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Reliability of Automobile Car Wheel Subjected to Fatigue Radial Loading by Weibull Analysis

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Abstract— While the car is running, the radial load becomes a cyclic load with the rotation of the wheel. This has become essential to test the wheel under radial fatigue load for the structural integrity. The survival of the wheel was analyzed through Weibull analysis. It was found that 50 percent of the wheels have survived at 4542041 cycles under radial fatigue loading.

Index Terms— car wheel, radial fatigue loading, ANSYS, Weibull analysis.

1 Introduction

AUTOMOTIVE wheels are part of a vehicle and are subjected to high loads. The durability of the wheel is important for the safe operation of the vehicle. Therefore it is essential to examine the wheel for both strength and fatigue resistance. Stearns et al. [1] summarized the application of finite element technique for analyzing stress and displacement distributions in the vehicle wheels subject to conjoint influence of inflation pressure and radial load. They used aluminum alloy A356-T6 for the wheel. They observed that the rim tend to ovalize about the point contact under radial load with a maximum displacement occurring at the location of the bead seat. Wright [2] presented various methods of testing the automotive wheels. The different tests were cornering fatigue test, radial fatigue test and impact test.

The automotive wheel has to pass three types of tests before going to use, they are cornering fatigue test, radial fatigue test and impact test. The objective this paper was to perform radial fatigue analysis find the number cycles at which the wheel would fail. The fatigue analysis was carried our using ANSYS software.

2 Estimation of Weibull Parameters

Weibull analysis is a method for modeling data sets containing values greater than zero, such as failure data. Weibull analysis can make predictions about a joint's life. The Weibull cumulative distribution function can be transformed so that it appears in the form of a straight line (Y=mX+c).To compute Weibull cumulative distribution the following formulae were used:

$$F(x) = 1 - e^{-\left(\frac{x}{\alpha}\right)^{\beta}} \quad (1)$$

$$\ln\left(\frac{1}{1-F(x)}\right) = \left(\frac{x}{\alpha}\right)^{\beta}$$

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$$\ln\left[\ln\left(\frac{1}{1-F(x)}\right)\right] = \beta \ln\left(\frac{x}{\alpha}\right)$$

$$\ln\left[\ln\left(\frac{1}{1-F(x)}\right)\right] = \beta \ln x - \beta \ln \alpha \quad (2)$$

Comparing this equation with the simple equation for a line, we see that the left side of the equation corresponds to Y, lnx corresponds to X, β corresponds to m, and -β ln α corresponds to c. Thus, when we perform the linear regression, the estimate for the Weibull β parameter comes directly from the slope of the line. The estimate for the α parameter must be calculated as follows:

$$\alpha = e^{-c/\beta} \quad (3)$$

3 Methodology

The material of wheel was aluminum A356-T6. The specifications of the wheel (figure 1) are given below:

Rim diameter	= 375 mm
Rim width	= 150 mm
Profile of the rim	= J
Offset	= 40 mm
Pitch circle diameter	= 100 mm
Hub diameter	= 60 mm
The yield strength	= 155 MPa
Tensile strength	= 260 MPa
Modulus of Elasticity	= 71 GPa
Density	= 2.685 g/cc
Poisson's ratio	= 0.33

The gross weight of the vehicle on the wheel is equal to kreb weight of vehicle + number of passengers x weight of each person +overages added (619 + 5x70 +50 = 1500 Kg). The load on each wheel is equal to 254.85 Kg (=1019/4) which is equivalent to 2500 N. the torque of the wheel is 500 N-m.

The 2D of the wheel was created in MDT (Mechanical Design Technologies), the drafting package [3] and the same was exported to ANSYS, the finite element package using IGES (Initial Graphics Exchange Specification) translator. The 3D model (figure 2) of the wheel was created in the ANSYS.

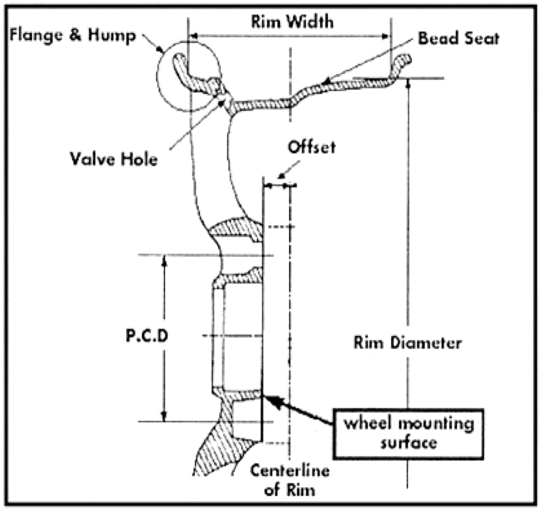

Fig. 1. Specification of the wheel.

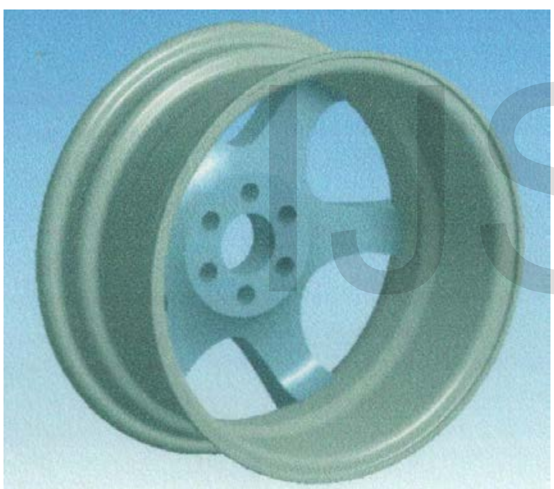

Fig. 2. Solid model of aluminum alloy wheel.

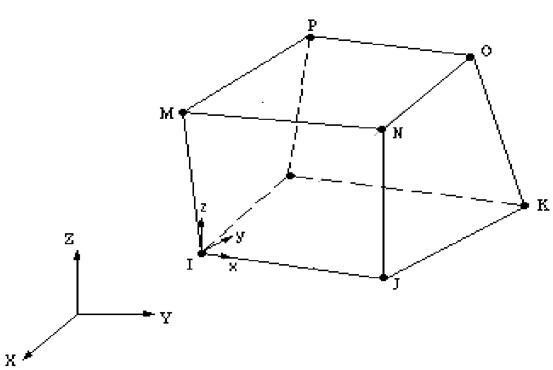

Fig. 3. Solid 45 element.

The wheel was meshed with SOLID 45 elements. This element as shown in figure 3 is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions [4]. The number of elements was found to be 9988 and the number of nodes was 19903 as shown in figure 4a. For boundary conditions a pressure of 0.207 N/mm2 was applied on the outer surface of the rim. The pitch circle holes were constrained in all degrees of freedom as shown in figure 4b. A load of 2500 N was applied on the inner surface of hub diameter by taking one middle node. The pitch circle holes were constrained in all degrees of freedom. The analysis was carried using fatigue module of ANSYS to find the life of the wheel. The material properties of interest in a fatigue evaluation was S-N curve, a curve of alternating stress intensity ((σmax - σmin)/2) versus allowable number of cycles.

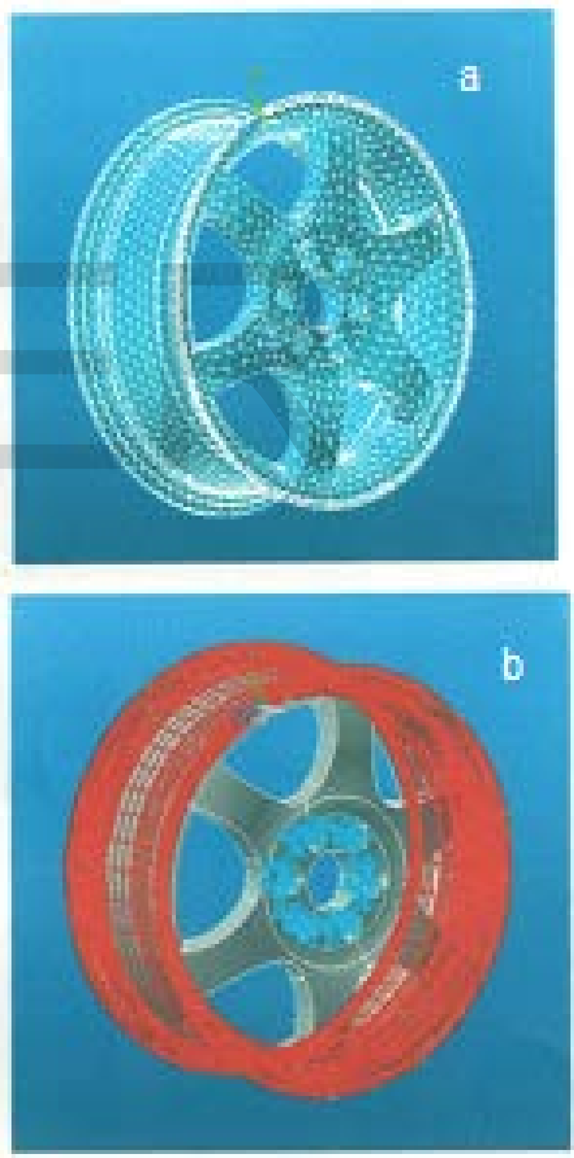

Fig. 4. Finite modeling of wheel (a) meshed model (b) boundary conditions on wheel.

4 Results and Discussion

The total weight of the car is to be balanced with vertical reaction force from the road through the tire. This load constantly compresses the wheel radially. While the car is running, the radial load becomes a cyclic load with the rotation of the wheel. Hence the evaluation of the wheel fatigue strength under radial load is an important performance characteristic for the structural integrity. The maximum deformation was 0.0515 mm at rim of the wheel as shown in figure 5a. The deformation on engine side was also 0.0515 mm as shown in figure 5b. The von-Mises stress and equivalent alternating stress were 9.205 MPa and 12.27 MPa respectively as shown in figure 6. After running the fatigue cycles it was found that the life of the wheel was 1.0x108 cycles (figure 7).

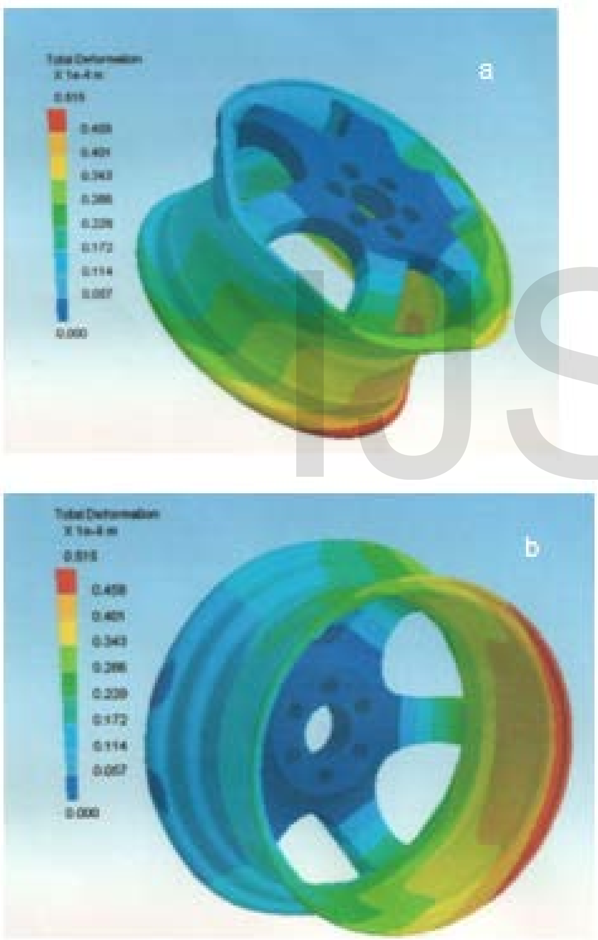

Fig. 5. Deformation of wheel (a) under radial load (b) on engine side

The Weibull shape parameter, β, indicates whether the failure rate is increasing, constant or decreasing. A β <1.0 indicates that the product has a decreasing failure rate. This scenario is typical of "infant mortality" and indicates that the joint is failing during its "burn-in" period. A β=1.0 indicates a constant failure rate. Frequently, components that have survived burn-in will subsequently exhibit a constant failure rate. A β >1.0 indicates an increasing failure rate. This is typical of products that are wearing out. The car wheel has β value higher than 1.0 as seen in figure 8. The joints fail due to fatigue, i.e., they wear out.

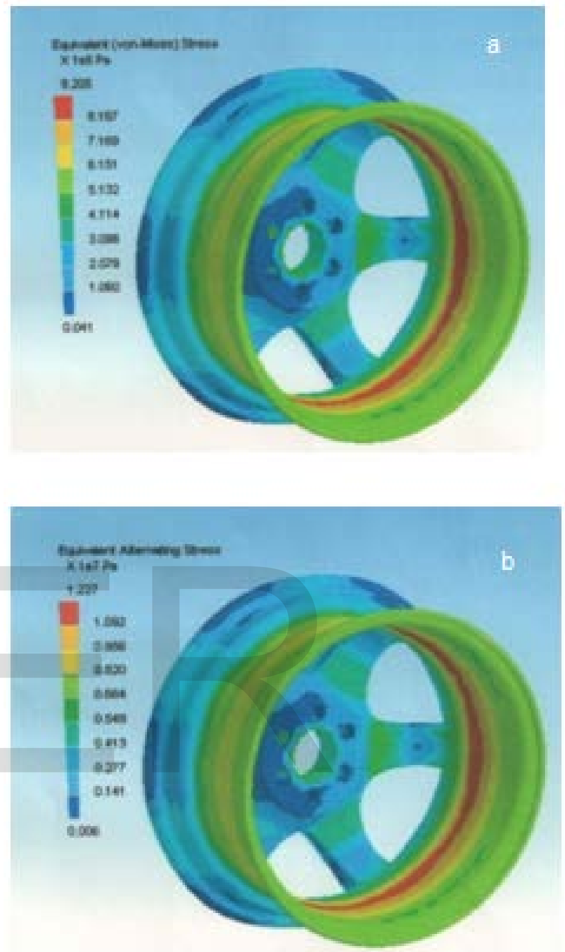

Fig. 6. Stress distribution (a) von-Mises stress (b) equivalent alternating stress.

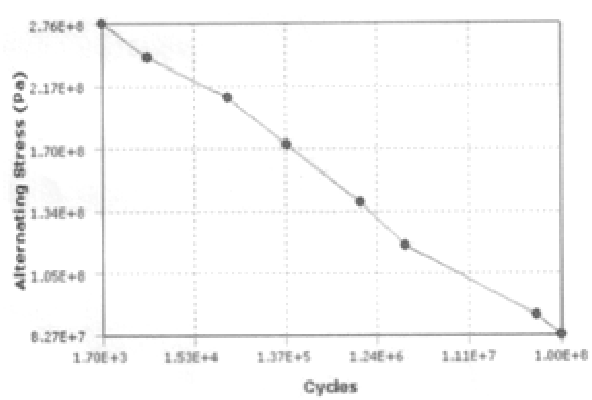

Fig. 7. S-N curve.

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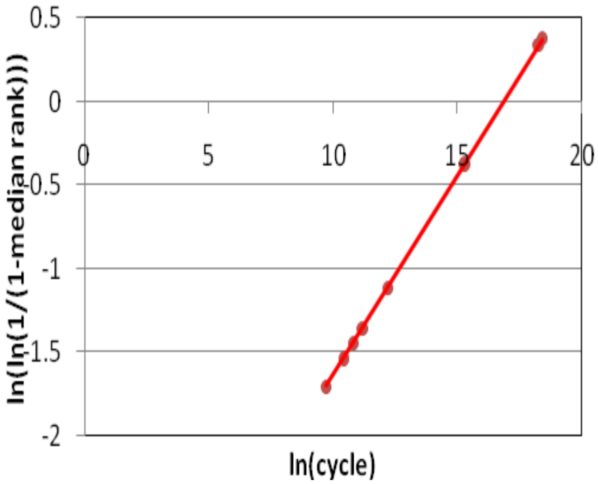

Fig. 8. Weibull criterion for wheel.

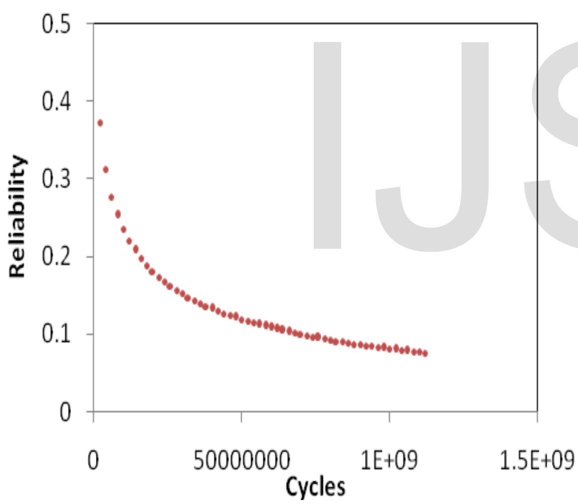

Fig. 9. Relaibility of wheel.

The straight line equation for the wheel was obtained as:

$$Y = 0.238x - 4.027 \quad (4)$$

The Weibull characteristic life is a measure of the scale in the distribution of data. It so happens that α equals the number of cycles at which 63.2 percent of the joint has failed. In other words, for a Weibull distribution R(=0.368), regardless of the value of β. For the vee-joint design about 37 percent of the joints survive at least 3189 cycles. For the plain-joint design about 37 percent of the joints survive at least 2497 cycles. About 37 percent of the wheels survive at least 21073184 cycles. Figure 9 allows a comprehensive comparison of the wheel survival rates. At 4542041cycles, about 50 percent of wheels have survived.

5 Conclusions

The automobile car wheel was tested for radial fatigue loading using ANSYS. The maximum deformation was 0.0515 mm at rim of the wheel. At 4542041cycles, about 50 percent of wheels have survived.

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