Modeling, Analysis and Optimization of Rail Wheel

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Abstract- *A rail wheel, along with an axle is one of the vital parts that assist the safe operation of railway vehicles. Rail wheel systems use friction to transmit power and braking, friction generates heat which results in deformation of the wheel as well as thermal loads in addition to the static and dynamic loads during their service. Therefore, conducting analysis of the rail wheel becomes essential to study and analyze the effect and behavior of these structural and thermal loads on the life of rail wheel.*

In this paper, Structural, Steady-State Thermal analysis and Thermal Stress analysis conducted has been discussed. Rail wheel modeling is done in CATIA V5 without affecting the existing design requirements. Meshing and analysis is done using ANSYS Workbench 15.0 analysis software. Three different materials have been used in this analysis. And also, obtained results of each material are compared with each other and data available over the years to ascertain most suitable material for the application.

I. INTRODUCTION

A rail wheel is rolling component, pressed onto an axle, and mounted directly on the rail car. The most important and fundamental characteristic in designing wheels is strength. There are mainly two approaches to improve the wheel performance: material designing and configuration designing. In particular, since wheels are expendable parts, their life plays a significant role in saving the maintenance cost. [2]
The wheels must support the weight of the car and steer it on rails. The brake shoes are applied directly on the wheel thread to stop or slow down the train. The wheels should withstand wear from mechanical and stresses caused by dynamic loading and brake friction.Rail systems utilize friction to transmit power, therefore high cyclic loads, dynamic loads; heat generation and wear are unavoidable.On these occasions, Wheel thread surface is heated due to friction. Material on the tread surface and the rim gets hotter and tries to expand.The fracture occurring on the railway wheels, are caused by thermal loads acting on the wheel due to long term braking for maintaining constant train speed on lower or in some case the wheels are locked. About 80% of wheels were re-profiled due to thermal damage. [3]

This paper is intended towards modeling of rail wheel and analyzing rail wheel subjected to structural, thermal and combined loading. Further, on basis of results obtained, a most suitable material for the application among three materials being analyzed is suggested.

II. PROBLEM DESCRIPTION

Rail wheel geometry used in this analysis has been shown in figure 1.The rail wheel was modeled using CAD package CATIA V5. Then it was imported to ANSYS Workbench analysis software.

The rail wheel is analyzed with three different material and four different mesh sizes. Three type of analysis are conducted namely Structural, Steady-State thermal and Thermal Stress analysis with suitable loads and boundary conditions.

The obtained results are compared with existing by plotting graphs between different materials and their respective deformations, Von-mises stress and maximum principal stress.

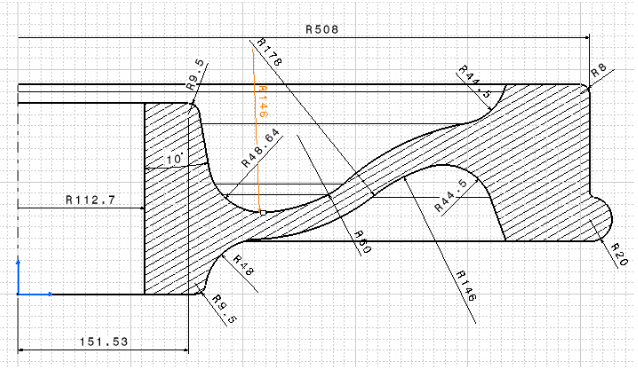


Figure 1: Rail Wheel Profile.

Assumptions

The following assumptions were considered during the analysis:

- In this analysis, a case of a 4 wheel rail car carrying a load of 220KN. The rail is travelling at 20 Km/h is brought to rest by one brake shoe on each in 20seconds.
- Due to the intensive braking, there will be generation of heat which acts as thermal load. This will help to maintain train speed constant.
- Heat generated is uniformly distributed around the rim periphery of the wheel.

- Apart from the thermal load induced due to braking, the rail wheel is subjected to a vertical and horizontal load of 320KN and 160KN respectively.
- The rail car load is distributed equally to the four wheels.

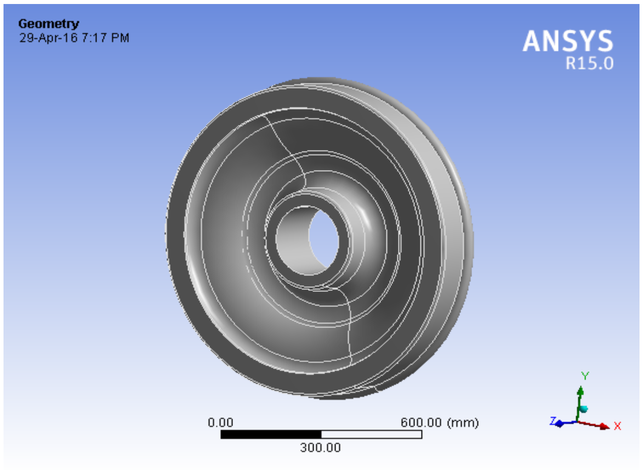


Figure 2: 3D Model of Rail Wheel.

III. MATERIAL DATA

a. Grey Cast Iron

Density	7.8334e-006 kg/mm^3
Coefficient of Thermal Expansion	1.6799e-006 per °C
Specific Heat	4.47e+005 mJ/kg °C
Thermal Conductivity	4.983e-002 W/mm°C
Young's Modulus	2.012e+005 MPa
Poisson's Ratio	0.3

b. IRS R19-93

Density	7.2e-006 kg/mm^3
Coefficient of Thermal Expansion	1.3e-005 per °C
Specific Heat	5.28e+005 mJ /kg C
Thermal Conductivity	5.2e-002 W/mm °C
Young's Modulus	1.1e+005 MPa
Poisson's Ratio	0.3

c. ASTM Grade 20 Grey Cast Iron

Density	7.2e-006 kg/mm^3
Coefficient of Thermal Expansion	1.1e-005 °C
Thermal Conductivity	4.6e-002 W/mm°C
Specific Heat	4.5e+005 mJ/kg °C
Young's Modulus	96527MPa
Poisson's Ratio	0.3

IV. FINITE ELEMENT MODEL

In this analysis, rail wheel model has been meshed by using hex dominant method, because in hex dominant method of meshing, shape of the element we obtain is quadrilateral, which was found to be optimum for the rail wheel meshing.This hex dominant method is applied by selecting whole body. Mesh obtained after applying this method was not proper that some triangular elements were created instead of quadrilateral elements as shown in figure 3.

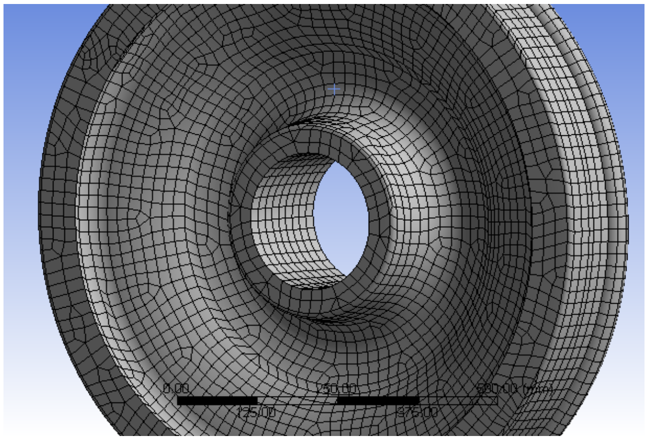


Figure 3:Hex Dominant mesh without mapping

And hencefaces have been mapped using Mapped face Meshing option, by selecting all the faces of wheel. Finally mesh that is obtained is shown as in figure 4 below.

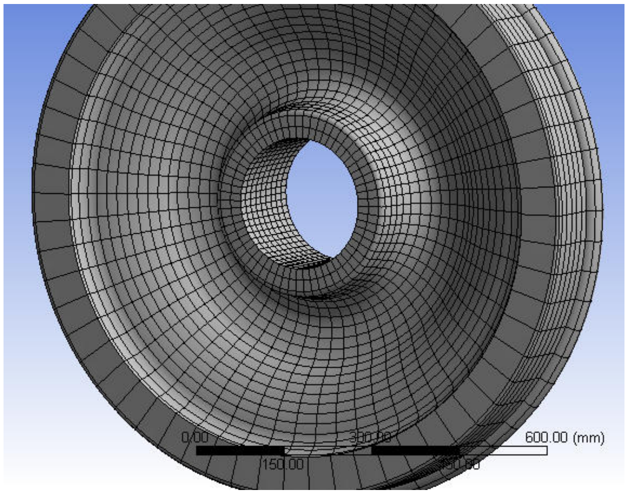


Figure 3:Hex Dominant mesh with mapping

As it is clearly seen from above figure that, mesh is uniform and hence optimum for conducting analysis.

V. ANALYSIS

a. Structural Analysis

In structural analysis, horizontal load and vertical load are applied on the rail wheel as point loads to reduce complexity. Horizontal load is acted on flange fillet of the outer wheel from the outer side of the curved track to the inner side. Vertical load is one that is supporting the car weight in the vertical direction as shown in figure 5.

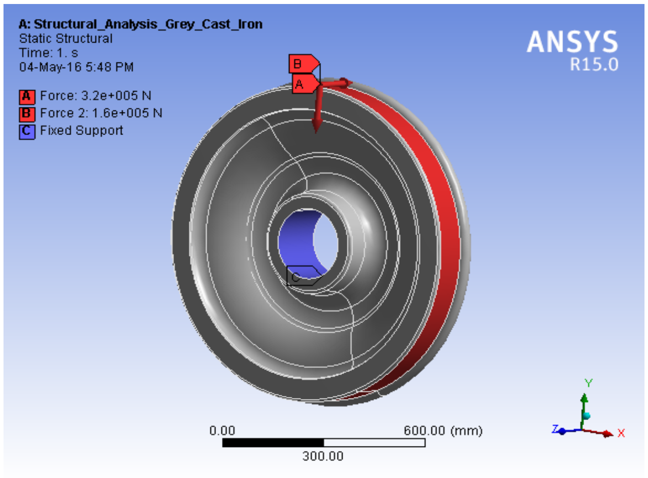


Figure 5: Structural Loads and Boundary Conditions.

b. Thermal Analysis

The main purpose of thermal analysis is to determine the temperature distribution and related quantities in the model. This analysis is used in many engineering industries such as automobile, piping, electronic, power generation, and so on.

In thermal analysis, heat flux is uniformly applied on the rim since the brake shoe application on the rim, increases its surface temperature. Medium of heat transfer is Convection for whole body.

Thus the temperature distribution of wheel due to this thermal load is ascertained. And also total deformation, Equivalent von-mises stress, maximum principal stress are also obtained.

Thermal loads like heat flux and convection are applied on the wheel as shown in figure 6.

Calculation

1. Load acting on four wheels=220 KN =22426.0958 Kg.
2. Load acting on one wheel = 5606.5239 Kg.
3. Velocity of the bogie (v)=20 Km/h = 5.55 m/s.
4. Time to bring bogie to rest = 20s.
5. Kinetic energy generated at wheel= 0.5*m*v2 = 86347.47621 J.
6. Power generated = Kinetic energy / time taken = 4317.3738 W
7. Heat flux generated at the rim = Power generated / area
8. The surface area which is in contact with the rail is :Area = π * Diameter of Wheel * Width = 117338.4856 mm^2
9. Heat flux generated = 0.0367941 W/mm^2

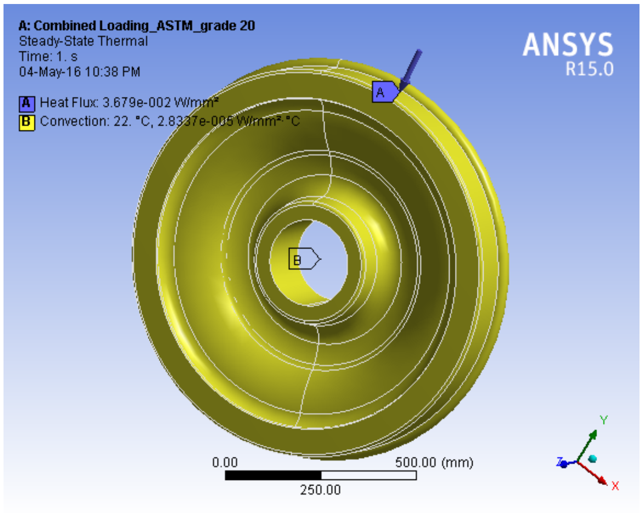


Figure 6: Thermal Loads and Boundary Conditions.

c. Thermal Stress Analysis.

In thermal Stress analysis, we can estimate the thermal stress using temperature distribution. The main objective of thermal stress analysis is to determine the stress in a model caused by a uniform temperature change. When a temperature change occurs in a component, its coefficient of thermal expansion causes an expansion or contraction of the model depending upon whether the temperature increases or decreases.

In this analysis, both thermal as well as structural loads are applied on the wheel at a time. This analysis is generally called as the combined loading analysis.

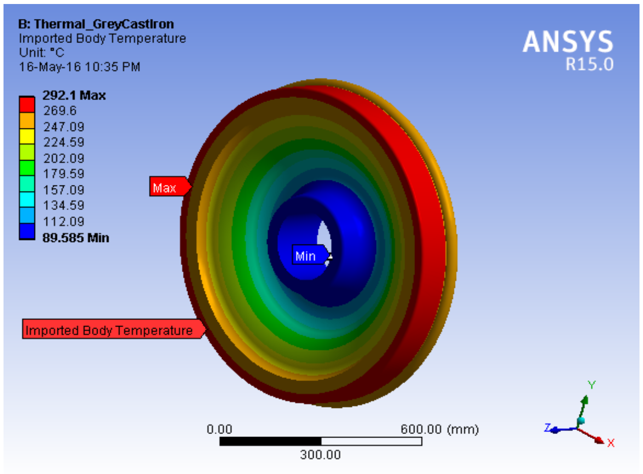


Figure 7: Imported Body Temperature.

Wherein, heat flux will act as a load in the form of imported body temperature (as shown in figure 7.) along with the structural load to induce the deformation and stresses. Loads and boundary conditions are which are applied are same as that we applied in case of structural and thermal analysis.

VI. RESULTS AND DISCUSSIONS

a. Material 1: Grey Cast Iron

First material considered in this analysis is Grey cast iron which is ductile in nature and having carbon percentage of 0.6 to 0.79.

Structural Analysis			
Type	Total Deformation	Equivalent (von-Mises) Stress	Maximum Principal Stress
Results			
Minimum	0. mm	0.15356 MPa	-9.5551 MPa
Maximum	0.47409 mm	94.859 MPa	100.99 MPa

Thermal Analysis			
Type	Total Deformation	Equivalent (von-Mises) Stress	Maximum Principal Stress
Results			
Minimum	0. mm	0.34752 MPa	-8.4185 MPa
Maximum	0.29974 mm	68.912 MPa	72.806 MPa

Thermal Stress Analysis			
Type	Total Deformation	Equivalent (von-Mises) Stress	Maximum Principal Stress
Results			
Minimum	0. mm	0.68562 MPa	-14.804MPa
Maximum	0.69633 mm	143.06MPa	163.35MPa

Results of structural, thermal and thermal stress analysis for the material 1 grey cast iron are tabulated in tables.

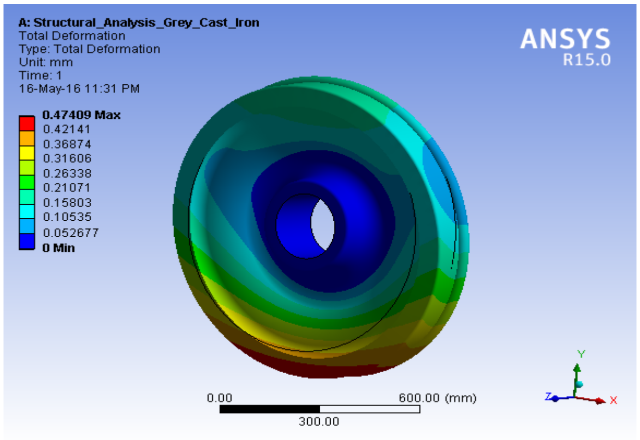


Figure 9: Total Deformation due to structural load.

Figure 9 shows the total deformation due to structural loads. It is observed that the total deformation of the wheel is 0.47409mmat the rim portion of the wheel.

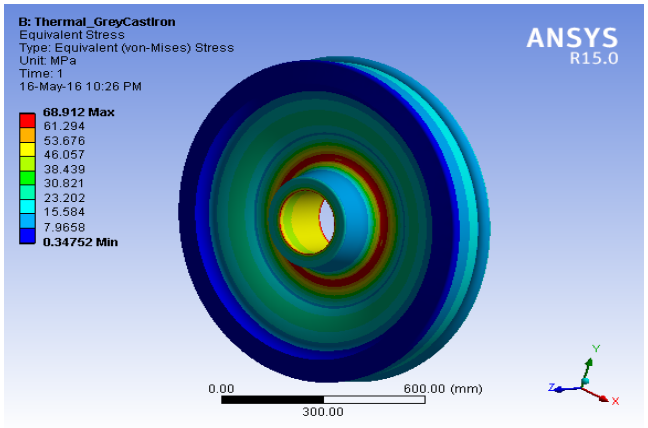


Figure 10: Equivalent (Von-Mises) Stress due to Structural loads

Equivalent (Von-Mises) stress is observed to be 68.912 N/mm2 as shown in figure 10. This is due to the contact load acting on the major portion of the rim.

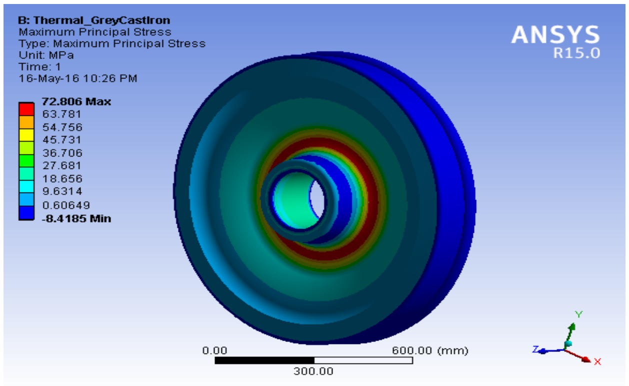


Figure 11: Maximum Principal Stress due to Structural Loads.

Maximum principal stress is observed to be 72.806 N/mm2 as shown in figure 11.

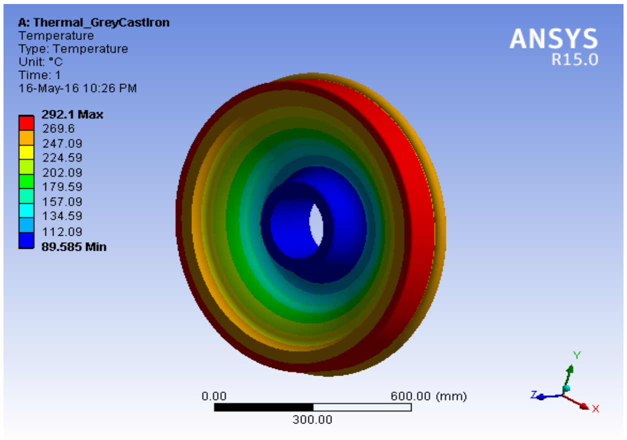


Figure 12: Temperature Distribution due to thermal loads.

Figure 12 shows the temperature distribution of rail wheel due to thermal load with a maximum temperature of 292.1 °C. Total deformation due to thermal load is observed to be 0.29974 mm at rim portion as shown in figure13. Von-Mises stress and maximum principal stress are 68.912 MPa and 72.806 MPa respectively as shown in figure 14&15.

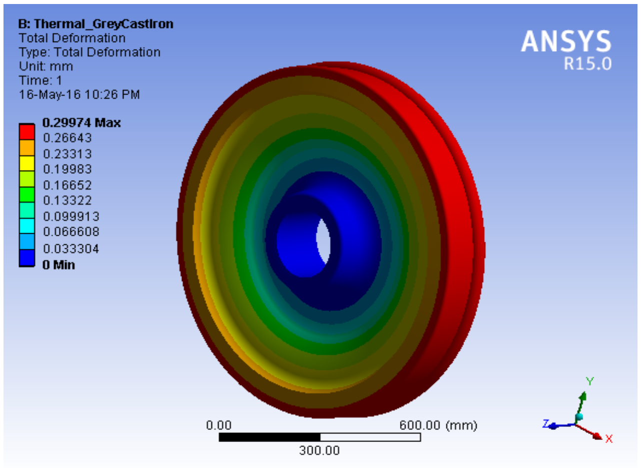


Figure 13: Total Deformation due to thermal load.

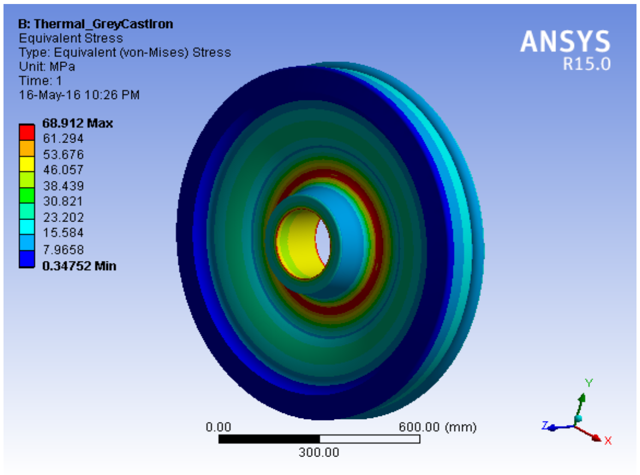


Figure 14: Equivalent (Von-Mises) Stress due to thermal load.

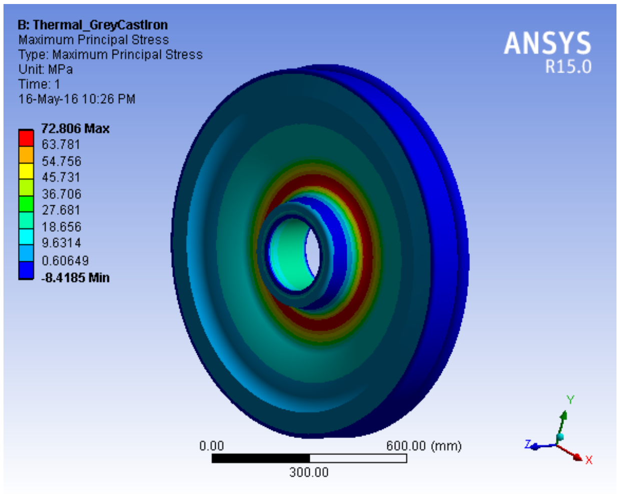


Figure 15: Maximum Principal Stress due to thermal load.

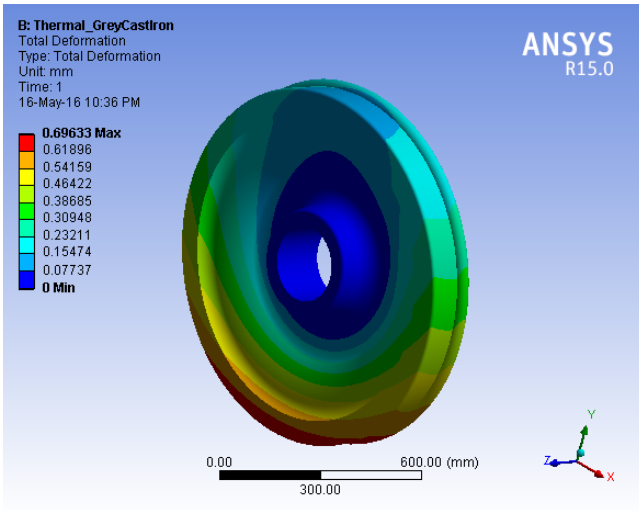


Figure 16: Total Deformation due to combined load.

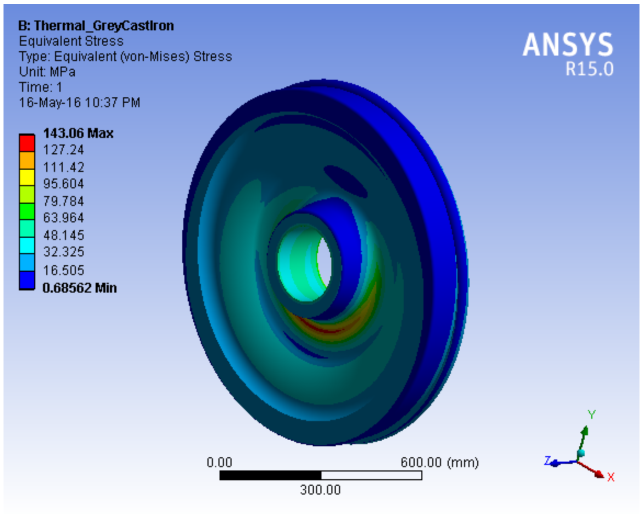


Figure 17: Equivalent (Von-Mises) Stress due to combined load.

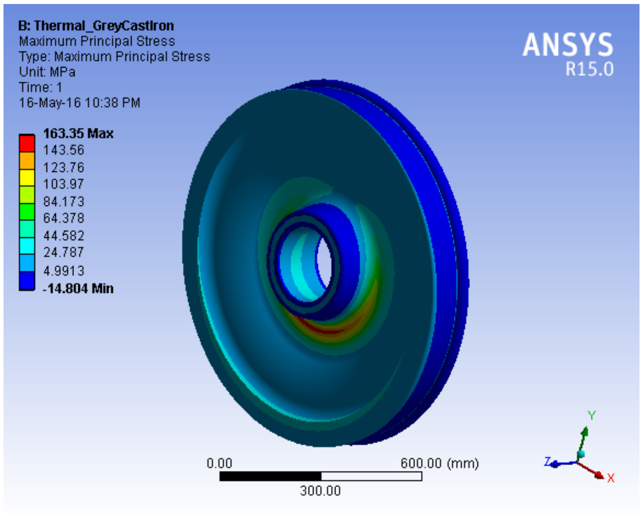


Figure 18: Maximum Principal Stress due to combined load.

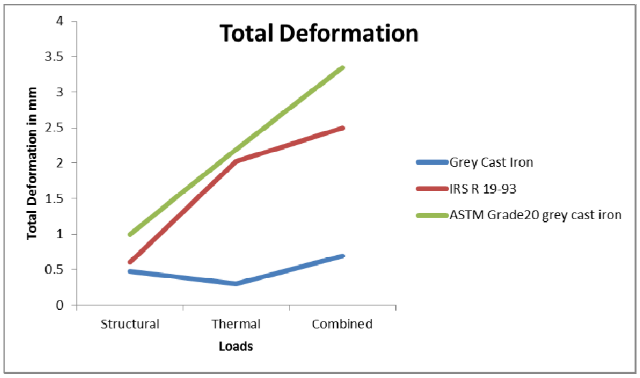
Figure 7 shows the imported body temperature. Total deformations due to combined load is observed to be 0.69633 mm at rim portion as shown in figure 16. Von-Mises stress and maximum principal stress are 143.06 MPa and 163.35 MPa respectively as shown in figures 17&18.

It is noticed that the deformation, von-mises stress, maximum principal stress only due to thermal load and only due to structural load are less than that of only due to the combined load.

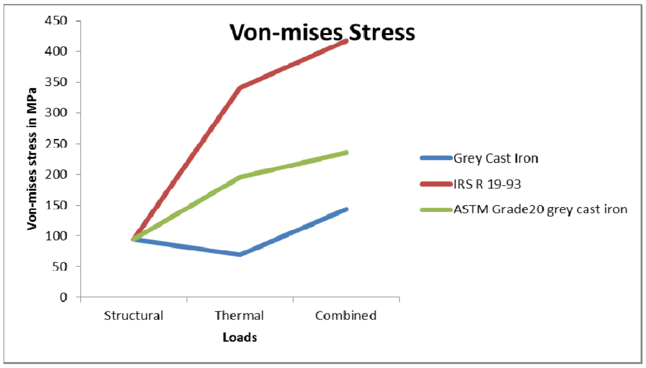
Similarly, analyses of other two materials were also conducted.

6.1 Graphs

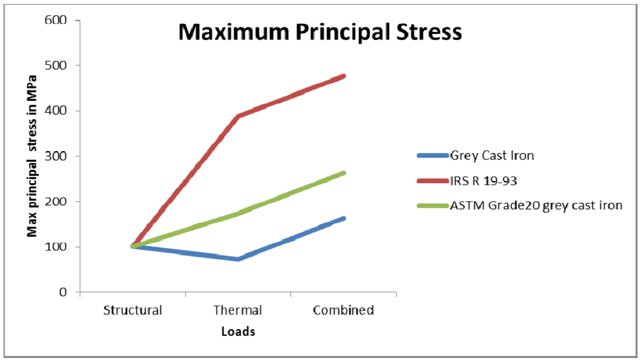
The following graphs shows the variation in total deformation, von mises stress and maximum principal stress due to the structural load, thermal load, and combined load for the all three materials.



Graph 1: Total Deformation variation due to different loading.



Graph 2: Von-Mises Stress variation due to different loading.



Graph 3: Maximum Principal Stress variation due to different loading.

It can be clearly observed that the values of deformation and stresses for combined loading are more than that of thermal and structural load when applied separately.

It can also be noticed that material 1 grey cast iron has least values of deformation and stresses and thus, it is the most suitable material for the application among these three materials.

VI. CONCLUSION

Analysis of rail wheel was carried out to determine the magnitude of deformation, Von-mises stress, and maximum principal stress under structural and thermal load separately and both combined generated during braking operation and during transmission of power using friction. It can be concluded that the induced stresses and deformations are within the allowable limits for all the three materials that have been analyzed. Also to reduce the magnitude of induced stresses and deformation re-profiling could be suggested where the stresses are varying.

The analysis results depict the behavior of wheel for different loading conditions. It is also noticed that the excessive braking of wheel lead to thermal overloading which results in fatigue, crack propagation leading to fracture and wear.

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