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Analysis of Railway Wheel to Study the Stress Variations

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***Abstract*— Wheel is one of the most intensively loaded components of rolling stock. When the brakes are applied, friction is generated between the wheel tread and the brake block, through which energy is dissipated. This friction generates heat which results in thermal loads on the wheel in addition to static and dynamic loads during their service. These thermal loads along with structural loads may cause failure of the wheels if they not designed properly. The present paper describes the behaviour of the wheel due to structural and thermal loads, as well as combined loading. For this investigation, stress analysis was carried out on rail loco wheel by using analysis software ANSYS, which was modelled as axisymmetric model using PRO-E. Also study has been done on the effect of re-profiling of the wheel on deformations and stresses due to both thermal and mechanical loads.**

I. Introduction

The failure occurring on the railway wheels are caused by thermal loads. About 80% of wheels were re-profiled due to thermal damage. Rail systems exploit friction to transmit power, therefore high cyclic loads, and dynamic loads and heat generation are inevitable. Premature rail replacement, re-profiling of wheels, increased noise, reduced performance and failure are the consequences of this phenomenon. Research is carrying out to define new design of wheel which is as little as possibly sensitive to thermal and structural combined loading.

Pramod Murali Mohan [2] was carried out the analysis of railway wagon wheel to study Thermal and Structural Behaviour" when subjected to thermal, structural and combined loading. That was intended to outline a simple first stage analysis of railway wheel and the analysis result depicts the behaviour of wheel for varying loading conditions.

The wheels must support the weight of the car and steer it on the rails. The wheels also act as brake drums. The brake shoes are applied directly to the wheel tread in order to stop or slow down the train. The wheels must withstand tremendous amounts of abuse from extreme thermal and mechanical stresses caused by factors such as brake shoe friction and high dynamic loading.

In railroad service the wheel acts as a brake drum in addition to supporting lateral and vertical mechanical loads. When brake shoes are applied to the wheel tread, the tread surface is heated due to friction. Severe thermal input into a wheel occurs when a loaded train descends a grade for an extended period of time. Also, the failure of the brake mechanism may keep the brake locked on the tread of the wheels. On these occasions, the wheel rim is heated to a high temperature for an extended period of time. The steel on the tread surface and in the rim under the tread surface gets hotter and tries to expand. The steel in the hotter part of the wheel rim will have a reduced yield strength and the compressive thermal stress will be higher than the yield strength. Therefore, the hotter part of the wheel rim will yield. However, during the wheel cooling, the situation is reversed. The tread surface and top part of the rim get cooler and shrink first. They are constrained by hotter lower part of rim and are in tension. After cooling and shrinking, the material in the top wheel rim could now be in tension due to the locally yielded material in the rim. As the result, the residual stress could be altered to tensile from compressive that is generated during the heat treatment.

Thermal fatigue due to repeated brake applications may initiate and propagate thermal-cracks. The presence of a thermal crack in a wheel with tensile residual stress in the rim may lead to failure by brittle mode rim fracture initiated from the thermal crack. Therefore, it is important to know the residual stress change in a wheel.

Fig.1 [1] shows the railway wheel profile which has been used for modelling and analysis.

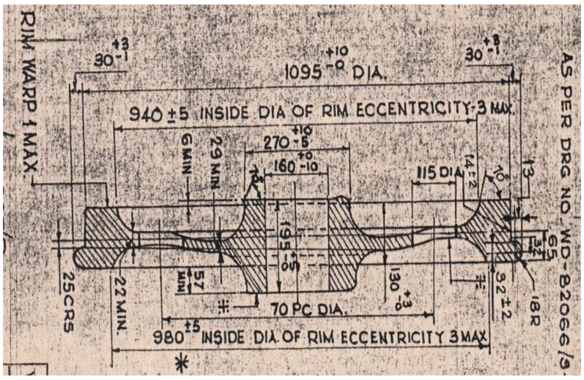

Fig1.Cross section of railway wheel

II. Problem Description

railway wheel was used for analysis, which was taken from the railway wagon workshop. The wheel was designed in PRO/E, and then it was modelled into ANSYS as a 2D axisymmetric model for the analysis. The analyses has been carried out are static, thermal and combined loading (static and thermal). Then after the rail wheel was re-profiled by considering a fillet at the interface of the wheel, and analysed by the above three analyses. The results are compared by plotting graphs between fillet radius and displacements, stresses. The following assumptions were considered during analysis.

- Due to intensive braking, there will be an increase in train traction consumed energy and thermal load. This is done to maintain the train speed constant.
- Considered a typical case of a 4 wheel bogie that carries a load of 220KN. The bogie is travelling at 80KM/h is brought to rest through one brake shoe on each wheel in 30s.
- Heat generated is uniformly distributed around the periphery of the wheel.
- Apart from the thermal load generated due to braking, the wheel is also subjected to a vertical load and horizontal load of 320KN and 160KN.
- The bogie load is equally distributed to the four wheels.

A. FE Model:

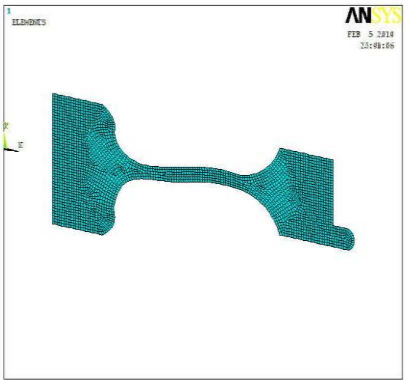

Fig2. FE model of railway wheel.

A solid wheel is used for analysis which presents the dominate influence of thermal loads. Because of axisymmetric nature of both the geometry and load, a two-dimensional axisymmetric model of the wheel cross section was constructed by using 8-node 2-D isoparametric elements. The same finite element mesh was used for both the thermal and mechanical analyses. However, different ANSYS element types were used: PLANE 77 for the thermal analysis and PLANE 183 for the structural analysis.

PLANE 77 is a 2-D, 8-node thermal solid and is a higher order version of the 2-D, 4-node thermal element. The element has one degree of freedom, temperature, at each node. The 8-node elements have compatible temperature shapes and are well suited to model curved boundaries.

PLANE 183 is a higher order 2-D, 8-node or 6-node element. It has quadratic displacement behaviour and is well suited to modelling irregular meshes. It has two degrees of freedom at each node, translations in the nodal X and Y directions.

B. Material Properties:

The material selected for the analysis is AAR M107 class U [3], is ductile in nature and it is a high carbon steel with a carbon percentage of 0.6-0.79 percent. The following table depicts the material properties used for analysis.

Property	**SI units**
Thermal conductivity	49.83063e-3W/mm-k
Specific heat	0.45757e3 J/ Kg-K
Density	7833.4114e-9 Kg/mm^3
Young's modulus	2.012e5 N/mm^2
Poisson ratio	0.3
Coefficient of thermal expansion	1.69971e-5 m /mm-K
Film coefficient	28.3768e-6 W/mm^2-K
Bulk temperature	291.11K

C. Loads and Boundary Conditions:

Wheels are heat treated to improve the wear resistance, and imbibe the circumferential residual compressive stress in the wheel's upper rim. These are meant to prevent fatigue cracks. This also includes axial tensile stress which could cause rapid fracture added with impact and thermal load.

- Case 1: Structural Analysis

In the static position the hub is fixed to the axle and total load is acting on the wheel rim. So the hub was constrained so that there is no deflection in the hub and restrains to rigid body motion. And the total load acting on rim is applied as vertical load of 320KN and a horizontal load of 160KN. Fig.3 shows the vertical and horizontal load applied on the wheel under consideration.

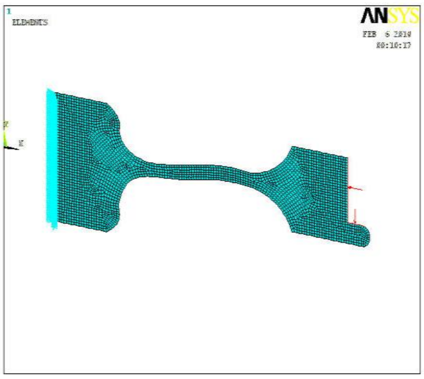

Fig3. Structural load and boundary condition applied on the wheel.

- Case 2: Thermal Analysis

The boundary conditions applied are hub of the wheel is considered to be maintained at ambient temperature, the edges of the plate are subjected to heat transfer as air is in contact with the outer surface and the rim edges which are in contact with the rail undergoes heat generation due to friction. This heat flux is calculated as,

The diameter of the wheel from the hub is 467.5mm. The width of the rim that is in contact with the rail is approximately 98.04mm for the selected wheel.

Load acting on for wheels = 220KN = 22426.0958Kg.

Load acting on one wheel (m) = 5606.5239Kg.

Velocity of the bogie (v) = 80KM/h = 22.22m/s.
Time the bogie brought to rest = 30s.
Kinetic energy generated at wheel = $0.5*m*v^2$ = 138432608 J.
Power generated = kinetic energy / time taken = 46144.226 W.
Area = π*diameter of wheel*width = $143990.815 mm^2$.
Heat flux generated = power generated / area = 0.320466454 W/mm^2
Fig.4 shows the thermal load and boundary conditions applied on the wheel.

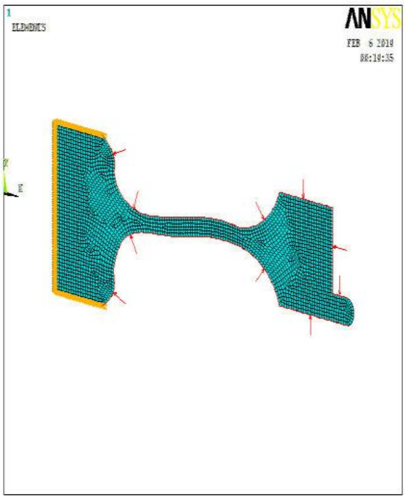

Fig4. Thermal load and boundary conditions applied on the wheel.

- Case 3: Combined Loading Analysis

In this analysis both thermal and structural loads are applied on the wheel. Fist we solved the static loading problem and then thermal loads are applied as body loads. Then the problem is under combined loading condition and then it was solved.

- Case 4:

The wheel was re-profiled by considering a fillet at the interface. The above analyses (static, thermal and combined loading) were done on the re-profiled wheel and the results are taken. From these results a graph was drawn between the fillet radius and the displacements, as well as stresses.

III. Results and Discussion:

The analysis has been done for the original profile and also for the changed wheel profile, by considering a fillet at interface. And the results are compared for these two analyses. Graphs are plotted for displacements and stresses verses fillet radius, by changing the fillet radius at interface of the wheel.

A. *Case 1: Structural Analysis*

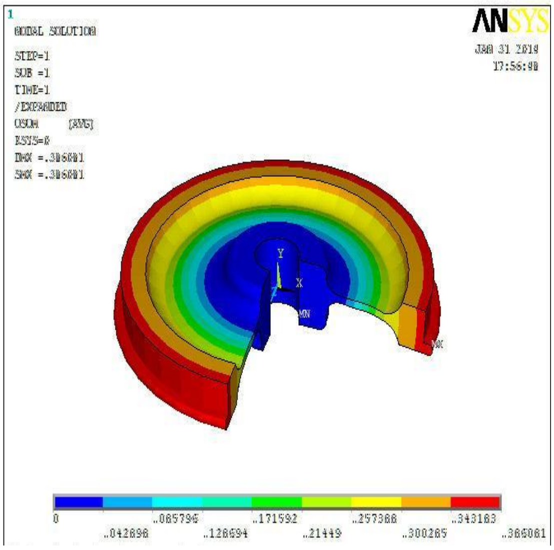

Fig5. structural displacement of the wheel due to structural loads.

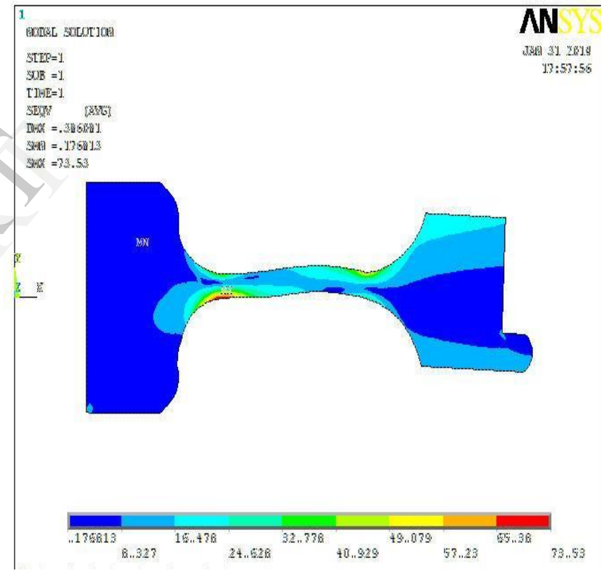

Fig6. Von mises stress distribution due to structural loads.

Fig.5 and fig.6 shows the structural displacement and von mises stress distribution for the structural loads acting on the wheel. The maximum deflection is observed as 0.386061mm at the rim portion of the wheel. The maximum stress is observed at the bottom portion of the plate with a stress of 73.53 N/mm^2. This along with the pre-stressed state of the plate has induced the maximum stress in the region.

B. Case 2: Thermal Analysis

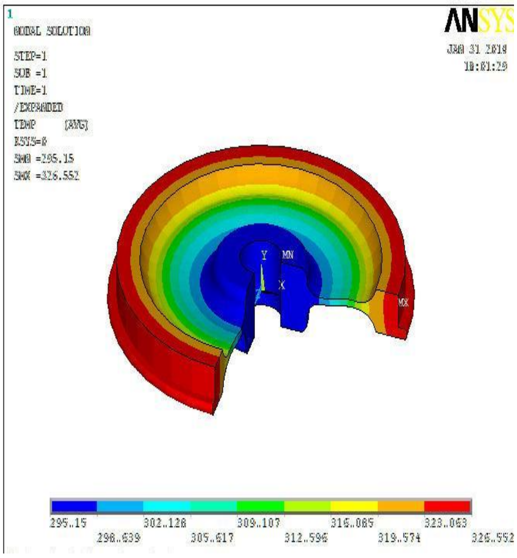

Fig7. Temperature distribution of the wheel.

The above fig.7 shows the steady state temperature distribution in the uniform annular disc. The maximum temperature attained is at the rim with a temperature of 326.552K. Due to convection around the plate of the wheel the temperature reduces even though it is conducted towards the web. If effective cooling is not employed and due to excessive braking, residual thermal stress will get induced which will lead to wear and fatigue failure of the wheel.

C. Case 3: Combined Loading Analysis

The displacement and von mises stress distribution due to combined loading is as shown in fig.8 and fig.9. Since temperature is applied as body load, thermal stresses are developed in the wheel. This along with the vertical and horizontal load has led to 0.876239mm of deflection of the wheel as compared to 0.386081mm of deflection due to structural loading. The maximum stress attained is 218.464N/mm^2 as compared to 73.53N/mm^2 during structural loading. Large amount of stress is induced due to thermal load.

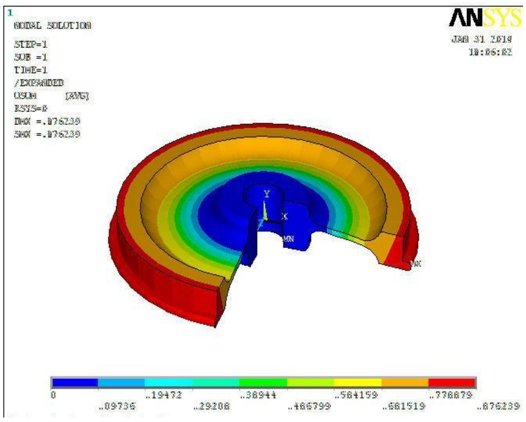

Fig8. Displacement due to combined loading.

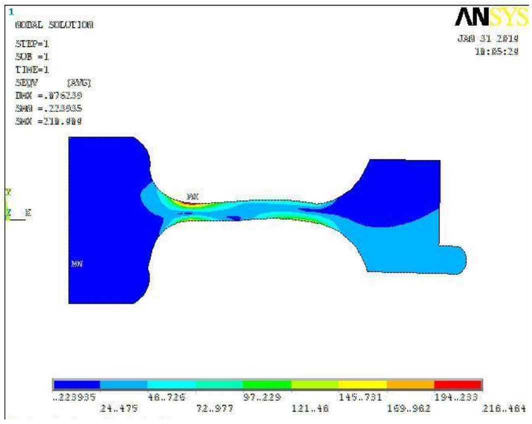

Fig9. Von mises stress distribution due to combined loading.

D. Case 4:

And then the wheel was re-profiled by considering a fillet at the interface. The above analyses (static, thermal and combined loading) were done on the re-profiled wheel and the results are taken. From these results a graph was drawn between the fillet radius and the displacements, as well as stresses. The following figures show graphs between fillet radius verses displacement, stress and temperature. Fig.10, Fig.11, Fig.12 depicts the variation in displacement, stress and temperature when the fillet radius was changed during static and thermal analysis.

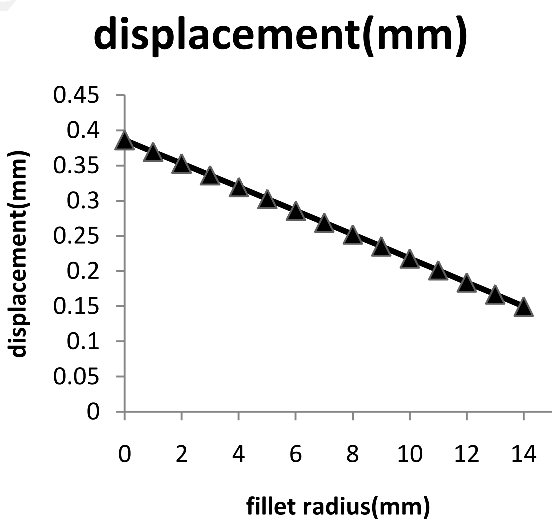

Fig10. Displacement variation in the wheel during static analysis.

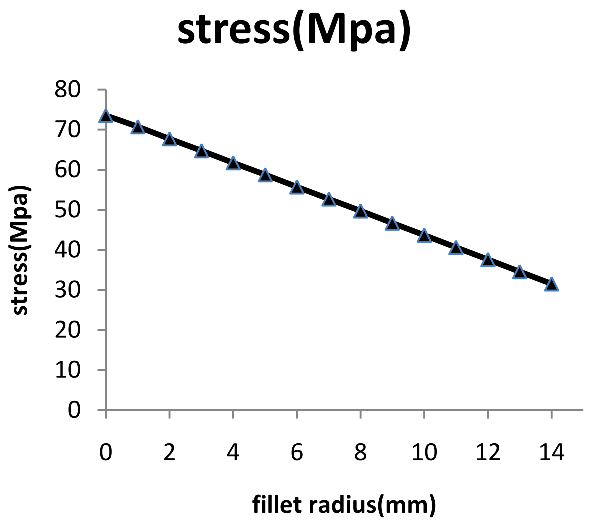

Fig11. Stress variation in the wheel during static analysis.

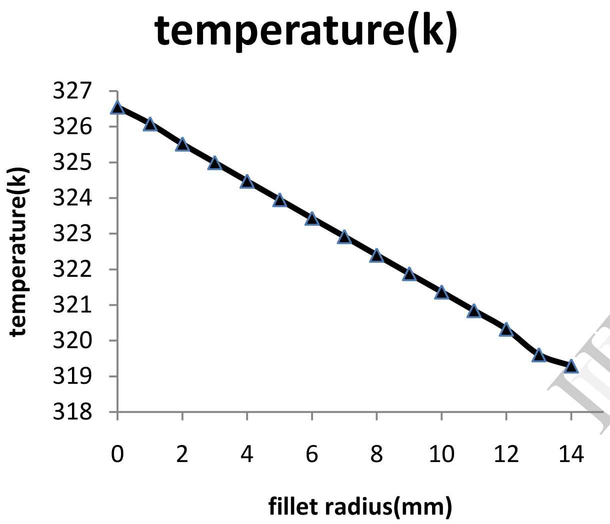

Fig12. Temperature variation in the wheel during thermal analysis.

Combined loading analyses are also done by varying the fillet radius of the rim. And the graphs are plotted as shown below.

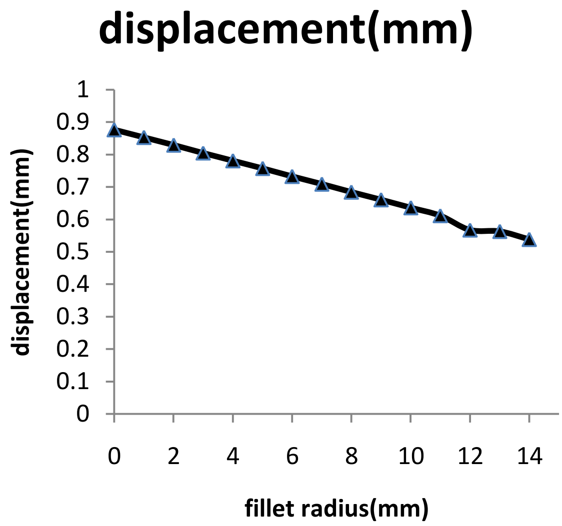

Fig13. Displacement variation of the wheel during combined loading.

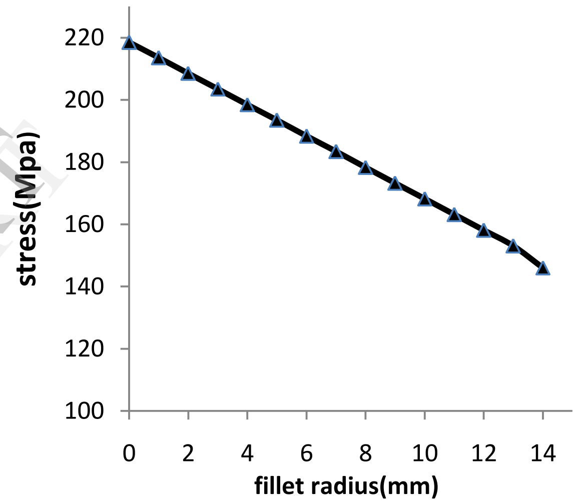

Fig14. Stress variation of the wheel during combined loading.

Fig.13, Fig.14 results the variations in the displacements and stresses with the effect of change in the fillet radius during combined loading. From the above figures we can say that by increasing the fillet radius, the displacements and stresses are decreased. And less stress causes to less failure.

IV. CONCLUSION:

Static analysis of a railway wagon wheel was carried out to evaluate the magnitude of the von-mises stress under both mechanical and thermal load generated during braking operation of the wagon. It is concluding that the induced deformations and stress are within the allowable limits. Also to reduce the magnitude of the induced stresses, profile modification for the wheel was suggested. With the profile modification the induced stresses are lower than the values without modification.

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