DESIGN AND STRESS ANALYSIS OF FLYWHEEL
Energy storage and stress analysis

[1]G. VenkatKumar, [2]K. Tharun,[3]P. VijayaBhaskaraReddy, [4]Y. SaiHarish
[1]Associate Professor,[2] Student, [3]Student, [4]Student
[1]Department of Mechanical Engineering,
[1]Prathyusha Engineering College, Thiruvallur, India

Abstract: Energy can be stored in the form of chemical, thermal, electromagnetic and mechanical form. The applications of mechanical energy storage devices include compressed gas facilities, pumped hydroelectric storage and flywheels. A flywheel stores energy in the form of kinetic (rotational) energy. Whereas each energy storage system has its inherent advantages and disadvantages compared to the others, it is the overall system performance and simplicity of flywheels that make them especially attractive for a variety of applications. Flywheel is mechanical device which is used to store the kinetic energy. It stores up energy when the demand for energy is less than the availability and delivers energy when there is a lean period (when demand is more). Mainly, the performance of a flywheel can be attributed to three factors, i.e., material strength, geometry (cross-section) and rotational speed. While material strength directly determines kinetic energy level that could be produced safely combined (coupled) with rotor speed, there are many causes of flywheel failure. But maximum tensile and bending stresses induced in the web and rim under the action of centrifugal forces are the main causes of flywheel Failure. By changing the dimensions and shape and the materials and use such materials which increases stored energy and maintain minimum stresses with reduce mass of flywheel. It shows that smart design of flywheel geometry could both have a significant effect on the Specific Energy performance and reduce the operational loads exerted on the shaft/bearings due to reduced mass at high rotational speeds. we will compare the theoretical values with the ANSYS values so that the clear objective of the project can be seen. Here another type of flywheels has chosen like rim type and it is compared with the actual shape and the results will be displayed.

***Index Terms* - Flywheel, Stress, ANSYS, Failure, Energy.**

I. INTRODUCTION

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. Flywheels have become the subject of extensive research as power storage devices for uses in vehicles. Flywheel energy storage systems are considered to be an attractive alternative to electrochemical batteries due to higher stored energy density, higher life term, and deterministic state of charge and ecologically clean nature.

Flywheel is basically a rechargeable battery. It is used to absorb electric energy from a source, store it as kinetic energy of rotation, and then deliver it to a load at the appropriate time, in the form that meets the load needs.

A. ORIGINS

Flywheel origins, initiated over 100 years ago, were solely to keep machinery running smoothly from cycle to cycle, as is the case of every automobile engine ever built. The first real breakthrough in analyzing flywheel rotor shapes and rotational stress was the seminal book by Dr. A. Stodola whose first translation to English was made in 1917.

The next big milestones occurred during the early 1970s when flywheel energy storage was proposed as a primary objective for electric vehicles and stationary power back-up.

In the years immediately following, fiber composite rotors were built and tested in the laboratory by US Flywheel Systems and other organizations. However, it was not until the 1980s when relatively low speed magnetic bearings and motor-generators made their advanced appearance.

The next decade proved that “mechanical battery” flywheels could surpass chemical batteries for many applications.

B. COMPARISON AMONG ALTERNATIVE FORMS OF ENERGY STORAGE

Chemical batteries are widely used in many applications currently. But there are a number of drawbacks of chemical batteries.

1. Narrow operational temperature range. The performance of the chemical battery will be deteriorated sharply at high or low temperature.
2. Capacity decreases over life. The capacity of the chemical battery cannot be maintained in a high level all through its life, the capacity will decrease with time goes on.

3. Difficulty in obtaining charge status. It is not so easy to know the degree of the charge of the chemical battery because the chemical reaction in the battery is very hard to measure and control.
4. Overcharge and over-discharge. Chemical battery can neither be over-discharged nor be over-charged, or its life will be shorted sharply.
5. Environmental concerns. Many elements of the chemical battery are poisonous, they will do harm to the environment and the people.

Obviously, the presence of the shortcomings of the chemical batteries makes them not so-appealing to the users nowadays. Instead, flywheel energy storage system becomes potential alternative form of energy storage.

Table1 shows the comparison among chemical battery and flywheel energy storage system. Given the state of development of flywheel batteries, it is expected that costs for flywheel can be lowered with further technical development. On the other hand, electro chemical batteries already have a tremendous economy of scale that has driven costs down as far as they are likely to go.

C. MATERIAL USED FOR FLYWHEEL:

1. Cast iron
2. Aluminum
3. Beryllium
4. Carbon steel

II. SOFTWARE

The software will start (by default) with all toolbars docked to the edges of the main window. The toolbars contain buttons, which when clicked, open the various information windows or operate features in the software. The toolbars and windows can be freely moved around inside the main program window, to create your own screen layout.

A. INRODUCTION TO CATIA

CATIA started as an in-house development in 1977 by French aircraft manufacturer Avion Marcel Dassault, at that time customer of the CADAM software to develop Dassault's Mirage fighter jet. It was later adopted by the aerospace, automotive, shipbuilding, and other industries. Initially named CATI (*conception assistée tridimensionnelle interactive* – French for *interactive aided three-dimensional design*), it was renamed CATIA in 1981 when Dassault created a subsidiary to develop and sell the software and signed a non-exclusive distribution agreement with IBM. In 1984, the Boeing Company chose CATIA V2 as its main 3D CAD tool, becoming its largest customer. In 1988, CATIA V3 was ported from mainframe computers to UNIX. In 1990, General Dynamics Electric Boat Corp chose CATIA as its main 3D CAD tool to design the U.S. Navy's Virginia class submarine. Also, Lockheed was selling its CADAM system worldwide through the channel of IBM since 1978. In 1992, CADAM was purchased from IBM, and the next year CATIA CADAM V4 was published. In 1996, it was ported from one to four UNIX operating systems, including IBM AIX, Silicon Graphics IRIX, Sun Microsystems SunOS, and Hewlett-Packard HP-UX. In 1998, V5 was released and was an entirely rewritten version of CATIA with support for UNIX, Windows NT and Windows XP (since 2001). In the years prior to 2000, problems caused by incompatibility between versions of CATIA (Version 4 and Version 5) led to $6.1B in additional costs due to years of project delays in production of the Airbus A380. In 2008, Dassault Systèmes released CATIA V6. While the server can run on Microsoft Windows, Linux or AIX, client support for any operating system other than Microsoft Windows was dropped. In November 2010, Dassault Systèmes launched CATIA V6R2011x, the latest release of its PLM2.0 platform, while continuing to support and improve its CATIA V5 software. In June 2011, Dassault Systèmes launched V6 R2012. In 2012, Dassault Systèmes launched V6 2013x. In 2014, Dassault Systèmes launched 3DEXPERIENCE Platform R2014x and CATIA on the Cloud, a cloud version of its software.

B. INTRODUCTION TO ANSYS WORKBENCH

ANSYS mechanical is a finite element analysis tool for structural analysis including linear, nonlinear and dynamic studies. This computer simulation product provides finite elements to model behavior and supports material models and equation solvers for a wide range of mechanical design problems. ANSYS mechanical also includes thermal HYPER LINK and coupled analysis capabilities acoustics, piezoelectric, thermal –structural and thermos electric analysis.

III.DESIGN

DESIGN CALCULATION:

1. SOLID TYPE:

Let,

R=radius of flywheel
b=breadth of flywheel

ρ=density of material
ω=angular speed
Cs=co-efficient of speed fluctuation
V=velocity of flywheel
μ=co-efficient of friction
R=outer radius of the flywheel
r= inner radius of the flywheel

FORMULA USED:

i) $I=\pi R^2 b\rho/(2)$
ii) $m=\pi R^2 b\rho$
iii) $\Delta E=i\omega 2C_s$
iv) $\sigma_{rad}=[(3+\mu)/8]\ \rho v^2(R^2-r^2)$
v) $\sigma_{tan}=[(\rho\omega^2)/8]\ [(3+\mu)\ R^2-(1+3\mu)\ r^2]$

Now substituting the values,

1. CARBON STEEL:

a) GENERAL:

i) $I=\pi R^2 b\rho/(2)$
$= [\pi*(0.056)^2*(0.030)*7800]/(2)$
$=1.152\text{kg-m}^2$

ii) $m=\pi R^2 b\rho$
$=\pi*(0.056)^2*(0.030)*7800$
$=2.3\text{kg}$

iii) $\Delta E=i\omega 2C_s$
$=1.152*(7600)^2*0.030$
$=1.996*10^6\text{N-m}$

b) STRESSES:

iv) $\sigma_{rad}=[(3+\mu)/8]\ \rho v^2(R^2-r^2)$
$= [(3+0.3)/8]*7800*(7600)^2*(1.384*10^{-4})$
$=25.727\text{MN/m}^2$

v) $\sigma_{tan}=[(\rho\omega^2)/8]\ [(3+\mu)\ R^2-(1+3\mu)\ r^2]$
$=[(7800*(7600)^2)/8][(3+0.3)(0.056)^2-((1+3(0.3))(0.005475)^2)]$
$= (5.6316*10^6)*(4.653*10^6)$
$=26.203\ \text{MN/m}^2$

2.CAST IRON:

a) GENERAL:

i) $I=\pi R^2 b\rho/(2)$
$=[\pi*(0.056)^2*(0.030)*7050]/(2)$
$=1.041\text{kg-m}^2$

ii) $m=\pi R^2 b\rho$
$=\pi*(0.056)^2*(0.030)*7050$
$=2.08\text{kg}$

iii) $\Delta E=i\omega^2 Cs$
$=1.041*(7600)^2*0.030$
$=1.803*10^6\text{N-m}$

b) STRESSES:

iv) $\sigma_{rad}=[(3+\mu)/8]\ \rho v^2(R^2-r^2)$
$=[(3+0.3)/8]*7050*(7600)^2*(1.384*10^{-4})$
$=23.247\text{MN/m}^2$

v) $\sigma_{tan}=[(\rho\omega^2)/8][(3+\mu)\ R^2-(1+3\mu)r^2]$
$=[(7050*(7600)^2)/8][(3+0.3)(0.056)^2-((1+3(0.3))(0.005475)^2)$
$=23.68\ \text{MN/m}^2$

3. BERYLLIUM:

a) GENERAL:

i) $I=\pi R^2 b\rho/(2)$
$= [\pi*(0.056)^2*(0.030)*1850]/(2)$
$=0.273\text{kg-m}^2$

ii) $m=\pi R^2 b\rho$
$=\pi*(0.056)^2*(0.030)*1850$
$=0.546\text{kg}$

iii)$\Delta E=i\omega^2C_s$

$=0.273*(7600)^2*0.030$

$=0.473*10^6$N-m

B) STRESSES:

iv)$\sigma_{rad}=[(3+\mu)/8]\ \rho v^2(R^2-r^2)$

$= [(3+0.3)/8] *1850*(7600)^2*(1.384*10^{-4})$

$=6.10MN/m^2$

v)$\sigma_{tan}=[(\rho\omega^2)/8]\ [(3+\mu)\ R^2-(1+3\mu)\ r^2]$

$= [(1850*(7600)^2)/8]\ [(3+0.3)\ (0.056)^2-((1+3(0.3))\ (0.005475)^2)]$

$=6.215MN/m^2$

4. ALUMINUM:

a) GENERAL:

i)$I=\pi R^2b\rho/(2)$

$= [\pi*(0.056)^2*(0.030) *2700]/ (2)$

$=0.399$kg-m^2

ii)$m=\pi R^2b\rho$

$=\pi*(0.056)^2*(0.030) *2700$

$=0.798$kg

iii)$\Delta E=i\omega^2Cs$

$=0.798*(7600)^2*0.030$

$=0.691*10^6$N-m

b) STRESSES:

iv)$\sigma_{rad}=[(3+\mu)/8]\ \rho v^2(R^2-r^2)$

$= [(3+0.3)/8] *2700*(7600)^2*(1.384*10^{-4})$

$=8.093MN/m^2$

v)$\sigma_{tan}=[(\rho\omega^2)/8]\ [(3+\mu)\ R^2-(1+3\mu)\ r^2]$

$= [(2700*(7600)^2)/8]\ [(3+0.3)(0.056)^2-((1+3(0.3))(0.005475)^2)]$

$=9.07MN/m^2$

2.RIM TYPE:

Let,

t=thickness of flywheel rim

b=breadth of flywheel rim

ρ=density of material

ω=angular speed

Cs=co-efficient of speed fluctuation

V=velocity of flywheel

μ=co-efficient of friction

R=outer radius of the flywheel

r= inner radius of the flywheel

FORMULA USED:

i) $I_r= 2\pi R_m^3t b\rho$

ii)$m_r=2\ \pi R_m t b\rho$

iii) $\Delta E_{max}= i\omega^2C_s$

iv) $\sigma_t=\rho v^2$

v) $\sigma_b= \rho v^2[(2\pi^2R)/(i^2h)]$

vi) $\sigma_{res}=0.75\sigma_t+0.25\ \sigma_b$

Now substituting the values,

1) CARBON STEEL:

a) GENERAL:

i) $I_r= 2\pi R_m^3t b\rho$

$=2*\pi*(0.10950)^3*0.005*0.030*7800$

$=19.302*10^{-3}$ kg-m^2

ii)$m_r=2\ \pi R_m t b\rho$

$=2*\pi*(0.10950) *0.005*0.030*7800$

$=0.804$kg

iii) $\Delta E_{max}= i\omega^2C_s$

$=33.446*10^3$N-m

b) STRESSES:

iv) $\sigma_t = \rho v^2$
$=7800*(25)^2$
$=4.875*10^6 N/m^2$
v) $\sigma_b = \rho v^2[(2\pi^2R)/(i^2h)]$
$=7800*(25)^2*[(2*\pi 2*0.056)/(16*0.020)]$
$=16.84 MN/m^2$
vi) $\sigma_{res}=0.75\sigma_t+0.25\ \sigma_b$
$= (0.75*4.875*10^6) +(0.25*16.84*10^6)$
$=7.866\ MN/m^2<40\ MN/m^2$
Design is safe
2) CAST IRON:
a) GENERAL:
i) $I_r= 2\pi R_m^3 tb\rho$
$=2*\pi*(0.10950)^3*0.005*0.030*7050$
$=8.723*10^{-3}$ kg-m^2
ii)$m_r=2\ \pi R_m tb\rho$
$=2*\pi*(0.10950) *0.005*0.030*7050$
$=0.727$kg
iii) $\Delta E_{max}= i\omega^2 C_s$
$=15.115*10^3$N-m
b) STRESSES:
iv) $\sigma_t = \rho v^2$
$=7050*(25)^2$
$=4.406*10^6 N/m^2$
v) $\sigma_b = \rho v^2[(2\pi^2R)/(i^2h)]$
$=7050*(25)^2*[(2*\pi 2*0.056)/(16*0.020)]$
$=15.22 MN/m^2$
vi) $\sigma_{res}=0.75\sigma_t+0.25\ \sigma_b$
$= (0.75*4.406*10^6) +(0.25*15.22*10^6)$
$=7.109\ MN/m^2<40\ MN/m^2$
Design is safe
3) BERYILLUM:
a) GENERAL:
i) $I_r= 2\pi R_m^3 tb\rho$
$=2*\pi*(0.1095)^3*0.005*0.030*1850$
$=2.28*10^{-3}$ kg-m^2
ii)$m_r=2\ \pi R_m tb\rho$
$=2*\pi*(0.10950) *0.005*0.030*1850$
$=0.1909$kg
iii) $\Delta Emax= i\omega^2 C_s$
$=3.95*10^3$N-m
b) STRESSES:
iv) $\sigma_t = \rho v^2$
$=1850*(25)^2$
$=1.156*10^6 N/m^2$
v) $\sigma_b = \rho v^2[(2\pi^2R)/(i^2h)]$
$=1850*(25)^2*[(2*\pi 2*0.056)/(16*0.020)]$
$=3.994 MN/m^2$
vi) $\sigma_{res}=0.75\sigma_t+0.25\ \sigma_b$
$= (0.75*1015*10^6) +(0.25*3.994*10^6)$
$=1.866\ MN/m^2<40\ MN/m^2$
Design is safe
4) ALUMINUM:
3) BERYILLUM:
a) GENERAL:
i) $I_r= 2\pi R_m^3 tb\rho$
$=2*\pi*(0.1095)^3*0.005*0.030*2700$
$=278.64*10^{-3}$ kg-m^2
ii)$m_r=2\ \pi R_m tb\rho$

$=2*\pi*(0.10950)*0.005*0.030*2700$

$=0.278kg$

iii) $\Delta E_{max}= i\omega^2 C_s$

$=0.482*10^6 N\text{-}m$

b) STRESSES:

iv) $\sigma_t=\rho v^2$

$=2700*(25)^2$

$=1.687*10^6 N/m^2$

v) $\sigma_b= \rho v^2[(2\pi^2 R)/(i^2 h)]$

$=2700*(25)^2*[(2*\pi 2*0.056)/(16*0.020)]$

$=5.829 MN/m^2$

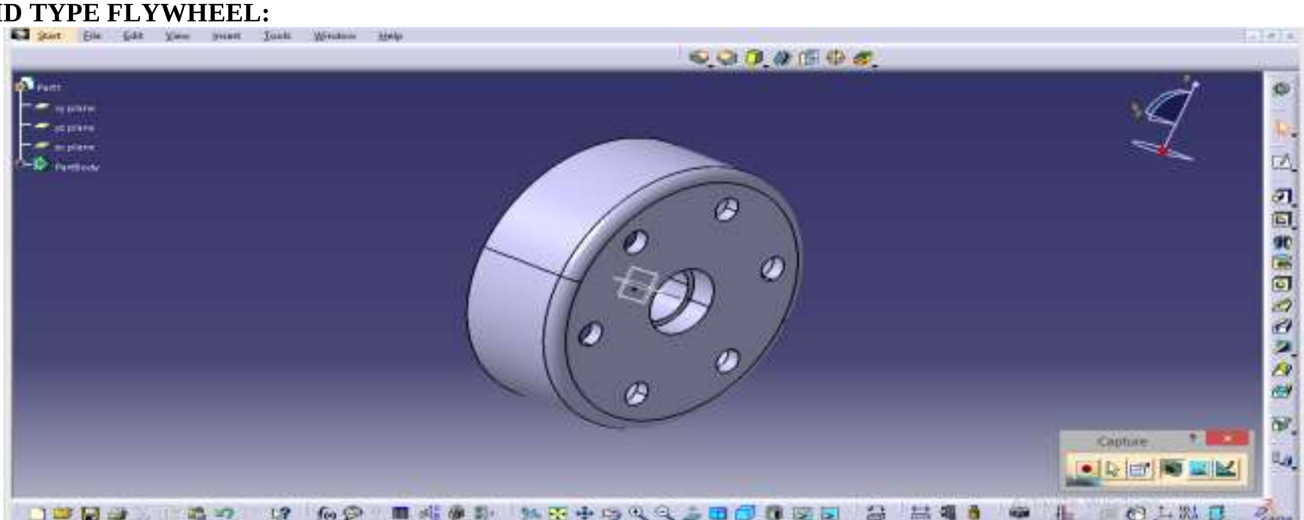
vi) $\sigma_{res}=0.75\sigma_t+0.25\,\sigma_b$

$= (0.75*1.687*10^6) +(0.25*5.829*10^6)$

$=2.722\ MN/m^2<40\ MN/m^2$

Design is safe

SOLID TYPE FLYWHEEL:



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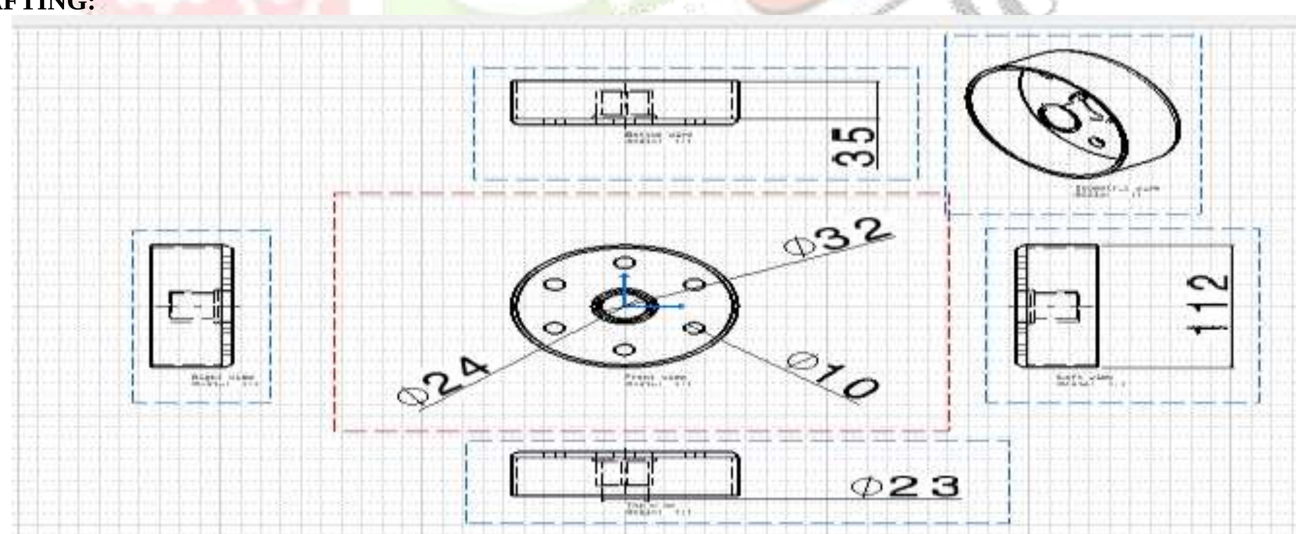
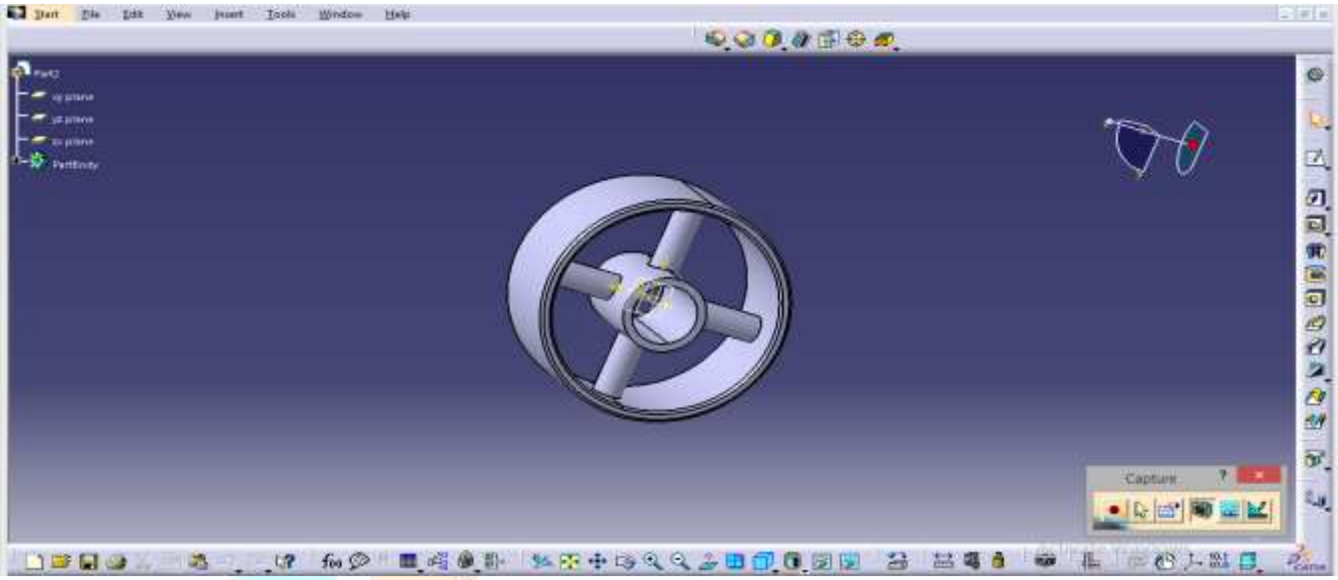


RIM TYPE FLYEHEEL:



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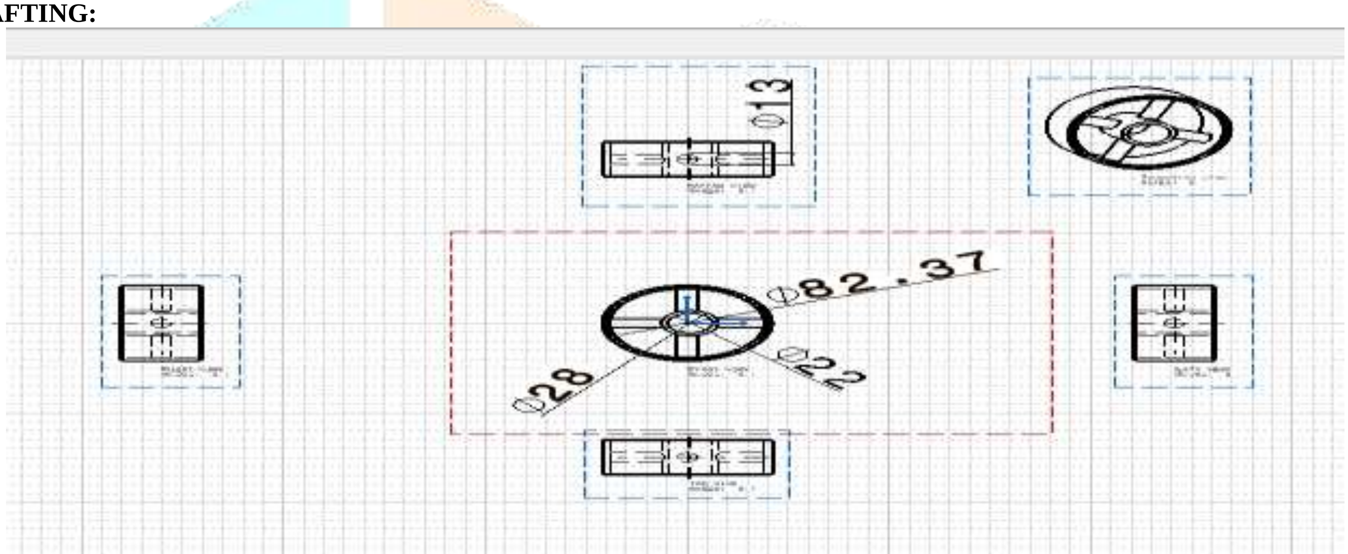


IV. LITERATURE SURVEY

1) Amol Chougule, S. B. Tuljapure: have proposed the stress induced in stem and web by finite element method and results are validated by analytical calculations this study solely focuses on exploring the effects of Centrifugal stresses on web type conventional steel and composite material flywheel and comparison of theoretical and ANSYS results of conventional steel with composite material flywheel.

2) AswinInbarajJaison, Karuppasamy: have made proper investigation on exploring the effects of flywheel geometry on its energy storage / deliver capability per unit mass, further defined as specific energy.

3) **Archana A Pihulkar, Dr. S. H. Sarjehave:** have proposed the method for design the flywheel, develop and optimize the mass of flywheel using composite materials like carbon fiber with cast iron.

4) N. N. Suryawanshi, Prof. D. P. Bhaskar: had proposed the method for which DMF is manufactured and done experiment or testing to see the results. And then results are comparing with the conventional flywheel.

5) T. RajaSanthoshKumar, Suresh Babu Koppula, Cr. Prakash, D.V. Srikanth: made proper investigation on weight reduction is major important and maintain minimum stresses, here another three types of flywheels have chosen like flywheel with extended hub support, rim type and elliptically rim type.

6) Ronak K. Patel, Vishal Darji: had experimented on the flywheel energy storage unit, which takes place of the conventional chemical battery unit, has the advantages of free maintenance, long life and no pollution. Finally, the experiment results testify the Dynamics UPS has better character and dynamical response.

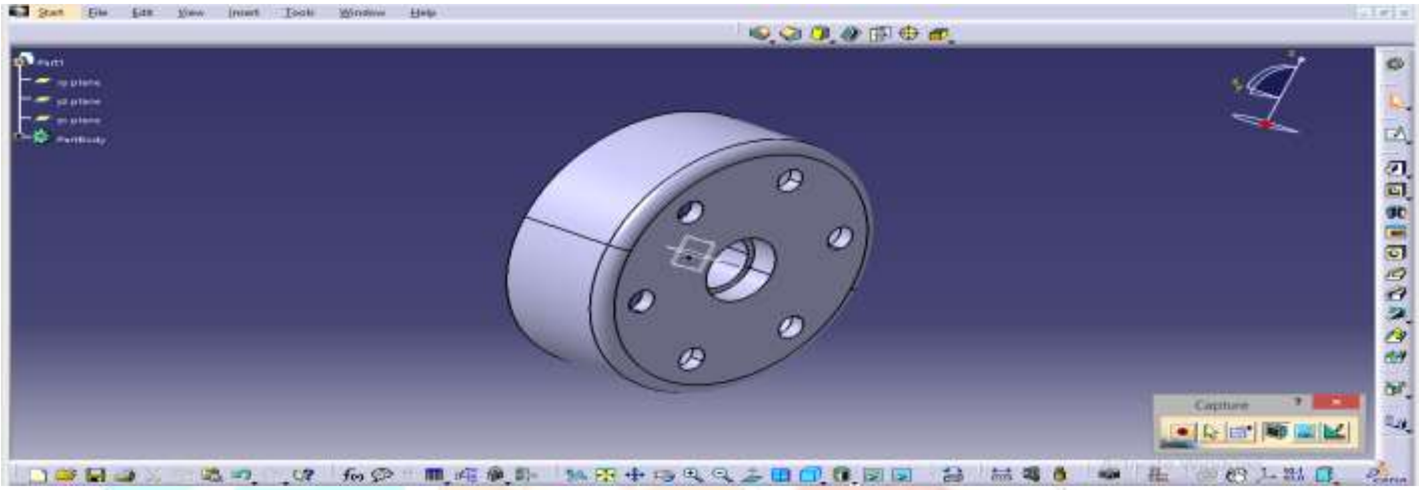
7) **X. Charles:** had proposed a method for Design and Stress Analysis of Composite Material Flywheel in Automotive in which light-weight ends up in fast engine response.

8) **Appala Narasimha Murthy B, P. Srinivas Reddy:** made a paper on Design and Optimization of a flywheel for the 4-Cylinder Diesel Engine in which the design and analysis of flywheel to minimize the radial and tangential stresses, the flywheel is subjected to a constant rpm.

9) **Wasim Akram, Vaibhav. H. Bankar:** had discussed about the Design and Analysis of Solid Disc Type Flywheel

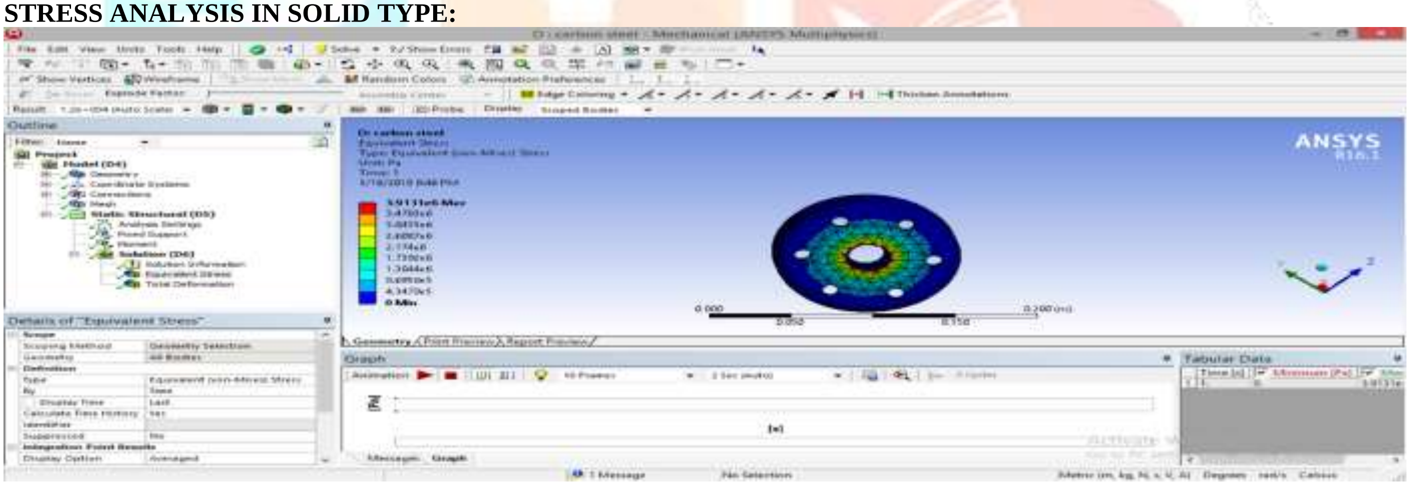
V. RESULT AND DISCUSSION

1.DESIGN RESULT OF SOILD TYPE:

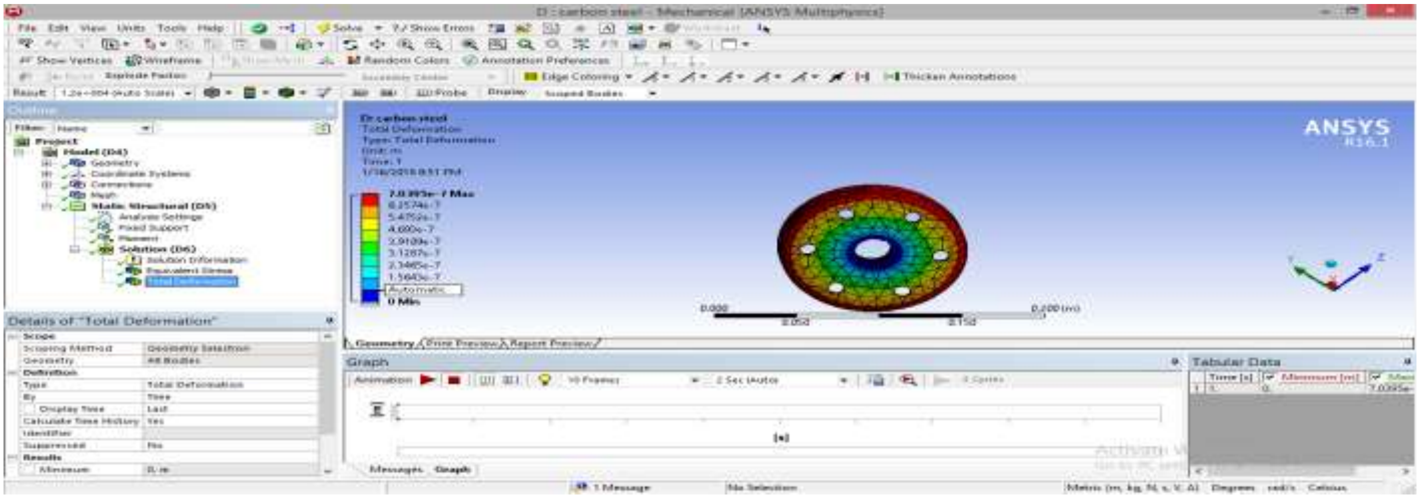


ANALYSIS RESULT OF CARBON STEEL:

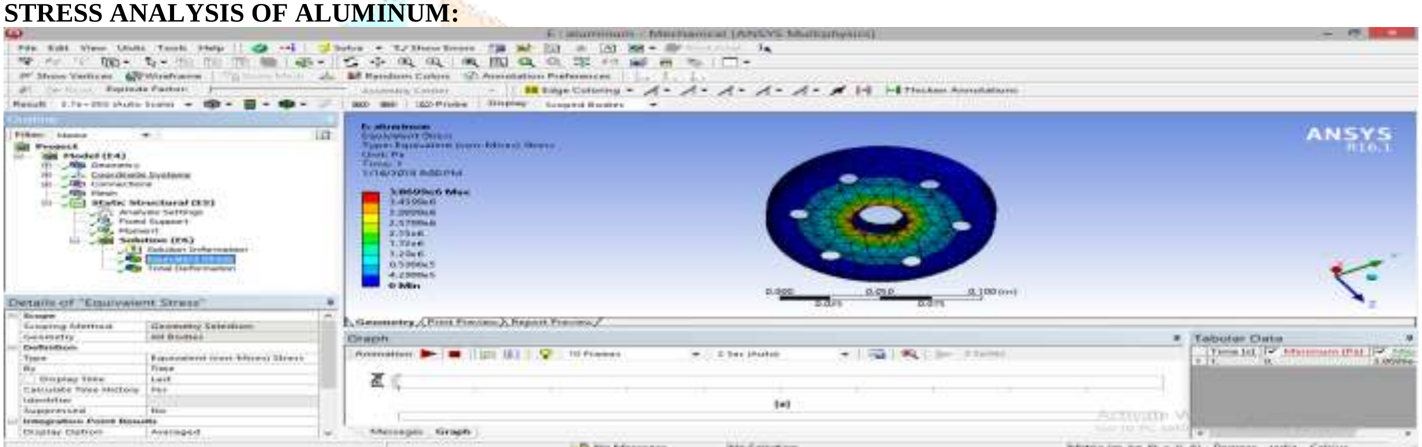
STRESS ANALYSIS IN SOLID TYPE:



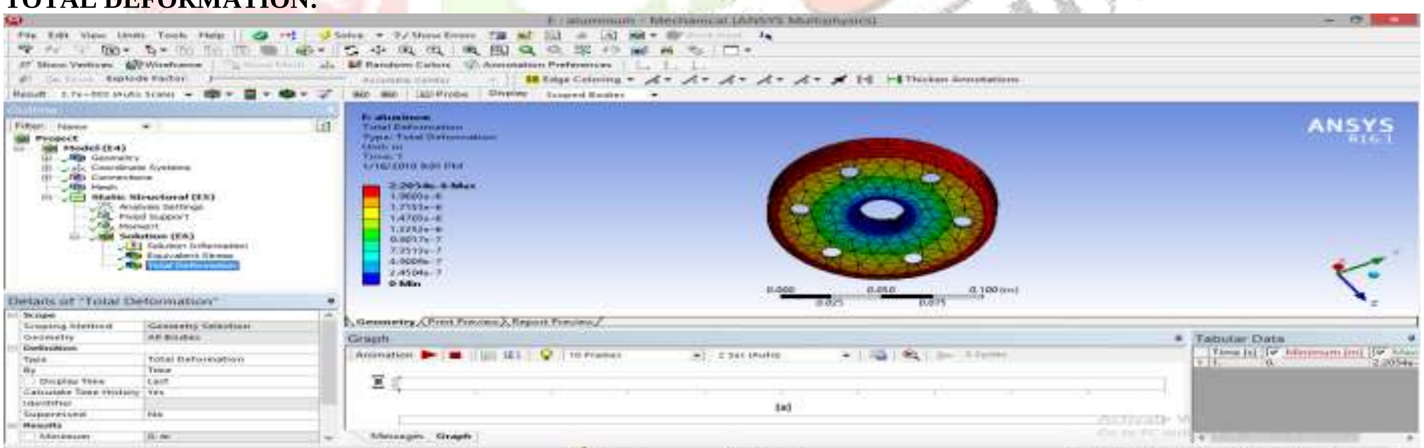
TOTAL DEFORMATION:



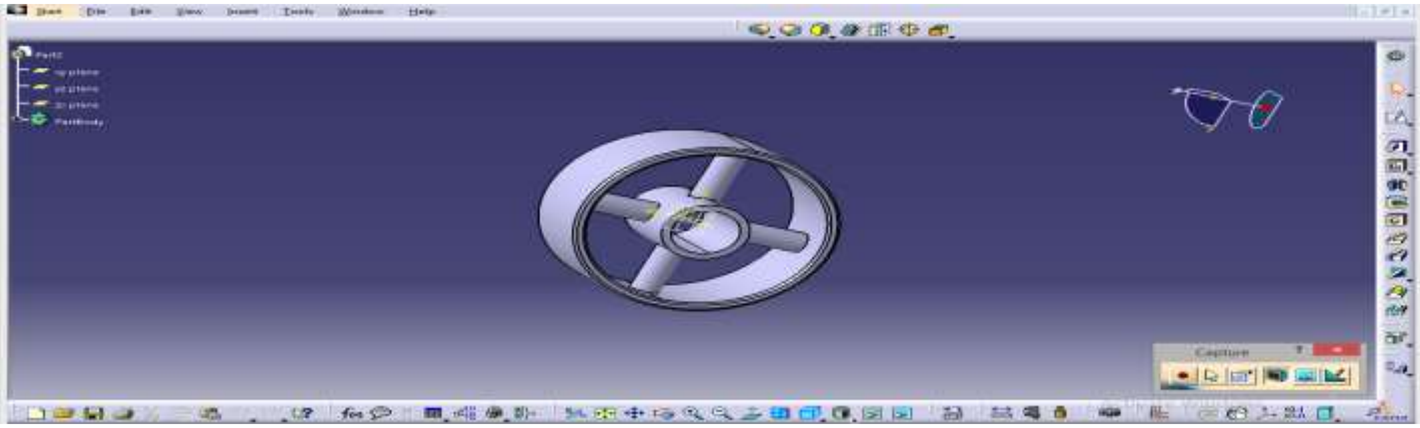
STRESS ANALYSIS OF ALUMINUM:



TOTAL DEFORMATION:



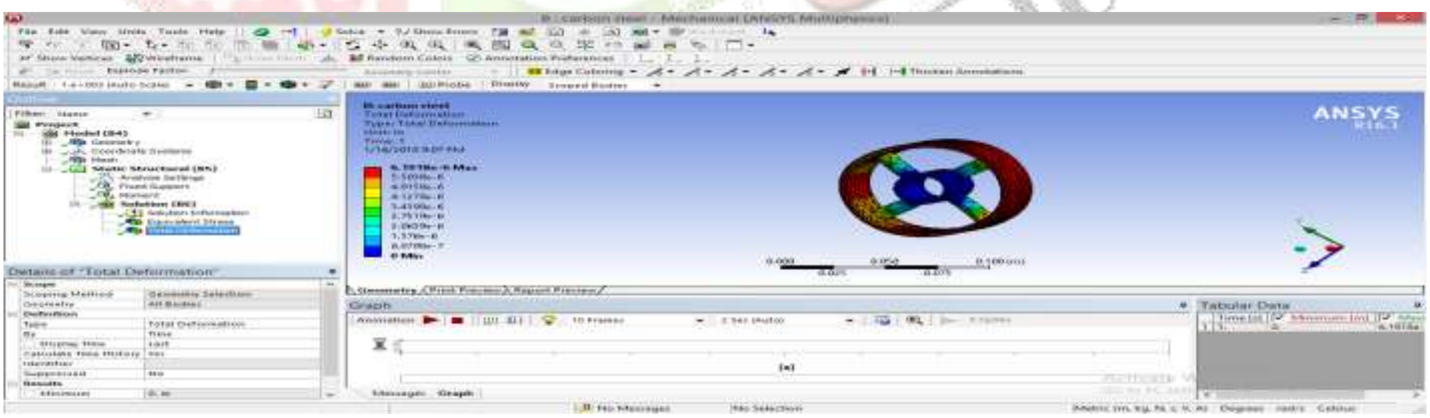
2. DESIGN RESULT OF RIM TYPE:



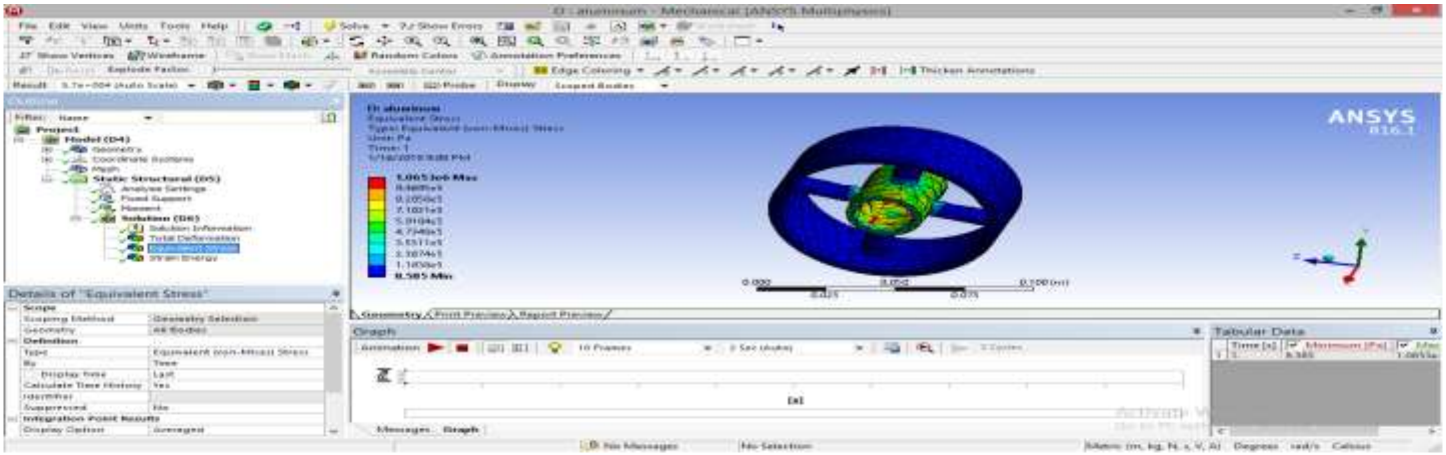
ANALYSIS RESULT OF RIM TYPE:

STRESS ANALYSIS OF CARBON STEEL:

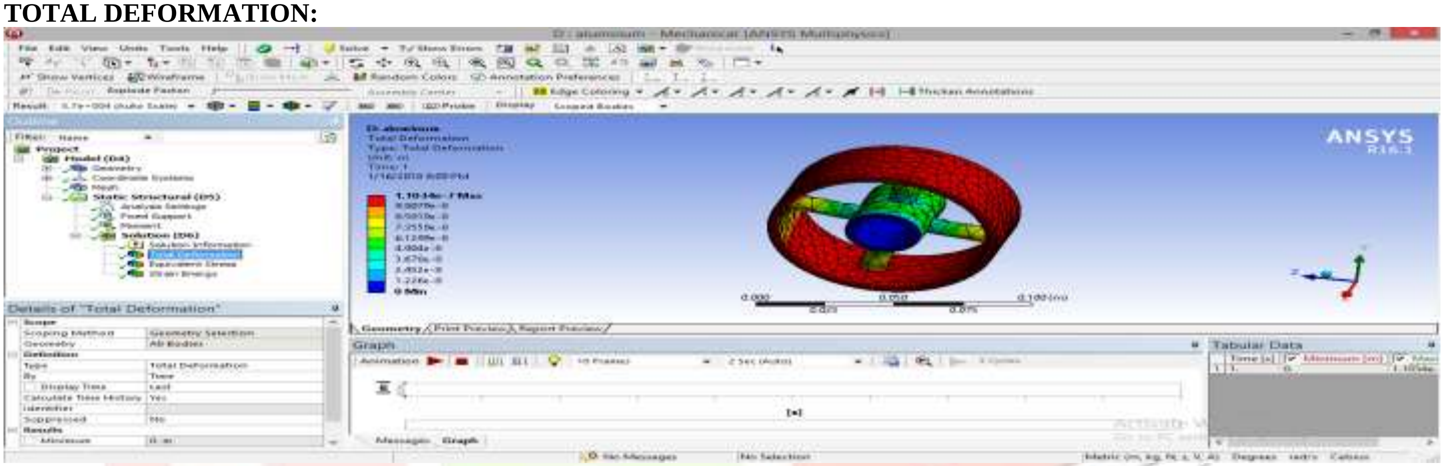
TOTAL DEFORMATION:



STRESS ANALYSIS OF ALUMINUM:



TOTAL DEFORMATION:



VI. CONCLUSION

Project is based on design, development and stress analysis of flywheel using different material. Flywheel is mechanical device which is used to store energy whenever required for machine or automobile etc. The amount of energy stored is directly proportional to square of its rotational speed. Here the failure due to the stress is find out by using the analysis method and development is made in design of the flywheel to rectify the failure. 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. The different models of flywheel are developed for analysis. The 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 and the results are evaluated. And from the results we can see that the carbon steel stores more energy and can withstand more stress than other three materials but due to properties of the cast iron it is more largely used.

STRESS CONCLUSION

S.NO	MATERIAL	ANSYS OF SOLID TYPE N\m^2	RIM TYPE N\m^2
1	CARBON STEEL	3.9191e6	1.9879e7
2	CAST IRON	3.9124e6	1.9558e7
3	ALUMINUM	3.8699e6	1.0653E6

4	BERYLLIUM	3.9175e6	1.2849e6

ENERGY STORAGE:

S.NO	MATERIAL	SOLID TYPE	RIM TYPE
1	CARBON STEEL	$1.996*10^6$N-m	$33.446*10^3$N-m
2	CAST IRON	$1.803*10^6$N-m	$15.115*10^3$N-m
3	ALUMINUM	$0.691*10^6$N-m	$3.95*10^3$N-m
4	BERYLLIUM	$0.473*10^6$N-m	$0.482*10^6$N-m

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