-LD	Low-density polyethylene(LDPE)	Ease of processing, strength, toughness, flexibility, ease of	Frozen food bags; squeezable bottles, e.g. honey, mustard; cling films; flexible container lids	Tm = 120;[49] Tg = -125[50]	0.17–0.28[48]

		sealing, barrier to moisture			
05 PP	Polypropylene(PP)	Strength, toughness, resistance to heat, chemicals, grease and oil, versatile, barrier to moisture.	Reusable microwaveable ware; kitchenware; yogurt containers; margarine tubs; microwaveable disposable take-away containers; disposable cups; soft drink bottle caps; plates.	Tm = 173;[51] Tg = -10[51]	1.5-2[44]
06 PS	Polystyrene(PS)	Versatility, clarity, easily formed	Egg cartons; packing peanuts; disposable cups, plates, trays and cutlery; disposable take-away containers	Tm = 240 (only isotactic);[46] Tg = 100 (atactic and isotactic)[46]	3-3.5[44]
07 O	Other (often polycarbonateor ABS)	Dependent on polymers or combination of polymers	Beverage bottles; baby milk bottles. Non-packaging uses for polycarbonate: compact discs; "unbreakable" glazing; electronic apparatus housings; lenses including sunglasses, prescription glasses, automotive headlamps, riot shields,panels.	Polycarbonate: Tg = 145;[53] Tm = 225[54]	Polycarbonate: 2.6;[44] ABS plastics: 2.3[44]

Table 1: Types of plastic

4.3 CARBON

Carbon fibers or carbon-based additives are significant components in the development of high-performance recycled plastic composites for the project. By incorporating carbon fibers into the composite matrix, mechanical properties such as strength, stiffness, and fatigue resistance can be greatly enhanced. Carbon-based additives can also improve the thermal stability and wear resistance of the composite, crucial factors for spur gear applications. Additionally, carbon reinforcements contribute to the lightweight nature of the composite, reducing overall system weight and inertia. The integration of carbon into recycled plastic composites underscores the project's commitment to sustainability while achieving superior performance and reliability in spur gear applications.

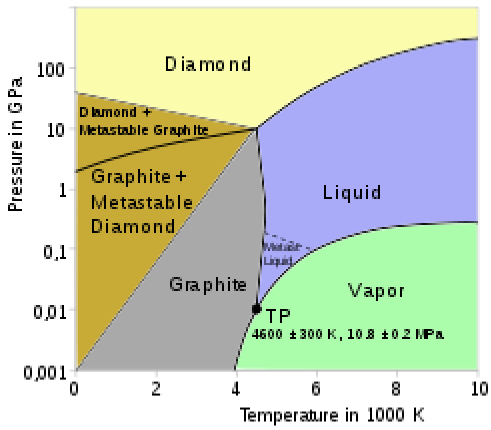


Fig 5: Theoretically predicted phase diagram of carbon

5. CALCULATION

5.1 MATERIAL PROPERTIES

S. No.	Material Property	Value	Unit
1	Density	1300	Kg/m3
2	Young's modulus	3.76E+9	pa
3	Poison's ratio	0.37	
4	Bulk modulus	5.74E+9	pa
5	Shear modulus	1.42E+9	pa
6	Tensile yield strength	100E+6	pa
7	Compressive yield strength	130E+6	pa
8	Coefficient of friction	0.18	
9	Thermal conductivity	0.25	W/m k
10	Coefficient of thermalexpansion	47E-6	K-1
11	Specific heat	1501	J/kg K
12	Endurance limit	41.2E+6	pa

Table 2: material properties

5.2 PARAMETRIC MODELLING OF SPUR GEAR

S. No.	Description	Symbol	Value	Units
1	Module	m	2.5	mm
2	Pressure Angle	ϕ	20	◦
3	No of teeth	Z	60	
4	Center distance	a	150	mm
5	Face width	b	25	mm
6	Pitch Circle Diameter	dp	150	mm
7	Base Circle Radius	rb	70.47	mm
8	Addendum Circle Radius	ra	77.5	mm
9	Dedendum Circle Radius	rd	71.8	mm
10	Addendum	ha	2.5	mm
11	Dedendum	hd	2.89	mm
12	Fillet Radius	rp	0.98	mm
13	Shaft Radius	rs	16	mm
14	Total angle	Ta	360	◦
15	Bottom clearance	c	0.25	

Table 3: Dimensions of the Spur Gears

5.3 DESIGN CALCULATION OF PLASTIC SPUR GEAR:

Specifications of gear:

Module (m) = 2.5 mm

Center distance (a)	=	150 mm
Pressure angle (α)	=	20 degree
Power (P)	=	2.25 Kw
Speed (N)	=	750 rpm

Design Calculation:

Power (P) = 2*π*N*T / 60

2250 = (2*π*750*T) / 60

σ = (2250*60)/ (2*π*750)

Torque = 28.64788 N-m

Torque T = F * (d/2)

Force F = T/ (d/2)

=28.64788/0.075

Force F = 381.97185 N

Calculation of tangential load:

Where, P= power

v= pitch line velocity

ε Service factor= 1.25 (medium)

τ ∗D ∗N

V = 60

π∗ ∗60∗750

V = 60 ∗ 1000

v = 2.356m m/s

Calculation of initial dynamic load:

Velocity factor1 +1 + 0.25

1+12

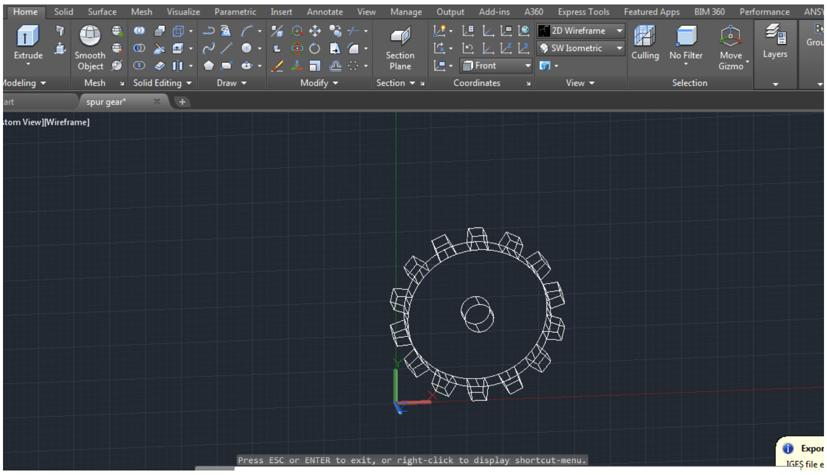
1+0.25∗12

=3.250

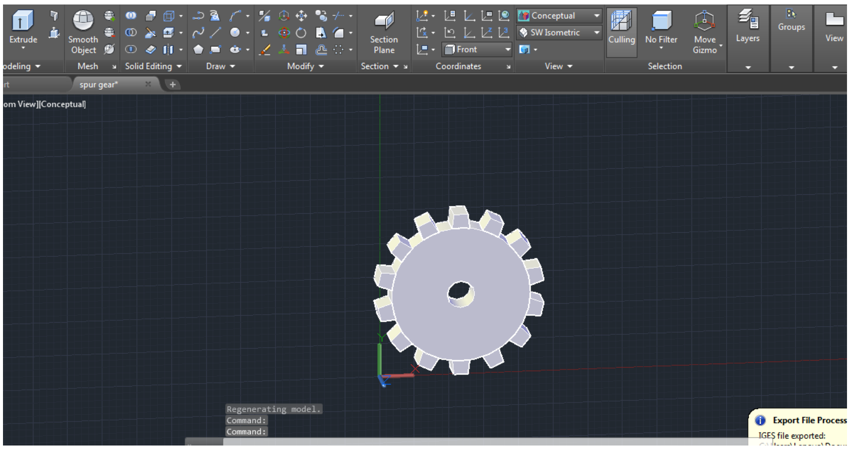
=1193.761

6. RESULT AND DISCUSSION

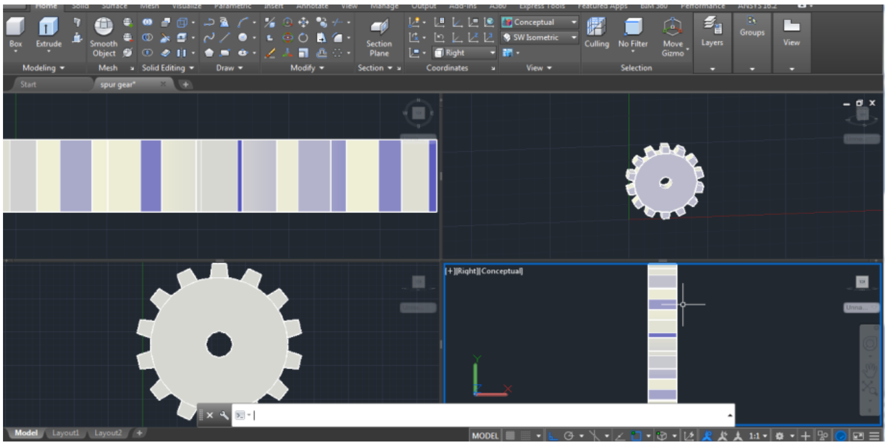
Cad modeling:



Solid model:

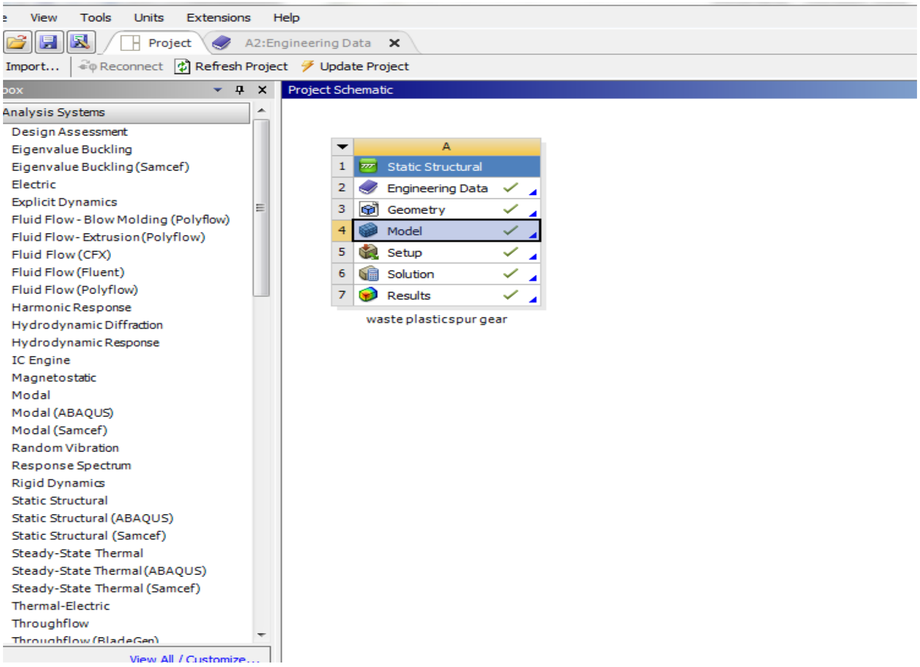


Multiple view:;

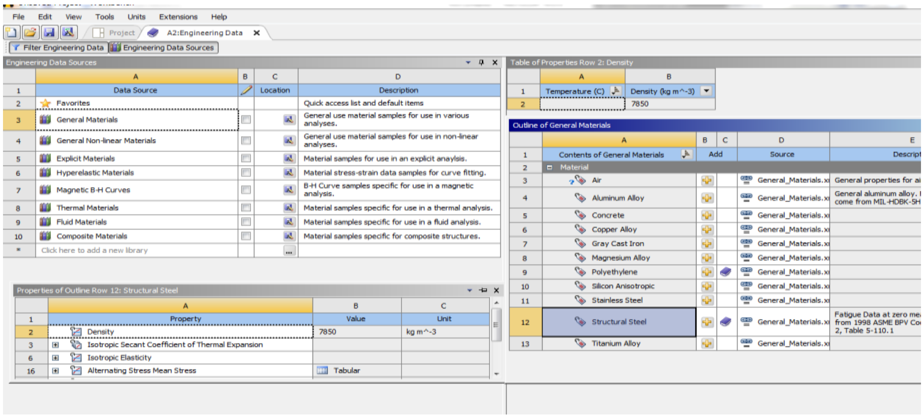


Ansys:

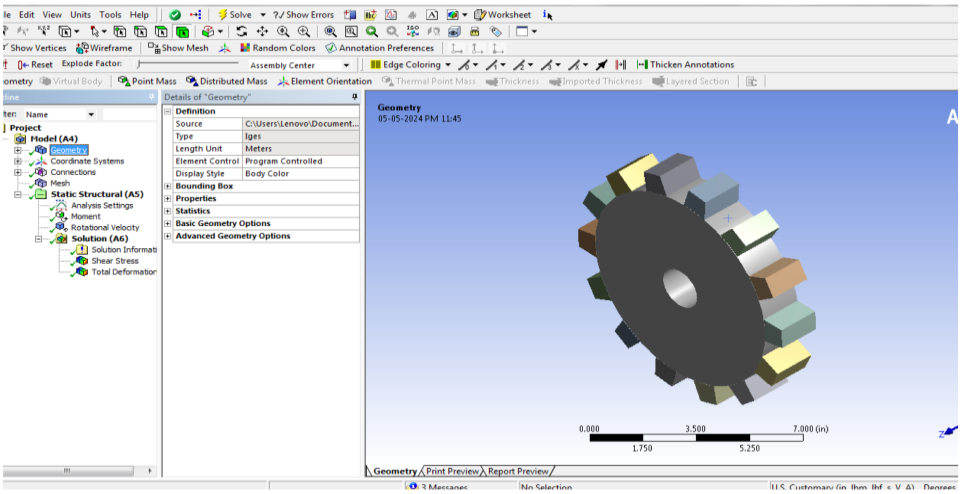
Testing selection:static structural



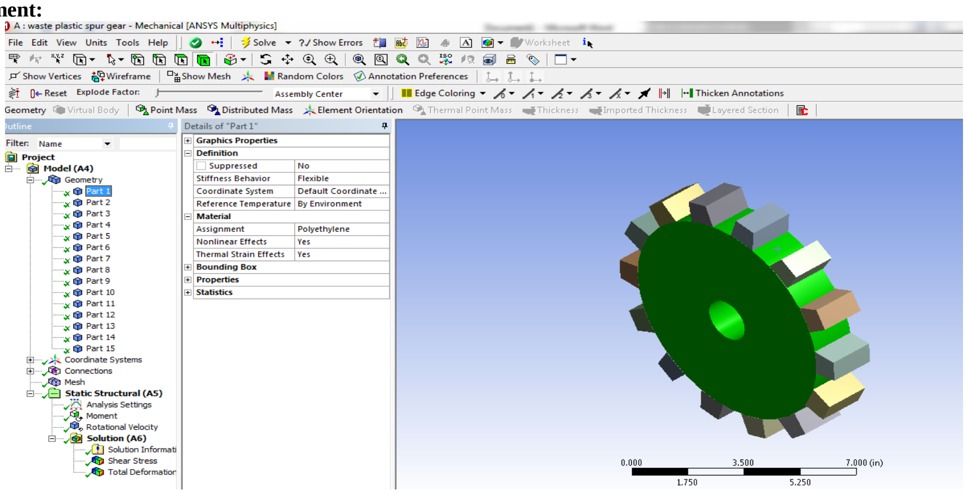
Material selection:



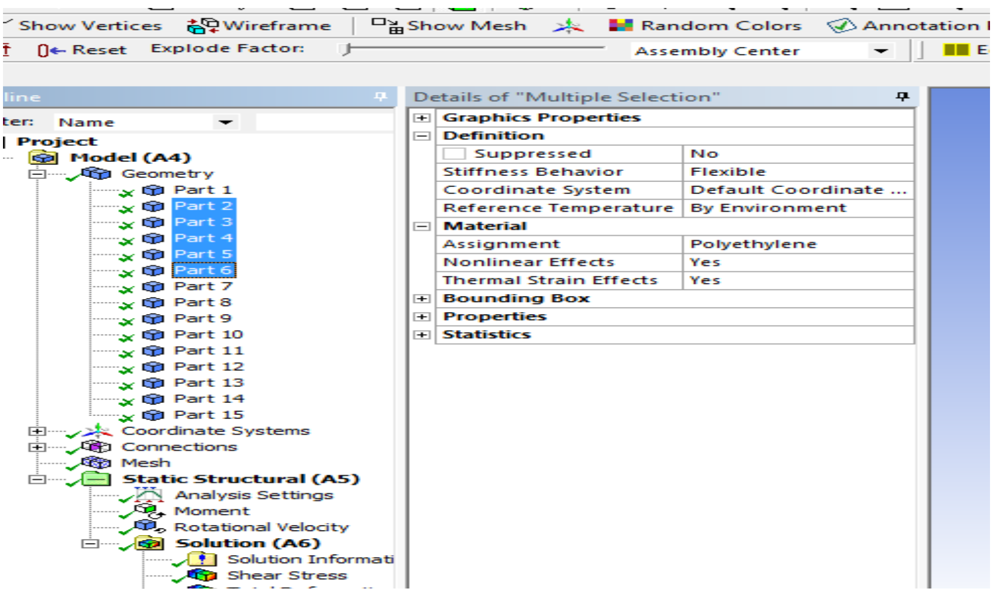
Geometry:



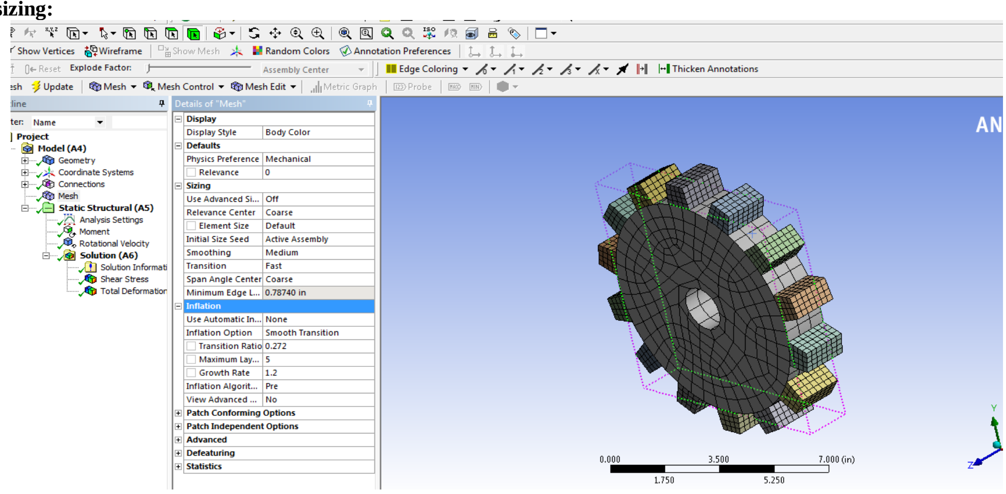
Material assignment:



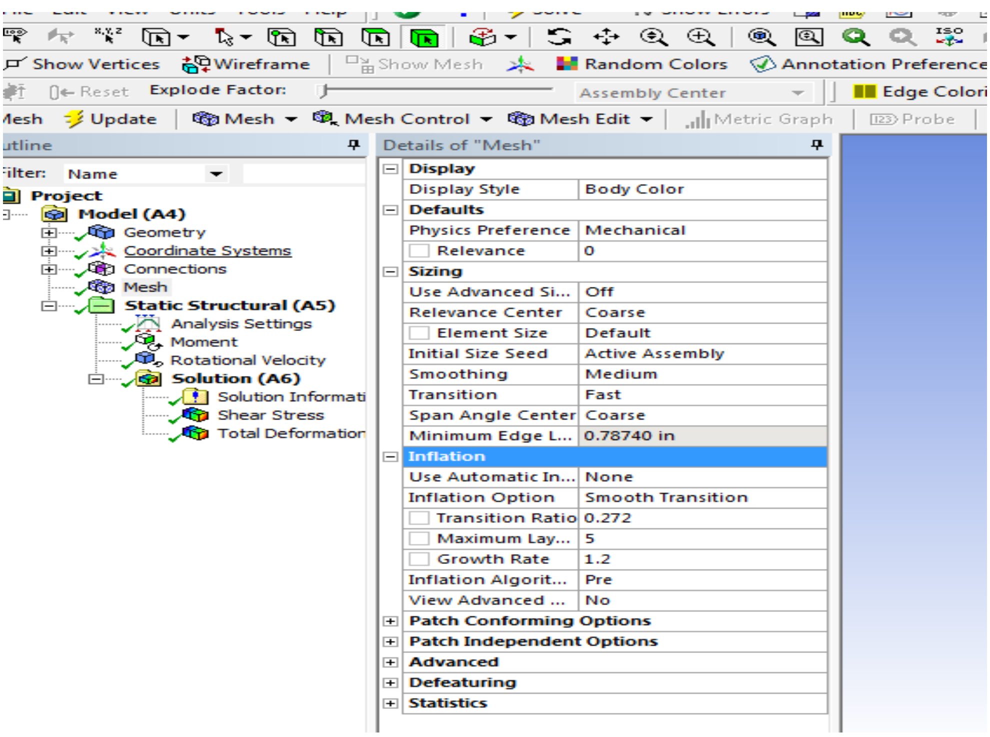
Material:polyetheline



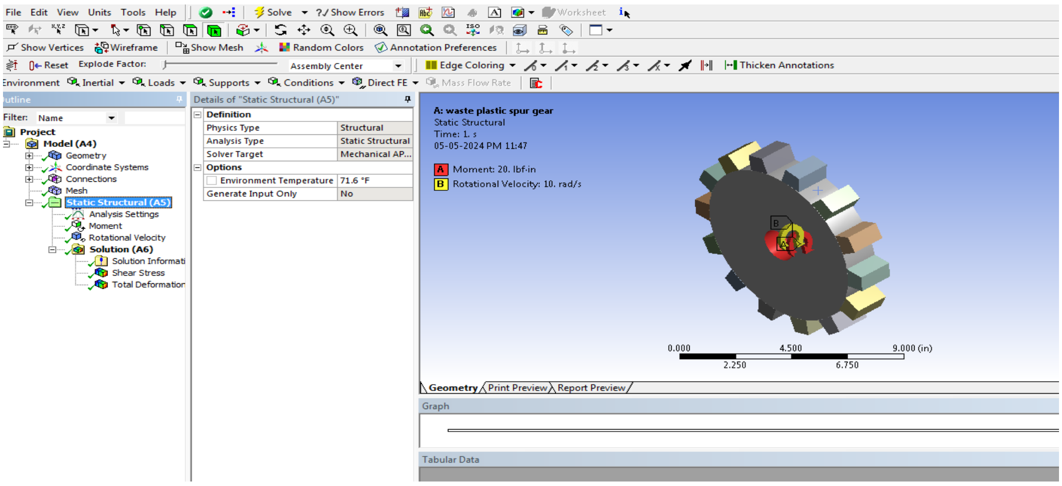
Meshing and sizing:



SIZING

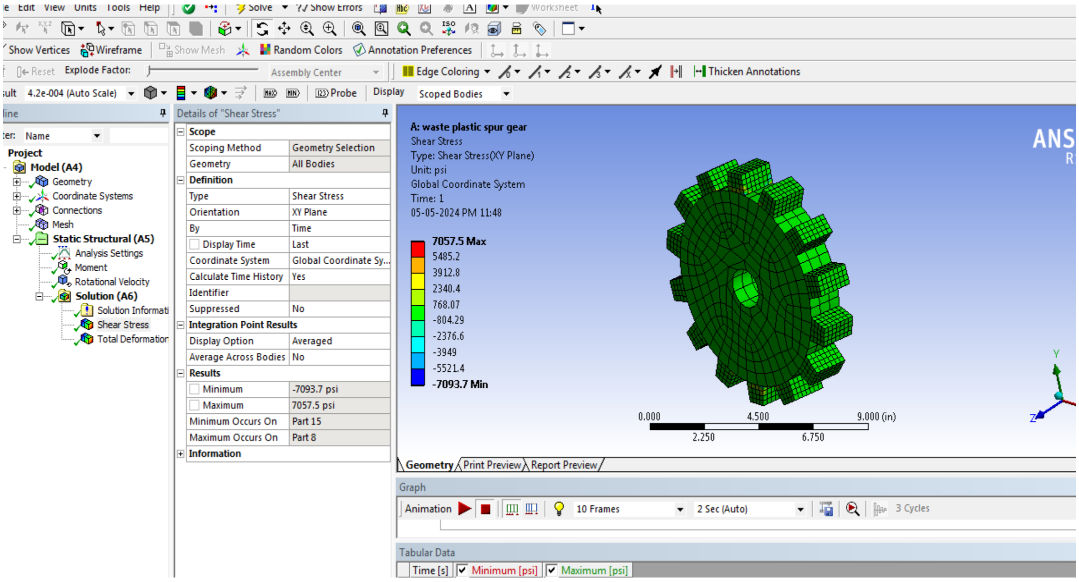


Input values:

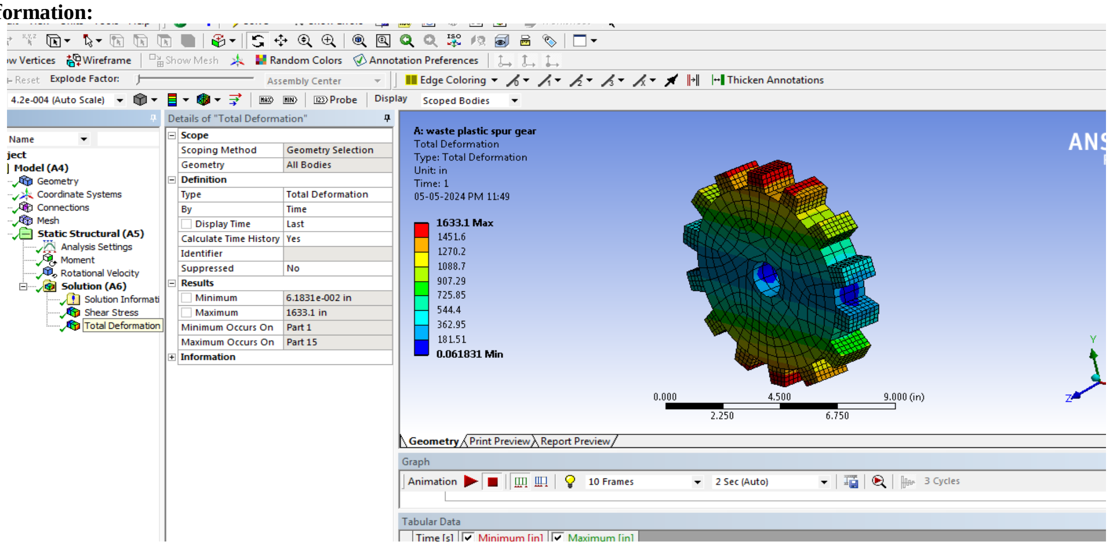


Solution information:

Shear stress:



Total deformation:

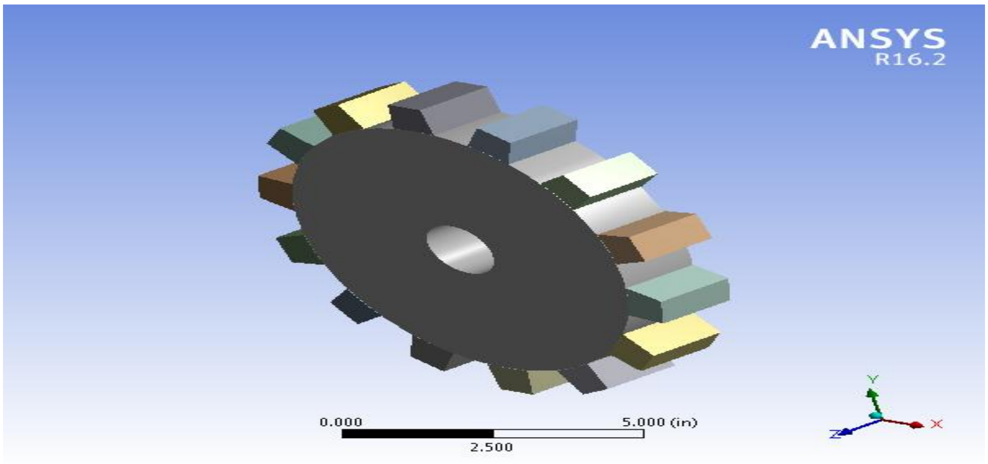


Final result:

ANSYS

Project

First Saved	Sunday, May 05, 2024
Last Saved	Sunday, May 05, 2024
Product Version	16.2 Release
Save Project Before Solution	No
Save Project After Solution	No



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  - Polyethylene

Units

TABLE 1

Unit System	U.S. Customary (in, lbm, lbf, s, V, A) Degrees rad/s Fahrenheit
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Fahrenheit

Model (A4)

Geometry

TABLE 2

Model (A4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\Lenovo\Documents\spur gear.igs
Type	Iges
Length Unit	Meters
Element Control	Program Controlled
Display Style	Body Color

Bounding Box	
Length X	9.4284 in
Length Y	9.4488 in
Length Z	1.5748 in
Properties	
Volume	89.048 in³
Mass	3.0562 lbm
Scale Factor Value	1.
Statistics	
Bodies	15
Active Bodies	15
Nodes	13039
Elements	2177
Mesh Metric	None
Basic Geometry Options	
Solid Bodies	Yes
Surface Bodies	Yes
Line Bodies	No
Parameters	Yes
Parameter Key	DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	No
Compare Parts On Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\Lenovo\AppData\Local\Temp
Analysis Type	3-D
Mixed Import Resolution	None
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	Yes

TABLE 3

Model (A4) > Geometry > Parts

Object Name	*Part 1*	*Part 2*	*Part 3*	*Part 4*	*Part 5*	*Part 6*	*Part 7*	*Part 8*	*Part 9*	*Part 10*	*Part 11*
State	Meshed										
Graphics Properties											
Visible	Yes										
Transparency	1										
Definition											
Suppressed	No										

Stiffness Behavior	Flexible										
Coordinate System	Default Coordinate System										
Reference Temperature	By Environment										
Material											
Assignment	Polyethylene										
Nonlinear Effects	Yes										
Thermal Strain Effects	Yes										
Bounding Box											
Length X	7.874 in	1.2312 in	1.2458 in	1.0135 in		1.2458 in	1.2312 in	0.97285 in	1.2312 in	1.2458 in	1.0135 in
Length Y	7.874 in	1.1587 in	1.2703 in	1.1304 in		1.2703 in	1.1587 in	0.81757 in	1.1587 in	1.2703 in	1.1304 in
Length Z	1.5748 in										
Properties											
Volume	73.616 in^3	1.1023 in^3									
Mass	2.5266 lbm	3.7833e-002 lbm									
Centroid X	4.3983 in	6.2685 in	7.7684 in	8.6008 in		7.7683 in	6.2684 in	4.398 in	2.5277 in	1.0278 in	0.19541 in
Centroid Y	5.1746 in	9.058 in	7.8618 in	6.1333 in	4.2148 in	2.4864 in	1.2903 in	0.86341 in	1.2903 in	2.4865 in	4.215 in
Centroid Z	0.7874 in										
Moment of Inertia Ip1	10.601 lbm·in^2	9.8603e-003 lbm·in^2									
Moment of Inertia Ip2	10.601 lbm·in^2	4.5137e-003 lbm·in^2									
Moment of Inertia Ip3	20.163 lbm·in^2	1.034e-002 lbm·in^2									
Statistics											
Nodes	3309	695									
Elements	609	112									
Mesh Metric	None										

TABLE 4
Model (A4) > Geometry > Parts

Object Name	*Part 12*	*Part 13*	*Part 14*	*Part 15*
State	Meshed			
Graphics Properties				
Visible	Yes			
Transparency	1			
Definition				
Suppressed	No			
Stiffness Behavior	Flexible			
Coordinate System	Default Coordinate System			
Reference Temperature	By Environment			
Material				
Assignment	Polyethylene			
Nonlinear Effects	Yes			

Thermal Strain Effects	Yes			
Bounding Box				
Length X	1.0135 in	1.2458 in	1.2312 in	0.97285 in
Length Y	1.1304 in	1.2703 in	1.1587 in	0.81757 in
Length Z	1.5748 in			
Properties				
Volume	1.1023 in³			
Mass	3.7833e-002 lbm			
Centroid X	0.19545 in	1.0279 in	2.5278 in	4.3982 in
Centroid Y	6.1335 in	7.8619 in	9.0581 in	9.4849 in
Centroid Z	0.7874 in			
Moment of Inertia Ip1	9.8603e-003 lbm·in²			
Moment of Inertia Ip2	4.5137e-003 lbm·in²			
Moment of Inertia Ip3	1.034e-002 lbm·in²			
Statistics				
Nodes	695			
Elements	112			
Mesh Metric	None			

Coordinate Systems

TABLE 5

Model (A4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Coordinate System ID	0.
Origin	
Origin X	0. in
Origin Y	0. in
Origin Z	0. in
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Connections

TABLE 6

Model (A4) > Connections

Object Name	*Connections*
State	Fully

	Defined
Auto Detection	
Generate Automatic Connection On Refresh	Yes
Transparency	
Enabled	Yes

TABLE 7
Model (A4) > Connections > Contacts

Object Name	*Contacts*
State	Fully Defined
Definition	
Connection Type	Contact
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Auto Detection	
Tolerance Type	Slider
Tolerance Slider	0.
Tolerance Value	3.3602e-002 in
Use Range	No
Face/Face	Yes
Face/Edge	No
Edge/Edge	No
Priority	Include All
Group By	Bodies
Search Across	Bodies
Statistics	
Connections	14
Active Connections	14

FIGURE 1
Model (A4) > Static Structural (A5) > Moment

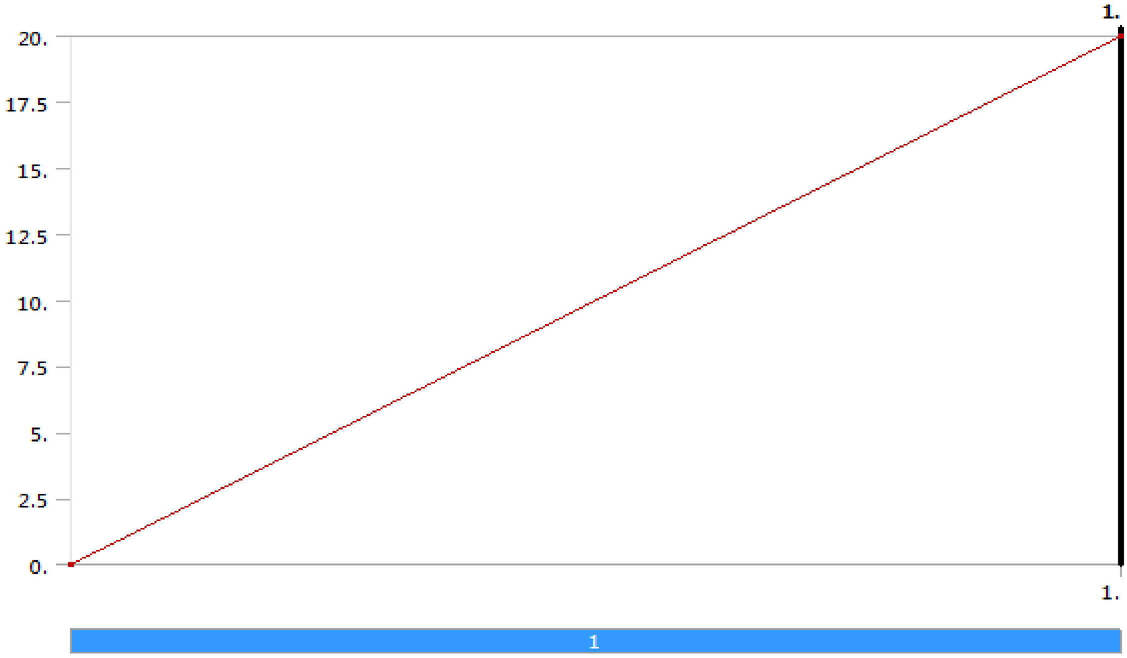
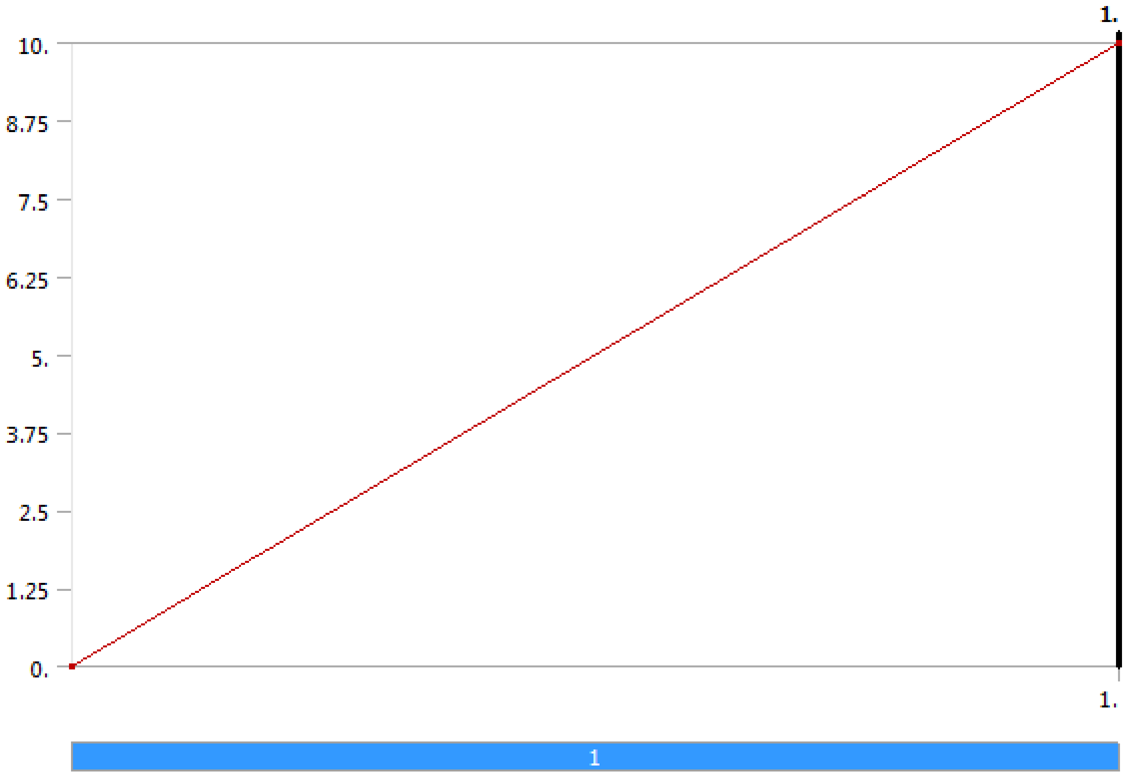


FIGURE 2
Model (A4) > Static Structural (A5) > Rotational Velocity



Solution (A6)

TABLE 8
Model (A4) > Static Structural (A5) > Solution (A6) > Solution Information

Object Name	*Solution Information*
State	Solved

Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All
FE Connection Visibility	
Activate Visibility	Yes
Display	All FE Connectors
Draw Connections Attached To	All Nodes
Line Color	Connection Type
Visible on Results	No
Line Thickness	Single
Display Type	Lines

TABLE 9

Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Shear Stress*	*Total Deformation*
State	Solved	
Scope		
Scoping Method	Geometry Selection	
Geometry	All Bodies	
Definition		
Type	Shear Stress	Total Deformation
Orientation	XY Plane	
By	Time	
Display Time	Last	
Coordinate System	Global Coordinate System	
Calculate Time History	Yes	
Identifier		
Suppressed	No	
Integration Point Results		
Display Option	Averaged	
Average Across Bodies	No	
Results		
Minimum	-7093.7 psi	6.1831e-002 in
Maximum	7057.5 psi	1633.1 in
Minimum Occurs On	Part 15	Part 1
Maximum Occurs On	Part 8	Part 15
Information		
Time	1. s	
Load Step	1	
Substep	1	
Iteration Number	1	

COMPARISON TABLE BETWEEN CAST STEEL AND COMPOSITE MATERIALS

Comparison table between cast steel and composite materials

FAILURE THEORIES	CAST STEEL			HONEY COMB EPOXY GEAR MATERIALS			% DIFFER ENCE
	2500 rpm	2000 rpm	1500 Rpm	2500 rpm	2000 rpm	1500 Rpm	
	140 Nm	170 Nm	230 Nm	140 Nm	170 Nm	230 Nm	
Von-mises stress (MPa)	12.9 60	15.7 37	21.2 92	12.8 91	15.6 54	21.1 79	0.5324
Von-mises strain	6.48 0 e- 5	7.86 8 e-5	10.6 46 e- 5	2.86 5 e- 5	3.47 9 e- 5	4.70 6 e- 5	55.787
Total deformation (mm)	18.0 73 e- 3	21.9 45 e-3	29.6 91 e- 3	8.02 1 e- 3	9.74 0 e- 3	13.1 78 e- 3	55.619
Maximum shear stress (Mpa)	7.37 6	8.95 6	12.1 17	7.34 2	8.91 5	12.0 62	0.4610
Strain energy (MJ)	157. 87 e- 3	232. 78 e-3	426. 09 e- 3	69.8 89 e- 3	103. 05 e- 3	188. 62 e- 3	55.730

7. CONCLUSION

In conclusion, the design optimization and material analysis of reused plastic composite spur gears offer a promising avenue for sustainable engineering solutions. Through careful consideration of material selection, design optimization, and environmental impact assessment, this study has demonstrated the viability of utilizing recycled plastics and carbon-based additives to create high-performance spur gears. The integration of epoxy resin further enhances the mechanical properties and durability of the composite, ensuring reliable operation in various applications. By leveraging recycled materials, the project not only addresses environmental concerns by reducing plastic waste but also contributes to resource efficiency and conservation. The successful development of these recycled plastic composite spur gears highlights the potential for eco-friendly alternatives in mechanical systems while maintaining performance standards. Moving forward, continued research and innovation in material science and design methodologies will further advance the sustainability and functionality of recycled plastic composite components in engineering applications.

REFERENCES :

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