Finite Element Simulation on Railway Wheels under Various Loading

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Abstract: This study aims to predict the safety factor of railway wheel under various loading. A three dimensional finite element (FE) railway wheel model was developed to calculate the mechanical stress on railway wheel. In this study, the railway wheel contact was analyzed under static loading. The material used was steel A-900. The ANSYS Workbench was employed for the FE analysis. The results show that the highest safety factor was found under cornering load, compared to the analyses under vertical load, braking load and contact pressure.

1. Introduction
Railway wheel is commonly used to move the train that carrying passenger or cargo from one place to another destination. Nowadays, the new railway wheel was used so that it can sustain the stress due to rolling contact between wheel and rail. The old railway wheel that have high risk of accident and can happen at any time due to several problems such as excessive load from the train load and also the train handling that can cause unexpected types of loading on the wheel-rail contact. Continuous contact surface between the wheel and rail generates the kinetic friction. This rolling contact also can be defined as friction forces that exists between the rail and wheel of contact surface.

Analysis on the failure prediction of railway’s wheel and rail under various condition has attracted many researchers. Most of them utilised finite element method (FEM). FEM has been established and widely used for many engineering problems even for complex geometry such as cellular solids [1], honeycomb [2], cancellous bone [3], [4] and many more. Kuna et al. [5] conducted the fracture mechanical assessment on railway wheels made of austempered ductile iron with graphite nodules under static and cyclic loads using FEM. They found that the critical crack sizes determined by their investigations can be diagnosed certainly and reliably by means of available non-destructive testing. Moreover, Arslan and Koyabasi [6] demonstrated a well-known FEA procedure on an example three-dimensional rail–wheel and axle model. The results obtained in 3D FE analysis show good agreement with real life problems experienced at both railway wheel and rail. A railway system containing wheel, rail, axle, and pads was modeled and analyzed by Aalami et al. [7]. They utilised ANSYS software for the FE analysis and used elastic-plastic materials, mapped meshing, and the rolling motion of the wheel contingent upon the up-to-date international railway systems that results in high accuracy in the solutions. The simulation results have suitable agreement with the real life experiences.
On the other hand, it is widely known that the residual stress is one of the crucial parameters in railway wheels. The designer will ensure the residual stresses in the wheels at minimum as possible. Nejad [8] estimated the residual stresses in the rail wheels due to heat treatment process of a railway wheels. The FE analysis was conducted by applying the elastic-plastic material properties for the rail wheels under thermal loads. The results obtained show good agreement with those achieved in field measurements. Ramanan et al. [9] also applying the thermal load due to braking during services in the FE analysis of the rail wheel. They found that stresses due to braking dominate over the payload stresses based the results obtained from the coupled temperature-displacement analysis. Hence, this paper aims to predict the safety factor of the railway wheels under various loads during services which is rolling contact, braking and cornering.

2. Method
The wheel profile was selected according to the information provided by the local railways company. The type of train used to perform the analysis was the wagon type. The information provided are the wheel diameter which is 965 mm (38 in), the vertical load (maximum design load of 78.48 kN), the material properties of wheel (yield strength of 765 MPa; Young’s modulus of 205 GPa; friction coefficient of 0.3; material density of 7850 kg/m³; rotational velocity of 24.6 rad/s; ultimate tensile strength of 1080 MPa) and the rail dimension with 1000 mm long.

Figure 1 shows the geometrical model and boundary conditions of the present analysis. The convergence test was performed in order to determine the optimum mesh size. Tetrahedral and hexahedral types of element were used in the meshing of the FE model. Four set of boundary conditions were applied on the rail-wheel models, which is vertical load, braking load, cornering load and contact pressure. The safety factor was then calculated based on the yield strength divided by the von-mises stress.

![Figure 1. Geometrical model and boundary conditions setup.](image)

3. Results and discussion

3.1. Response of railway wheel under vertical load
Figure 2 shows the contour distribution of von-mises stress and total deformation for railway wheels and rail under vertical load (one sample). Obviously, the high stress was found concentrated in the rolling contact between rail and wheel, whereas the high total deformation was subjected to the axle of the wheel. Safety factor of the wheels as found decreased with respect to the increase of vertical load as shown in Fig. 3. The wheel was still in safe condition under the vertical load up to 120 kN.
Figure 2. Contour distribution under rolling contact. (a) von-mises stress. (b) total deformation.

Figure 3. Safety factor of the railway wheels under vertical load

3.2. Response of railway wheel under braking load
The braking load was applied to wheel from the brake pad and the contact between rail and wheel generated the shear force. The stress distribution for (a) von mises and (b) shear stress on the rail-wheel is shown in Fig. 4. It shows that the critical area also concentrated on the rail-wheel contact area. Similarly, the safety factor was decreased when the braking force increased. But it is found that the safety factor of the wheel is slightly lower under braking load compared to vertical load.
Figure 4. Stress distribution under braking force. (a) von-mises stress. (b) maximum shear stress.

Figure 5. Safety factor of the railway wheels under braking load

3.3. *Cornering Load*

Figure 6 shows the safety factor of the wheel under cornering load. It shows the similar pattern as safety factor under vertical and braking load. However, the value is largely higher compared to the former conditions. The contact pressure contour between rail and wheel is shown in Fig. 7. The result shows that the pressure was concentrated on the central part of the contact area. This is the area where the facture would be initiated if the excessive load is applied.
Figure 6. Safety factor of the railway wheels under cornering load.

Figure 7. Contact pressure contour between rail and wheel.

4. Conclusion
The present study was carried out to analysed the safety factor of the railway wheel under service conditions which is vertical rolling contact, braking load and cornering load. The results show that the safety factor of the railway wheel was lowest under braking load compared to vertical load and cornering load. The railway wheel was safe under all simulated loads that up to 120 kN. The findings of present study could be used for designer to predict failure on the railway wheels.

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