International Journal of Research in Engineering, Science and Management
Volume-1, Issue-5, May 2018
www.ijresm.com

Stress Analysis on Rail Wheel Contact

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***Abstract*—The report describes a detailed analysis of the wheel/rail interaction of railroad car wheels. The main goal is to determine the contact stresses due to mechanical loading under static conditions. Knowledge of, and the ability to predict, these stresses is useful in assessing the ability of wheels to perform safely under expected service contacts and is useful for wear predictions. Stresses in Wheel/Rail are important as they determine the capacity to carry load and failure in operation. Stress analysis can be done using Analytical methods, Experimental methods, and using tools like Boundary Element Method, Finite Element Method etc. In the present work stress analysis of Wheel/Rail is carried out with Finite Element based on the commercial software ANSYS.**

Index Terms—Ansys, Finite Element Method, Rail, Solid Works, Wheel

I. Introduction

Railroad vehicles are among the most widely used methods of transporting passengers and goods. So, the study of rail-wheel interaction is one of the fundamental areas of research in the railway engineering. As trains operating speed increases, safety, and comforts remain paramount concerns. In present years, loads on an axle of railway cars increase because of increase in transport of goods and faster infrastructural growth. High contact stresses are observed over the rail wheel contact area. The railway wheels mainly fail due to fatigue under these loads. These complicated geometries are solved using Finite element analysis software's. The present work is focused on the interaction between rail track and wheels. The principal parts of the rail are:

- The head that is in contact with the wheels,
- The foot that is connected with the sleepers and
- The web that connects together the head and foot part of the rail, and its help to connect the two rails at rail joint.

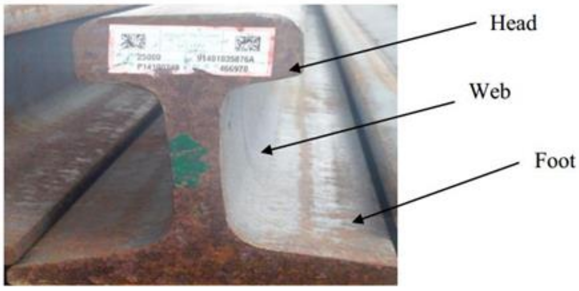

Fig. 1. Rail profile

Rail is a critical track element subjected to wheel loads and must withstand various loads applied and transfers them to the underlying supports. Rail track is in direct contact with the rolling stock. Therefore, it is necessary, for safety and to ensure the proper functioning of rails in the track system.

Defects in a rail occur from fatigue cracks that form and grow in the rail as a result of cyclic forces caused by repeated passage of trains. The running trains create discontinuities on surface of the rails. These discontinuities produce different static and dynamic stresses on the running surface.

Interaction in the contact zone between a wheel and rail is determined under static load of the vehicle and by various physical phenomena that occur in the contact zone. The wheel and rail interaction, which may be severe in curves, has a significant effect on the present work stress analysis of wheel/rail for two different rail profiles that are carried out as they have significant effect on the contact state using Finite Element Method.

The main purpose of this paper is to analyze various types of stress and its effect on the rail wheel contact at different location of the standard rail due to the presence of the vertical wheel load by using 3D finite element method. It helps to demonstrate how stresses contribute to the wear and deterioration of the rail track with different support location. The ultimate goal of this study is neither to reduce stress nor to succeed the rail joint, rather to show stress distribution, strain, deformation, and their contributions to wear standard rail joint.

II. Literature Review

This section of the paper reviews the previous studies, which are assisting to introduce the current study. Some of them are direct and the others are indirectly related to the current study. However, it is useful to develop the recent idea.

Telliskivi ET at. [1] Developed ANSYS macros that will generate wheel rail contact models from a measured wheel and rail profiles. Analysis was carried out for various wheel rail profiles and results were compared with traditional methods. This work does not include the effect of thermal loads.

Rail wheel failures in service have been reported by Wise [2], Edel and Schaper [3], Michael and Huseyin [6] and Ramanan et al. [5]. The failure in the disc region is found to be more common than the failure in the tread region failures. Wise [2] has discussed extensively the evolution of wheel sets and has outlined the changes that occurred in the wheel design during the last 30 yr. Wise briefly described different failures experienced by the rail wheel and explained the necessity to quantify the stress distribution due to mounting of the axle into the wheel.

Contact region fatigue of railway wheels under combined mechanical rolling pressure and thermal loads has been extensively studied by Lunden [6] by considering the problem using an axisymmetric model. The mechanical load acting on the wheel was approximated as a time-variant axisymmetric pressure. This pressure was calculated based on the Hertzian contact between the wheel and the rail.

Lunden [7] formulated a mathematical model, for the prediction of relative life times of railway wheel, exposed to block braking under stop braking cycles. Analytical and finite element thermo elastic calculations are employed together with a model for low-cycle fatigue.

Fermer and Lunden [8] established a linear analytical model for calculating transient axisymmetric temperature distributions in finite hollow cylinders and adopted for practical use. The thermal power from braking is applied as prescribed heat influxes over parts of the lateral and radial surfaces of the cylinder.

American association of rail standards [12] established the standards for the analytical evaluation of rail wheel designs. However, it does not address the effect of axle push into the wheel and restricts the stress calculations to an elastic analysis only.

L. Ramanan [15] in his work, considered stress analysis due to the mechanical forces on a three-dimensional elasto-plastic model, determination of contact stresses using a global-local elasto-plastic approach, and the coupled thermo mechanical analysis due to the mechanical and brake loads. But he neglected the change in material properties due to thermal loads in the contact region and he didn't consider residual stress developed in service.

Knothe et.al [16] discussed the historical development of the rolling contact solution methods. Analysis is carried out with the three-dimensional rolling contact model using boundary element method as well as finite element method considering rough contact surfaces.

Aleksander and Marek [17] presented the influence of interacting wheel and rail profiles on the distribution of contact zones and stresses. The quasi-Hertz method as well as a finite element method was included as the basis of mathematical simulation.

III. Fundamental Theory of Analysis

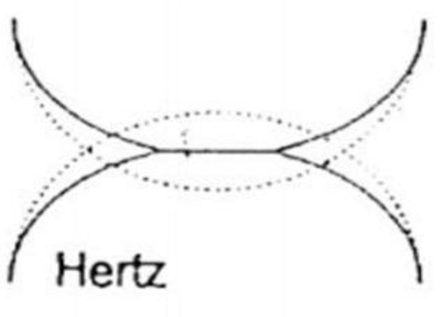

Fig. 2. Full elastic contact mechanics model of hertz

The study of geometry is necessary in the analysis of the wheel/rail contact in railroad vehicle system. The contact mechanics between two surfaces was studied by Hertz (1882). Hertz assumed that the area of contact is elliptical. In studying the wheel/rail interaction, the assumptions of conformal contact are justified because of the shape of wheel and rail surfaces. The contact region is assumed to be elliptical, and its dimensions taken as per standard dimensions. Surfaces of engineering components are consistently subjected to contact, thermal and others loading due to these large stresses applied over localized area.

Hertz contact theory is a classical theory of contact mechanics and is a powerful tool for engineers and researchers. Even, though the derivation of the theory is relatively difficult, the final solution is a set of simple analytical equations relating the properties of the system to the developed stress.

A. Modeling of Rail Wheel Contact:

The wheel profile consists of a flange to guide the trains along the rails and a conical tread that contacts rail head, and rail has many curvatures to guide wheel properly. The contact positions of the wheel / rail are different in the Different situation. However, this paper uses the contact between the wheels tread and rail head. The contact area between wheel and rail are very small compared to their dimension.

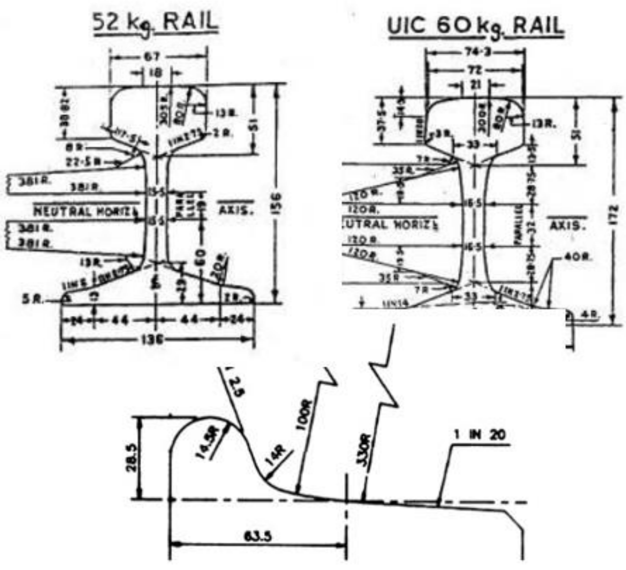

Fig. 3. UIC 52 kgs and 60 kgs Cross Sectional Views And Wheel Profile as per Indian Standards

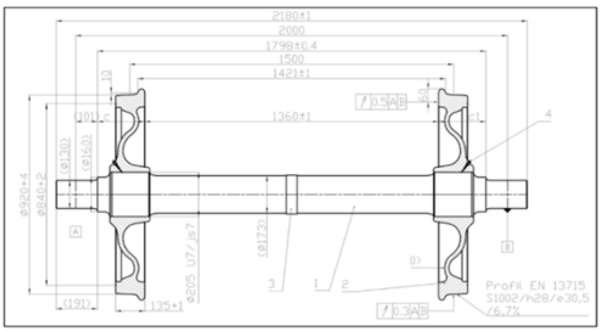

Fig 4: Wheel Rail Assembly for Broad Gauge Rail

IV. SIMULATION WITH ANSYS SOFTWARE

Generally, there are two kinds of analysis one is experimental and other is simulation analysis. The biggest problem with experimental analysis is the cost and time. Therefore, simulation software's have been used in different engineering fields, because it just needs a computer and the suitable software. Moreover, simulation software can offer the results in much shorter time period.

The software used in this research is ANSYS. The software is constructed on the finite element analysis method and is often used in various industries. The ANSYS software is carried out in three basic principles. They are:

A. Preprocessor
   i. Define material properties
   ii. Define element model
   iii. Build analysis model

B. Processor
   i. Define the boundary conditions
   ii. Application of loads
   iii. Define the load characteristics
   iv. Control the convergence mode
   v. Evaluate the solution

C. Postprocessor
   i. Evaluating the results
   ii. Drawing diagrams with the results
   iii. Listing the results.

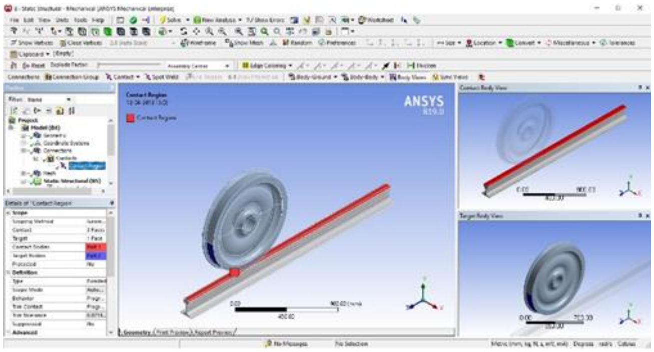

Fig. 5. Ansys model used in research

V. FINITE ELEMENT METHOD AND ANALYSIS

The basic assumptions for analyze the wheel and rail are listed below:

1. Material of wheel and rail are uniform and isotropic
2. Material properties are nonlinear and temperature independent.
3. Straight track is considered and standard rail profile is used for analysis.
4. Residual stress form manufacturing and in operation are not considered in this study.

A. Geometric Model:

The rail standardized for Indian railways are 60kg, 52kg for BG and 90R, 75R and 60R for MG. In this research, we used 60 kgs and 52 kgs standard rail dimensions for analysis. The wheel model studied is a practical wheel design the integral coach factory (ICF) madras, India. The actual material modeled in this work has a yield strength of 780 MPA with an ultimate strength of 1400 MPA at web region and yield strength of 840MPA and ultimate strength of 1440 MPA at rim region.

B. Mechanical forces considered in the analysis:

1. *Vertical Force*: The vertical force (F_V) acting on the wheel is due to the passenger and payload. These forces are transferred to the wheel through the axle. A static load of 56 KN is considered on each wheel is considered in this work on each wheel is considered in this work.
2. *Lateral Force*: the lateral force (F_L) acting on the wheel is due to the irregularities in the level of track. In the present work, the lateral force is considered to be 20 KN.
3. *Brake Force*: the brake force acting on the wheel is due to braking torque applied to stop the train. In this paper, we considered 12KN on each wheel.

C. Material Selection:

The railway tracks are mostly steel material. High Strength Structural Steel is the most common and widely used metallic material in modern society. Steel contains 50% iron and one or more alloying element. These elements generally include carbon, manganese, silicon, chromium, phosphorus, Sulphur etc.

D. Finite Element Modeling:

Finite element method is used to analyses the response of the rail joint to the static and dynamic load. The Finite Element analysis is performed using structural analysis of the ANSYS R19 workbench software after imported 3D assemblies form SOLIDWORKS software. ANSYS is a general-purpose finite element of modeling package for numerical solved problems. Like any finite element software, ANSYS solves governing differential equations by breaking the problem into small elements. When the wheel is contact element and the rail is target element, the wheel and rail will be different. The wheel structure discretized using CONTA173 element. CONTA 171 three-dimensional elements are used to discretize rail. The contacts point of wheel and rail are used fine mesh to make the solution accurate.

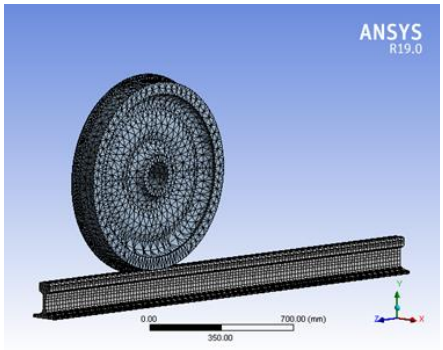

Fig. 6. Mesh of assembled part in ANSYS workbench

E. Ansys procedure for contact analysis:

1. File of the wheel and track is saved in IGS format.
2. 3D model of assembly is inserted in ANSYS.

3. Simulation is selected for analysis of wheel and track.
4. Connection is made between wheel and rail.
5. Rough Contact between wheel and rail is selected.
6. Tetrahedral element is selected mesh is generated.
7. Track is fixed in all 3 DOF by fixture option.
8. Permissible load is applied on wheel.
9. Stress result is obtained by showing the final result option.

VI. Results and Discussion

A. *Equivalent Von-Mises Stress:*

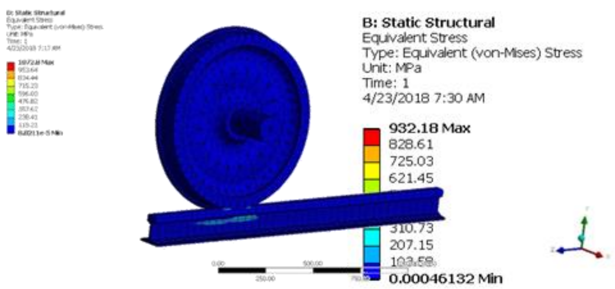

Fig. 7. Equivalent Von-Mises Stress Analysis for 60 kgs Rail

B. *Equivalent Elastic Strain:*

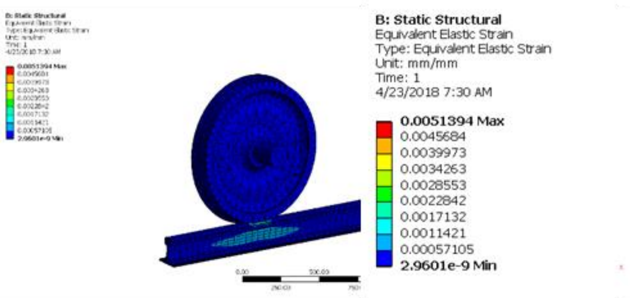

Fig. 8. Equivalent Von-Mises Stress Analysis for 52 kgs Rail

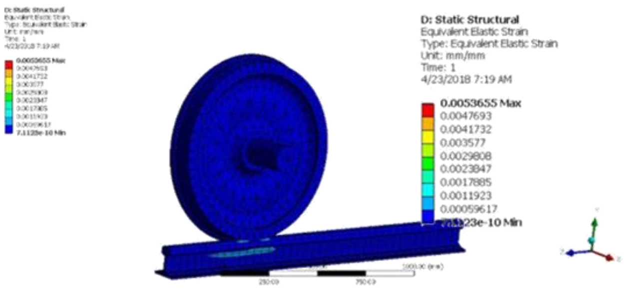

Fig. 9. Equivalent Elastic Strain for 60 kgs Rail

The analysis is performed by using finite element model consists of the static analysis and modal analysis to determine the impact of the wheel load. Different support location is used to perform finite element analyses, although the geometry and load application are the same for all support location. The design of the model of rail was according to International Union of Railways (UIC) and also according to weight per unit length used in India. The rail cross section is UIC 52 kg and 60 kg and the wheel standards were according to the Indians standards of BOXN Wagon manufactured by Rail wheel factory. The results for the contact stress on the rail were found safe and in the permissible range as the values were lying below the permissible stresses. Material used for the analysis is Cast steel of Grade R370, which has the desired properties and is being used by the leading industries (Tata Steels, Jindal steels, SAIL and Bhilai steel plant of India) for manufacturing of rails.

C. *Total Deformation:*

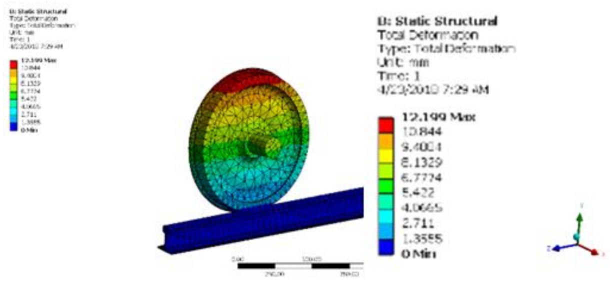

Fig. 10. Total Deformation for 52 kgs Rail

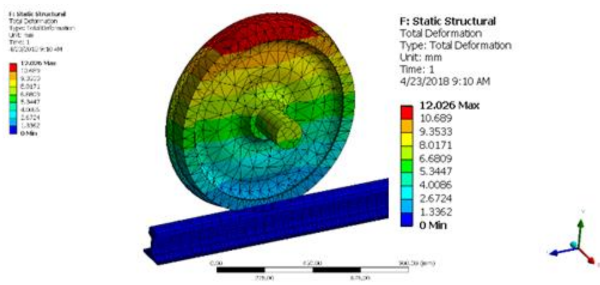

Fig. 11. Total Deformation for 60kgs Rail

D. *Frictional Stresses:*

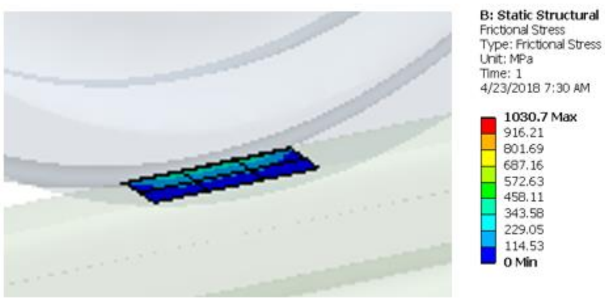

Fig. 12. Frictional Stress for 52kgs Rail

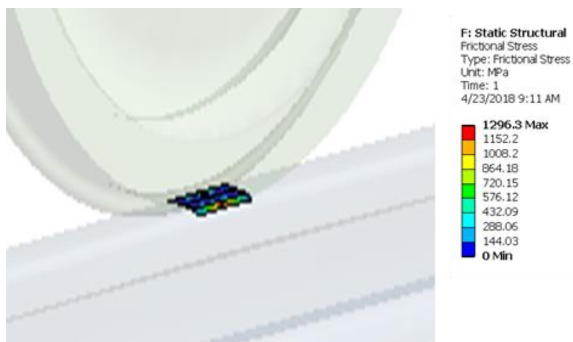

Fig. 13. Frictional Stress for 60kgs Rail

E. Contact Pressure:

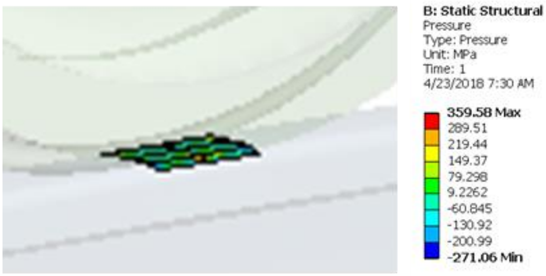

Fig. 14. Contact Pressure for 52 kgs Rail

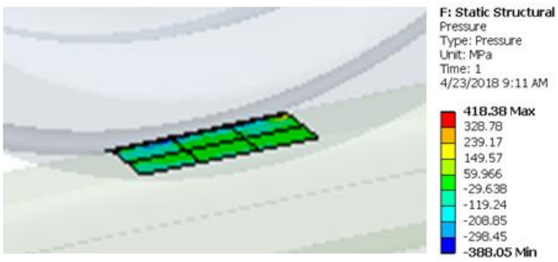

Fig. 15. Contact Pressure for 60 kgs Rail

This section of the paper specifies the result obtained from the ANSYS software based on hertz contact theory. The above result shows different stress types due to vertical applied load at the contact region. There are two different types of rail tracks compared each other like this. Following table shows the results obtained in the ANSYS solution. The importance of these results is to correlate results obtained in two Rail systems with each other and to check how results satisfy the research objective.

TABLE I
RESULTS SUMMARY

Type of Load		60 Kgs Rail	52 Kgs Rail
Von Mises Stress (MPA)	max	932.18	1072.8
	min	4.6 x e^{-5}	8.82 x e^{-5}
Equivalent Elastic Strain(mm/mm)	max	5.1 x e^{-3}	5.36 x e^{-3}
	min	2.96 x e^{-9}	7.11 x e^{-10}
Total Deformation (mm)	max	12.199	12.026
	min	0	0
Frictional Stress (MPA)	max	1030.7	1296.3
	min	0	0
Contact Pressure (MPA)	max	359.58	418.38
	min	-271.06	-388.05

VII. CONCLUSION

In this study, the responses of a rail wheel contact are determined under static mechanical load, the results are assumed to be significant. The analysis can include stress, strain and fatigue responses of the contact caused by vertical wheel load. The analysis is taking into account by using various position of contact on the sleepers. Finite element analysis (FEA) is utilized as a tool for contact mechanics modeling, assessment, and simulation of the Rail-Wheel contact through improving the traditional approaches of investigating the impact of the wheel motion on the rail. Most of the conventional methods and computational approaches are limited to static solutions without taking into consideration the complete rolling of the wheel. Furthermore, some simplifications of models of the railway system, that is, ignoring the setting pads in these studies, decreased the exactness of the solution. This paper studies mainly on finite element analysis, but to improve the problem related to the joint, it is also needed field data to identify the exact place of failures' and causes of failure.

VIII. RECOMMENDATION

The present study can be as one of fundamental researches for rolling contact causing fatigue, wear, and abrasion, and therefore, improving and pursuing this study can be considered in future works. Directions of the future research are to investigate the influence of sleepers in nodal forces, stress distribution, and strains created by the wheel on the rail. It is worth to note that sleepers are also subjected to different types of lateral and vertical loads. Therefore, stresses and strains on sleepers are needed to be studied. In the above proposed work only force acting circumferentially on the wheel track is only considered, this can be extended to other forces that act on the wheel rim and structural analysis is carried out, this can be extended to Transient Analysis.

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