International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 7, July - 2014

Disc Wheel Rim: CAD Modeling and Correlation between FEA and Experimental Analysis

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***Abstract*- This paper includes the comparison of stress values in Disc Wheel Rim by Finite Element Method and Experimental method. Identified locations for measuring stress values are Bead seat, Stud Hole and Vent Hole. While CAD modeling of Disc Wheel Rim in CATIA software, macros are used. Linear static analysis of Disc Wheel Rim was done using FEM software (Hyperworks). PSolid element was used for brake drum meshing and for remaining parts PShell elements were used Simulation was done for Tyre pressure and Radial load condition. The results of the analysis were validated with the results of the physical testing. This testing was carried out with the help of strain gauging technique. Both software and experimental methods shows the similar results. Final conclusion was designed Disc Wheel Rim part was safe for radial loading condition.**

Key words- Macros; Automobile Disc Wheel Rim; Modeling; Finite Element Analysis; Strain Gauging

I. INTRODUCTION

A wheel is a circular object that revolves on an axle and is fixed below a vehicle to enable it to move over the ground. Researchers date the first use of wheels at around 3000 BC (many even suggest as early as 3500 BC) [8]. At that time, they probably took the simple form of potters wheels, attached to a vertical shaft. Present day varieties of wheels are available. Classification of wheels in brief is as follows:

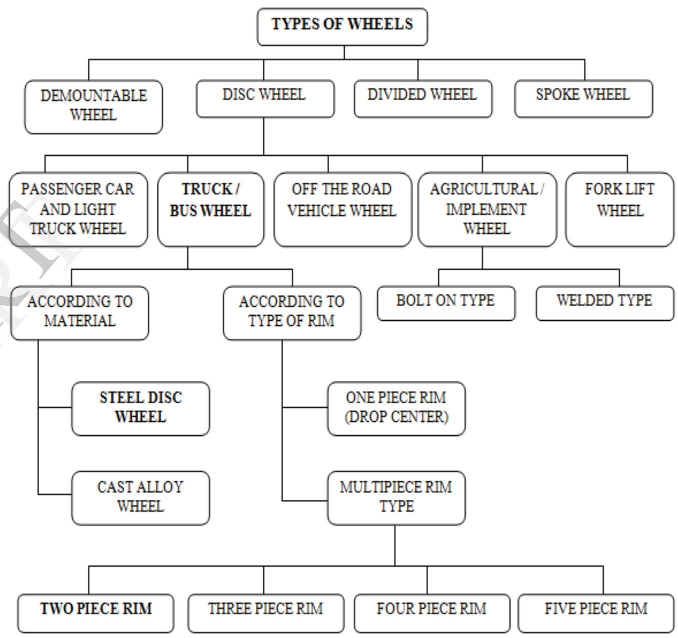

Fig. 1. Classification of Wheel

In present case we use two piece rim wheel made up of steel material. Two piece rim consists of rim base and detachable flange.

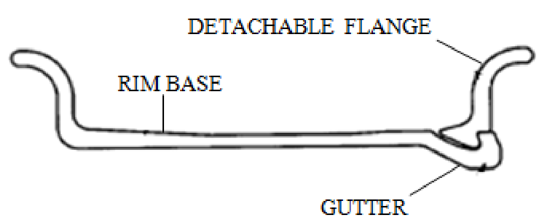

Fig. 2. Two-piece rim

Wheel is one of the safety component of automobile. Analysis of disc wheel rim is must, to predict the stress values at different locations. In this paper we use Finite Element Method to predict stress values in disc wheel rim and results are validated by strain gauging technique. For FEM analysis three dimensional model of disc wheel rim is required. Macros are used to reduce modeling time. Automobile wheel include two main parts welded to each other, which are the disc and rim. Macros are only for hole creation on disc surface. Three types of holes are required on simple disc surface – Center bore hole, Stud hole, Vent hole.

Types of stud holes:

- Simple stud hole
- Conical stud hole (uni or bilateral)
- Spherical stud hole (uni or bilateral)

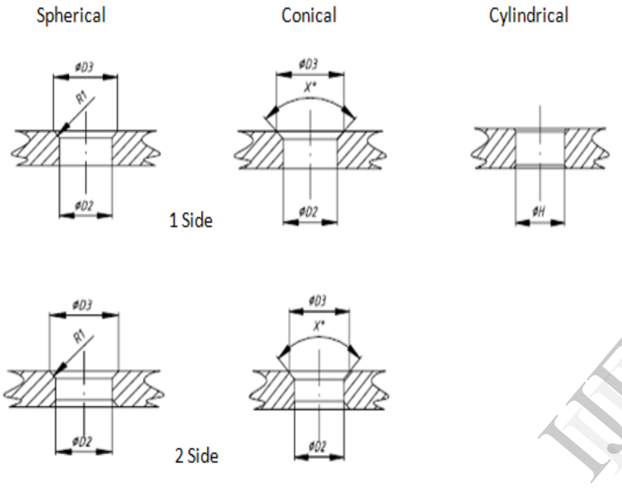

Fig. 3. Types of Stud Hole: (a) Simple, (b) Conical uni, (c) Conical bilateral, (d) Spherical uni, (e) Spherical bilateral.

As per literature review and industry experts identified possible failure locations are:

- Bead seat
- Stud hole
- Vent hole

To check, whether the design is safe or not we measure stress values at identified locations udre radial load condition and validated by experimental method.

II. RELATED WORD

Neerajkumar D Wayzode uses the macro technique for modeling and design of marine coupling. They utilizes standard design equations of marine coupling and links them together with the help of program called macros. That created macro itself calculates the required data and that data is used to create three dimensional model of marine coupling in CATIA V5. [1]

The origin of fatigue failure that occurs on the air ventilation holes of a heavy commercial vehicle steel wheel in dynamic rotary fatigue tests was studied by M. M. Topac. In these tests, all of the test samples failed in the same regions and they studied the cause of this damage by finite element analysis. For determining the reason of the fatigue failure, stress analysis was performed and stress concentrated regions where fatigue failure was expected, was determined. [2]

An investigation of stress and displacement distribution in a aluminum alloy automobile rim was done by J Stearns. Experimental observations were compared with Finite Element Analysis results. For measuring strain at different circumferential angle strain gauges was used. [3]

III. RELATED TERMINOLOGY

The purpose of the wheel is to connect the axle to the tyre and to transmit forces from one to the other. The principle components of any wheel are the rim and, depending on type, the disc or wheel bodies.

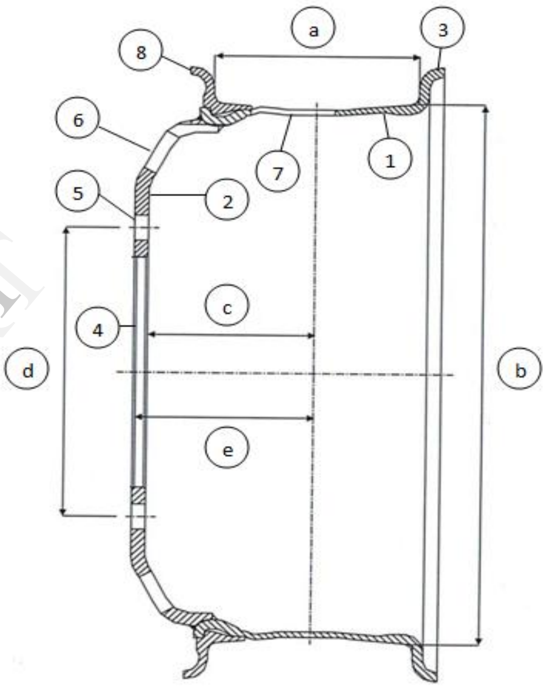

Fig. 4. Basic terms for wheel

Where,

a) Rim width
b) Rim diameter
c) Offset
d) Pitch circle diameter
1) Rim
2) Disc
3) Flange
4) Canter hole
5) Stud hole

6) Vent hole
7) Valve opening
8) Side ring

- **Rim:** Rims serve as seat of the tyre.
- **Disc:** The wheel disc serves as connection between rim and wheel hub. Disc contains center bore hole, stud hole and vent hole.
- **Rim width:** Rim width is the linear distance between the flanges of the rim.
- **Specified rim diameter:** It is the diameter at the planes of the rim bead seat and the rim flange. Depending on the rim design, it can be either smaller or larger than the nominal rim diameter.
- **Pitch circle diameter:** It is the imaginary diameter on which centers of stud holes are located.
- **Offset:** The offset is the dimension from the rim center to the attachment face of the wheel disc on side of the hub. The dimension can be either positive or negative.
- **Flange:** Part of rim which holds the both beads of the tyre.
- **Bead seat:** Bead seat is the portion of the wheel rim below the rim flange providing radial support to the bead of the tyre. The bead seat centers the tyre in the radial direction and, in particular, absorbs the forces attributable to the weight of the vehicle.
- **Valve opening:** This is the passage provided for valves of tube.

IV. MODELING

For FEA analysis three dimensional model of component is required. An increasing trend of reduction in the lead time can be seen in recent years due to advancement of industrialization. To reduce lead time effectively, different methods are used at different stages of design. By reducing the modeling time one can achieve minimum lead time. Modeling for disc wheel rim is done by Catia software. While modeling disc wheel rim macros are used.

A macro is a series of functions, written in a scripting (programming) language, that you group in a single command to perform the requested task automatically. Language used for programming is VBA. To create a hole on disc surface user has to just fill the appeared input form. This input form contains type of hole and dimension information. Hole creation on disc surface is repetitive task. To reduce modeling time programs are developed for disc holes only. We can create any standard hole within short time hence modeling time reduced.

Holes of Different Dimensions on Sample Disc:

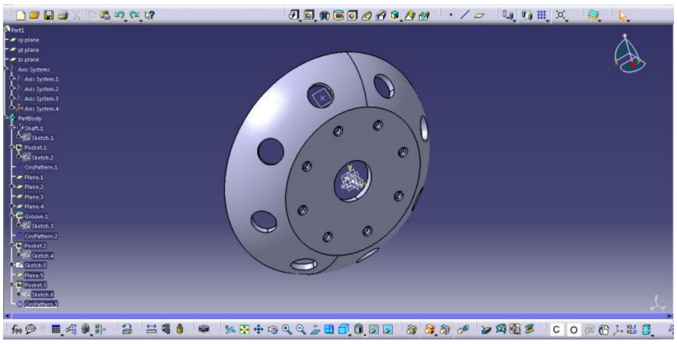

Fig. 5. (a) Holes on sample disc

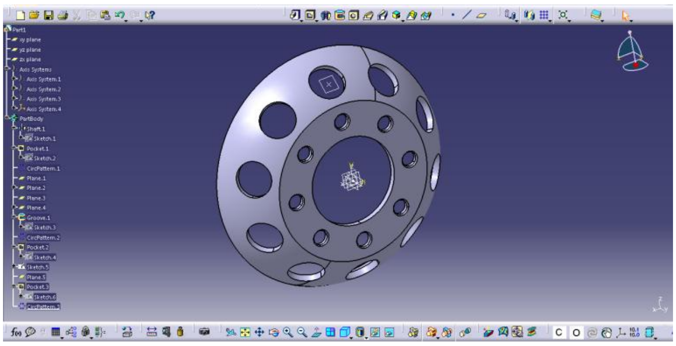

Fig. 6. (b) Holes on sample disc

The three dimensional model help to visualize the actual product. Three dimensional model for disc wheel rim is shown in fig.

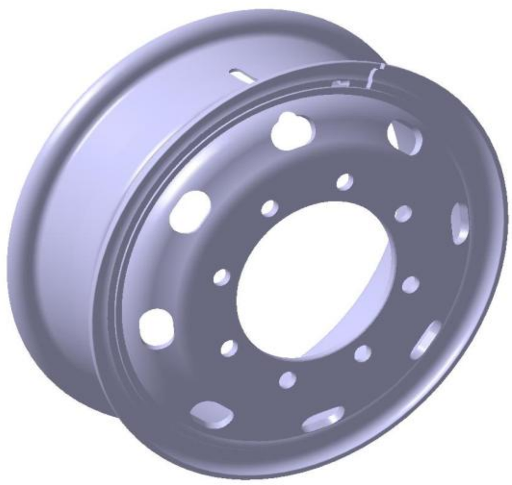

Fig. 7. CAD model of disc wheel rim

V. STATIC STRESS ANALYSIS USING FEM

The present work deals with examine the stress values at critical regions under radial loading case. The stress distribution on the disc wheel rim is due to radial test load (Fr) and the tyre pressure (P_0) and axial force (T_f). CAE software used for this static analysis is Hyperworks. The meshing (preprocessing) is done in Hypermesh, solver (processing) used is Radioss and representation of results (postprocessing) is carried out in Hyperview.

The wheel specification is as shown in table. The CAD model prepared in Catia is exported to IGES format. This IGES file is imported in Hypermesh for further process. Three dimensional model replicates the actual model so use of actual shape while modeling minimizes the error.

TABLE I. Wheel specifications

PARAMETERS	DATA
Wheel diameter	514.4 mm
Rim width	190.5 mm
Offset	160 mm
Pitch circle diameter (PCD)	335 mm
Center bore diameter	281 mm
Number of holes	10
Weight	46 kg
Wheel load	3750 kg
Material	Steel
Yield strength	375 N/mm^2
Ultimate tensile strength	500 N/mm^2
Tyre	10R20

Meshing:

The Hypermesh uses a finite element method to discretize the CAD model. wheel is meshed using PShell elements, with an size on 5 mm. In meshing, the system is divided into fine elements. Number of nodes and elements used in meshing are 59803 and 61763 respectively. For wheel 2D PShell and for brake drum PSolid elements are used. For dense meshing washer is used around the stud hole.

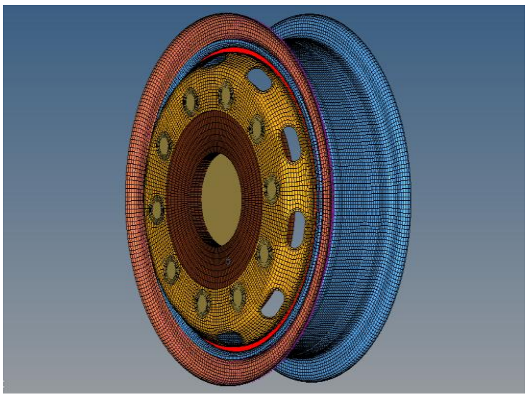

Fig. 8. Mesh model of disc wheel rim

Boundary conditions:

Loading and boundary conditions were applied similarly those in the experimental test. The driven drum exacts a radial load (Fr) on the wheel assembly during rotating condition while the tyre exacts a tyre air pressure (P_0) and axial force (T_f) on the rim. According to the Association of European wheel manufactures (EUWA), the radial test load (Fr) is calculated as [10]:

$$Fr = k \cdot g \cdot Fv$$

Where, Fr is the radial test load, Fv is the nominal or maximum design load of the wheel. Here wheel design load is 3750 kg for this specific wheel design, k is the accelerated test load factor which is taken as 2.2. Normally this accelerated test load factor is 2 or 2.2. To calculate Fr value using Fv and k from table.

Fr = 2.2 x 3750 x 9.81 = 80932.5 kg.

This radial load we convert into radial load pressure. The value of radial load pressure is calculated from,

Radial load pressure = (Half radial load / Bead seat surface area)

Parameters used for static study:

TABLE II. Parameters used for static study

PARAMETERS	DATA
Radial test load (Fr)	80932.5 kg
Radial load pressure	3.325 N/mm^2
Wheel design load (Fv)	3750 kg
Accelerated test load factor (k)	2.2
Tyre pressure (P_0)	10 bar
Axial force (T_f)	217.20 N
Element type	1D bar (bolt connection) PShell (rim and disc) PSolid (brake drum)

VI. EXPERIMENTAL ANALYSIS

Strain gauge is an electrical conductor whose resistance changes as it is strained. Strain is the elongation ratio of deformed length to the original length. The strain gauge used is of universal general purpose type (CEA-06-062UW-350)

The requirement of experimentation is to measure the strain level during static loading at three identified locations on disc wheel rim on Radial Fatigue Test (RFT) machine set up for the following conditions:

- Specified radial load
- Specified tyre pressure and axial load.

The wheel is mounted in such a way that, the drum axis is parallel to the axis of test wheel. Load is applied in radial direction with the help of hydraulic mechanism. We measure the strain values only for one complete rotation. By changing the specified angle, we determine the effect of radial load on disc wheel rim.

VII. RESULTS AND DISCUSSION

Stress distribution results in Hyperview:

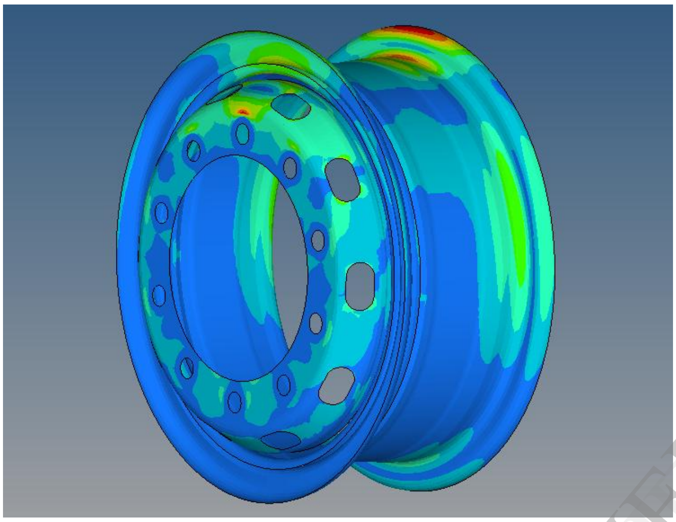

Fig. 9. Stress distribution of disc wheel rim

The readings for stud hole and vent hole are taken at rotation angle (θ) 36° and for bead seat 30°. Aim is to determine the maximum stress value among identified regions.

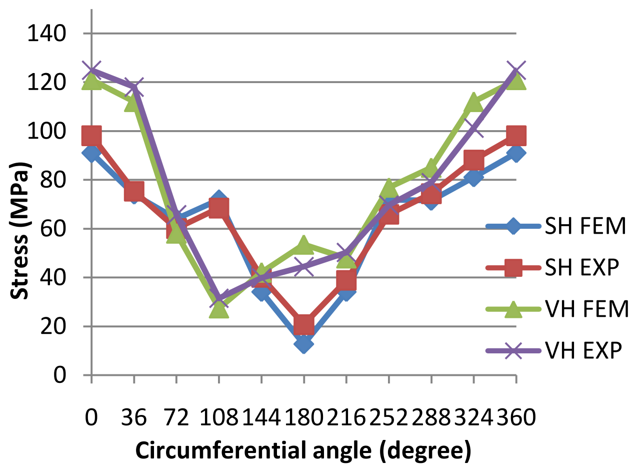

Fig. 10. FEM and experimental results for stud and vent hole

FEM and experimental results shows the same pattern. The maximum stress induced in stud hole region is less than vent hole region for both FEM and experimental case. For stud and vent hole maximum stress value is observed at circumferential angle of 0 degree. Stud hole values shows the symmetric pattern. The stress value first reduces and again increases. The observed stress values in both cases are far below compared to yield strength of material.

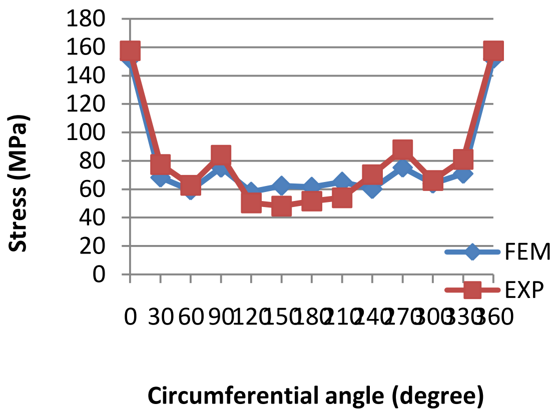

Fig. 11. FEM and experimental results for bead seat

Bead seat region is observed high stress region for disc wheel rim. The experimental and software results show the same pattern. Maximum stress values are 151.77 MPa and 154.98 MPa for software and experimental cases respectively at circumferential angle of 0 degree. Both graph shows symmetric nature. Maximum % variation observed for bead seat is 14.42%.

The yield strength for wheel material is 375 MPa and maximum stress value at identified location i.e. at bead seat is 154.98 MPa by experimental method. So observed stress value is far below compared to yield strength of wheel material. So the design of disc wheel rim analyzed in this research is safe.

VIII. CONCLUSION

Modeling time is reduced by using macro method. It also reduces possibility of human error along with standard procedure is set for modeling. The stress distribution values in the disc wheel matches well with the stress values from experimental testing. Though the values are not exactly same, they show similar patterns. Some error in results of FEM is due to optimum element size. Bead seat region shows maximum stress value among identified critical regions. In whole model maximum stress value is on flange. Displacement and stress values for stud hole region is minimum. The stresses are much higher in rim compared to disc. Design of wheel analyzed here by FEA and experimental method is safe when compared to yield strength of material.

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