Comparison of Performance of Flywheels with Webs Made of Different Composite Materials

Amol J. Chougule
M. E Design,
Department of Mechanical Engineering
Walchand Institute of Technology Solapur
Solapur University Solpue, India

S. B Tuljapur
Asst. Prof
Department of Mechanical Engineering
Walchand Institute of Technology Solapur
Solapur University Solpuer, India

***Abstract*— Flywheel is a device to smoothen the cyclic fluctuation of speed change when delivering constant output power from the engine. It has no influence on the mean speed of the prime mover. It has no influence on the varying load demand on the prime mover or the delivered power from the prime mover.**

Flywheel rim contributes 92% of the flywheel effect and web contributes 8% of flywheel effect. Hence in this work evaluation of stresses in the steel rim and webs made up of different composite materials are studied using finite element method and results are validated by analytical calculations. This study solely focuses on exploring the effects of Centrifugal stresses on webs made up of different composite materials flywheel and comparison of theoretical and Ansys results of composite materials flywheel with each other is done. To find out best suitable composite material for flywheel manufacturing.

Keywords—Flywheel, FEA, Analysis..

1. INTRODUCTION

In today's society energy storage plays a vital role, where almost all the things we use for our day –to-day life needs energy to work. Sometimes energy can be supplied directly or taken it from some kind of local energy storage. Flywheel technology is a very bright future for storing energy. As Flywheels are very "green" technology they have been widely used for a long time as mechanical energy storage devices.

2. LITERATURE REVIEW.

S. M. Dhengle et al. have discussed the many cases of Flywheel failure. Among them maximum tensile stress and bending stress induced in the Rim and tensile stress induced in the Arm under the action of centrifugal forces are the main cause of the Flywheel failure. Hence their work evaluation of stresses using the Finite Element Method and results are validated by analytical calculations. The Finite Element Analysis is carried out for different cases of loading applied on the Flywheel and maximum Von-Misses stress and deflection in the rim are determined. From this Analysis they have found that Maximum stresses induced are in the rim &arm junction. Due to tangential forces maximum bending stresses occurs near the Hub end of the arm.

Nagaraj R. M. et al. presented a work on comparison of existing Flywheel material with composite one. They got a result from design & analysis methods that for energy storage low density and high strength is required in turns stresses and deformation should be low. So the Existing Gray cast iron Flywheel is having more stress and deformation whereas the test material is comparatively low. Therefore they suggest to use aluminum in Flywheel for high energy storing purpose with low density and less mas

*J. G. Bai ET al.*have developed prototype of Flywheel Energy Storage System (FESS) with Active Magnet Bearing (AMB) and AMB's-parameters are obtained by parameter Identification. They have make Analysis on Flywheel parameter as mass, diameter, rotating speed and energy storage. They have placed two AMB on the top of rotor and two AMB on bottom that control the unbalanced force and gyroscopic effect of the Flywheel rotor and energy loss covered by the bearing is also minimize by carefully design.

Francisco Diaz-Gonzalez al. have proposed an energy management strategy for a Flywheel based energy storage device. They formulate the optimum operation to determine storage. The main objective of the Flywheel is to smooth the net power flow injected to the grid by a variable speed wind turbine. The result show that the higher mean wind power, the higher mean rotating speed of the Flywheel. The simulation results for the Flywheel with proposed energy management algorithm are able to achieve a 91.9 % of the turbulent energy component reduction in the high frequency components of the wind power. This result is close to the 91.7 % obtained by the optimal operation of the Flywheel

The objectives of research work:-

- To determine the stresses in composite material flywheel analytically & using Finite Element Method.
- To compare performance of flywheels with webs made of different composite materials with each other to find out the best suitable composite material for flywheel.

3.1. Analytical solution:-

Here we have to find out the maximum centrifugal stress for the above different composite material flywheels theoretically.

3.1 Case 1: Composite Flywheel (with Steel Rim and Carbon Fiber web)

Given: Model –1.2 Riverton engine

Power, [P] = 66 KW

Speed, N = 3250 rpm

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 04, April-2017

Torque, T = 140 N-m

Now, Mean Rim Speed,

$$v = \frac{\pi DN}{60} \quad \ldots\ldots\ldots\ldots\ldots \text{(PSG 7.120)}$$

Where, D = mean diameter of rim (m) = 0.222 m

N = speed (rpm)

$$\therefore v = \frac{(\pi \times 0.222 \times 3250)}{60}$$

$$\therefore v = 37.75 \text{ m/sec}$$

Now, Tensile stress due to centrifugal force,

$$\sigma = \frac{\gamma \times v^2}{g} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(PSG 7.120)}$$

Where, γ = specific weight = ρ×g

g = gravitational acceleration 9.81m/sec^2

$$\therefore \sigma = \frac{(\rho \times g) \times v^2}{g}$$

$$\therefore \sigma = \rho \times v^2$$

Where, ρ = density of steel = 7850 kg/m^3

$$\therefore \sigma = 7850 \times (37.75)^2$$

$$\therefore \sigma = 11.1867\text{Mpa}$$

B). Mean angular speed during the cycle

ω = 2π × 3250 / 60 = 340 rad / s

Since for internal combustion engine fluctuation of speed is ± 1.5% of the mean speed, therefore total fluctuation of speed,

N1 – N2 = 3% of mean speed = 0.03 N

And coefficient of fluctuation of speed,

Cs = N1−N2 /N = 0.03

We know that maximum fluctuation of energy (ΔE)

Let m =Mass of steel rim 3.95 (m=A x π d x ρ)

$$\Delta E = m.R^2.\omega^2.C_s = 3.95 \times (0.111)^2 \times (340)^2 \times 0.03$$

$$\Delta E = 168 \text{ N-m}$$

Same analytical calculation done for Composite Flywheels (with Steel Rim and Carbon Fibre web, S-Glass web, E-Glass web):-

3.1 Case 2: Composite Flywheel (with Steel Rim and Carbon Fiber web)

- By ANSYS analysis, we get Max. Equivalent (Von Mises) stress induced,
  σ = 2.0759 MPa
- By analytical calculations, we get Max. Permissible stress,
  [σ] = 2.021MPa
- Maximum fluctuation of energy carbon fiber flywheel **(Δ*E*),**
  ΔE =168 N-m

3.1 Case 3: Composite Flywheel (with steel rim and S-Glass web body)

- By ANSYS analysis, we get Max. Equivalent (Von Mises) stress induced,
  σ = 3.881MPa
- By analytical calculations, we get Max. Permissible stress,
  [σ] = 3.633Mpa
- Maximum fluctuation of energy S-Glass web flywheel (ΔE),
  ΔE =168 N-m

3.1 Case 4: Composite Flywheel (with steel rim and E-Glass web body)

- By ANSYS analysis, we get Max. Equivalent (Von Mises) stress induced,
  σ = 3.689MPa
- By analytical calculations, we get Max. Permissible stress,
  [σ] = 3.633Mpa
- Maximum fluctuation of energy E-glass web flywheel (ΔE),
  ΔE =168 N-m

4. MODELLING:-

Modelling is very important part of the analysis mainly two types of models are used for analysis and they are 2-D modelling and 3-D modelling. These 2-Dmodelling and 3-D modelling are differ by memory they consume and accuracy. For the accurate results flywheel is given in 3-D model which is shown below.

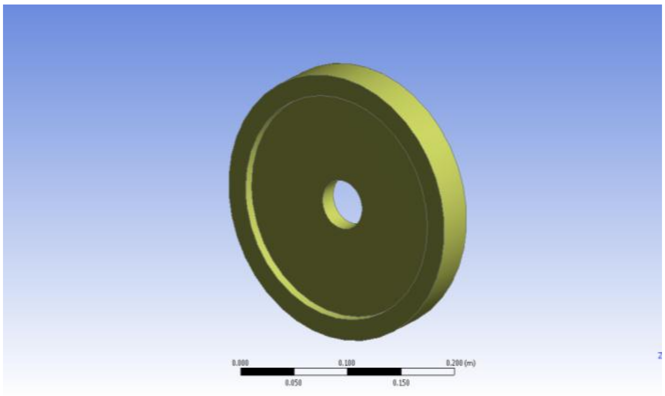

Fig 1: Steel Flywheel model in CATIA V5

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 04, April-2017

5. FLYWHEEL ANALYSIS

5.1. Material Properties:-The material properties are as follows

Table 1: Material properties

Sr. No.	Material Properties	Unit	Carbon Fiber	S-glass	E-glass
1	Density	kg/m^3	1800	2550	2470
2	Poisson's ratio	-	0.23	0.21	0.21
3	Young's Modulus	MPa	2×10^5	$8.6\text{x}10^5$	$8.5\text{x}10^5$
4	Tensile Yield stress	MPa	1040	4700	2050

5.2. Element Type

It is pertaining to the element solid 72, a 3dimension 8-noded Hex-Dominant structural solid with rotation is used for meshing.

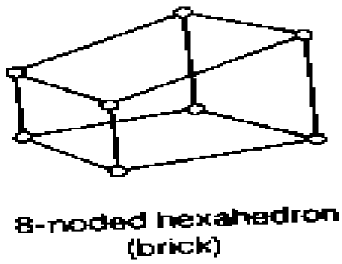

Fig.2: Types of elements

5.3. Meshing Method

Mesh generation is the practice of generating a polygonal or polyhedral mesh that approximates a geometric domain. For structural analysis quad and hex are preferred over tetras, Penta's. Here geometry size and shape have more values for meshing purpose. The meshing related diagrams are given below as per the nodes and elements chosen. By using the Hex-Dominant Method, we get Nodes 18350 and Elements 4310 with fine meshing.

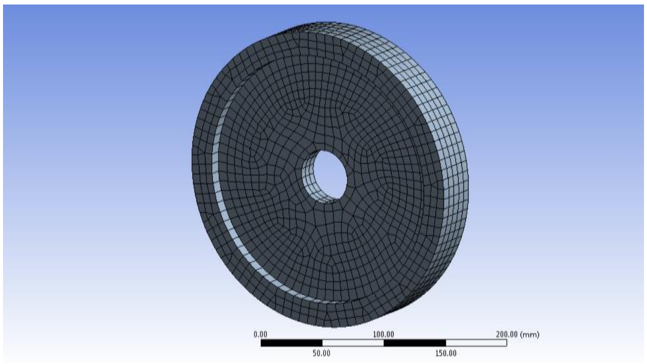

Fig.3: Fine Meshing with Hex-Dominant method.

5.4. Boundary Conditions and Loads

In boundary condition all the six degrees of freedom are taken into account as region of a part selected is shaft hole based on angle and boundary condition type is displacement/rotation. All degrees of freedom of nodes on inner surface of hole are restricted.

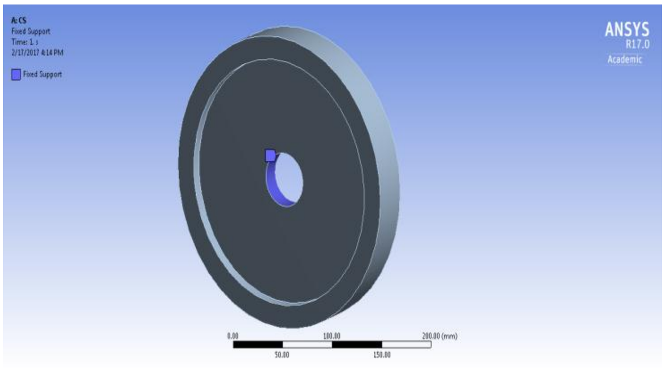

Fig 4: support at shaft hole

As per the load consideration here rotational body force is selected with rotational velocity 3250 rpm.

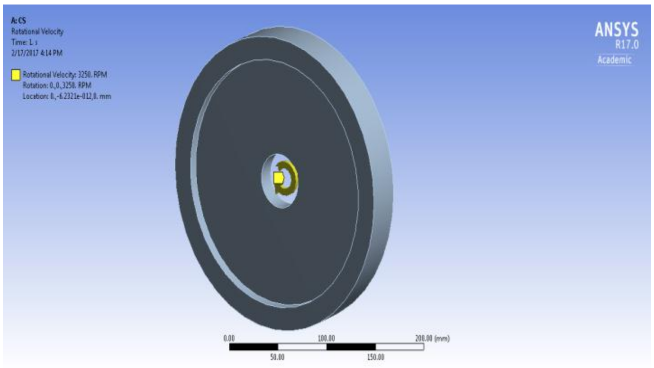

Fig 5: Location of Moment application

5.5 FE ANALYSIS

Case 1: Fully Steel Flywheel: -Max. Equivalent (Von Mises) stress induced in the steel flywheel is 11.548 MPa. Max. Total deformation in the flywheel is 0.0016943mm&mass of flywheel is 8.3kg.

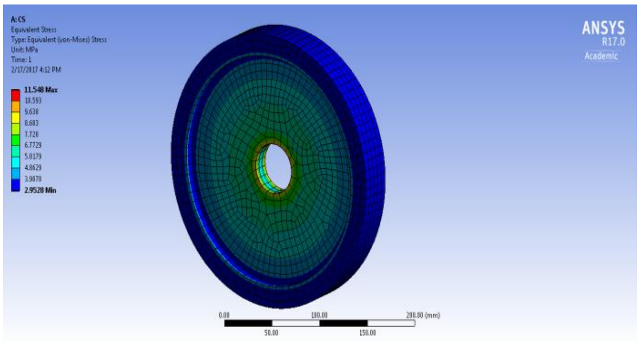

Fig.6: Equivalent Stress in Fully Steel Flywheel

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 04, April-2017

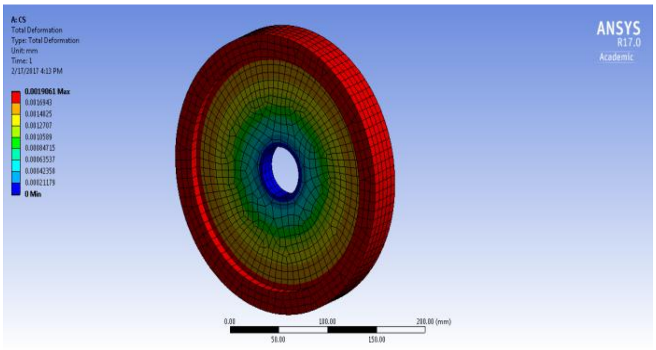

Fig.7: Total deformation in full steel flywheel

Case 2: Composite Flywheel (with Steel Rim and Carbon Fibre web):-

Max. Equivalent (Von Mises) stress induced in the flywheel is 2.0759MPa, Max.

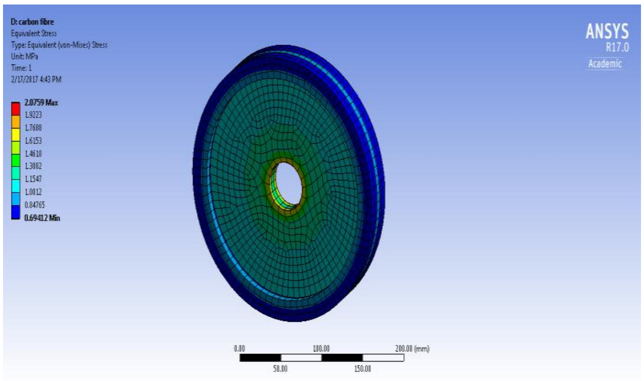

Fig.8: Stress in steel rim and Carbon fibre

Total max. Deformation in the flywheel is 0.00046733mm and total mass of flywheel is 5.13kg

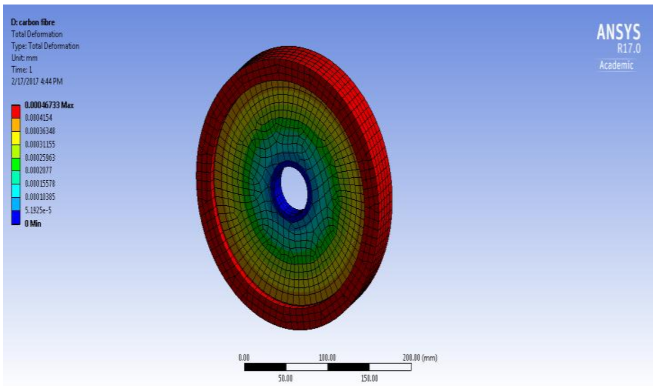

Fig.9: Total deformation in Composite Flywheel. Flywheel.

5.5 Case 2: Composite Flywheel (with steel rim and S-Glass body)

Max. Equivalent (Von Mises) stress induced in the flywheel is 3.881MPaand total mass of flywheel is 6.68kg.

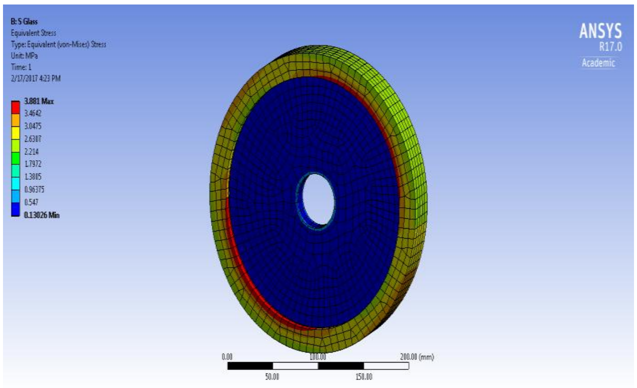

Fig. 10: Equivalent Stress in Composite Flywheel

Max. Total deformation in the flywheel is 0.0032132mm

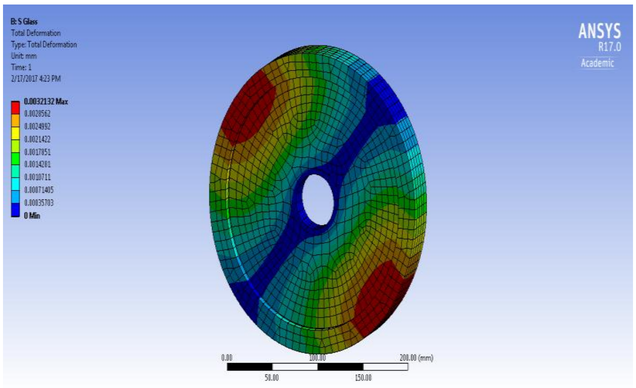

Fig.11: Total deformation in Composite Flywheel

5.5 Case 3: Composite Flywheel (with steel rim and E-Glass body)

Max. Equivalent (Von Mises) stress induced in the flywheel is 3.689MPa and total mass of flywheel is 6.76kg.

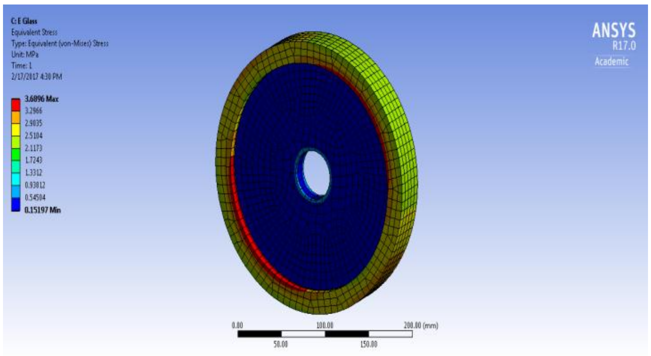

Fig.12: Equivalent Stress in Composite Flywheel

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 04, April-2017

Max. Total deformation in the flywheel is 0.0029325mm

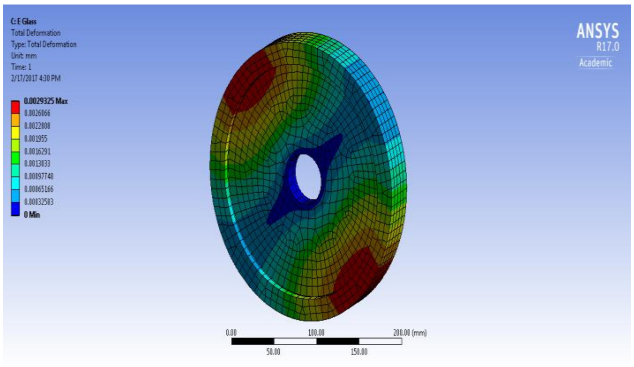

Fig. 13: Total deformation in Composite Flywheel

6. RESULTS AND DISCUSSION:-

- For steel flywheel by analytical calculations and, By ANSYS analysis we get Max. Centrifugal stress are,[σ] = 11.186 MPaσ = 11.548 MPa respectively and max deformation is 0.0032132mm
- For composite flywheel (steel rim and carbon fibre web) by analytical calculations Max. centrifugal stress (2.0759MPa) and, By Ansys (2.021MPa)
- Also, the mass of flywheel obtained is 5.13 kg and deformation is 0.00046733mm
- From total mass of steel flywheel mass of composite material carbon fiber web is subtracted. This will give increased mass of rim. i.e(m $_{modified}$) carbon fiber web

Let (m $_{modified}$) carbon fiber web = Mass of steel rim the is 7.1 kg

$\Delta E = m.R^2.\omega^2.C_s$

$168 = 7.1\ (0.111)^2 \text{ x } (340)^2 \text{x } C_s$

Fluctuation of speed C_s = 0.0166

- For composite flywheel (steel rim and S-glass web) by analytical calculations Max. centrifugal stress (3.633MPa) and, By Ansys (3.881MPa)
- Also, the mass of flywheel obtained is 6.81 kg and deformation is 0.0016943mm
- From total mass of steel flywheel mass of composite material web is subtracted. This will give increased mass of rim. i.e. (m $_{modified}$) S-glass

Let (m $_{modified}$) S-glass = Mass of steel rim the is 5.57 kg

$\Delta E = m.R^2.\omega^2.C_s$

$168 = 5.57\ (0.111)^2 \text{ x } (340)^2 \text{x } C_s$

Fluctuation of speed C_s = 0.021177

- For composite flywheel (steel rim and E-glass web) by analytical calculations Max. centrifugal stress (3.519MPa) and, By Ansys (3.689MPa)
- Also, the mass of flywheel obtained is 6.75 kg and deformation is 0.0029325mm
- From total mass of steel flywheel mass of composite material web is subtracted. This will give increased mass of rim. i.e. (m $_{modified}$) E-glass

Let (m $_{modified}$) E-glass = Mass of steel rim the is 5.49 kg

$\Delta E = m.R^2.\omega^2.C_s$

$168 = 5.49\ (0.111)^2 \text{ x } (340)^2 \text{x } C_s$

Fluctuation of speed C_s = 0.02148

- By using composite material web we will increase the weight of the rim and reduce the fluctuation of speed

7. RESULTS IN TABULAR FORM:-

7.1Equivalent stress, percentage error and deformation flywheel:

Table 2: Equivalent stress, percentage error and deformation

Material	Total Mass [kg]	Mass of web	Mass of rim	Co-eff. of fluctuation of speed
Carbon Steel	8.3	4.35	3.95	0.03
Carbon Fiber web	8.3	1.2	7.1	0.016
S-Glass web	8.3	2.73	5.57	0.02177
E-Glass web	8.3	2.81	5.49	0.02148

7.2 Total mass of flywheel and co-efficient of fluctuation of speed

Table 3: Mass of flywheel and co-efficient of fluctuation of speed

Material	Equivalent Stress (Analytical)	Equivalent Stress[MPa] (ANSYS)	% Error	Total max deformation (mm)
Carbon Steel	11.186	11.548	-3.236	0.0032132
Carbon Fiber web	2.021	2.075	-2.671	0.00046733
S-Glass web	3.633	3.881	-6.826	0.0016943
E-Glass web	3.519	3.689	-4.830	0.0029325

8. CONCLUSIONS:-

- Stresses in flywheels obtained using Finite Element method are nearly equal to the stresses determined using analytical equations.
- Deformation in S-glass and E-glass flywheel is slightly more than that of carbon fibre web & steel rim flywheel
- Mass of the carbon fiber flywheel less than the S-glass web &E-glass web flywheel.
- Using carbon fibre web & keeping the same total weight of flywheel by increasing the weight of rim, coefficient of fluctuation of speed can be reduced to a large extent.
- Coefficient of fluctuation of speed of S-glass web & E-glass web material flywheel are almost same.
- Coefficient of fluctuation of speed of carbon fiber web is less than S-glass, E-glass web material flywheel so recommended for carbon fiber web flywheel.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 04, April-2017

9. REFERENCES.

[1] Sushama G Bawane, A P Ninawe And S K Choudhary,‖ Analysis and Optimization of flywheel‖, International Journal of mechanical Engineering and Robotic research, Issn 2278 – 0149, Vol. 1, No. 2, July 2012.

[2] Akshay P. Punde, G.K.Gattani,‖ Analysis of flywheel ―, International Journal of Modern Engineering Research, vol.3, Issue.2, March-April. 2013.

[3] Phanindra Mudragadda1, T. Seshaiah, ‖ Analysis of flywheel used in petrol engine car‖, International Journal of Engineering Research &Technology, ISSN: 2278-0181, Vol. 3 Issue 5, May – 2014.

[4] Nagaraj.R.M, ‖ Suitability of composite material for flywheel analysis ―, International Journal of Modern Engineering Research, ISSN: 2249 6645 Vol. 4, iss. 6, June. 2014.

[5] Snehal.R.Raut, Prof .N.P.Doshi,prof .U.D.Gulhane,‖ FEM Analysis of flywheel used for punching press operation‖, IORD Journal of Science & Technology, E-ISSN: 2348-0831 Volume 1, Issue V JULY 2014.

[6] Kishor D.Farde, Dr.Dheeraj.S.Deshmukh, ―Review: Composite flywheel for high speed application‖, International Journal of Innovative Research in Advanced Engineering, ISSN: 2349-2163, Volume 1, Issue 6, July 2014.

[7] S.M.Choudhary, D.Y.Shahare2,‖ Design optimization of flywheel of Thresher using FEM , International Journal of Emerging Technology and Advanced Engineering , ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 3, Issue 2, February 2013 .

[8] 8)M.Lavakumar, R.Prasanna Srinivas,‖ Design and analysis of light Weight motor vehicle flywheel‖, International Journal of Computer Trends and Technology – Volume 4 Issue 7–july 2013.

[9] Francisco Díaz-gonzález A, Andreas Sumper A, b, Oriol Gomisbellmunt A, c, Fernando D. Bianchi,‖ Energy management of flywheel based Energy storage device for wind power smoothing‖, Applied Energy 110 (2013) 207–219.

[10] Balasaheb SR, Rajmane M. A case study on design of a flywheel for punching press operation. International Journal of Engineering and Advanced Technology. 2014; 3(4):32–5

[11] Arnold SM, Saleeb AF, Al-Zoubi NR. Deformation and life analysis of composite flywheel disk systems, Elsevier. Composites Part B: Engineering. 2002; 33(6):433–59