Combined Load Analysis of Re-profiled Railway Wheel

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Abstract - *The wheels are most stressed components of railway vehicles. The axial and vertical load is up to 10.5 and 21 tons respectively or more on the wheel. The most considerable parameter for the railway vehicle is the ability to break the vehicle safely and effectively.*

The present article minimizes the stresses, by generating a re-profile of Electro Motive Diesel (EMD) Locomotive wheel. The stress is generated on wheel due to thermal load, vertical load, and lateral load. The present article analyses the various combination of these loads and compare its result with Research Design and Standard Organization (RDSO) design. It was found in the earlier researches that about 80% damage of the wheel is only due to thermal load or thermal stresses which are generated due to the braking block. The present article gives details about thermal analysis on various diameters of the wheel at different velocity for four materials. This study gives a mathematical model to the problem of temperature distribution over the wheel of a railway locomotive (EMD). A geometrical 3D model was generated using CATIA V5 R20. The model uses finite element analysis to predict the temperature distribution over the various radiuses as well as the maximum temperature at three operating speed values of the locomotive for four different materials. Also the finite element analysis is used for stress distribution over the various loads (mechanical or thermal) of the wheel. This analysis has been done on ANSYS 16.0 and MATLAB 2012.

Key Words: Railway, Breaking Block, Electro Motive Diesel (EMD) locomotive wheel, Thermal stresses, Finite Element Analysis.

Nomenclature

Symbol	Explanation
f_f	Friction force per unit contact area (N/m^2)
ω	Angular velocity(m/s)
ω_o	Initial angular velocity of the railway wheel (m/s)
r	Radius of railway wheel (mm)
α	Angular acceleration of the railway wheel (m/s^2)
μ	Friction coefficient
FN	The normal braking force on the wheel (N)
V	Velocity of the railway wheel (km/h or m/s)
ρ	Density of the wheel (kg/m^3)
k	Thermal conductivity (W/m K)
Cp	Specific heat (J/kg K)
u	Velocity field (m/s)
Q	Heating power per unit volume (W/m^3)
h	Convective film coefficient(W/m^{2}K or W/m^2 C)
ε	Material's emissivity
σ	Stefan-Boltzmann constant (5.67×10^{-8}W/m^{2}K^4)
$Tref$	Temperature of the surrounding air (K)
ka	Thermal conductivity of air(W/m K)
ρa	Density of air(kg/m^3)
μva	Viscosity of air (Pa.s)
Cpa	Specific heat capacity of air(J/kg K)
q	Heat Flux (W/m^2)

1. INTRODUCTION

One of the most important control systems of an EMD Locomotive is Brake system. Brakes are required to stop the Train within the smallest possible distance. In the braking process, vehicle's kinetic energy is converted into the thermal energy due to friction generated between braking block and wheel because of which the temperature of the wheel increases. This raised temperature is dissipated upon cooling and it reduces residual thermal stresses. If we apply the hard brake to the wheel, it results in the increase in the temperature of the wheel rim which will continuously keep on increasing. This random change in the temperature is the reason of developing thermal stresses in the wheel. If there is a very large thermal expansion or contraction, then it is a case of plastic deformation. After applying brake repeatedly, due to the structural loading there might be a crack initiated on the disc surface which is the reason of failure of wheel. A metallurgical survey was carried out by BR Research in 1992 and it was found that about 80% wheel profile was changed because the wheels were not able to withstand against the thermal damage. When there is a failure of breaking system, it means that the brake energy is higher than its estimated designed value [1].

M. Milosevic et. al. (2012) carried out an analysis of modeling thermal effects in breaking system of Railway vehicles. They suggested that for the designing process of the braking assembly, shape and size of a braking block, wheel and block contact surfaces and modeling of thermal effects are very important parameters. L. Ramanan et. al. (1999) carried out a thermal and mechanical finite element analysis of a railway wheel. They analyzed that stresses were generated at the contact of rail-wheel interaction. They also made a three-dimensional elasto-plastic finite element model by using a global-local approach. J. P. Srivastava et. al. (2016) reviewed the effects of the thermal loads on the wheel and rail contact surfaces. Ertz and Knothe (2003) analyzed thermal stresses at wheel and rail contact. Finally they suggested in their result that these thermal stresses have a significant role on material to reach its elastic limit at a contact between wheel and rail. If the wheel is at initial temperature, mechanical and thermal stresses are quite equal. But if this initial temperature increase, the thermal stresses becomes higher in the rail part, whereas mechanical stresses are higher in the wheel part. This situation of higher thermal stresses leads rail to the failure.

Klebanov and Kuraeva (2015) used Melan's Theorem to develop the lower bound in cyclic thermal and mechanical loads, by practically implementing it to a practical contact problem. P. Vinod et. al. (2014) analyzed the railway wheel to study the stress variations in their paper. They carried out a static analysis of a locomotive wheel to examine the magnitude of von-mises stress under both mechanical and thermal load which were generated during the braking operation. They suggested profile modification for the wheel to reduce the magnitude of induced stresses. S. Teimourimanesh et. al. (2016) discussed the sequential stop braking operation in metro and suburban operations using the finite element modeling. P. M. Mohan, (2012) analyzed the railway wheel to study their thermal and structural behavior. He discussed two types of problems in his paper, first the behavior of wheel due to thermal and structural loading and second the behavior of wheel due to combined loading. He observed that regular hard braking on the wheel leads to increase in thermal stresses which result in fatigue and creep propagation thus leading to the fracture and wear. V. Blanusa et. al. (2015) presented a finite element mathematical model for analyzing the moment of friction and the thermal elastic behaviour of the cylindrical roller bearing in railways. R Bhargava (2014) discussed the roadmap for the future in the wheel making technology in the Rail Wheel factory (RWF) Bangalore. Tudor and Khonsari (2006) presented a paper on analysis of heat in wheel/rail and wheel/brake shoe friction contact. In this paper they developed an analytical model to find the steady-state temperature distribution in a wheel undergoing heating situation. Haidari and Tehrani (2014) analyzed the railway wheels under the combined thermal and mechanical loads. Based on the literature the objective of the present work is to analyze the railway braking wheel for thermal and structural stresses and to propose a possible design change to reduce the stresses. For this a wheel profile using CATIA V5 R20 is generated and the thermal and stress analyses is carried out using the ANSYS 16.0 and MATLAB 2012 software. The following theoretical analysis has been done in this study.

- Variation of heat flux with different velocity and different radius of railway wheel.
- Variation of convection film coefficient with velocity.
- Temperature distribution of different radius of railway wheel at various velocities.
- Comparison of the temperature distribution of the different material wheel at various velocities and radius of wheel.
- Stress distribution due to the mechanical and thermal load.
- Comparison of the stress distribution of this present study design to the RDSO [14] S shape design.
- Comparison of the stress distribution of this present design for the best material to the RDSO [14] wheel material.

2. MODELING

As already stated that few results have been addressed mathematically and using MATLAB. For the designing consideration, the wheel profile is modeled using the CATIA software. This model is then analyzed for its varying loading conditions using ANSYS.

2.1. Analytical Modeling of Thermal Effects

An analytical model to study the thermal analysis describing the heat transfer at the surface by friction due to the contact between the braking block and railway wheel is defined here. The heat exhausted to the entire braking system due to cooling of the surrounding air is an important parameter which is also described by this analytical model.

The heat flux evacuated of surfaces in contact (between block and railway wheel) is equal to the power friction [2].

$$(r,t) = -f_f \times r \times \omega = -f_f \times r \times (\omega_o + \alpha \times t) \quad ...(1)$$

The friction force per unit contact area [2] can be calculated by following formula:

$$f_f = \frac{\mu.F_N}{A} \quad ...(2)$$

Here A is the area of the contact surface between wheel and one breaking block and the angular velocity ω [2] can be calculated by

$$V = r \times \omega \quad ...(3)$$

The thermal analysis is performed on an EMD Locomotive of the Indian Railway, moving with different velocities (60 km/h, 80 km/h and 100 km/h respectively) and for three different radiuses (i.e. 546 mm, 625 mm and 700 mm). The time of the braking is t = 35 s which is same for all cases. So totally there are 09 cases for the analysis.

The normal braking force on one braking block [2] is taken as FN= 20379 N and the friction coefficient for materials of the wheel and block is taken as μ = 0.115.

2.1.1 Calculation of Heat flux, film co-efficient and angular velocity

The heat flux, film coefficient and angular velocity are calculated from the equation (1), (3) & (6) with the help of equation (2). Calculated values of these quantities are shown in Table 1.

This analytical model includes the heat conduction through the block and the wheel by the transient heat transfer equation [2]:

$$\rho \times C_p \times \frac{\partial T}{\partial t} + \Delta(-k \times \Delta T) = Q - \rho \times C_p \times u \times \nabla T \quad \dots (4)$$

The heat dissipation from the free surfaces of the wheel and block to the surrounding air is described by both convection and radiation [2]:

$$q_{diss} = -h \times (T - T_{ref}) - \varepsilon \times \sigma \times (T^4 - T_{ref}^4) \quad \dots (5)$$

In equation (5), to calculate the convective film coefficient [2] as a function of vehicle velocity v, following formula has been used:

$$h = \frac{0.037k_a}{2r} Re^{0.8} Pr^{0.33} = \frac{0.037k_a}{2r} \left(\frac{2\rho_a r v}{\mu_{va}}\right)^{0.8} \left(\frac{C_{pa}\mu_{va}}{k_a}\right)^{0.33} \quad .. (6)$$

Table 1: Angular velocity of the wheel, applied Heat Flux and film coefficient for different radius and velocities

Radius and Friction Force	V1=60km/h (16.66m/s)	V2=80km/h (22.222m/s)	V3=100km/h (27.778m/s)
R1=0.546 m f_f1=7421.998 N	ω=30.30 q=123699.47 h=58.0317	ω=40.40 q=164916.8 h=73.0486	ω=50.50 q=206146 h=87.32
R2=0.625 m f_f2=6531.366 N	ω=26.66 q=108856.10 h=56.5667	ω=35.555 q=145141.45 h=71.2053	ω=44.444 q=181426.67 h=85.1217
R3 =0.700 m f_f3=5831.562 N	ω=23.809 q=97190.566 h=55.299	ω=31.746 q=129590.14 h=69.6095	ω=39.6825 q=161987.67 h=83.214

2.2. Software Based Modeling of the Railway Wheel

The 3-dimensional geometric model of the railway wheel is created on CATIA software. The radius of the railway wheel is 546mm, 625mm, and 700mm and the diameter of the hub is 190mm.

To Increase the stiffness of the wheel and to reduce the heat affected zone produced in the wheel during braking, the wheel is required to be designed as a spline Fig. 1.

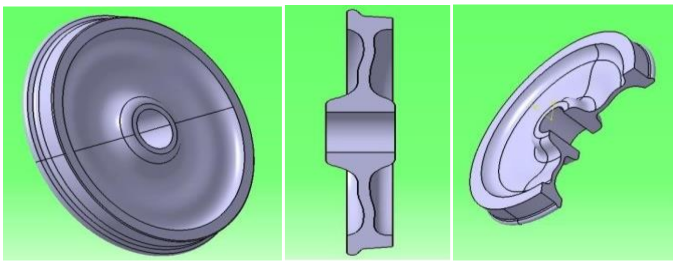


Fig 1: 3D Model and Cross-section of the S-Shape Railway wheel

2.2.1 Finite Element Mesh of Railway wheel:

The basic concept of Finite element analysis is to analyze the structure which is an assembly of discrete pieces. These discrete pieces are generally called elements, connected together at a finite number of points called nodes. A structure of these elements is called mesh. To analyze the temperature at each and every point of the braking wheel, finite element method has been used which is provided in ANSYS16. Meshing of this wheel is shown in Fig. 2. Number of elements are 65361 having 114015 nodes.

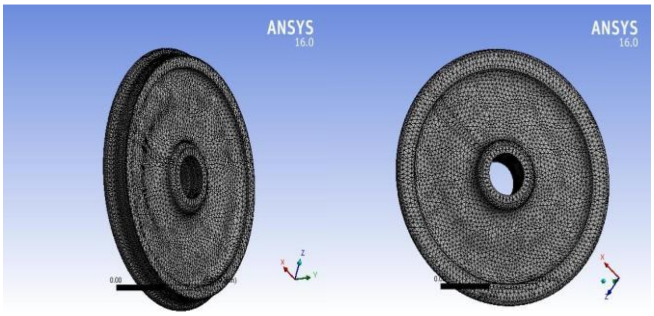


Fig 2: Meshing of solid wheel

2.2.2 Boundary Conditions:

It is necessary to apply boundary conditions after completion of the finite element model for further solution. These boundary conditions provide limiting conditions to which the entire model is subjected. Following heat transfer conditions were subjected to the analyzed railway wheel

- Heat applied on the contact surface between the wheel and one braking block.
- Heat transfer by convection for surfaces of braking block and railway wheel, but not heat transfer for the contact surface of breaking block and railway wheel.
- Heat transfer by radiation for surfaces of braking block and railway wheel but not for the contact surface of breaking block and railway wheel.

Heat input is the amount of heat transferred per unit area per unit time from or to a surface. The heat flux input to the wheel is only from the friction effects on the rim of the wheel by the braking block in braking. This Heat Flux calculated by the equation (1) and calculated heat flux is shown in Table 1. Numerical value of this heat flux is used in the ANSYS 16 Workbench according to radius and velocity of the wheel to find temperature distribution.

In railway wheel analysis, there are two modes of heat dissipation, first through the Radiation and second through the Convection. The radiation is the energy emitted by matter in the form of electromagnetic waves that comes from a source (Heat Flux). It travels through space. Radiation doesn't require any medium. Let's take the ambient environment temperature is 22^0C and the emissivity of the wheel materials is given Table 2. The convection is a combined movement of group of molecules within fluids. Convective heat transfer involves conduction (heat diffusion) and advection (heat transfer by bulk fluid flow). It is denoted by convection film coefficient which is calculated by the equation (6).

3. LOADING ON THE WHEELS

The wheels were subjected to three basic loadings viz. Vertical load, Lateral load and Thermal load. The Vertical load is the load applied to the wheels as axial load of locomotive. This includes loads on the wheels due to weight of locomotive car body, bogie frame & other supported sub-assemblies. These loads are represented by **V1** and **V2** at wheel rim & bore respectively, Fig. 3. The Lateral load is the force applied to the wheel flange due to lateral movement, curve negotiation and dynamic augmentation of locomotive represented by **L1**, Fig. 3. The Thermal load distributed on the tread surface of the wheel due to the heat generation at the time of braking represented by **TH** Fig. 3.

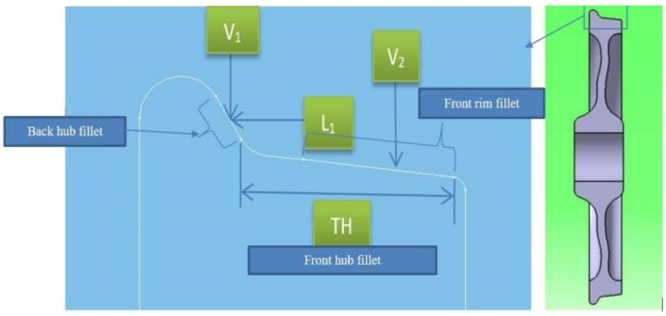


Fig -3: Load applied on the wheel profile of EMD Locomotive

3.1. Load Combinations:

Five load cases are used as per the load conditions mentioned in the specification of RDSO [14]. The load cases are as follows:

- **Load case 1 (L1+V1):** Vertical load V1 (21000 Kg) + Lateral load L1 (10500 Kg)
- **Load case 2 (V2):** Vertical load V2 (21000 Kg)
- **Load case 3 (TH):** Thermal load TH (18.67 KW)
- **Load case 4 (V2+TH):** Vertical load V2 + Thermal load TH
- **Load case 5 (L1+V1+TH):** Vertical load V1 + Lateral load L1+ Thermal load TH

4. DIFFERENT RAILWAY WHEEL MATERIALS AND THEIR PROPERTIES

In this study, four different types of material have been used and then comparison has been done among each material. Properties of these four materials along with the properties of air are described in Table 2.

- Material M1: (AISI 1039) UNS (G10390) [15]
- Material M2: (AISI 1010) [16]
- Material M3: (AARM107/208, EN1326) [7]
- Material M4: (AAR S-660) [14]

Table 2: Properties of wheel materials along with air

Property	M1	M2	M3	M4	Air
ρ (kg/m^3)	7850	7872	7833.41	7820	1.17
Cp (J/kg-k)	486	448	457.5	427	1100
K (W/m-k at 100 ^{0}C)	50.7	60.7	49.83	48.6	0.026
ε	0.28	0.29	0.3	0.2	-
μva(Pa-S)	-	-	-	-	1.8×10^{-5}

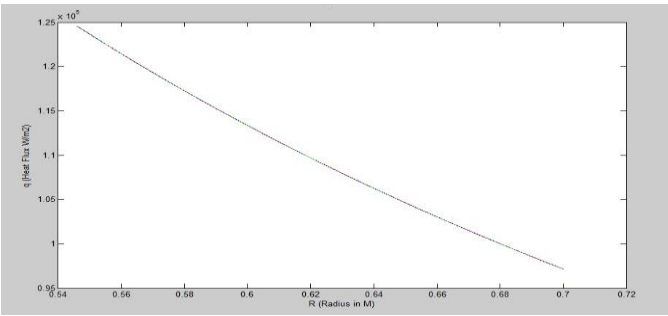
5. RESULTS OF THERMAL ANALYSIS OF EMD LOCOMOTIVE WHEEL

The results are generated on MATLAB and ANSYS with the help of mathematical modeling equation. There is the brief thermal analysis of the EMD Locomotive.

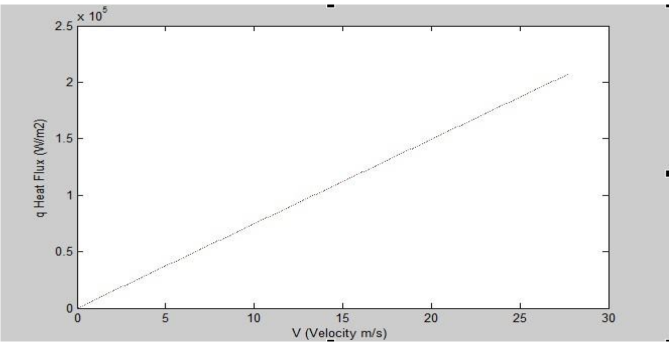
5.1. Graphs of Heat Flux and Convective Film Co-Efficient

The graphs are generated on the MATLAB using the equation (1), (2), (3) and (6). Fig. 4(a) demonstrates the variation of heat flux along wheel radius at 60 km/h velocity.

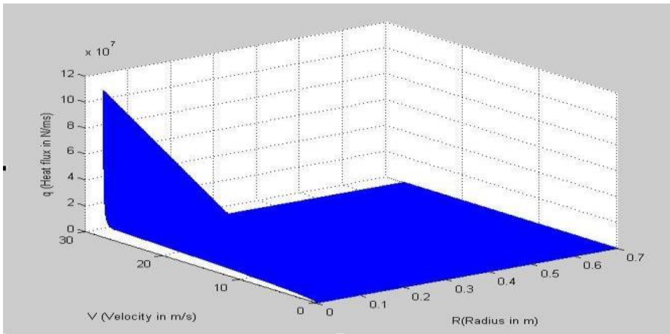
From equation (1), (2), (3) and above Fig. 4 (a), it is shown that heat flux decreases as wheel radius increases. This is because area increases if radius increases, and friction force decreases as area increases and if friction force decreases then heat flux also decreases.



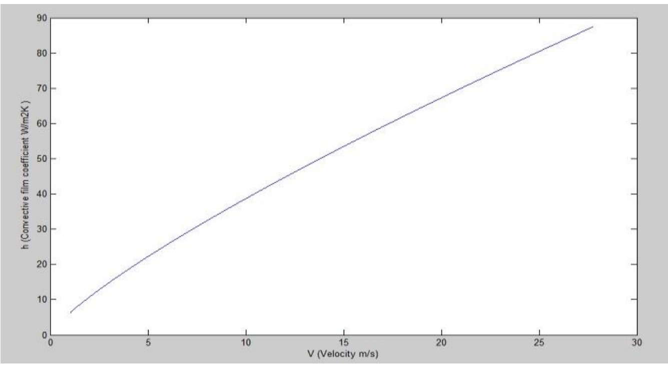
(a)



(b)



(c)



(d)

Fig 4: Graphs represent (a) Variation of Heat Flux along wheel radius at 60 km/h, (b) Variation of Heat Flux along velocity for wheel diameter 1092mm, (c) Variation of Heat Flux along radius and velocity, (d) Variation of conv. film co-eff. along velocity for wheel dia. 1092mm

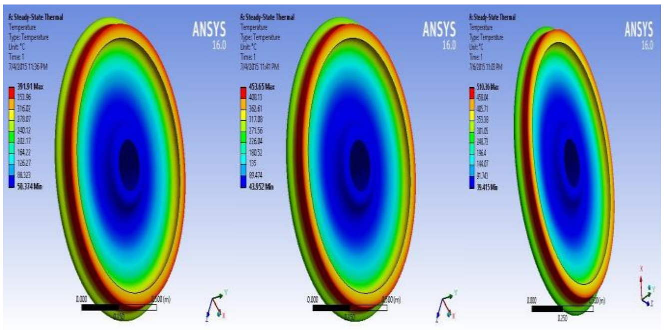
All of this suggests that heat flux is inversely proportional to the wheel radius. Fig. 4(b) demonstrates the variation of heat flux along velocity for wheel diameter 1092mm. From equation (1) and (3) it is shown that heat flux is directly proportional to velocity. Fig. 4 (c) demonstrates the variation of heat flux along velocity and radius from the equation (1), (2) & (3). Fig. 4 (d) demonstrates the variation of convective film coefficient with respect to velocity from the equation (6)

5.2. Result of Thermal Analysis

The Fig. 5, Fig. 6 and Fig.7 show the calculated temperature distribution of the wheel, due to the braking on the wheel. As the velocity of the EMD locomotive increases, the generated heat due to the friction between contact surfaces increases. Temperature on the rim of wheel is also increases.

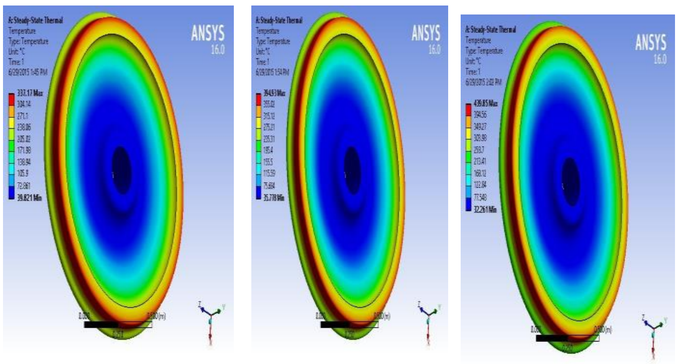
There S-shape wheel diameter 1094mm were originally fitted in EMD locomotive, are analyzed on the ANSYS for three velocity (60km/h, 80km/h, 100km/h) and three radius (546mm, 625mm, 700mm). AAR S-660 materials (M4) used in the EMD locomotive.

Temperature distribution is shows in Fig. 5, Fig. 6 and Fig.7.



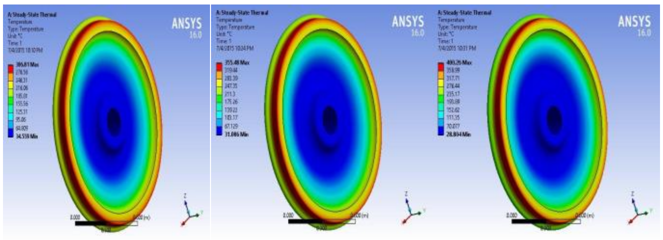
(a) (b) (c)

Fig 5: Thermal analysis of wheel radius 546mm at velocity (a) 60km/h (b) 80km/h (c) 100km/h



(a) (b) (c)

Fig 6: Thermal analysis of wheel radius 625mm at velocity (a) 60km/h (b) 80km/h (c) 100km/h



(a) (b) (c)

Fig 7: Thermal analysis of wheel radius 700mm at velocity (a) 60km/h (b) 80km/h (c) 100km/h

From the above figures it can be say that as increases the velocity, temperature at constant radius increases. This is because heat flux increases as increases the velocity at constant radius from the Fig. 4(b). So temperature will also increase as increases the heat flux from the equation (5). It can also be say that increases the radius, decreases the temperature at constant velocity. This is because heat flux decreases as increases the radius at constant velocity from the Fig. 4 (a). So temperature will also decrease as increases the heat flux from the equation (5). Temperature distribution on the wheel for three radiuses and three velocities are shown in the Table 3.

Table 3: Min and Max temperature (ºC) at the wheel rim

Radius (m)	V1=60km/h		V2=80km/h		V3=100km/h	
	Min(T) ℃	Max(T) ℃	Min(T) ℃	Max(T) ℃	Min(T) ℃	Max(T) ℃
R1=0.546	50.37	391.91	43.92	453.65	37.67	510.36
R2=0.625	39.82	337.17	35.77	394.93	32.26	439.85
R3=0.700	34.55	306.81	31.08	355.48	28.80	400.26

5.3. Results of Temperature Distribution Comparison of Various Materials

Four different types of materials i.e. AISI 1039, AISI 1010, AAR M107/208 and AAR S660 have been used in this analysis which is shown in Table 2. The wheel domain for these materials with three different radiuses i.e. 546mm, 625mm and 700mm are analyzed for the three velocities conditions viz. 60km/h, 80km/h and 100km/h respectively. Table 4 showcases the maximum temperature values according to the respective radius, velocity and material.

Table 4: Temperature (ºC) at the wheel rim

		V1=60km/h	V2=80km/h	V3=100km/h
R1 (546mm)	M1	381.09	441.29	496.5
	M2	358	411.9	461.76
	M3	383.47	443.08	498.79
	M4	391.91	453.65	510.36
R2 (625mm)	M1	331.99	384.64	433
	M2	311.53	358.69	402.2
	M3	333.17	386.3	435.2
	M4	337.17	394.9	439.8
R3 (700mm)	M1	298.99	346.45	390.09
	M2	279.22	322.87	362.12
	M3	399.4	348.09	392.19
	M4	306.81	355.48	400

Thermal conductivity is the main factor to decreasing the temperature. As increase the thermal conductivity, decrease the maximum temperature. The maximum temperature is generated by the friction between braking block and wheel.

From Table 4, it can be see that material M2 has minimum temperature in all case because its thermal conductivity is greater than all materials. So it is the best Material in terms of temperature distribution. Thermal stress depends on the temperature distribution. It reduces the temperature distribution so thermal stress also reduces.

6. RESULTS OF COMPARASION BETWEEN STRESS ANALYSES TO THE RDSO

This paper is based on comparative analysis of indigenous wheel designed to RDSO [14] wheel for EMD Locomotives. RDSO make 1092mm diameter S-shaped wheels which are originally fitted in EMD locomotives. The present Paper develop an S-shaped wheel for these locomotives to design and FEM analysis has been done to analyze the stress levels in wheel under the same simulated loading conditions. Material of both wheel is M4 (AAR-S660), its mechanical and thermal properties given in table 2. Stress analysis of wheel for different loading conditions (as explained earlier) is given as following:

6.1. Results of Stress Analysis

6.1.1. Load Case 1 (L1 + V1):

Vertical load (V1) has been applied at the flange of the wheel vertically in downward direction. Lateral load (L1) has been applied at flange of the wheel. Restraints (R) have been taken at surface of wheel bore.

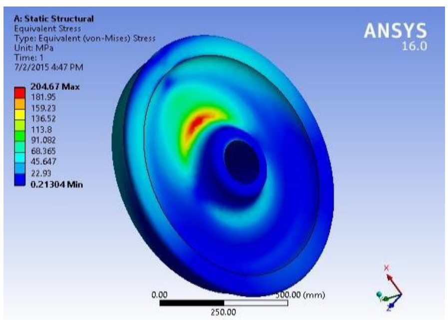


Fig.8: Stress distribution on the wheel of EMD Locomotive

6.1.2 Load Case 2 (V2):

Vertical load (V2) has been applied at a distance of 25mm from the front rim face on tread of the wheel in downward direction. Vertical (R) has been taken at surface of wheel bore.

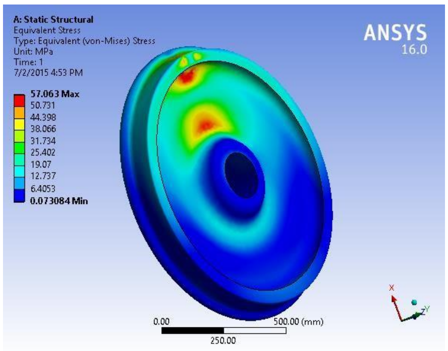


Fig.9: Stress distribution on the wheel of EMD Locomotive

6.1.3 Load Case 3 (TH):

Thermal load (TH) has been applied at surface of the tread to simulate braking.

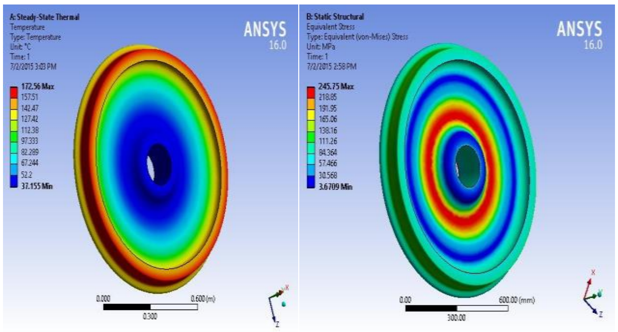


Fig. 10: (a) and (b) Temperature and Stress distribution of EMD Locomotive

6.1.4. Load Case 4(V2 + TH):

Axle load (V2) has been applied vertically at front face of the wheel in downward direction. Vertical (R) has been taken at inner surface of wheel bore. Thermal load (TH) has been applied at surface of the tread to simulate braking. The loading are shown in Fig 3.

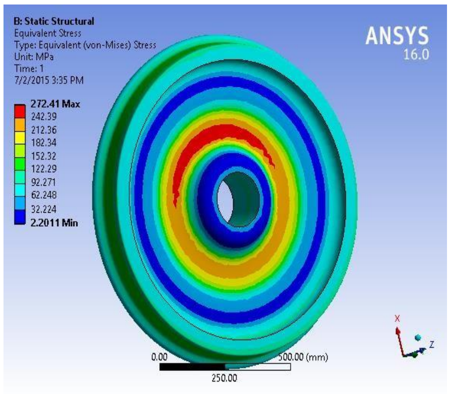


Fig. 11: Stress distribution on the wheel of EMD Locomotive

6.1.5. Load Case 5(V1+L1+TH):

Axle load (V1) has been applied vertically at the flange of the wheel in downward direction. Lateral load (L1) has been applied at the flange of the wheel. Vertical & lateral restraints (R) have been taken at inner surface of wheel bore. Thermal load (TH) has been applied at surface of the tread to simulate braking.

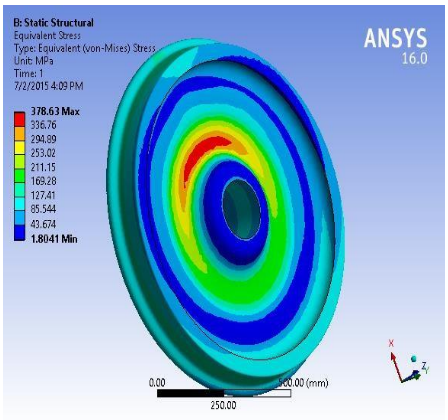


Fig. 12: Stress distribution on the wheel of EMD Locomotive

The results thus obtained from the above analysis are summarized in the Table 5

Table 5: Comparison of this present design to RDSO [14] design for various loading conditions

S.No.	Load Cases	Parameter	RDSO Design		This present design		
			Location	Value	Location	Value	%Less by RDSO
1	L1+V1	Max. Stress (N/mm2) or (MPa)	Back hub fillet	221	Back hub fillet	204.67	7.39

2	V2	Max. Stress (N/mm2) or (MPa)	Front rim fillet	92	Front rim fillet	57.063	37.9
3	Thermal Load (TH)	Max. Temp. (^{0}C)	Tread/ Axisymmetric	196	Tread/ Axisymmetric	172.56	11.95
		Max. Stress (N/mm2) or (MPa)	Front hub fillet/ axisymmetric	258	Front hub fillet/ axisymmetric	245.7	4.7
4	V2+TH	Max. Stress (N/mm2) or (MPa)	Front hub fillet	305	Front hub fillet	272.4	10.75
5	L1+V1+TH	Max. Stress (N/mm2) or (MPa)	Front hub fillet	383	Front hub fillet	378.63	1.14

In load case 1, the maximum stress of 204.67 N/mm^2 has been obtained at back hub fillet location in this present design and maximum stress of 221 N/mm^2 has been obtained in RDSO [14] design also at the same location. In load case 2, the maximum stress of 57.063 N/mm^2 has been obtained at front rim fillet location in this present design and maximum stress of 92 N/mm^2 has been obtained in RDSO [14] design also at the same location. In load case 3, the maximum stress of 138 N/mm^2& 245.7 N/mm^2 (MPa) have been obtained at tread & front hub fillet/ axisymmetric in this present design and maximum stress of 196 N/mm^2 and 258 N/mm^2 have been obtained in RDSO [14] design also at the same locations. And the maximum temperature 172.56 ^{0}C has been obtained at the tread of wheel in this present design and maximum temperature 196 ^{0}C has been obtained in RDSO [14] design also at same location. In load case 4, maximum stress of 272.4 N/mm^2 has been obtained at Front hub/180^0 location in this present design and maximum stress of 305 N/mm^2 has been obtained in RDSO [14] design also at front hub/180^0 location. In the load case 5, the maximum stress of 378.63 N/mm^2 has been obtained at front hub/180^0 location in this present design and maximum stress of 383 N/mm^2 has been obtained in RDSO [14] design also at front hub/180^0 location.

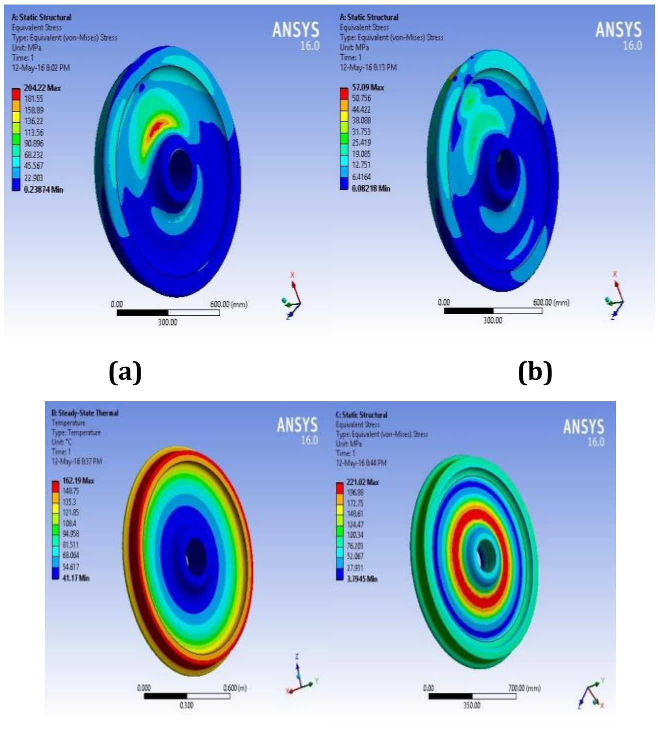
From the above analysis, it is clearly seen that this present design of EMD locomotive wheel is better as compared to the RDSO [14] design under the simulated operating conditions mentioned above. This comparison has been done by taking same material M4 (AAR S-660) for same load conditions.

It is evident from Table 4, that the material M2 gives lower maximum temperature for different radius and different velocities. So material M2 (AISI 1010) is the best material on the basis of temperature among various materials those have taken for analysis. A comparative analysis could also be performed between material M2 and M4 to find best material which gives lower temperature and stresses for different loading conditions, which is shown below.

6.2 Comparison between M4 & M2:

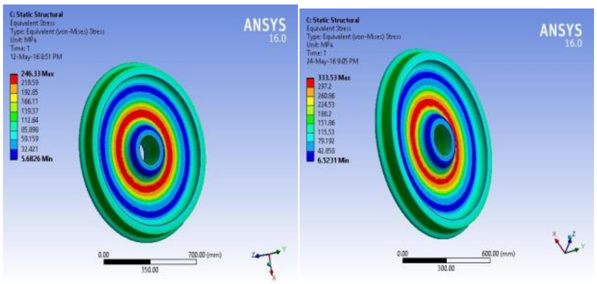
6.2.1 Thermal and Stress analysis of M2 on different loads:

This present design is analyzed by taking material M2 for different load conditions. Different load combinations, shown in Fig. 3, are applied on this present design for material M2. Thermal and stress analysis for these load combinations has been shown in following Fig. 13.



(a) (b)

(c) (d)



(e) (f)

Fig. 13: Thermal and stress analysis of this present design for material M2 which is represent in (a) Load Case 1 (L1 + V1), (b) Load Case 2 (V2), (c) Load Case 3 (TH) Temperature distribution, (d) Load Case 3 (TH) Stress distribution, (e) Load Case 4(V2 + TH), (f) Load Case 5(V1+L1+TH)

Table 6: Comparison of the design for material M2 and M4for various loading conditions

S.No.	Load Cases	Parameter	This present design for Material M4		This present design for Material M2		Difference
			Location	Value	Location	Value	
1	L1+V1	Max. Stress (N/mm2) or (MPa)	Back hub fillet	204.67	Back hub fillet	204.22	0.45
2	V2	Max. Stress (N/mm2) or (MPa)	Front rim fillet	57	Front rim fillet	57	0
3	Thermal Load (TH)	Max. Temp. (ºC)	Tread/ Axisymmetric	172.56	Tread/ Axisymmetric	162.19	10.37
		Max. Stress (N/mm2) or (MPa)	Front hub fillet/ axisymmetric	245.7	Front hub fillet/ axisymmetric	221.02	24.68
4	V2+TH	Max. Stress (N/mm2) or (MPa)	Front hub fillet	272.4	Front hub fillet	246.33	26.07
5	L1+V1+ TH	Max. Stress (N/mm2) or (MPa)	Front hub fillet	378.63	Front hub fillet	333.53	45.1

From the Table 6 it can be see that material M2 is much better than Material M4 (Railway wheel EMD Locomotive material). Material M2 is having much lower maximum stresses and maximum temperature for different loads cases than material M4, which has been shown in above Table 6.

7. CONCLUSIONS

In the existing model of the EMD Locomotive, the heat generated on the wheel due to the friction between block and wheel rim. The maximum temperature is obtained on the rim (coning of wheel Tread) and minimum temperature is obtained on the wheel hub. It means that the distribution of temperature of the wheel from the rim to hub is in decreasing order.

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- This present Design for the EMD locomotive wheel profile obtain the maximum temperature 391.9 ºC on the rim which is less than the maximum temperature 437.22 ºC at same speed 60 km/h [2].

- Temperature distribution on the wheel of different radius and different velocity for various materials viz. M1 (AISI 1039), M2 (AISI 1010), M3 (AARM107/208, EN1326) and M4 (AAR S-660) and also the comparison of the temperature distribution on the wheel with respect to different wheel materials has been shown. On the basis of minimum temperature, material M2 is the best material.

- The maximum temperature obtain on the rim of the wheel in ascending order in terms of material at a constant velocity, is M2<M1<M3<M4.

- The result can be helpful in predicting the maximum temperature in the railway wheel according to its running condition or operating speeds.
- In the whole analysis, it is found that EMD locomotive wheel has minimum temperature (279.2ºC) for material M2 (AISI 1010) among various materials at radius 700mm and velocity 60 km/h. Also the wheel has maximum temperature (510.36 ºC) for material M4 at velocity 100 km/h and 546 mm radius.
- As the radius increase the maximum temperature on the rim decreases.
- From the above discussion it can be see that this present re-profile design give much better result of temperature and stresses for various loading condition (same as applied by RDSO [14]) than RDSO wheel profile.
- From the above discussion, it is proposed that material M2 (AISI 1010) is much better than RDSO [14] railway wheel's material M4 (AAR S-660) because of having much lower thermal stresses and temperature on different loads than material M4. So material M2 can be used for designing of EMD locomotive Railway wheel.

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