Comparative Analysis of Flywheel under Conventional and Composite Materials

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Abstract

This paper presents "COMPARATIVE ANALYSIS OF FLYWHEEL UNDER CONVENTIONAL AND COMPOSITE MATERIALS". Our objective is to demonstrate the application of composites over conventional materials like steel. Conventional engineering materials like steel has high density due to which the inertia of the components are more. Especially during rotations the forces are more due to higher mass. hence, this will give rise to more vibrations due to high imbalance force. So this can be reduced by using composite materials over conventional materials whose density is less and has higher strength to weight ratio.

Keywords: *stress analysis, composites materials, stress, deformation.*

INTRODUCTION

A flywheel is a mechanical device which efficiently stores rotational energy. A flywheel is an energy storage system and can be described as a substituent for mechanical battery since it need not have to create electricity. It simply converts and stores energy in the form of kinetic energy and utilises as and when the energy requirement arises.

Composite materials are the materials which are made from two or more constituent materials and are combined together at macroscopic level with significantly different physical or chemical properties ultimately to produce a new material with characteristics different from individual components (matrix phase and reinforcement phase) which are used to fabricate. Composite materials becomes the material of choice for the fabrication of various mechanical components and parts due to their variety of properties which is better compared to the conventional materials.

PROBLEM DEFINITION

Analysis of flywheel for stress and model condition for conventional and composite materials is the main definition of the problem. The main objective of the problem includes analysis of flywheel with conventional materials and also with composite materials.

The figure 1 shown describes the position of flywheel on rotor. It also shows the positioning of the flywheel on the shaft system. The flywheel is mounted on one side of rotor system.
The flywheel has opening to reduce the weight of the structure.

Figure 2 shows the geometry of the flywheel which is built so as to increase the mass moment of inertia by increasing radius of the structure but at the same time weight is reduced by using stiffness.

We are not designing the flywheel

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structure but we are taking the existing geometry of the flywheel for our convenience. Thus the geometry of the flywheel which is already existing is taken for the analysis purpose. The existing design of the flywheel is imported to the software for further analysis purpose. Here we extract the mid surface of the flywheel which makes our analysis process simpler, easier and more accurate. Meshing is carried out with the help of software - hyper mesh which has an option to import the design existing and to extract the mid surface from it. The extracted mid surface of the flywheel is shown in fig 3.

Fig: 1. *Position of the flywheel*

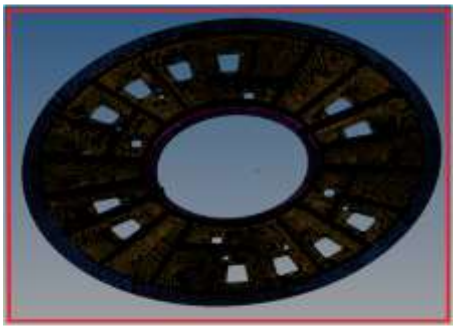

Fig: 2. *Mesh of the structure*

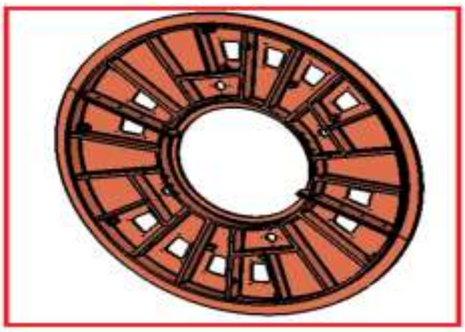

Fig: 3.a. *Geometry of the flywheel*

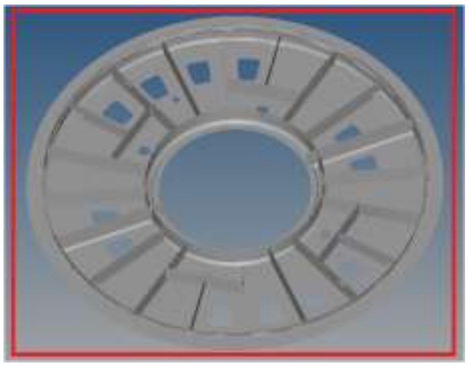

Fig: 3.b. *Mid surface of the flywheel*

MESHING

Here in hyper mesh the geometry available is split and grouped to different components for surface or shell meshing. Various components are created and grouped for applying thickness properties while analysing the problem. The meshing of the whole flywheel geometry is shown in fig 4.

The meshed components of the flywheel geometry are shown from fig 4.a. to 4.d.

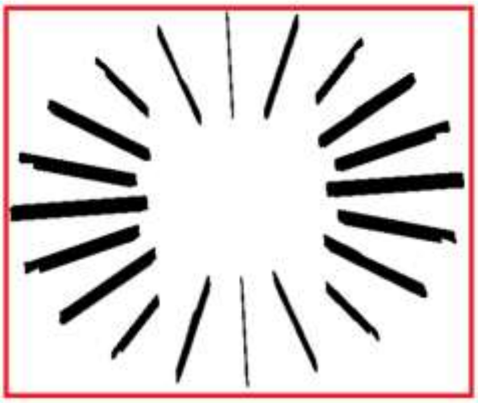

Fig: 4.a. *COMPONENT-1*

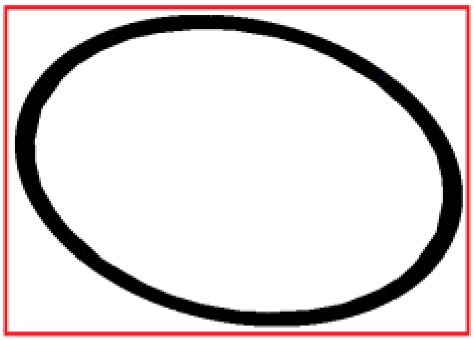

Fig: 4.b. *COMPONENT-2*

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Fig: 4.c. *COMPONENT-3*

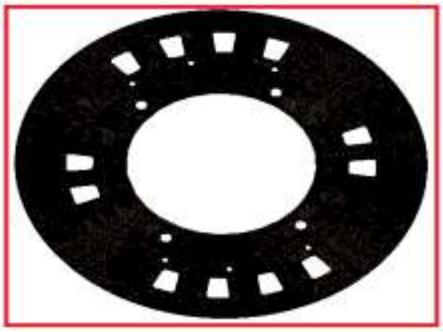

Fig: 4.d. *COMPONENT-4*

In the above figures

- Component-1 indicates:-Mesh of radial ribs
- Component-2 indicates:-Mesh of outer flange
- Component-3 indicates:-Mesh of inner flange
- Component-4 indicates:-Mesh of inner web

2-DESIGN REQUIREMENTS

- The factor of safety should be maintained above 2
- The defection should be limited to 82 microns for the given flywheel design.

3-Assumptions for the analysis process

- Analysis is done in the linear range.
- Analysis is done within the elastic limits.
- Material is assumed to be homogeneous and continues.
- Straight sided elements are used as elements.

4- Materials chosen for the analysis purpose

As we are doing comparative analysis between conventional and composite materials, we are considering steel which is most common conventional material and e-glass epoxy, carbon fibres which are presently the most commonly used composites .

The various mechanical properties of few composites and conventional materials are shown below in the table 1.

Table: 1. *Mechanical properties of few materials*

	Symbol	Units	Std CF Fabric	HMCF Fabric	E glass Fabric	Kevlar Fabric	Std CF UD	HMCF UD	M55** UD	E glass UD	Kevlar UD	Boron UD	Steel S97	AL L65	Tit. dtd 5173
Young's Modulus 0°	E1	GPa	70	85	25	30	135	175	300	40	75	200	207	72	110
Young's Modulus 90°	E2	GPa	70	85	25	30	10	8	12	8	6	15	207	72	110
In-plane Shear Modulus	G12	GPa	5	5	4	5	5	5	5	4	2	5	80	25	
Major Poisson's Ratio	v12		0.10	0.10	0.20	0.20	0.30	0.30	0.30	0.25	0.34	0.23			
Ult. Tensile Strength 0°	Xt	MPa	600	350	440	480	1500	1000	1600	1000	1300	1400	990	460	
Ult. Comp. Strength 0°	Xc	MPa	570	150	425	190	1200	850	1300	600	280	2800			
Ult. Tensile Strength 90°	Yt	MPa	600	350	440	480	50	40	50	30	30	90			
Ult. Comp. Strength 90°	Yc	MPa	570	150	425	190	250	200	250	110	140	280			
Ult. In-plane Shear Stren.	S	MPa	90	35	40	50	70	60	75	40	60	140			
Ult. Tensile Strain 0°	ext	%	0.85	0.40	1.75	1.60	1.05	0.55		2.50	1.70	0.70			
Ult. Comp. Strain 0°	exc	%	0.80	0.15	1.70	0.60	0.85	0.45		1.50	0.35	1.40			
Ult. Tensile Strain 90°	eyt	%	0.85	0.40	1.75	1.60	0.50	0.50		0.35	0.50	0.60			
Ult. Comp. Strain 90°	eyc	%	0.80	0.15	1.70	0.60	2.50	2.50		1.35	2.30	1.85			
Ult. In-plane shear strain	es	%	1.80	0.70	1.00	1.00	1.40	1.20		1.00	3.00	2.80			
Thermal Exp. Co-ef. 0°	Alpha1	Strain/K	2.10	1.10	11.60	7.40	-0.30	-0.30	-0.30	6.00	4.00	18.00			
Thermal Exp. Co-ef. 90°	Alpha2	Strain/K	2.10	1.10	11.60	7.40	28.00	25.00	28.00	35.00	40.00	40.00			
Moisture Exp. Co-ef 0°	Beta1	Strain/K	0.03	0.03	0.07	0.07	0.01	0.01		0.01	0.04	0.01			
Moisture Exp. Co-ef 90°	Beta2	Strain/K	0.03	0.03	0.07	0.07	0.30	0.30		0.30	0.30	0.30			
Density		g/cc	1.60	1.60	1.90	1.40	1.60	1.60	1.65	1.90	1.40	2.00			

Out of the many materials available in the table we are considering e glass epoxy, carbon fibre, and steel for our analysis process and their corresponding mechanical properties are considered for arriving at our results.

5- Load consideration for analysis purpose

For the analysis purpose we take the following load considerations to obtain

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the results. The load considerations are as follows,

- Rotational load considerations of 1000RPM
- Torque load of 75N-M
- Dynamic modal conditions

Load considerations indicates that for that particular load the design parameters like stress and deformations are calculated.
For example for 1000rpm rotational speed of flywheel stress like Von-Mises stress and deformation results are obtained.

6- Reasons for selection of load conditions:
A flywheel is a rotating element so the rotational speed is considered and similarly torque load is considered as it is subjected to bending moments and likewise, to find the frequency of the flywheel it is subjected to modal conditions.
So we are considering only the above load conditions for arriving at results. Mechanical properties for these load conditions of the materials are obtained from the table 1.

RESULTS AND DISCUSSION

The results are as follows:
1. Results of conventional steel material under rotational load (1000rpm)

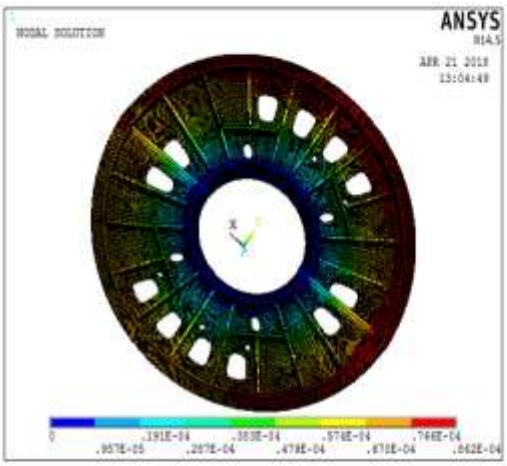

***Fig: 5.** Deformation plot for steel*

Fig 5 shows deformation of conventional steel material under rotational load of 1000rpm. The figure shows the deformation generated is 86 microns for the steel structure. Maximum deformation is observed at outer ends. This can be attributed to the distance from the constrained region.

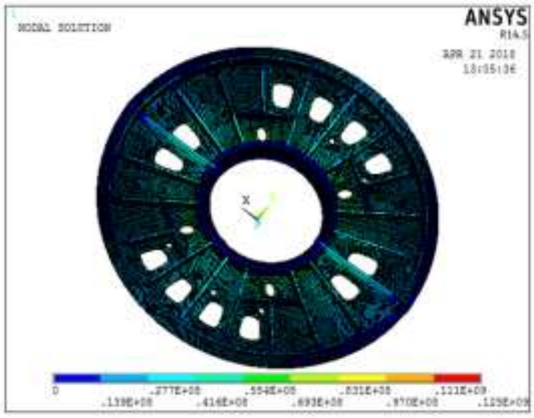

***Fig: 6.** Von-Mises stress for steel*

Fig 6 shows Von-Mises stress that is generated in the flywheel for the given rotational load of 1000rpm. From the figure, it indicates maximum stress developed is 125Mpa for given rotational speed. Maximum stresses are observed at the rib connecting to the central web. This can be attributed to the stress concentration effect due to sudden change of geometry. Rib height plays a major role in increasing strength of flywheel.

2. Results with carbon fibre material under rotational load of 1000rpm:

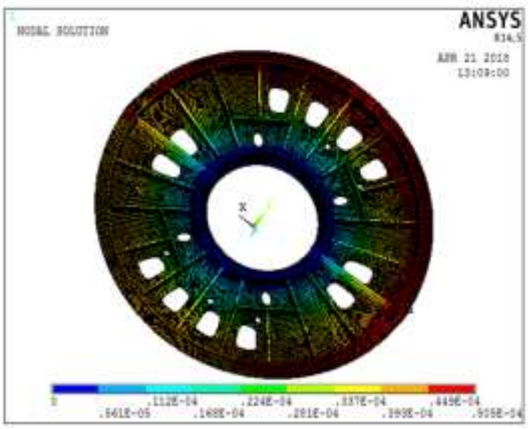

***Fig: 7.** Deformation plot for carbon fiber*

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Fig 7 indicates deformation plot for carbon fiber. Here the maximum deformation obtained is 50.5 microns (under rotational load of 1000rpm)

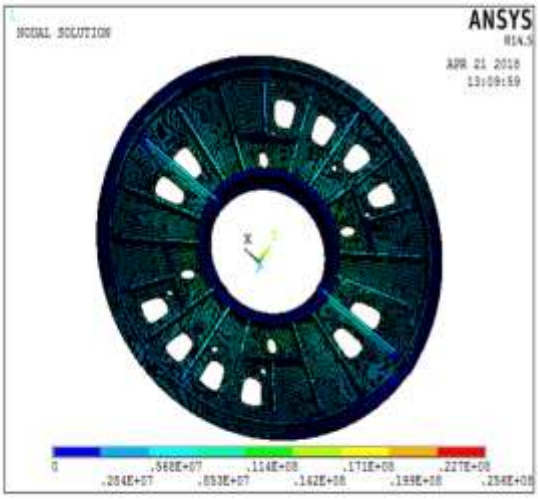

Fig: 8. *Von-Mises stress for carbon fiber*

Fig 8 shows the Von-Mises stress for the carbon fiber where in the maximum stress developed is 25.6Mpa.

3. Results with E-glass epoxy under rotational load of 1000rpm

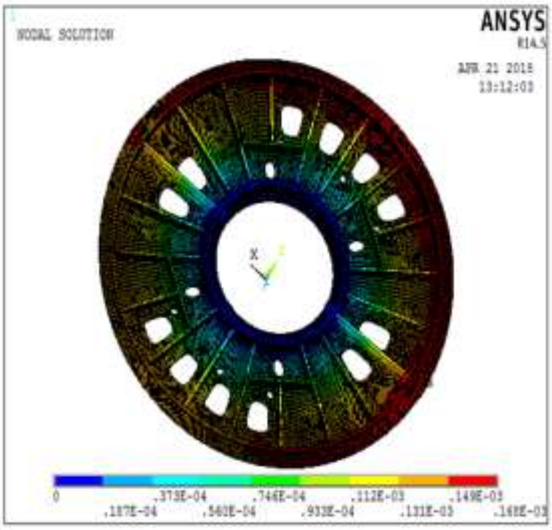

Fig: 9. *Deformation plot for E-glass epoxy*

Fig 9 shows deformation plot for E-glass epoxy fiber wherein the maximum deformation developed is 168 microns under rotational speed of 1000rpm

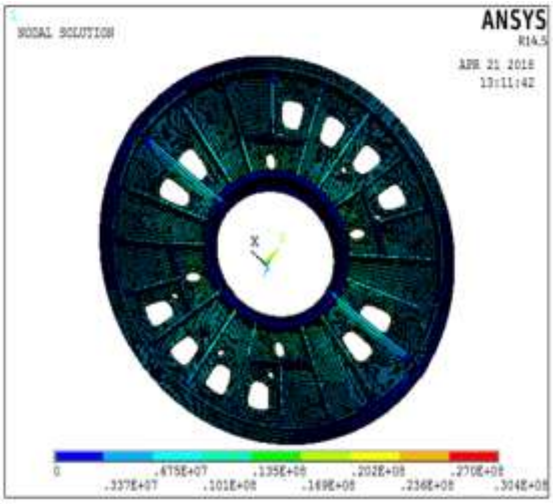

Fig: 10. *Indicates Von-Mises stress for E-glass epoxy fiber*

Fig 10 indicates Von-Mises stress for E-glass epoxy wherein the maximum stress developed is 30.4Mpa under rotational load of 1000rpm.

RESULTS WITH TORQUE LOADING

Results for conventional steel under the torque loading of 75N-M are as follows;

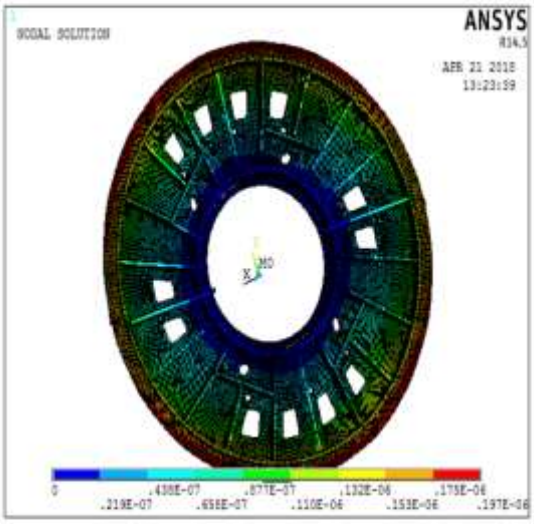

Fig: 11. *Deformation plot for steel*

Fig 11 shows the deformation plot for the conventional steel material where in the deformation obtained is 0.19 microns under torque load of 75N-m.

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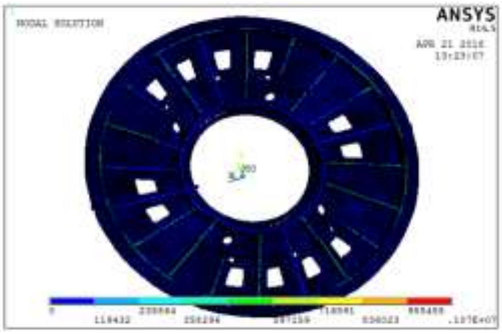

Fig: 12. *Von-mises stress for steel*

Fig 12 indicates the Von-Mises stress for the conventional steel materials where in the maximum stress obtained is 10.7Mpa under the torque load of 75N-M.

Similarly, for the same torque load of 75N-M the results of deformation and Von-Mises stress are tabulated for carbon fibre and e-glass epoxy and it is shown in the table 2 and 3.

Table: 2. *Results Comparison table for rotational load of 1000rpm*

Material	Stress (Mpa)	Deflections (Microns)	Factor of safety
Steel	125	86	250/125=2
Carbon fibre	25.6	50.5	600/25.6=23.4
E-glass epoxy	30.4	168	440/30.4=14.47

Table: 3. *Results comparison table for torque load of 75N-m.*

Material	Stress (Mpa)	Deflection (Microns)	Factor of safety
Steel	10.7	0.197	250/10.7=23.36
Carbon Fibre	10.7	0.564	600/10.7=56
E-glass epoxy	10.7	1.58	440/10.7=41

RESULTS FOR THE MATERIALS UNDER MODAL CONDITIONS

Analysis is carried out to check modal dynamic conditions (refer table 4 for the results) to find the natural frequencies which will decide the stability of the system. Natural frequencies are obtained to find the possible resonant condition of the problem even they give mode shapes which are useful to study the weak regions of the component under the study. For better dynamic stability the fundamental frequency should be as high as possible this can be attributed by stiffness of the structure also. Analysis is carried out for three material combination, their mode shapes are presented in figure 13, 14 and 15.

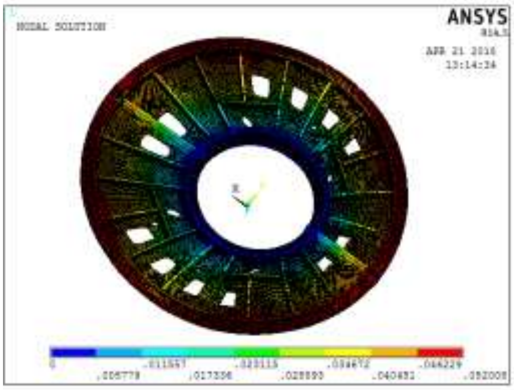

Fig: 13. *Mode shape for steel*

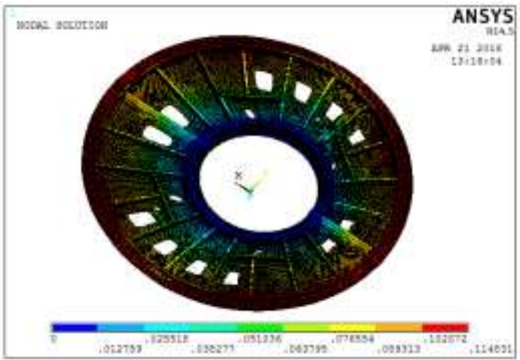

Fig: 14. *Mode shape for carbon fibre corresponding to first natural frequency.*

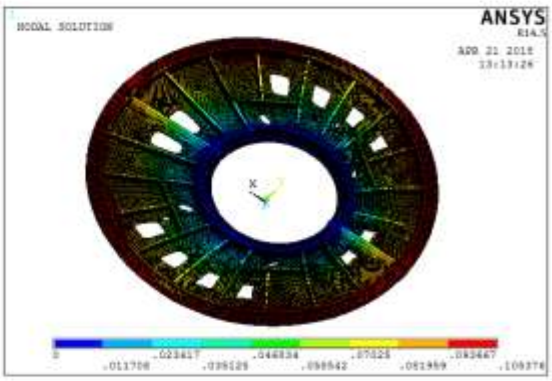

Fig: 15. *Mode shape for E-glass epoxy corresponding to the first natural frequency*

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***Table: 4.** Result of Materials under Dynamic Load Conditions*

Set no	Modal frequency for steel	Modal frequency for carbon fibre	Modal frequency for E-glass epoxy
1	1651	2156	1182
2	1717	2243	1230
3	1808.8	2362	1295
4	1835.5	2397	1314
5	1841.8	2405	1319
6	1983.6	2591	1421
7	2193.7	2865	1571
8	2265	2958	1622
9	2406	3143	1723
10	2431	3175	1741

DESIGN OPTIMIZATION BASED ON CARBON FIBER FLYWHEEL

Weight with conventional material (steel) for flywheel chosen for the study is 492kgs.Due to advantage of carbon fibre for the given loading conditions, the design optimization is carried out maintaining the structural safety. The design summary is as follows

***Table: 5.** Design iteration summary for carbon fibre flywheel*

Iterat-ions	1	2	3	4	Deflection(Microns)	Vonmises Stress	Fos	Weight (kg)
1	12	20	15	10	50.5	25.6	23.4	101
2	10	18	13	8	62.1	40.3	14.92	84.9
3	8	16	12	6	69.8	51	11.7	70.63
4	6	12	10	4	81.9	67.6	8.8	53.98

In the above table 5, 1 2 3 4 represents components of optimization. The first iteration shows initial thickness of the components later iterations are continued with change in thickness and finally stop due to convergences of deformation near 82microns which is the limiting deformation of the problem so finally the carbon fibre composites weight can be reduced to 53.98kgs compared to initial weight of 492kgs of conventional steel. It indicates that weight of carbon fibre is less for same loading conditions as of conventional material like steel. So it makes the flywheel weight less easy to handle and composites have greater strength.

CONCLUSION

A flywheel structure has been analysed for general loading conditions to find the advantage of using composite materials over conventional materials. Here this paper has clearly demonstrated the application of composites over conventional materials. The analysis has proved that Carbon fiber reinforced with epoxy is more compatible than the conventional steel and E-glass fiber reinforced with epoxy material.

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