Static & Dynamic Analysis of Spur Gear using Different Materials

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Abstract: Today gears play very important role in our daily lives. Considering this fact, present research work is devoted to the investigations on spur gears considering stress distribution, deformation, and weight reduction criteria. In the research work, ranking of gears is accomplished using different materials and best options are suggested. The alternatives for the research work were structural steel (existing material), grey cast iron, epoxy e glass UD composite, and aluminum alloy, which were evaluated for the criteria permissible working stresses, static loads, Von misses stresses and total deformations. Beside these parameters, modal analysis for the gears was also carried out. For this purpose, first of all a model of gear used in Hero Passion Pro 100 CC was generated using CATIA software and its performance was evaluated on different criteria using analytical as well as simulation approaches for different materials. Modal analysis governs the suitability of different materials for the application. Static and dynamic analysis yielded different rankings of the materials. In order to get preferred ranking system, a well-known technique relative standard deviation was used. The results of research work show the suitability of Al alloy for gear making application.

***Index Terms* – Spur gear, structural analysis, CATIA.**

1. Introduction

Spur gears are simple in construction, easy to manufacture and cost less. They have highest efficiency and excellent precision rating. They are used in high speed and high load application in all types of trains and a wide range of velocity ratios. Hence, they find wide applications right from clocks, household gadgets, motor cycles, automobiles, and railways to aircrafts. Typically spur gears are used in internal combustion engine gear boxes (for producing small torques).

Gears are usually subjected to fluctuating loads. Due to these loads bending and compressive stresses will be developed in the gears. While designing the gear it is very important to analyze the stresses for safety operation, and weight reduction of gear is also one of the design criteria (Keerthi *et al.*, 2016).

The objective of the research is to reduce the stress distribution, deformation and weight of spur gear by using composite materials in the application of gear box. For this purpose, analysis of shall be made on a gear used in Hero Passion Pro 100 CC motorcycle. During the research work, the mechanical properties bending stresses, tangential load, dynamic load, total deformation and von misses stresses on gears, along with the modal analysis parameters shall be investigated. The proposed materials for the research work are Structural Steel (existing material), Grey Cast Iron, Epoxy E Glass UD composite, and Aluminum alloy.

Following are the objectives of present research work:

a) To design gears of different materials;
b) To determine different mechanical properties of the gears made up of different materials; and
c) To rank different gear materials in accordance with the properties shown by them.

2. Literature Review

Following points represent the survey of available literature in the field of spur gears.

1) Simon *et al.* (2017)

According to the researchers a very important feature of high quality gears is a low noise emission in all operating conditions. Micro-geometry of the gear is of relevance for the vibration excitation in the tooth contact and significantly affected by the manufacturing process, especially the finishing operations. In the research work a detailed simulation of the production process is presented, providing crucial information about characteristic process properties and enabling investigations on the impact of manufacturing process on gear mesh acoustics.

2) Dirk *et al.* (2017)

Researchers tell that forming processes are generally characterized by a high degree of material utilization as well as short process times and, consequently, a decent economic efficiency. Considering their application in the manufacturing of large spur gears, forming processes offer a significantly attractive characteristic for the production of essential gearing components commonly used in wind turbines or marine engines.

3) Wei *et al.* (2017)

Researchers report that during cold precision forging of helical gears, the die experiences high forming pressure resulting in elastic deformation of the die, a main factor affecting dimensional accuracy of a formed gear. It shows the importance of optimizing the relief-hole diameter to minimize the dimensional inaccuracy of forging gears caused by the die elastic deformation.

4) Wuhao *et al.* (2017)
In the research work, cold orbital forging and traditional cold forging of a spur bevel gear are simulated under the same conditions in the Deform-3D software platform. The results show that, comparing with traditional cold forging of a spur bevel gear, cold orbital forging can increase the degree and homogeneity of plastic deformation and improve the gear tooth accuracy.

5) Sánchez *et al.* (2017)
In the research work, the meshing stiffness of spur gear pairs, considering both global tooth deflections and local contact deflections, is evaluated at any point of the path of contact and approximated by an analytical, simple function.

6) Suslin *et al.* (2017)
According to the researchers, the main limiting factor in high-speed aviation gear systems is contact strength. There are two main ways for reducing contact stresses in gears with involute tooth profile: 1) by using a standard basic rack profile with increased pressure angle; 2) by using a non-standard basic rack profile i.e. increasing the overlap ratio.

7) Raghuwanshi & Parey (2017)
Researchers report that time varying mesh stiffness is an important parameter in the study of gearbox vibration analysis. Mesh stiffness is affected by gear parameters (e.g. pressure angle, contact ratio, back-up ratio, module etc.) and due to presence of gear tooth faults (e.g. crack, pitting, spalling etc.).

8) Kalashnikov *et al.* (2017)
The researchers considered the continuous cylindrical grinding wheel of the planetary transmission with the use of highly porous worm grinding wheels. The process of continuous grinding of teeth by the method of generating is characterized by high accurate of relative rotation of tool and work piece gears.

9) Dhamande and Choudhari (2016)
The work presents a laboratory investigation carried out through an experimental set-up for the study of combined gear –bearing fault. This paper proposes a novel approach of damage detection in which defects in multiple components are analyzed using vibration signal.

10) Sari *et al.* (2016)
According to researchers, high performance gears require high geometrical qualities. For these aspects expensive grinding processes are indispensable as finishing processes. Researchers concluded that WEDM finished gears last three times longer than the ground gears due to a beneficial running-in topography formation with increased tribological characteristics.

11) Pawar and Utpal (2015)
In this work metallic gears of steel alloy and Aluminium Silicon carbide composite have been manufactured. According to researchers, composites provide much improved mechanical properties such as better strength to weight ratio, more hardness, and hence less chances of failure.

2.1 Gaps in the Research
During survey of available literature, following gaps are being observed.
a) There is very limited research which uses different materials for modeling a gear;
b) There is very limited research which tells about ranking of different materials used for making gears.

On the basis of these gaps, objectives of the proposed research work are formulated.

3. Solution Methodology
Present section tells about the investigated parameters in the research work and the software used, the details of which are presented in upcoming sections.

3.1 Investigated Parameters in the Research Work
Following are the details of parameters used in present research work (Rattan ,2014, Khurmi and Gupta, 2008, and Bhandari, 2010).
a) Outside Circle Diameter = (Z+2)×m
b) Module (m) = D/t
c) Module (m) = Pitch circler diameter / z
d) Base Circle diameter = Dcosα
e) Deddendum D = Addendum + Clearence
f) Addendum = 1m
h) Deddendum circle diameter = (d-2.5m)
i) Fillate Radius = Pc/8
j) Hole Depth = 2.25m
k) Thickness of the tooth = 1.571 x m
l) Face Width = (b) = 0.3 x PCD
m) Diametral Pitch = z/D
n) Velocity, v = ΠdN/60, m/s
o) Permissible Tangential load, W_T = P/V, N

p) Dynamic load, $W_D = W_T + \frac{21v(bC+W_T)}{21v+\sqrt{bC+W_T}}$, N

q) Static Load , $W_S = \sigma_e.b.\pi.m.y$, N (where, $\boldsymbol{\sigma}_e$ is the endurance strength of the material)

r) Bending Stress, $\sigma_W = \sigma_o \times C_v$, MPa

…………where, σ_o is allowable static stress, MPa; and

C_v = 4.15/(4. 5+v), for carefully cut gears with velocity up to 12.5 m/sec.

3.2 Software used in the Research Work

The software used in the research work is CATIA V5.CATIA enables the creation of 3D parts, from 2D sketches, sheet metal, composites, and molded forged or tooling parts up to the definition of mechanical assemblies. The software provides advanced technologies for mechanical surfacing as well as structural analysis. It provides tools to complete product definition, including functional tolerances as well as kinematics definition. CATIA provides a wide range of applications for tooling design, for both generic tooling and mold & die. CATIA offers a solution to shape design, styling, surfacing workflow and visualization to create, modify, and validate complex innovative shapes from industrial design to top class surfacing with the ICEM surfacing technologies. CATIA supports multiple stages of product design whether started from scratch or from 2D sketches (blueprints). In present research work, design and analysis of gear is accomplished in the software.

4. Problem Formulation and Solution

Table 3.1 shows the details of solution methodology adopted for formulation and solution of the problem.

Table 3.1: Solution Methodology

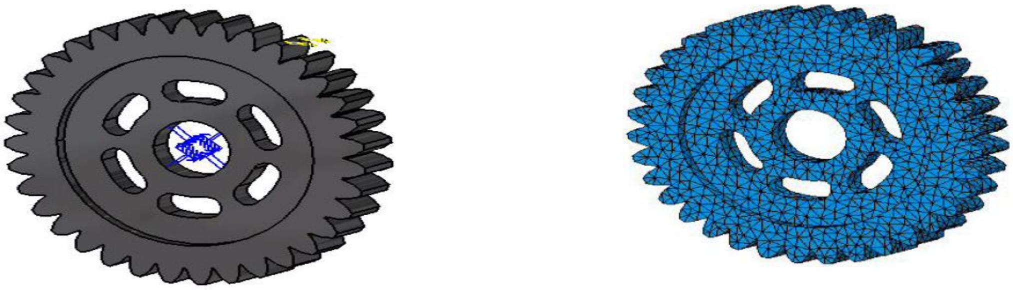
S.No	Step No.	Remarks
1.	Selection of a standard automobile engine	The targeted automobile is Hero Passion Pro 100 CC.
2.	Calculation of dimensions of gear	calculated from specifications of the vehicle
3.	Investigations on materials	Selected materials are structural steel, gray cast iron, epoxy resin and Al alloy
4.	Investigations of parameters for static and dynamic analysis, analytically and using software approach	The targeted software was CATIA V5
5.	Comparison of different materials on parameters	
6.	Ranking of different materials	

Details of different steps of procedure for application of research tool to the case problem are as follows.

1) First of all, the automobile was selected for analysis. The targeted automobile was Hero 100 CC motorcycle. Its specifications were torque 8.05 N-m and 5000 RPM. After this selection, I st gear of automobile was selected and its dimensions were calculated, the details of which are presented as follows.

a) Outside diameter of gear = 70.3 mm
b) No. of teeth (Z) = 35
c) Pitch circle diameter (PCD) = 66.5 mm
d) Base Circle diameter = 62.48 mm
e) Clearence = 5.97 mm
f) Clearence = 0.29 mm
g) Addendum = 1.90
h) Deddendum =2.19
i) Deddendum circle diameter = 61.86 mm
j) Fillate Radius = 0.7472 mm
k) Hole Depth = 4.275 mm
l) Thickness of the tooth =.9849 mm
m) Face Width = (b) = 19.98 mm

2) In next step, a model of gear was prepared in the modelling software, and its meshing was carried out. Figure 4.1 shows the details of model and its meshing.



(a) Model of Gear **(b) Mesh of Gear**

Figure 4.1: Model and its Mesh

Table 4.1 and 4.2 shows the details of meshing parameters for Structural analysis and Modal analysis

Table 4.1: Meshing Specifications for Structural Analysis

S.No	Entity	Details
1	Element type	Tetrahedron
2	Number of nodes	20039
3	Number of elements	11149

Table 4.1: Meshing Specifications for Modal Analysis

S.No	Entity	Details
1	Element type	Tetrahedron
2	Number of nodes	1172
3	Number of elements	3402

3) In next step, properties of materials were investigated. Following are the details.

Table 4.2: Properties of Proposed Materials (Keerthi *et al.*, 2016, www.ozomaterials.com, www.weldguru.com, Mahadevan an Reddy, 2013, www.aboutsteel.com, www.steelconstruction.info, www.substech.com, www.unitedaluminum.com and others)

S. No	Mechanical Property	Unit	Material			
			Structural Steel (existing)	Gray Cast Iron	Epoxy E Glass UD	Al Alloy
1.	Density	Kg/m^3	7850	7200	2000	2770
2.	Young's modulus	GPa	200	110	450	71
3.	Poisson's ratio	-	0.3	0.28	0.30	0.33
4.	Ultimate Tensile strength	MPa	460	430	1100	310
5.	Yeild strength	MPa	275	827	847	219
6.	Bulk Modulus	GPa	166	83.3	-	69.9
7.	Endurance Limit	MPa	168	130	96	84

4) In next step, the obtained properties were fed to analytical expressions and simulation software for obtaining results.

5. Results and Discussion

Present section tells about the results obtained and discussion made about the results, the details of which are presented in the upcoming sections.

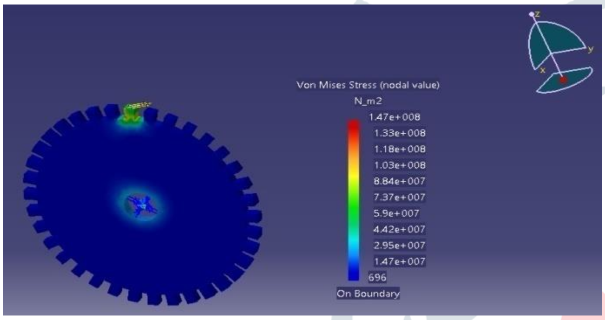
5.2 Results

Following results were obtained from analytical calculations.

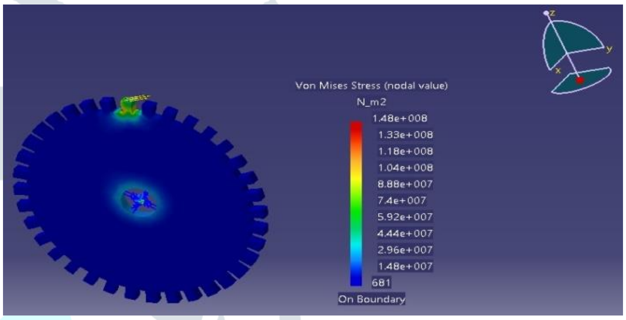
Table 5.1: Summary of Results

S.No	Material	Bending Stress (6w) MPa	Static load (N)
1	Structural Steel	49.22	2543.26
2	Gray Cast Iron	46.01	1968.85
3	Epoxy Resin	118.61	1453.29
4	Al Alloy	33.17	1271.63

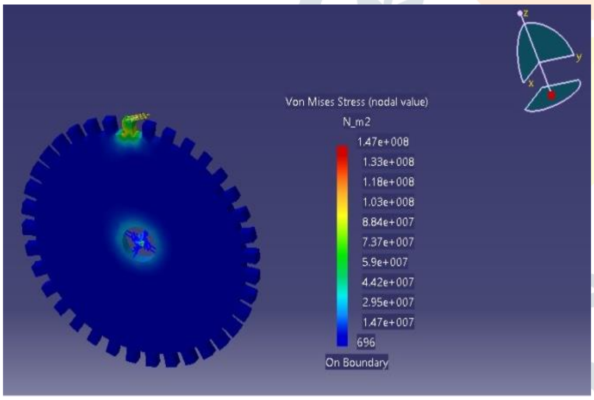
On applying simulation approach, following results obtained for von misses stresses and total deformations.



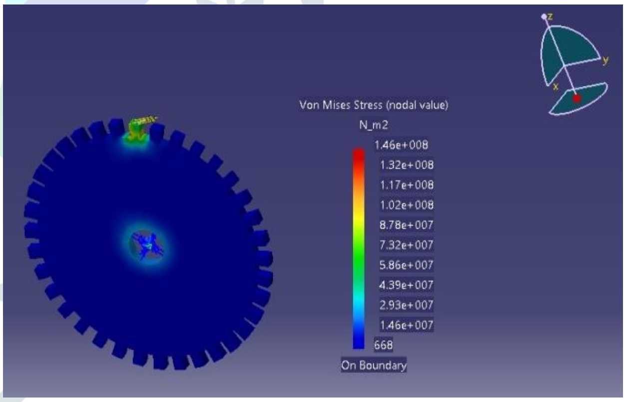
(a) Structural Steel



(b) Gray Cast Iron

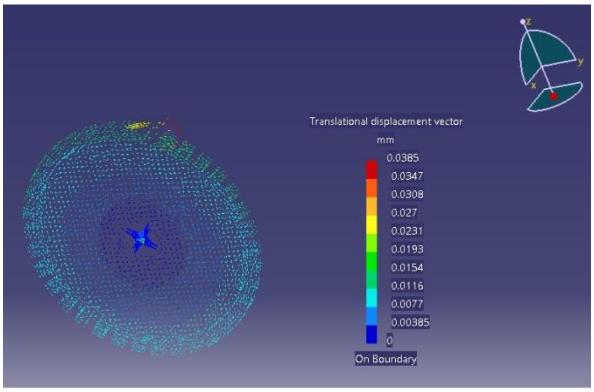


(c) Composite

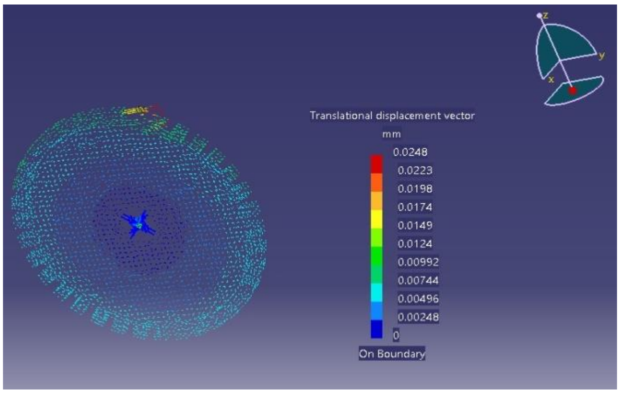


(d) Al Alloy

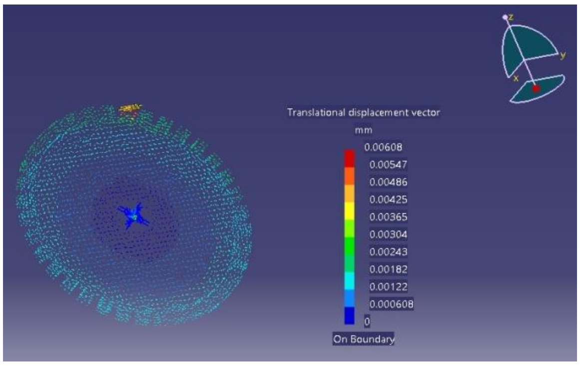
Figure 5.1: Details of Von misses Stresses



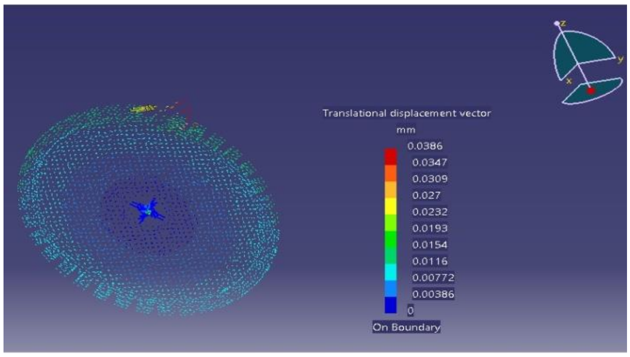
(a) Structural Steel



(b) Gray Cast Iron



(c) Composite



(d) Al Alloy

Figure 5.2: Details of Total Deformation

Table 5.2 shows the summary of results.

Table 5.2: Summary of Results

S.No	Material	Bending Stress (6w) MPa	Static load (N)	Von Misses Stresses (Pa)	Total Deformation (mm)
1	Structural Steel	49.22	2543.266	1.47E+08	0.0385
2	Gray Cast Iron	46.01	1968.857	1.48E+08	0.0248
3	Epoxy Resin	118.61	1453.295	1.47E+08	0.00608
4	Al Alloy	33.17	1271.633	1.46E+08	0.036

On the basis of above results, ranking of the materials can be performed as follows.

Table 5.3: Ranking of Materials

S.No	Materials	Bending Stress (6w) MPa	Rank	Static load (N)	Rank	Von Misses Stresses (N/m^2)	Rank	Total Deformation (mm)	Rank
1	Structural Steel	49.22	3	2543.266	4	1.47E+08	2	0.0385	4
2	Gray Cast Iron	46.01	2	1968.857	3	1.48E+08	3	0.0248	2
3	Epoxy Resin	118.61	4	1453.295	2	1.47E+08	2	0.00608	1
4	Al Alloy	33.17	1	1271.633	1	1.46E+08	1	0.036	3

Following are the details of results obtained from modal analysis.

Table 5.4: Results of Modal Analysis

S.No	Material	Natural Frequency 1	Natural Frequency 2	Natural Frequency 3	Natural Frequency 4	Natural Frequency 5	Natural Frequency 6
1.	Structural Steel	2108.15	2149.48	2842.69	2978.78	4323.22	4361.02
2.	Gray Cast Iron	1629.54	1660.85	2195.52	2313.83	3348.39	3375.48
3.	Composite	6264.88	6387.69	8447.73	8852.17	12847.5	12959.8
4.	Al Alloy	2125.2	2168.35	2868.87	2976.72	4342.59	4385.58

Figure 5.3 shows the graphical representation of results.

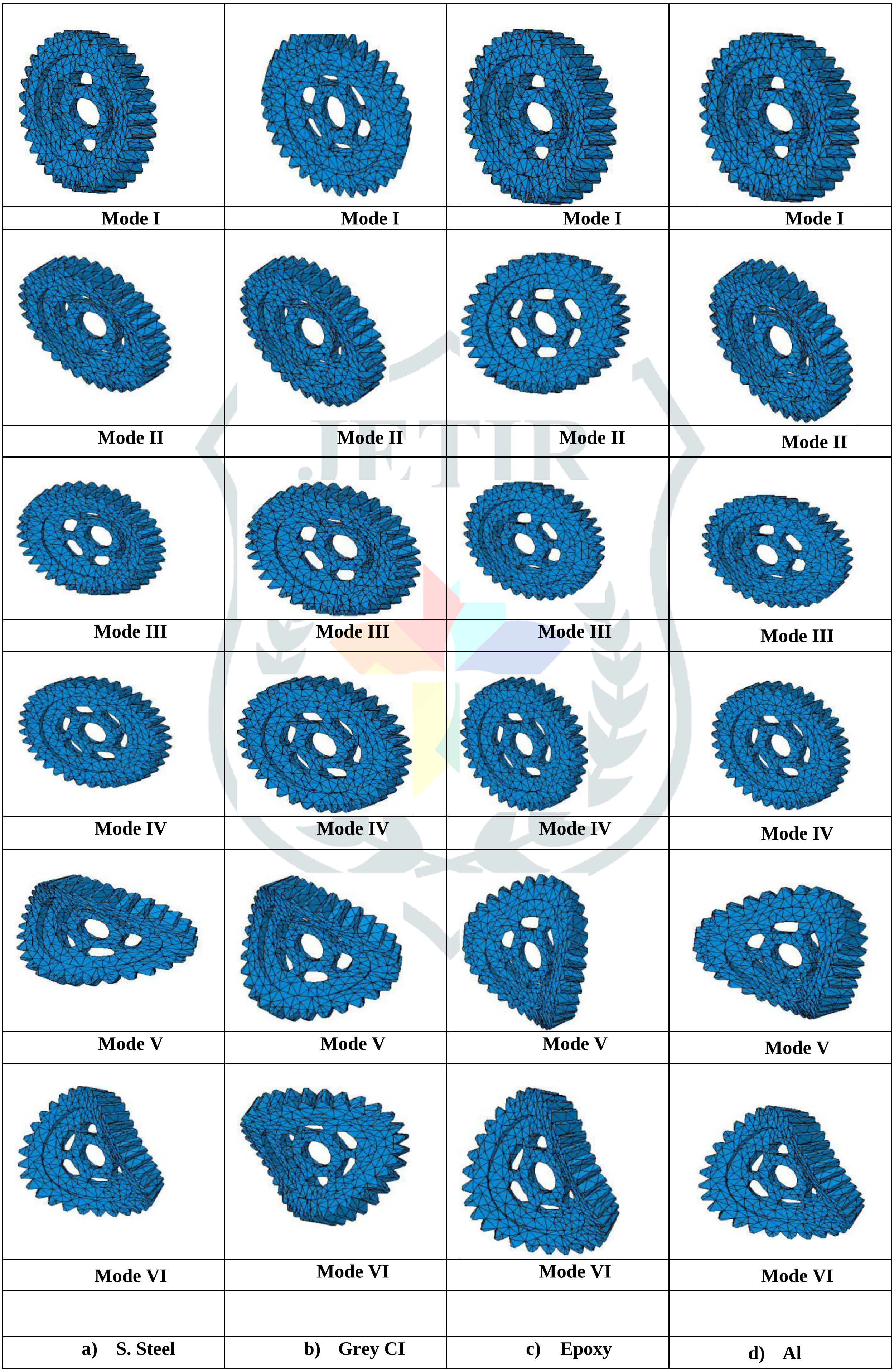


Figure 5.3: Details of Failure Mode Shapes

5.2 Discussion

Table 5.5 shows the values of static loads and associated dynamic load for different materials.

Table 5.5: Static Loads for Different Materials

S.No	Materials	Static Load (N)	Dynamic Load (N)
1	Structural Steel	2543.26	90.88
2	Gray Cast Iron	1968.85	90.88
3	Epoxy Resin	1453.29	90.88
4	Al Alloy	1271.63	90.88

From above comparison, one can analyze that as static loads are greater than dynamic loads, the designs of different gears are safe. From Table 5.3 one can find that different rankings were scored by different materials. In order to solve above problem, relative standard deviation (RSD) of the results were taken, which is the ratio of standard deviation and average of scores in percentages. In case of RSD, the alternative is chosen which shows the minimum value of RSD. Table 5.6 shows the values of RSD for different criteria.

Table 5.6: Values of RSD for Different Criteria

S.No	Evaluation Parameter	Relative Standard Deviation	Remark
1.	Permissible Working Stress (6w)	62.40446	
2.	Static load (N)	31.58992	
3.	Von Misses Stresses (N/mm^2)	10.14483	**Preferred Ranking**
4. .	Total Deformation (mm)	56.04499	

From above, one can find that as the criteria Vonmises stresses shows the minimum value of % RSD, rankings shown by are considered as basis of rankings of materials. Table 5.7 shows the overall rankings of materials.

Table 5.7: Overall Ranking of Materials

S.No	Materials	Von Misses Stresses (N/m^2)	Overall Rank
1	Structural Steel	1.47E+08	2
2	Gray Cast Iron	1.48E+08	3
3	Epoxy Resin	1.47E+08	2
4	Al Alloy	1.46E+08	1

From the results of modal analysis, comparison of natural frequencies was made with system's excitation frequency, which is 83.333 Hz. As a result, one can analyze that *as the system's natural frequencies are more than excitation frequency, all the materials are appropriate for gear making application from frequency analysis view point.*

6. Conclusion, Limitations and Future Scope of the Research

Present work is dedicated to investigations on material changes on existing gear dimensions, due to which efficiency of existing gearing system can increase. For this purpose, four materials namely, structural steel, gray cast iron, epoxy material and aluminum alloy were chosen and parameters, static load, bending stress, von misses stresses and total deformation were investigated with the help of analytical expressions and CATIA software. Beside these parameters, modal analysis was also carried out for the purpose of investigating natural frequencies of the systems. Following points represent the conclusion of the research work.

- Best material for the spur gear for targeted automobile is Al alloy;
- Second best materials for spur gear for targeted automobile are epoxy composite and structural steel; and
- Considering modal analysis, all materials are suitable for gear making application.

Following are the limitations of research work.

- The research work is limited to investigations of a particular automobile;
- The research work is also limited to investigations about limited properties of spur gear; and
- The research work is also limited to performance evaluation of a small set of gear materials.

Following points indicate the future scope of research work.

- A research work considering a broader set of automobiles may be initiated;
- A research work can also be initiated which shall consists of a broader set of properties of gear to be investigate; and
- A research work considering broader sets of material can also be undertaken.

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