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STUDY OF INFLUENCE OF PRESSURE AND LOAD ON WHEEL RIM BY RADIAL FATIGUE TEST

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ABSTRACT

This paper highlights the use of the study of influence of pressure and load on wheel by experimental method using Radial Fatigue Test (RFT) and finite element technique for analyzing stress and displacement distributions in wheels of automotive vehicles when subject to the conjoint influence of inflation pressure and radial load. The most commonly used considerations in the design of the rotating body are elucidated. A potentially viable technique for finite element modeling of wheel, subjected to loading, is highlighted.

KEYWORDS: pressure and load, experimental method, Radial Fatigue Test (RFT), finite element technique, stress and displacement distributions.

INTRODUCTION

Wheels can be looked upon as safety-related components. Consequently, fatigue performance and state of stress distribution in the rim, under various loading conditions, is a subject of concern. Furthermore, a comprehensive study of performance of the rotating wheel continues to receive significant importance as increased emphasis is laid on decreasing weight by either using lightweight materials or using materials of thin gauge. Although the loads applied on the rotating wheel are complex in nature and the resultant state of stress is usually high, the weight of the rotating body continues to remain as one of the most significant requirement desiring attention. This has necessitated the emergence and use of cast aluminum alloys in both existing and emerging rim designs. Lightweight rims made from a lightweight aluminum alloy are increasingly popular. Further, end-users consider the nature of the rotating wheel on their vehicle as a symbol of status. The sustained drive to reduce fuel consumption provided the impetus for car manufacturers to make rapid strides in altering traditional vehicle designs. Research efforts have found that a smooth outer wheel surface facilitates a reduction in air resistance. The conjoint influence of inflation pressure and radial load on stress and concomitant displacement distribution in the rim of a rotating body, the wheel, is studied. The influence of circumferential angle on stress and displacement distribution is also examined. Influence of tire inflation pressure on performance of the rotating body is rationalized. [1]

INFLUENCE OF RADIAL LOAD AND PRESSURE

The vertical reaction forces exerted by the road surface on four tires balance the total weight of a car on a horizontal and vertical reaction of the weight of the automobile on the road surface. The radial load is considered to be equivalent to a static load imparted on both the rim and tire in a direction normal to the surface of the road. Summing horizontal components of the force vector due to the normal loads does not change the resultant state of stress in the rotating wheel. This enables significantly less computation time. For a radial load, the tensile strength of the rim exerts a profound influence on durability, or fatigue life, of the rotating wheel. This ensures a precise evaluation of the stresses to be centered on the rim. In this study, the contact condition between the disk-spoke and the rim well is assumed to be perfectly bonded. [1]

Figure:

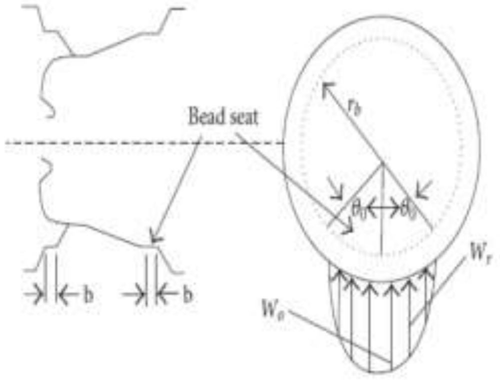

Fig.1.Radial Load effect

Pressure is applied to the bead seats on both the inboard side and the outboard side. Half of the pressure on the inboard side is applied to the inboard rim flange, while the other half is applied to the inboard bead seat. This is done because the inboard rim flange tends to deflect easily due to the long inboard rim leg. Consequently, it becomes susceptible to loading from the tire. The loading condition is determined from comparisons made between the measured and calculated stresses on the rim. In a real sense, the ratio of the applied load on the bead seat to the applied load on the rim flange is thought to vary in accordance with the contact condition between the tire and the rim. This is affected by the conjoint and interactive influences of the following:

(a) type of tire (bias or radial),
(b) air pressure in the tire,
(c) reinforcement structure or architecture of the tire, and
(d) type of rim used. [1]

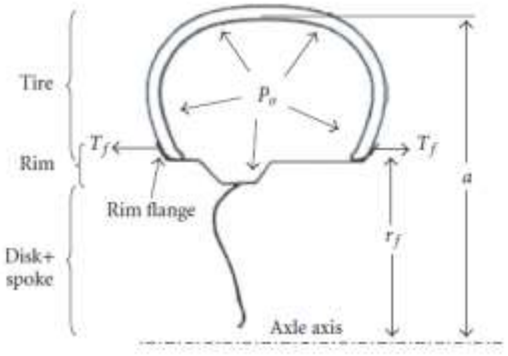

Fig.2.Load By Tyre Air Pessure

FATIGUE ANALYSIS

Fatigue is an important consideration for components and structures subjected to repeated loadings is one of the most difficult design issues to resolve. Experience has shown that large percentage of structural failure are attributed to fatigue and as a result, it is an area which has been and will continue to be the focus of both fundamental and applied research. Fatigue design provisions are only recently included in the aluminum association specialization. Related loadings of a component or structure at stresses above the design allowable for static loadings may cause a crack or racks to form. Under cyclic loading these cracks may continue to grow and precipitate a failure. When the remaining structure can no longer carry the loads, the mechanism of crack formation and growth is called fatigue. [6]

EXPERIMENTAL METHOD: DYNAMIC RADIAL FATIGUE TEST (RFT)

Sheet metal wheel rims are being widely used for scooters and scooter derivatives.

Considering the importance of the wheel as a critical part influencing the driving safety, this standard has been prepared.

Equipment- The test machine shall be equipped with a means of imparting a constant radial load only as the wheel rim rotates. The suggested equipment incorporates a driven rotatable drum set which presents a smooth surface wider than the loaded test tire section width. The diameter of the drum is 1700 mm with tolerance of + 1%. (See Fig. 3). [3]

Radial load determination- The radial load Fr, in newtons, is determined as follows:

$$Fr = Fv \times K$$

Where,

Fv = Maximum design load of wheel rim in newtons (N) and

K = Accelerated test factor=2.25 [3]

Failure criteria-

a) Inability of wheel rim to sustain load
b) A fatigue crack penetrating through a section of the wheel rim
c) The wheel rim shall withstand a minimum of 4,00,000 test cycles without failure. [3]

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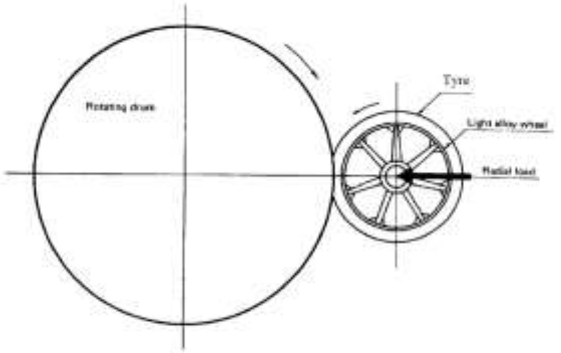

Fig. 3.Schematic Diagram of RFT

Procedure:
The tire selected for this wheel rim test shall be representative of the maximum size and type specified by the vehicle/wheel rim manufacturer or at the discretion of the testing agency. The recommended cold inflation pressure of the tire will be equal or higher than the maximum recommended Inflation Pressure. [3] There will be a slight increase in pressure during the test. This increase is normal and no adjustment is necessary. The loading system shall maintain the specified load within ± 2.5 percent. [3]

Fig.4.Failure during RFT

FATIGUE ANALYSIS USING FEA PACKAGE

A simple methodology to predict crack initiation life is described in the fatigue damage assessment of metallic structures typically used in ground vehicle industry. A phenomenological constitutive model is integrated with a notch stress–strain analysis method and local loads under general multi axial fatigue loads are modeled with linear elastic FE analyses. The computed stress–strain response is used to predict the fatigue crack initiation life using effective strain range parameters and two critical plane parameters. The proposed methodology is employed in the fatigue test cycle prediction of the biaxial cornering tests of light-alloy wheels. Numerical simulations indicate that estimates using critical plane models provide better correlations between the cornering test cycles and predicted cycles. Also, comparisons in terms of test failure locations and estimated crack initiation sites are given. [6]

MODELING OF WHEEL RADIAL FATIGUE TESTS

The fatigue damage modeling approach presented in the previous section were implemented into Mete software and applied in the numerical simulation of radial fatigue tests of a truck wheel. The wheel radial fatigue test is one of sign-off tests commonly used by wheel manufactures in the case of major design changes or for brand-new designs. In these fatigue tests, a tire–wheel–hub assembly is loaded against a rotating rigid-drum under a prescribed static force by means of a hydraulic actuator and the tire–drum contact is established at a fixed inclination (Fig. 5). The test load is intended for vehicle dead weight acting on the wheel assembly during straight line driving, and a fixed inclination angle provides a lateral force simulating the cornering maneuvers so that the actual tire and road interaction during the service is simulated in the test rig. An analysis of fatigue performance is required for geometric design parameters such as the disk thickness or welding size and to ensure a durable design before submitting into radial fatigue tests. Consequently, an engineering analysis indicating wheel failure locations and estimating number of test cycles is a practical need during design studies. 20-inc Disk-type wheels made of high strength steel blank of thickness 3.5 mm were tested under a constant vertical load for three test conditions. The wheel assembly is mounted to the test machine using a base plate via 10 bolts, with a 115 Nm assembly moment, to the flange connection of a rotation shaft. At the start of tests, vertical load for a given camber angle are set to the test level and kept static throughout the test, then the rotation of the drum starts and the rotational speed reaches a constant value of 250 rpm approximately in 300–400 cycles. For all loading conditions, three wheels were tested and numbers of wheel rotations are determined. In order to calculate local fatigue loading on the wheel, linear elastic FE analyses were done using Ansys program, and a FE mesh composed of 55,672 solid elements was generated for the wheel–hub assembly (Fig. 6).

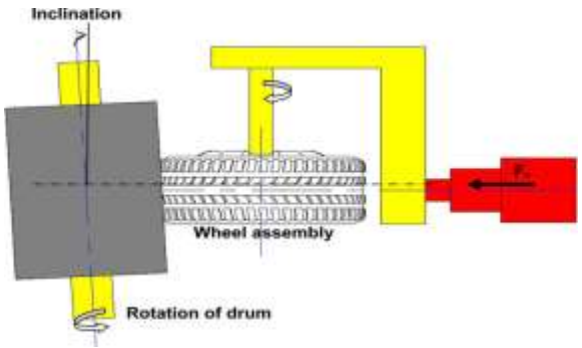

Fig.5. Simulation of RFT

The mechanical stresses on the wheel are considered in three groups. Firstly, there are manufacturing stresses left on the wheel due to processes such as the blank stamping forming and welding. In the second group, pre-stresses exist on part of the wheel due to the assembly with the other mechanical elements, mainly on the disk region due to bolt pretension and on the rim due to tire pressure. In addition, there are dynamic loading stresses caused by the vertical wheel force, cornering force with the wheel alignment and the centrifugal forces due to the rotation of assembly. Due to the complexities associated with the description of manufacturing stresses, no attempt is done to describe their contribution to the total stress state at a material point on the wheel. Furthermore, spring elements were used to apply vertical and horizontal tire loads, and the dynamic forces due to tire–drum interaction is neglected. Transient effects during start-up are also ignored, and centrifugal force acting on the wheel is modeled with distributed body forces at a constant rotational speed. As a result, the total stress at any material point of the wheel is assumed to be the sum of the stress due to the bolt pretension, the stress due to constant centrifugal force and the stresses due to the vertical and lateral forces for a given camber angle. Initially, two linear elastic stress analyses were conducted to simulate assembly process and tire loading. In the same way, linear elastic FE analyses were employed to calculate the scaling constants for the vertical and horizontal test loads of unit magnitude. [2]

Fig.6. Meshing of Wheel

STATIC & FATIGUE ANALYSIS PROCEDURE

The present work deals with estimating the fatigue life of aluminum alloy wheel by conducting the tests under radial fatigue load and comparison of the same with that of finite element analysis. Fatigue life prediction using the stress approach is mostly based on local stress, because it is not possible to determine nominal stress for the individual critical areas. The necessary material data for fatigue life prediction with the stress concept is the well-known S–N curve. Therefore, S–N curves are required for each specimen which reflects the stress condition in the critical area of the component. In the fatigue life evaluation of aluminum wheel design, the commonly accepted procedure for passenger car wheel manufacturing is to pass two durability tests, namely the radial fatigue test and cornering fatigue test. Since alloy wheels are designed for variation in style and have more complex shapes than regular steel wheels, it is difficult to assess fatigue life by using analytical methods. In general, the newly designed wheel is tested in laboratory for its life through an accelerated fatigue test before the actual production starts. Based on these test results the wheel design is further modified for high strength and less weight, if required. [6]

The fatigue tests simulations are conducted in two steps. First, a global analysis is performed in that all material points on the surface of wheel are analyzed for a single test cycle following a pre-loading step including the bolt pre-tension and centrifugal forces. The fatigue damage distribution is predicted, and the test cycles for all nodes on the wheel surface are calculated with critical plane parameters described in pervious sections. Next, a local analysis is performed considering the most-critical damage locations determined in the global analysis. In this step, the computational settings as in global analyses, local stress–strain response is calculated up to 100 cycles using the same.

A computational methodology is proposed for fatigue life and failure prediction of automotive components and its application is presented with numerical simulations of radial fatigue tests of a disk-type wheel. Regarding the fatigue failure sites identified during the radial fatigue tests, four wheels failed due to cracks initiated along the welding of the rim-well, and in all tests, relatively small fatigue cracks were observed on the edges of cooling holes (Fig.4). It is observed that both locations were predicted with critical plane parameters. In addition, two wheels in the zero-camber angle tests retained its service performance even though fatigue cracks were determined around the cooling holes. For all wheels tested, secondary fatigue cracks were also observed on the backside of rim welding region at closest side to the closing hole. A comparison of estimated fatigue test failure sites shows that none of the parameters is successful for all tests. However, the critical plane parameters involving mean stress correction terms perform significantly better predictions under non-proportional cyclic loadings, and Fatemi–Socie and Smith–Watson–Topper parameters in conjunction with critical plane concept provide practical estimates for both test cycles and damage critical locations. It should be also noted that Fatemi–Socie parameter correlates best considering all testing conditions simulated. In the second step, the local analyses are conducted using Fatemi–Socie parameter in order to evaluate the local stress– strain response as well as the variation of fatigue damage with loading cycles. For this purpose, a single node close to the failure location in actual tests is selected at which the highest damage was also predicted in global analysis (Fig. 7). The stress–strain history is computed up to 100 cycles, and the variation of fatigue damage per cycle is determined at this material point. The model parameters and analysis conditions are retained with those employed in the global analyses. There is a slight movement of the stress loop due to mean stress components in local stress history. Furthermore, variations in in-plane stress and strain components cause a fairly small decrease in the damage values per cycle, and consequently the change of fatigue damage appears to be insignificant. [6]

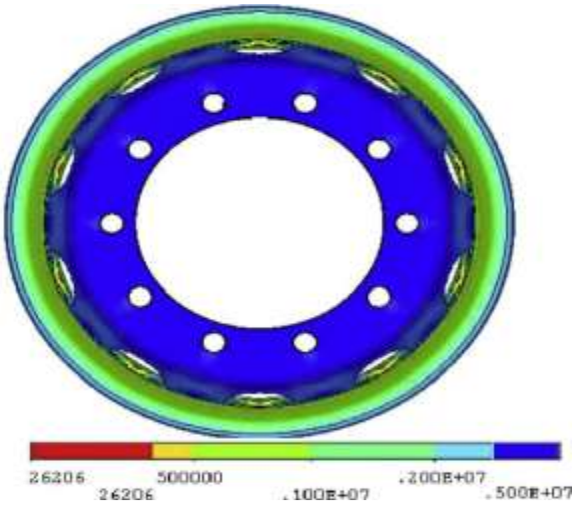

Fig.7. Example FEA of RFT

A location on the rim surface that is of concern is the “well” primarily because maximum stress occurs as a result of “local” bending stresses. A detailed examination of rim geometry reveals, that the inside surface essentially remains unsupported by the disk. In this case, it is free to flex about the well. However, if the applied forces are high then it can cause the tire to dislodge itself from the bead seat on the inside or alternatively the impact loading can cause the occurrence of permanent damage to the rim. In summary, the wheel can be considered a safety device. Damage occurring as a result of an optimized geometry and resultant fluctuations in stress is not an option for the designer, since most wheels are designed to last a lifetime, the predicted finite element analysis validates this point.

CONCLUSION

Based on the analysis performed on the influence of pressure and radial load on stress and resultant displacement response of a rotating wheel, the following are the observations made.

(1) Inflation pressure does have a direct effect on the state of stress in an automobile rim under the influence of a load of the maximum tire rating.

(2) Under a radial load, the rim tends to ovalise about the point of contact, with a maximum displacement occurring at location of the bead seat.

(3) The inside bead seat deflects the highest and is prone to loss of air pressure as a result of dislodgement of the tire on the rim.

(4) The stresses are much higher in the rim than in the disk.

(5) The critical design areas of the wheel are the inboard bead seat and the well.[1]

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