Fatigue Analysis of Diesel Engine Flywheel by Using S-Glass Composite Material

Yantrapati Murali Krishna
Assistant Professor, Department of Mechanical Engineering, Geethanjali Institute of Science & Technology, Nellore, A.P, India.

Venkatesh INellore
Assistant Professor, Department of Mechanical Engineering, Geethanjali Institute of Science & Technology, Nellore, A.P, India.

Abstract – In this thesis, the main aim is to design a flywheel for a multi cylinder diesel engine flywheel using the empirical formulas. A 2D drawing is drafted using the calculations. A parametric model of the flywheel is designed using 3D modelling software Pro/Engineer.

The material used for flywheel is Cast Iron. In this thesis, it is replaced with aluminum alloy A 360 and composite material S Glass. The present material is replaced since by using Cast Iron, the weight of the flywheel is more. By using Aluminum alloy A360 and S Glass, the weight is reduced.

Structural analysis, modal analysis and fatigue analysis are done on the flywheel. Analysis is done for three materials Cast Iron, Aluminium Alloy A360 and S Glass to compare the results.

By observing the analysis results, the analyzed stress values are less than their respective yield stress values. So using all the three materials is safe under working conditions. And also by comparing the materials, the stress values are almost same for all the materials.

Index Terms – Flywheel, Diesel engine, S-glass.

1. INTRODUCTION TO FLYWHEEL

A flywheel is a mechanical device with a significant moment of inertia used as a storage device for rotational energy. Flywheels resist changes in their rotational speed, which helps steady the rotation of the shaft when a fluctuating torque is exerted on it by its power source such as a piston-based (reciprocating) engine, or when an intermittent load, such as a piston pump, is placed on it.

Flywheels can be used to produce very high power pulses for experiments, where drawing the power from the public network would produce unacceptable spikes. A small motor can accelerate the flywheel between the pulses. Recently, flywheels have become the subject of extensive research as power storage devices for uses in vehicles and power plants.

1.1 PHYSICS OF FLYWHEEL

A flywheel is a spinning wheel or disc with a fixed axle so that rotation is only about one axis. Energy is stored in the rotor as kinetic energy, or more specifically, rotational energy:

$E_k = 0.5\ I\ \omega^2$

Where, ω is the angular velocity, and

I is the moment of inertia of the mass about the center of rotation. The moment of inertia is the measure of resistance to torque applied on a spinning object (i.e. the higher the moment of inertia, the slower it will spin after being applied a given force).

The moment of inertia for a solid-cylinder is $I = 0.5mr^2$

For a thin-walled empty cylinder is $I = mr^2$

For a thick-walled empty cylinder is $I = 0.5m(r_{external}^2+r_{internal}^2)$

Where *m* denotes mass, and *r* denotes a radius.$\sigma_t = \rho r^2\omega^2$

When calculating with SI units, the standards would be for mass, kilograms; for radius, meters; and for angular velocity, radians per second. The resulting answer would be in joules.

The amount of energy that can safely be stored in the rotor depends on the point at which the rotor will warp or shatter. The hoop stress on the rotor is a major consideration in the design of a flywheel energy storage system.

Where:

- σ_t is the tensile stress on the rim of the cylinder
- ρ is the density of the cylinder
- *r* is the radius of the cylinder, and
- ω is the angular velocity of the cylinder.

1.2 APPLICATIONS

In application of flywheels in vehicles, the phenomenon of precession has to be considered. A rotating flywheel responds to any momentum that tends to change the direction of its axis of rotation by a resulting precession rotation. A vehicle with a vertical-axis flywheel would experience a lateral momentum when passing the top of a hill or the bottom of a valley (roll momentum in response to a pitch change). Two counter-rotating flywheels may be needed to eliminate this effect.

In a modern application, a momentum wheel is a type of flywheel useful in satellite pointing operations, in which the flywheels are used to point the satellite's instruments in the correct directions without the use of thruster rockets. Flywheels are used in punching machines and riveting machines, where they store energy from the motor and release it during the operation cycle (punching and riveting).

For internal combustion engine applications, the flywheel is a heavy wheel mounted on the crankshaft. The main function of a flywheel is to maintain a constant angular velocity of the crankshaft.

2. LITERATURE SURVEY

There are many causes of flywheel failure. Among them, maximum tensile and bending stresses induced in the rim and tensile stresses induced in the arm under the action of centrifugal forces are the main causes of flywheel failure. Hence in this work evaluation of stresses in the rim and arm are studied using finite element method and results are validated by analytical calculations .The models of flywheel having four, six and eight no. arms are developed for FE analysis. The FE analysis is carried out for different cases of loading applied on the flywheel and the maximum Von mises stresses and deflection in the rim are determined. From this analysis it is found that Maximum stresses induced are in the rim and arm junction. Due to tangential forces, maximum bending stresses occurs near the hub end of the arm. It is also observed that for low angular velocity the effect gravity on stresses and deflection of rim and arm is predominant.

2.1. COMPUER AIDED DESIGN

Computer-aided design (CAD), also known as computer-aided design and drafting (CADD), is the use of computer technology for the process of design and design-documentation. Computer Aided Drafting describes the process of drafting with a computer. CADD software, or environments, provide the user with input-tools for the purpose of streamlining design processes; drafting, documentation, and manufacturing processes. CADD output is often in the form of electronic files for print or machining operations. The development of CADD-based software is in direct correlation with the processes it seeks to economize; industry-based software (construction, manufacturing, etc.) typically uses vector-based (linear) environments whereas graphic-based software utilizes raster-based (pixelated) environments.

CADD environments often involve more than just shapes. As in the manual drafting of technical and engineering drawings, the output of CAD must convey information, such as materials, processes, dimensions, and tolerances, according to application-specific conventions.

CAD may be used to design curves and figures in two-dimensional (2D) space; or curves, surfaces, and solids in three-dimensional (3D) objects.

2.2. PRO/ENGINEER WILDFIRE BENEFITS

•Unsurpassed geometry creation capabilities allow superior product differentiation and manufacturability

•Fully integrated applications allow you to develop everything from concept to manufacturing within one application

•Automatic propagation of design changes to all downstream deliverables allows you to design with confidence

•Complete virtual simulation capabilities enable you to improve product performance and exceed product quality goals

•Automated generation of associative tooling design, assembly instructions, and machine code allow for maximum production efficiency

Pro ENGINEER can be packaged in different versions to suit your needs, from Pro/ENGINEER Foundation XE, to Advanced XE Package and Enterprise XE Package, Pro/ENGINEER Foundation XE Package brings together a broad base of functionality. From robust part modelling to advanced surfacing, powerful assembly modelling and simulation, your needs will be met with this scaleable solution. Flex3C and Flex Advantage Build on this base offering extended functionality of your choosing.

The main modules are

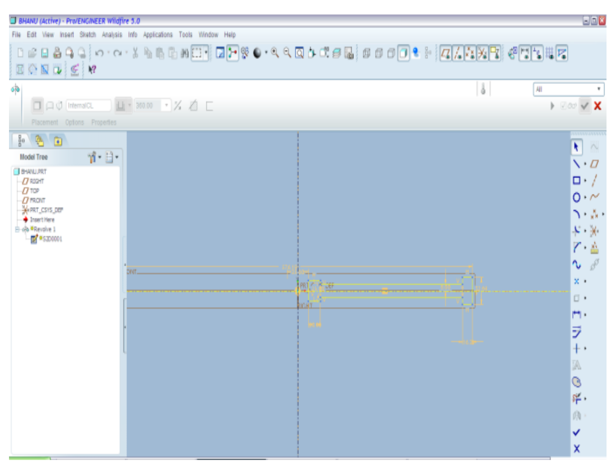
Part Design

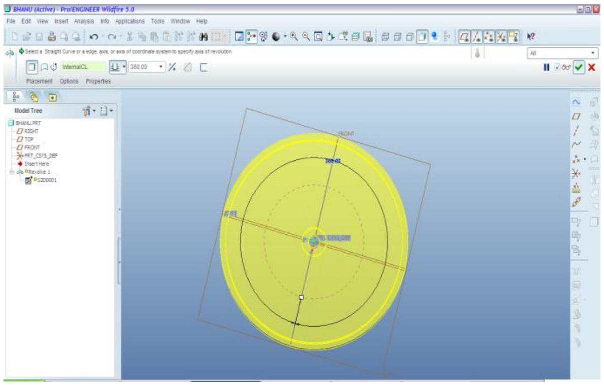
Assembly

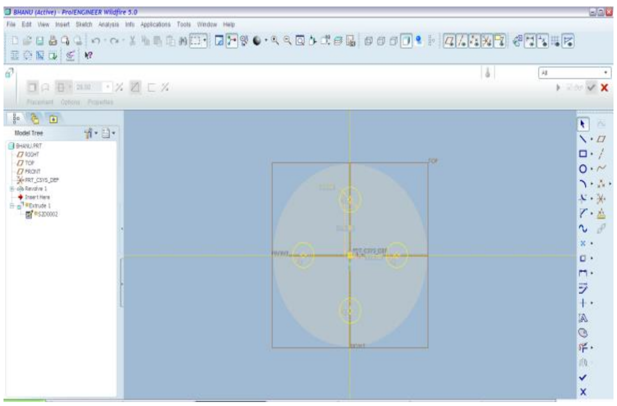
Drawing

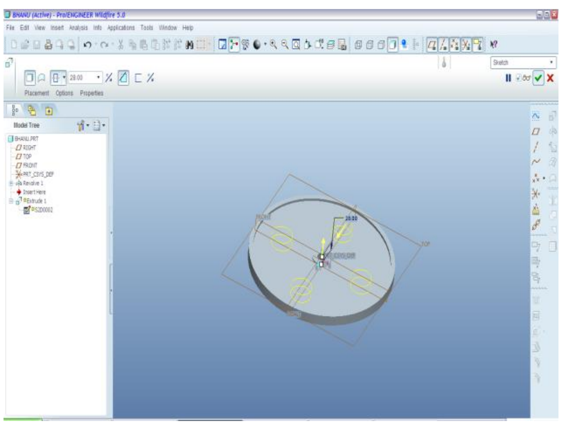
Sheet Metal

2.3 MODEL OF FLYWHEEL

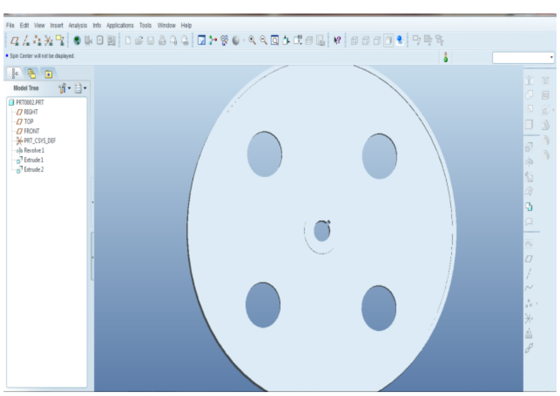




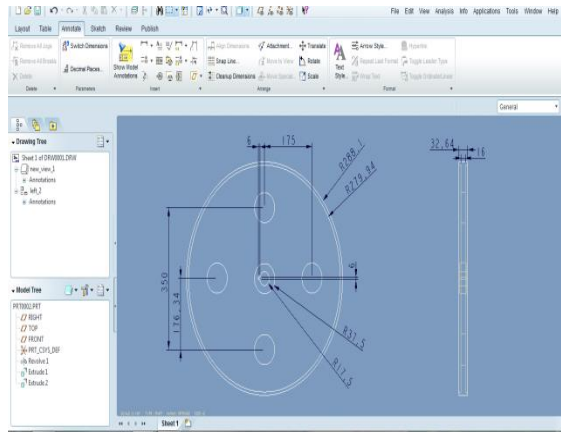




2.4 FINAL MODEL



2.5. 2D DRAWING



3. ANALYSIS OF FLY WHEEL

3.1 Fatigue Analysis of Cast Iron Material

3.1.1Four load cases applied:

a. Load: 0.138, the time at the end of the load step is 10 seconds

b Load: 0.138, the time at the end of the load step is 20 seconds.

c. Load: 0.138, the time at the end of the load step is 30 seconds

d. Load: 0.138, the time at the end of the load step is 30 seconds

3.1.2 The loads are used in the analysis are given below

Load No.	Load	Number of Repetitions	Scale Factor
1	0.138	500,000	1
2	0.138	500,000	1
3	0.138	5000	1
4	0.138	5000	1

4.1.3 Stress Locations

NLOC = *1*

NODE = *2220*(node at the constrained area)

NLOC = *2*

NODE =3402 (node at the pressure area)

NLOC = *1*

NODE = *1742* (node at the open area)

General Postproc

Fatigue

Property Table

S-N Table

3.1.4 RESULTS

3.1.4.1 NODE AT CONSTRAINED AREA

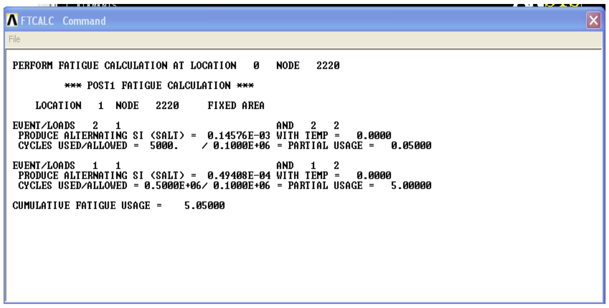


Fig: 3.1 Node at Constrained Area- Post Fatigue Calculation

Location: 1 Node 2220 at the constrained area.

The combination of event 2, load 1 and event 2, load 2 produces an alternating stress intensity of 0.14576e-03 N/mm². The flywheel was subjected to 5000 cycles while from the S-N Table, the maximum number of cycles allowed at that stress intensity is 1,000,000.

The partial usage value, 0.05, is the ratio of cycles used/cycles allowed.

The combination of event 1, load 1 and event 1, load 2 produces an alternating stress intensity of 0.49408e-04 N/mm². The flywheel was subjected to 500,000 cycles while from the S-N Table, the maximum number of cycles allowed at that stress intensity is 1,000,000. The partial usage value, 5.0, is the ratio of cycles used/cycles allowed.

3.1.4.2 NODE AT PRESSURE AREA

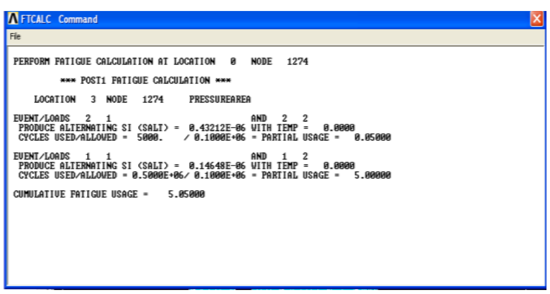


Fig: 3.2 Node at Pressure Area- Post Fatigue Calculation

Location: 2 Node 1274 at the pressure area.

The combination of event 2, load 1 and event 2, load 2 produces an alternating stress intensity of 0.43212e-06 N/mm². The flywheel was subjected to 5000 cycles while from the S-N Table, the maximum number of cycles allowed at that stress intensity is 1,000,00.

The partial usage value, 0.05, is the ratio of cycles used/cycles allowed.

The combination of event 1, load 1 and event 1, load 2 produces an alternating stress intensity of 0.14648-06 N/mm². The flywheel was subjected to 500,000 cycles while from the S-N Table, the maximum number of cycles allowed at that stress intensity is 1,000,00. The partial usage value, 5.0, is the ratio of cycles used/cycles allowed. The Cumulative Fatigue Usage value is 5.05, is the sum of the partial usage factors.

3.1.4.3 NODE AT OPEN AREA

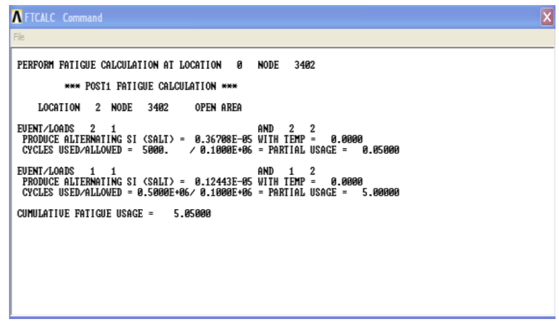


Fig: 3.3 Node at Open Area- Post Fatigue Calculation

Location: 3 Node 3402 at the open area.

The combination of event 2, load 1 and event 2, load 2 produces an alternating stress intensity of 0.36708e-05 N/mm². The flywheel was subjected to 5000 cycles while from the S-N Table, the maximum number of cycles allowed at that stress intensity is 1, 00,000.

The partial usage value, 0.05, is the ratio of cycles used/cycles allowed.

The combination of event 1, load 1 and event 1, load 2 produces an alternating stress intensity of 0.12443-05 N/mm². The flywheel was subjected to 500,000 cycles while from the S-N Table, the maximum number of cycles allowed at that stress intensity is 1,00,000. The partial usage value, 5.00000, is the ratio of cycles used/cycles allowed. The Cumulative Fatigue Usage value is 5.05, is the sum of the partial usage factors.

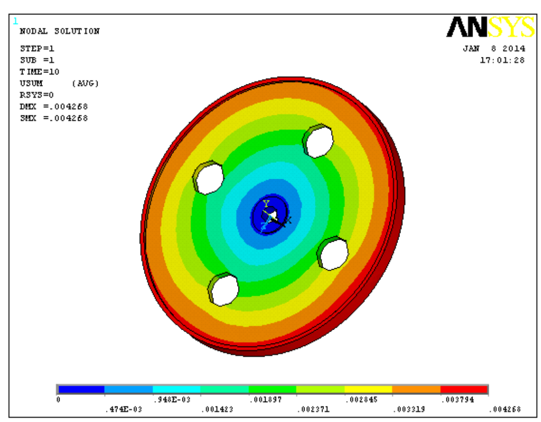


Fig: 3.4 Displacement

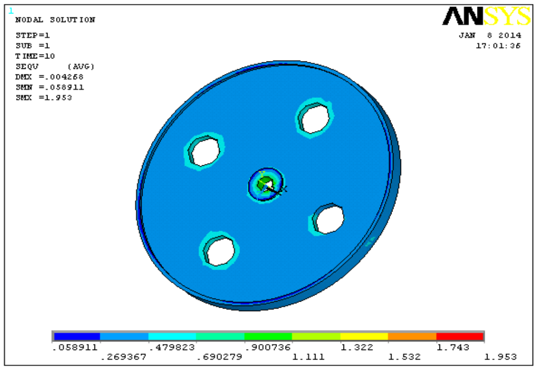


Fig: 3.5 Stress

3.2 FATIGUE ANALYSIS ALUMINUM ALLOY A360

3.2.1 Stress Locations

NLOC = *1*

NODE = *2220*(node at the pressure area)

NLOC = *2*

NODE = 3402 (node at the open area)

NLOC = *3*

NODE = *1274*(node at the constrained area)

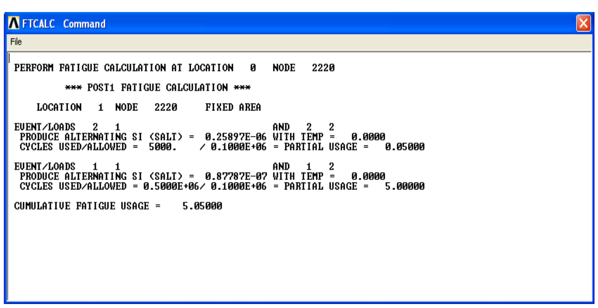
General Postproc

Fatigue

Property Table

3.2.2 RESULTS

3.2.2.1 NODE AT CONSTRAINED AREA



```
FTCALC  Command
File

PERFORM FATIGUE CALCULATION AT LOCATION   0   NODE   2220

        *** POST1 FATIGUE CALCULATION ***

    LOCATION   1  NODE   2220     FIXED AREA

EVENT/LOADS   2   1                        AND   2   2
 PRODUCE ALTERNATING SI (SALT) =  0.25897E-06 WITH TEMP =   0.0000
 CYCLES USED/ALLOWED =  5000.    / 0.1000E+06 = PARTIAL USAGE =   0.05000

EVENT/LOADS   1   1                        AND   1   2
 PRODUCE ALTERNATING SI (SALT) =  0.87787E-07 WITH TEMP =   0.0000
 CYCLES USED/ALLOWED = 0.5000E+06/ 0.1000E+06 = PARTIAL USAGE =   5.00000

CUMULATIVE FATIGUE USAGE =    5.05000
```

Fig: 3.6 Node at Constrained Area- Post Fatigue Calculation

Location: 1Node 2220at the constrained area.

The combination of event 2, load 1 and event 2, load 2 produces an alternating stress intensity of

0.25807-06 N/mm^2. The flywheel was subjected to 5000 cycles while from the S-N Table, the maximum number of cycles allowed at that stress intensity is 1,000,000.

The partial usage value, 0.05, is the ratio of cycles used/cycles allowed.

The combination of event 1, load 1 and event 1, load 2 produces an alternating stress intensity of 0.87787e-0- N/mm^2. The flywheel was subjected to 500,000 cycles while from the S-N Table, the maximum number of cycles allowed at that stress intensity is 1,00,000. The partial usage value, 5.000, is the ratio of cycles used/cycles allowed.

The Cumulative Fatigue Usage value is 5.0500, is the sum of the partial usage factors

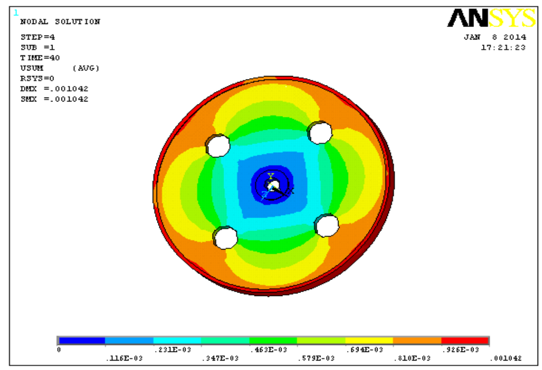


Fig 3.9 Displacement

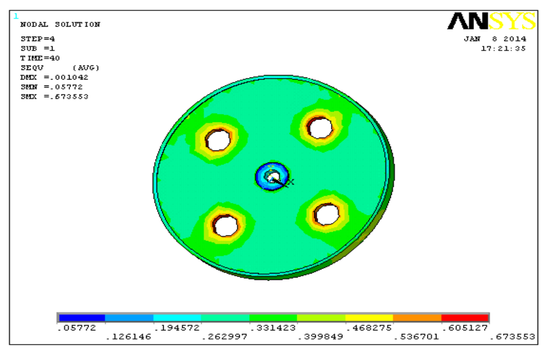


Fig: 3.10 Stress

3.3 FATIGUE ANALYSIS - S GLASS

3.3.1 Stress Locations

NLOC = *1*

NODE = *2220*(node at the pressure area

NLOC = *2*

NODE = 3402 (node at the open area)

NLOC = *3*

NODE = *1274*(node at the constrained area)

General Postproc

Fatigue

Property Table

S-N Table

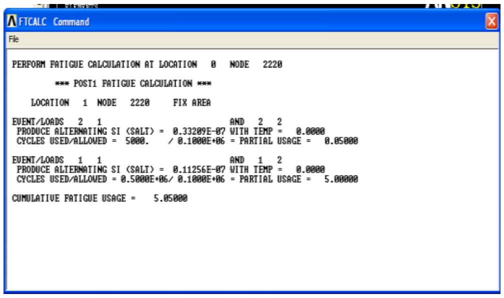


Fig: 3.11 Node at Constrained Area- Post Fatigue Calculation

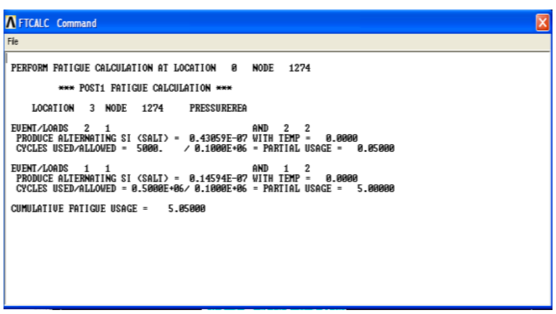
Location: 1Node 2220 at the constrained area.

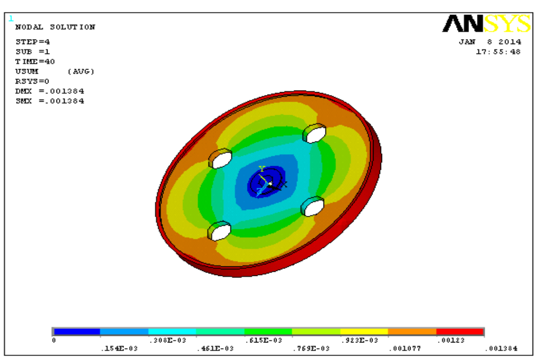
The combination of event 2, load 1 and event 2, load 2 produces an alternating stress intensity of 0.33209e-07 N/mm^2. The flywheel was subjected to 5000 cycles while from the S-N Table, the maximum number of cycles allowed at that stress intensity is 1,000,00. The partial usage value, 0.05, is the ratio of cycles used/cycles allowed.

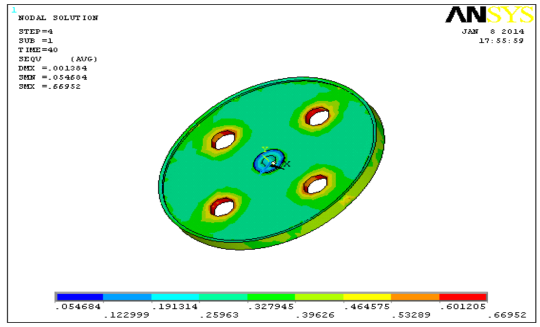
The combination of event 1, load 1 and event 1, load 2 produces an alternating stress intensity of

0.11256e-07 N/mm^2. The flywheel was subjected to 500,000 cycles while from the S-N Table, the maximum number of cycles allowed at that stress intensity is 1,000,00. The partial usage value, 5.000, is the ratio of cycles used/cycles allowed.

The Cumulative Fatigue Usage value is 5.05, is the sum of the partial usage factors.







4. RESULTS AND DISCUSSIONS

Table .3 FATIGUE RESULTS

	CAST IRON	AL A360	S GLASS
Constrained area			
Event 1 Load1, Event 1 Load 2	0.49408E-04	0.87787E-07	0.11256E-07
Event 2 Load1, Event 2 Load 2	0.14576E-03	0.25897E-06	0.33209E-07
Pressure area			
Event 1 Load1, Event 1 Load 2	0.14648E-06	0.15879E-07	0.14594E-07
Event 2 Load1, Event 2 Load 2	0.43212E-06	0.46848E-07	0.43059E-07

Open area Event 1 Load1, Event 1 Load 2 Event 2 Load1, Event 2 Load 2	0.12443E-05 0.36708E-05	0.25899E-08 0.76411E-07	0.23563E-07 0.69518E-07

5. CONCLUSION

In this thesis, the main aim is to design a flywheel for a multi cylinder diesel engine flywheel using the empirical formulas. A 2D drawing is drafted using the calculations. A parametric model of the flywheel is designed using 3D modeling software Pro/Engineer.

The material used for flywheel is Cast Iron. In this thesis, it is replaced with aluminum alloy A 360 and composite material S Glass. The present material is replaced since by using Cast Iron, the weight of the flywheel is more. By using Aluminum alloy A360 and S Glass, the weight is reduced.

Structural analysis, modal analysis and fatigue analysis are done on the flywheel. Analysis is done for three materials Cast Iron, Aluminum Alloy A360 and S Glass to compare the results.

By observing the analysis results, the analyzed stress values are less than their respective yield stress values. So using all the three materials is safe under working conditions. And also by comparing the materials, the stress values are almost same for all the materials.

Fatigue analysis is also done on flywheel to verify the stress values at the selected nodes. The nodes are selected at constrained area, pressure area and open area. The loading is done for two cycles 5000 and 5,00,000 cycles. But by observing the results, the maximum number of cycles allowed is 1,00,000 cycles.

By observing the fatigue analysis results, the stress values are less for composite material S Glass.

So we can conclude that using S Glass is better for flywheel due to its high strength capability and less weight.

REFERENCES

[1] Dilip.; P.N., Kamal, R. (2010) " An evolutionary approach for the shape optimization of flywheel" I.E. (I) Journal – MC, Vol.90, pp 8- 12.
[2] Aziz A. A. (2001) "Structural analysis of composite flywheel an integrated NDE and FEM approach.", NASA/TM 2001-210461 pp 1– 17
[3] Xu X., Yu Z. (2005) " Failure analysis of diesel engine flywheel.", Science direct_ engineering failure analysis Vo.12, Issue 1, pp 25 –34.
[4] Yilmaz D., (2009) " Finite element analysis of failure in rear mounted mower pulley", Journal of food Agriculture and Environment,Vol. 7 (3 & 4) pp 856 – 868
[5] Hawkins L. (2002) "Shock vibration testing of an amb supported energy storage flywheel", 8th International Symposium on Magnetic Bearing, Aug, 26 – 28, Mito, Japan, pp 581 – 586
[6] Addas J.S. (2005) "Design of flywheel with a moving hole", American Journals of applied science 2 (1), pp 436 – 439.
[7] Colozza A. J. (2000) "High energy flywheel contentment evaluation", NASA/CR, 2000-210508, pp. 1 – 12
[8] Alex F. A., (2003) "Control of flywheel assisted drive line with continuously variable transmission", Journal of dynamic system measurement and control, Vol-125, pp 455-461.
[9] Wan J. (1996) "Optimization design and analysis of a flywheel.", A Project for MIE 605, pp. 1 – 31.
[10] Bhope D.V. (1992) "Investigation of stress pattern in arms of the pulley", UG Project, RCERT, Chandrapur.