Design and Material Optimization of an Automobile Wheel Rim by Finite Element Analysis

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Abstract

An unmodified existing automobile wheel rim has modelled and analyzed for Aluminium alloy 6061, S-Glass epoxy and E-Glass epoxy material to evaluate the distribution of equivalent Von-mises stress and deformations raised in an automotive wheel rim subject to the radial dynamic load. A comprehensive three-dimensional model of an existing automobile wheel rim has modelled from the existing design data's by using commercial modeling package with customary specifications. This analysis is spotlight the suitable lightweight and high strength material optimization for an automobile wheel rim. Structural analysis also conceded on the wheel rim by using finite element technique. Equivalent stress distribution and total deformation accomplished by an unmodified existing automobile wheel rim has represented as contour plots, which has obtained for Aluminium alloy 6061, S-Glass epoxy and E-Glass epoxy materials respectively. Results obtained from the finite element analysis exposed that the S-Glass epoxy material automobile wheel rim has deformed less and produced higher equivalent Von-mises stress distribution than Aluminium alloy 6061 wheel rim and E-Glass epoxy wheel rim.

Keywords: Automobile wheel rim, design, analysis, material optimization, FEM.

Introduction

Automobile have various parts, which are important for good running of the vehicle. The most important safety components from a structural point of view are the road wheels. They are required to be lighter and more fascinating to the buyer all the time [1]. Improvement of the safety and the crashworthiness features is a continuous process in the automotive industry. One of the most important development is the force-deflection characteristic of the vehicle. The force-deflection characteristic is correlated to, change of momentum, or the change of velocity during the impact. Car wheel rim is also one of the aspect that been studied it force-deflection when subjected to crash [2]. The steel wheel, which is one of the basic structural elements of motor vehicle tyre assemblies, connects the vehicle body and the tyre and enables the wheel rotation. It also transmits vertical and lateral tyre forces to the axle housing or the axle beam [3]. In automotive engineering, the wheels are one of the most critical components and their function is of vital importance in human safety. With the changing requirements in the automotive industry in the last decade, the wheel manufactures have been taking increasing attention to lightweight designs by new materials [4]. Road wheel is an important structural member of the vehicular suspension system that supports the static and dynamic loads encountered during vehicle operation. Since the rims, on which cars move, are the most vital elements in a vehicle, they must be designed carefully. Safety and economy are particularly of major concerns when designing a mechanical structure so that the people could use them safely and economically. Style, weight, manufacturability and performance are the four major technical issues related to the design of a new wheel and/or its optimization. The wheels are made of either steel or cast/forge aluminium alloys. Aluminium is the metal with features of excellent lightness, corrosion resistance, etc. In particular, the rims, which are made of aluminium casting alloys, are more preferable because of their weight and cost [5]. Wheel of a car is one of the important safety components. It can not only suffer the vertical force under the wheels, but also suffer the irregular forces resulting from cars starting, braking and turning the process of moving, and road shock. As a high-speed rotation of the wheel, its quality will have a major impact to the vehicle stability, handling and other properties. The development direction of the wheel is to reduce the quality and beautify its appearance as far as possible when it can ensure sufficient strength and reliability [6]. The wheel being a critical component in the vehicle has to meet strict requirements of driving safety. The wheel design must meet both the styling appearance and engineering functions. The wheel also must be durable enough to withstand rough loads and harsh environments. Besides, wheel weight and manufacturing cost should be minimized without contradicting the safety requirements [7]. The vehicle may be towed without the engine but it is not possible without the wheels. Road wheel is a significant structural member of the vehicular suspension system that supports the static and dynamic loads encountered during vehicle operation. As in the case of an automobile wheel, maximum load is applied on the alloy wheel. Proper analysis of the alloy wheel plays a significant role for the safety of the passenger cars [8]. In automotive engineering, the wheels are one of the most critical components and their function is of vital importance in human safety [9]. Optimum usage of the material and unwanted art that will lead to the heavy weight and at the same time will reduce the performance of the component [10]. Since rims, on which cars move, are the most vital elements in a vehicle, they must be designed carefully [11]. Durability assessment of mechanical components early in the design phase plays a key role in the automotive industries [12]. 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 [13]. During the last two decades, the procedures have significantly improved with the emergence of a variety of innovative experimental and analytical methods for structural analysis [14]. However, many wheels are still designed with traditional or aesthetical patterns that may not be efficient enough to overcome the realistic design process. Engineers gain benefits through understanding the efficiency of materials used in existing wheel designs and can seek improvements in such designs following a set of optimality design criteria [15]. The auto industry is moving toward increased use of lightweight aluminum alloy castings for many components previously made from steel and cast iron. In the case of wheels, the increased utilization of aluminum alloys relates predominantly to improved aesthetic appearance and design flexibility over the traditional stamped and welded steel wheels [16]. The 6061 aluminum alloys applied for the wheel forging processes in the present study have characteristics that are more desirable in those aspects than other materials [17]. The rim stiffness finite element model, 13-degree impact strength finite element model and bending analysis finite element model of the wheel were established firstly. The influence of the rim stiffness, wheel impact strength and bending fatigue strength of the wheel were synthetically considered [18]. Many research works have been carried out here before to analyze the effect of wheel model and wheel material for the smooth running of automobile [19]. In present research work, an unmodified existing automobile wheel rim's complete three-dimensional model has created by using commercial modeling software package to establish the deformation and stress behaviour under the steady dynamic load for Aluminium alloy 6061, S-Glass epoxy and E-Glass epoxy material by using commercial analysis software.

2. Materials Selection for automobile wheel rim 3D model

Material selection for automobile rim is one of the most significant stuff for the betterment of the vehicle's performance. In this numerical analysis, an unmodified existing automobile wheel rim has analyzed with the Aluminium Alloy 6061, E-Glass Epoxy and S-Glass Epoxy materials due to its lightweight and high strength. The material used in the analysis model has assumed isotropic, homogeneous, and temperature-independent. During the finite element analysis on an unmodified existing automobile wheel rim, different mechanical properties of these materials have feeded in the ANSYS software to simulate the material changes effects on total deformation and the distribution of equivalent Von-mises stress over the rim surfaces.. Mechanical properties of these materials are approximately equivalent to the existing steel wheel rim, due to this reason above materials have taken for the numerical analysis on wheel rim.

3. Three dimensional model generation for automobile wheel rim

Three-dimensional model generation of an existing wheel rim has started with the collection of basic dimensions from the physically available wheel rim by reverse engineering concept. The standard specifications of an unmodified existing automobile wheel rim were measured with the help of standard measuring instruments with tolerances and clearances, in order to get the exact three-dimensional model of the rim. A commercial modeling software (CREO) is used to create the two dimensional views of the wheel rim by means of the measured value with proper specifications. Different two-dimensional views are created with the help of the measured dimensions through the modeling software. Entire two-dimensional views are checked for the conversion of three-dimensional model. The complete three-dimensional model of an unmodified existing automobile wheel rim was created with the help of the same modeling software through the two dimensional sketches. Comprehensive three-dimensional model of an unmodified automobile wheel rim that is modeled by the commercially available software is shown in figure.1. In order to understand the wheel rim architecture, the entire three-dimensional model of the wheel rim has converted also a wire frame model. The complete wire frame model of the wheel rim has illustrated in figure.1. Different orientations have applied on the wheel rim model to obtain the various configuration views for the better understanding of wheel rim architecture. The three dimensional model, that was created by sing the commercially available software is ready of the finite element analysis to establish the deformation and stress distribution behaviour under the three different materials like, Aluminium Alloy 6061, E-Glass Epoxy and S-Glass Epoxy materials respectively.

4. Finite element analysis on automobile wheel rim

In this finite element analysis through the ANSYS R18.1 software, comprehensive three-dimensional model of an unmodified existing automobile wheel was undergone the structural analysis by applying the steady dynamics load of the middle portion of the rim. Before the structural analysis on the rim, the complete comprehensive three-dimensional model of the wheel rim has converted as IGES file through the modeling software for the analysis process in ANSYS R18.1 software.

Figure 1 Comprehensive three-dimensional and wire frame model of an unmodified automobile wheel rim

The converted IGES model of wheel rim has imported in ANSYS workbench through import module of external geometry file and the imported IGES model of wheel rim has generated as per the requirements for the ANSYS R18.1 software to carry out structural analysis in the new geometry creation module. In mesh creation module, the entire imported geometry of the wheel rim has selected and the different meshing parameters like, physical preference, type of mesh, number of mesh elements and element size has assigned on the mesh model of the wheel rim. By using the mesh generation option, the entire wheel model has converted as mesh model through the simulation conversion option under the predefined meshing parameters. The exclusive mesh model of an unmodified existing automobile wheel rim has demonstrated in figure.2. By using the solid geometry tree menu, the material for meshed wheel model has assigned by means of the new material definition option. The required wheel rim material properties like, young’s modulus, poisons ratio and density were feeded into the ANSYS R18.1 software by means of the new material menu. After the material properties assignment on the mesh model of wheel rim, new analysis option has selected in the software to fix the support for the wheel rim to apply the load.

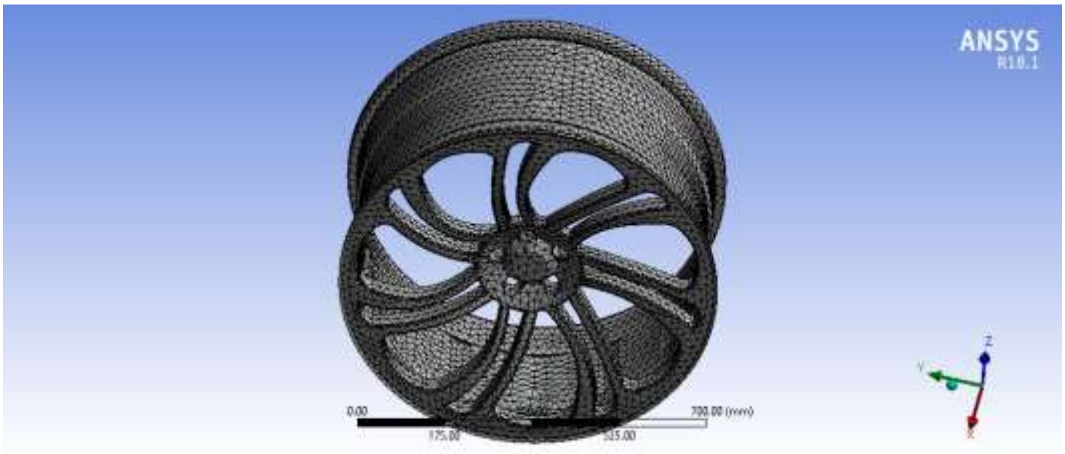

Figure 2 Exclusive finite element model of automobile wheel rim

In new analysis menu, top end of the wheel rim part has constrained with zero degrees of freedom, in order to arrest the all movements in that point. The zero degrees of freedom have applied on the mesh geometry of the wheel rim. An unmodified existing automobile Wheel rim with applied boundary conditions for fixed support has shown in figure.3.

Figure 3 Wheel rim with applied boundary conditions for fixed support

Static structural analysis option has opted to apply the stable dynamic load on the wheel rims axis. Automobile wheel rim with forces applied configuration has illustrated in figure. 4. The complete loaded wheel rim geometry has selected and the to insert the total deformation, directional deformation, equivalent elastic strain, equivalent stress, shear elastic strain, shear stress, maximum shear elastic strain and maximum shear stress attained by the wheel rim model in the load applied directions. Finally by using the solve icon option, the entire analysis were computed for the given inputs and for the selected outputs from the ANSYS R18.1 software. After the solver command execution process, the required results for the wheel rim has obtained from the software in the form of color counter plots for the specific inputs. In this research, the specific outputs like total deformation attained by an unmodified existing automobile wheel rim and the equivalent Von-mises stress distribution of the same wheel rim has obtained in the form of color plots with minimum and maximum magnitudes accordingly. The same analysis process has followed for the remaining two materials, the corresponding outputs for those materials has obtained, and the analysis results were illustrated and compared with all three material wheel rim in results and discussions chapter.

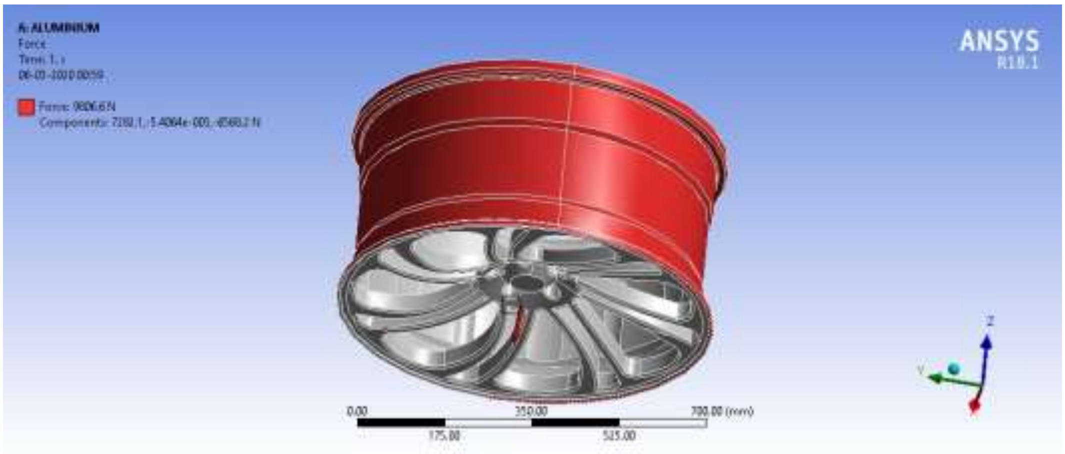

Figure 4 Wheel rim with force applied boundary conditions

5. Results and Discussions

A typical finite element analysis has carried out successfully on an unmodified existing automobile wheel rim by changing the wheel rim materials such as Aluminium Alloy 6061, E-Glass Epoxy and S-Glass Epoxy materials for the establishment of total deformations and equivalent Von-mises stress distributions exhibited by the wheel rim under the stable dynamic loads, which has applied on it theoretically. The following results have obtained from the finite element analysis for the three different wheel rim materials.

5.1 Total deformation - Aluminum Alloy 6061 wheel rim

Total deformation attained by an unmodified existing automobile wheel rim analyzed with Aluminium Alloy – 6061 material under the dynamic load from the ANSYS R18.1 software has illustrated in figure.5. From the figure.5, it was observed that the maximum total deformation of 0.666080 mm that has exhibited by the wheel rim at its inner circumferential surface. Minimum amount of 0.074009 mm deformation has established by the wheel rim at the middle portion. The minimum deformation has observed at the middle portion of the wheel rim due to the arrested degrees of freedom conditions. Applied load on the Aluminum Alloy 6061-wheel rim has distributed from the centre of the wheel rim to outer surface of the wheel rim. Similarly, the total deformation attained by the Aluminum Alloy 6061-wheel rim has progressively increased from the centre portion of the rim to the outer surface the rim.

5.2 Total deformation – S Glass Epoxy wheel rim

An automobile wheel rim analyzed with S Glass Epoxy wheel rim material under the dynamic load for the establishment of attained total deformation from the finite element analysis has illustrated in figure.6. It was noted that the maximum total deformation of 0.55494 mm that has exhibited by the wheel rim at its inner circumferential surface. Minimum amount of 0.06166 mm deformation has established by the wheel rim at the middle portion. The minimum deformation has observed at the middle portion of the wheel rim due to the arrested degrees of freedom conditions. Applied load on the S Glass Epoxy wheel rim has distributed from the centre of the wheel rim to outer surface of the wheel rim. Similarly, the total deformation attained by the S Glass Epoxy wheel rim has increasingly from the centre portion of the rim to the outer surface the rim.

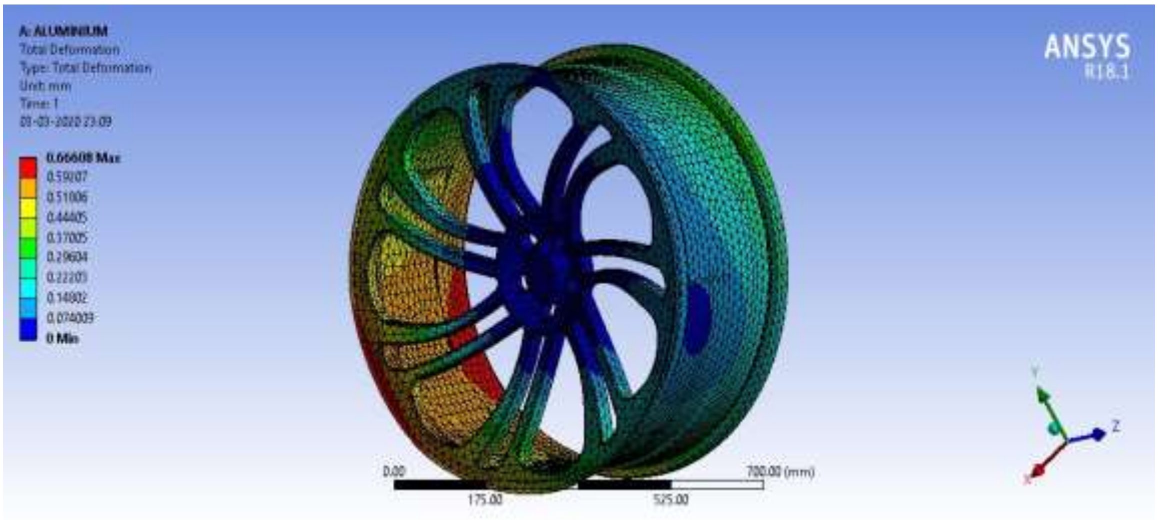

Figure 5 Total deformation attained by the Aluminum Alloy 6061 wheel rim

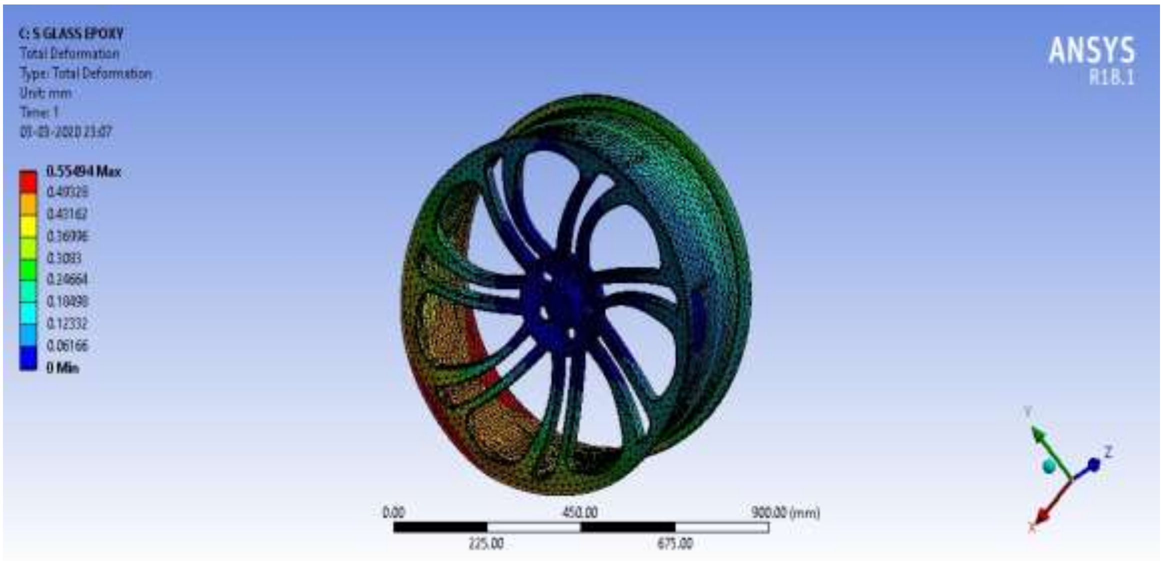

Figure 6 Total deformation under the applied load for S Glass Epoxy Wheel rim

5.3 Total deformation – E Glass Epoxy wheel rim

Deformation produced by an E Glass Epoxy wheel rim under the specific applied loading conditions for E Glass Epoxy wheel rim has shown in figure.7. It was found that the maximum total deformation of 0.59366 mm that has exposed by the wheel rim at its innermost circumferential surface. Minimum amount of 0.074207 mm deformation has recognized by the wheel rim at the middle portion. The minimum deformation has observed at the middle portion of the wheel rim due to the arrested degrees of freedom conditions. Applied load on the E Glass Epoxy wheel rim has circulated from the centre of the wheel rim to outermost surface of the wheel rim significantly. In the same way, the total deformation conquered by the E Glass Epoxy wheel rim has steadily increased from the centre portion of the rim to the outermost surface the rim correspondingly.

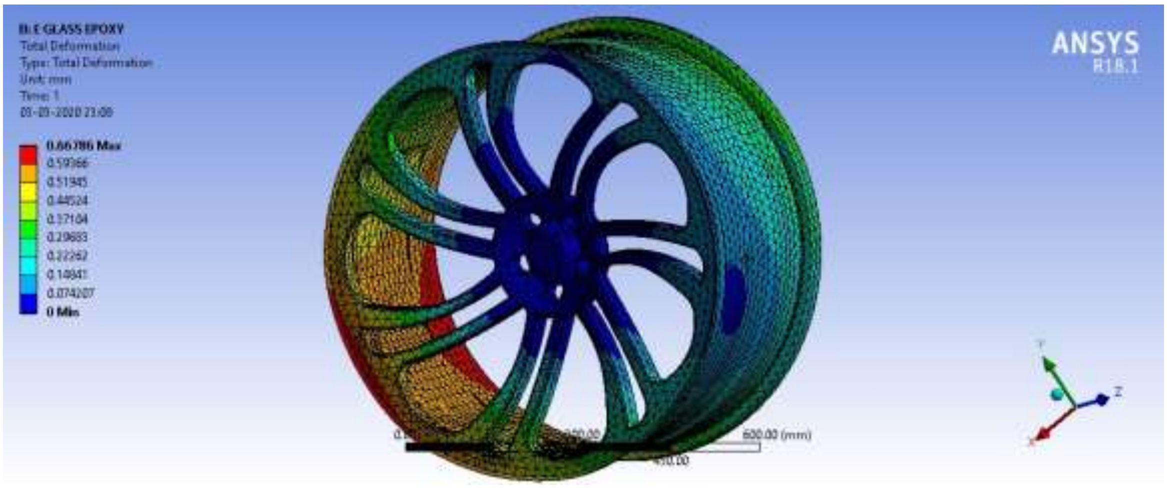

Figure 7 Total deformation of E-Glass Epoxy wheel rim under the applied loading condition

5.4 Location wise total deformation – E Glass Epoxy, S Glass Epoxy and Aluminum Alloy 6061 wheel rim

Location wise deformation accomplished by the E Glass Epoxy, S Glass Epoxy and Aluminum Alloy 6061 wheel rim from minimum level to maximum level have represented with location number in figure.8. According to the magnitude of the deformation, which have attained by the wheel rim during the finite element analysis, location number has allotted in the total deformation color plot. Minimum total deformation has established at the wheel rim base and then it has gradually increased with respect to the increasing location number i.e. the innermost surfaces to the outermost surfaces of the wheel rim significantly. Maximum total deformation has exhibited by the wheel rim at the innermost circumferential area due to the transformation of higher magnitude load.

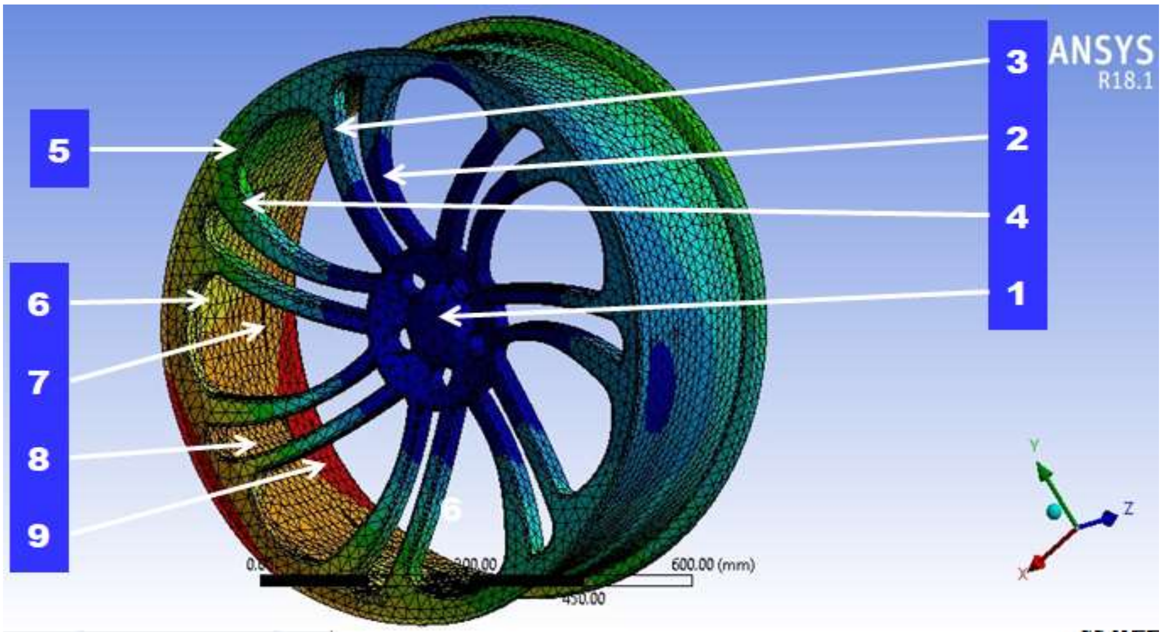

Figure 8 Representation of location wise deformation accomplished by the wheel rim from minimum level to maximum level

The total deformation attained by an unmodified existing automobile wheel rim with respect to the applied dynamic load for the three different materials such as Aluminum Alloy 6061, S-Glass Epoxy and E-Glass Epoxy from minimum to maximum level has represented in figure.9. It has found that the total deformation of wheel rim has significantly increased from the middle portion to the extreme outermost circumferential surfaces of the rim. An unmodified existing automobile wheel rim, which has analyzed with S Glass Epoxy revealed the minimum total deformation of 0.55494 mm at outermost circumferential area due to the high strength of the corresponding material. On the other hand, maximum total deformation of 0.66786 mm has revealed by an unmodified existing automobile wheel rim outermost circumferential area, which has analyzed with E Glass Epoxy material.

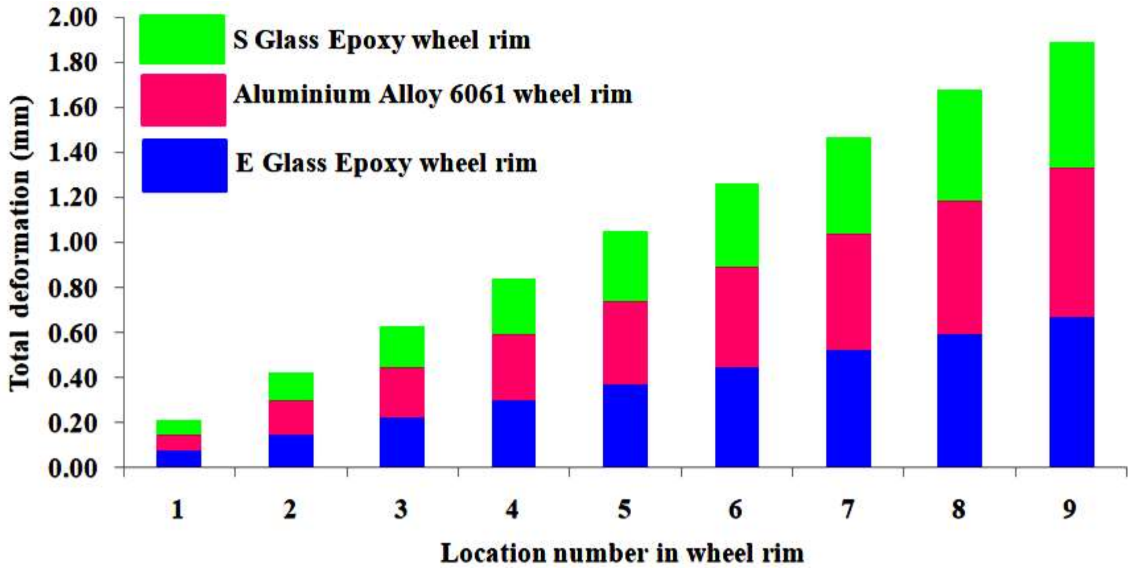

Figure 9 Minimum to maximum deformation exposed by S-Glass Epoxy, Aluminium Alloy 6061 and E-Glass Epoxy wheel rim

5.5 Comparison of maximum outermost circumferential area total deformation

Comparison of maximum total deformation attained by an unmodified existing wheel rim at its outermost circumferential area for Aluminium Alloy 6061, S-Glass Epoxy and E-Glass Epoxy material have represented in the graphical form in figure.10. Maximum total deformation for E-Glass Epoxy wheel rim has observed with the magnitude of 0.66786 mm. Wheel rim analyzed with Aluminium Alloy – 6061 has exposed the maximum total deformation of 0.666080 mm at the outermost circumferential surfaces. Surprisingly, S-Glass Epoxy wheel rim has not allowed the maximum deformation under the applied dynamic load. S-Glass Epoxy wheel rim has exposed the maximum total outermost surface deformation of 0.55494 mm considerably. Compared with Aluminium Alloy 6061 wheel rim and E-Glass Epoxy wheel rim, the S-Glass Epoxy wheel rim does not produce the maximum deformation at the outermost rim surfaces.

5.6 Equivalent Von-mises stress distribution - Aluminum Alloy 6061 wheel rim

Equivalent Von-mises stress distribution exposed by an unmodified existing automobile wheel rim analyzed with Aluminium Alloy – 6061 material under the dynamic load from the ANSYS R18.1 software has illustrated in figure.11.

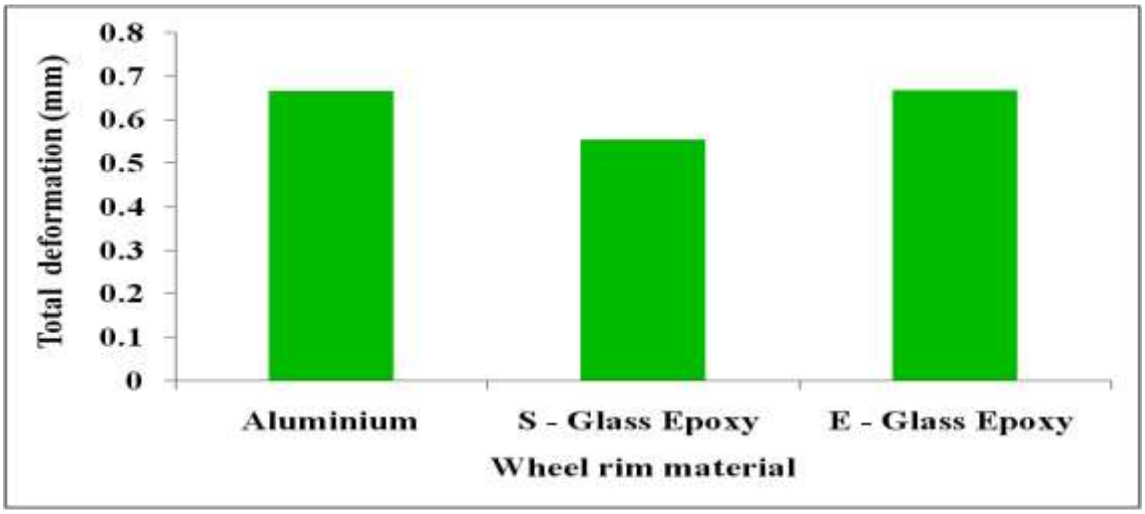

Figure 10 Maximum total deformation attained by the wheel rim for Aluminium Alloy 6061, S-Glass Epoxy and E-Glass Epoxy material

From the figure.11, it has observed that the maximum equivalent Von-mises stress of 37.408 MPa that has exhibited by the wheel rim at its inner circumferential surface. Minimum equivalent Von-mises stress of 4.1644 MPa has established by the wheel rim at the middle portion. The minimum equivalent Von-mises stress has observed at the middle portion of the wheel rim due to the applied load distribution. Applied load on the Aluminum Alloy 6061-wheel rim has distributed from the centre of the wheel rim to outer surface of the wheel rim. Similarly, the equivalent Von-mises stress attained by the Aluminum Alloy 6061-wheel rim has progressively increased from the centre portion of the rim to the outer surface the rim.

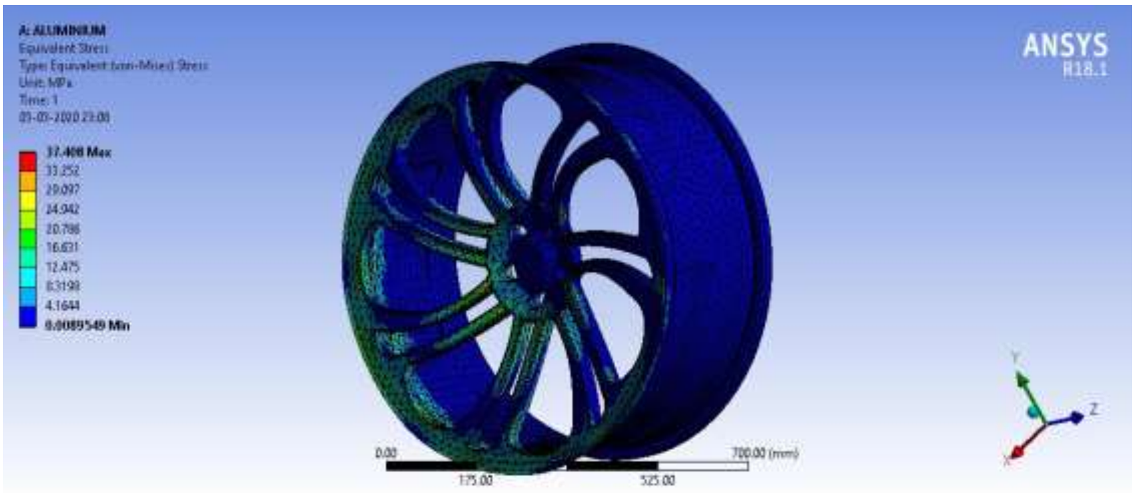

Figure 11 Equivalent Von-mises stress distribution in Aluminium Alloy 6061 wheel rim

5.7 Equivalent Von-mises stress distribution – S Glass Epoxy wheel rim

Equivalent Von-mises stress distribution exposed by an unmodified existing automobile wheel rim analyzed with S Glass Epoxy wheel rim under the dynamic load from the ANSYS R18.1 software has illustrated in figure.12. From the figure.12, it has observed that the maximum equivalent Von-mises stress of 37.408 MPa that has exhibited by the wheel rim at its inner circumferential surface. Minimum equivalent Von-mises stress of 4.1644 MPa has established by the wheel rim at the middle portion.

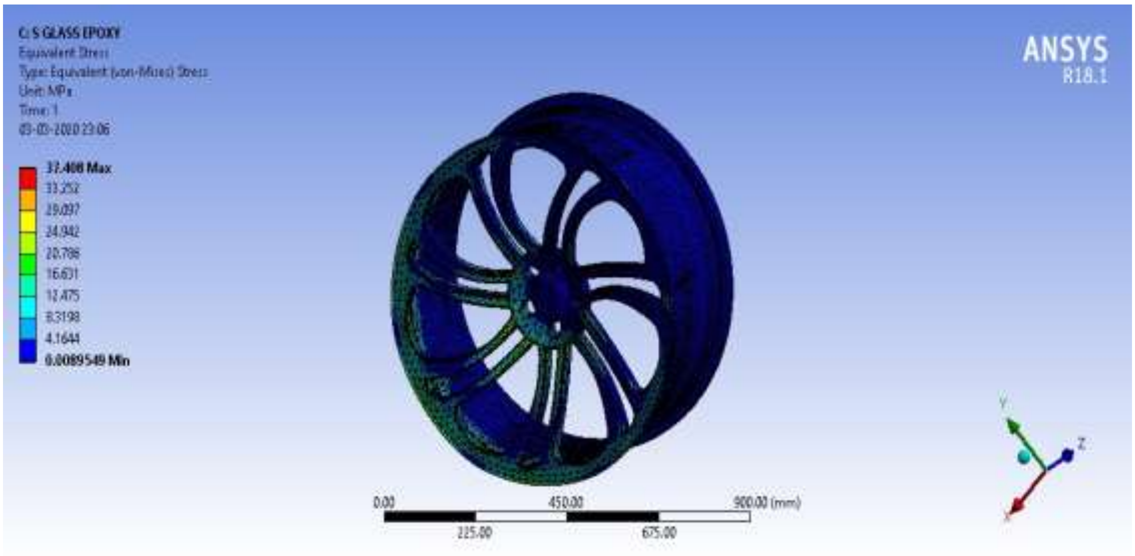

Figure 12 Distribution of equivalent Von-mises stress in wheel rim for S-Glass epoxy material

5.8 Equivalent Von-mises stress distribution – E Glass Epoxy wheel rim

Equivalent Von-mises stress distribution exposed by an unmodified existing automobile wheel rim analyzed with E Glass Epoxy wheel rim under the dynamic load from the finite element results has illustrated in figure.13. From the figure.13, it has observed that the maximum equivalent Von-mises stress of 37.766 MPa that has exhibited by the wheel rim at its inner circumferential surface. Minimum equivalent Von-mises stress of 4.2067 MPa has established by the wheel rim at the middle portion.

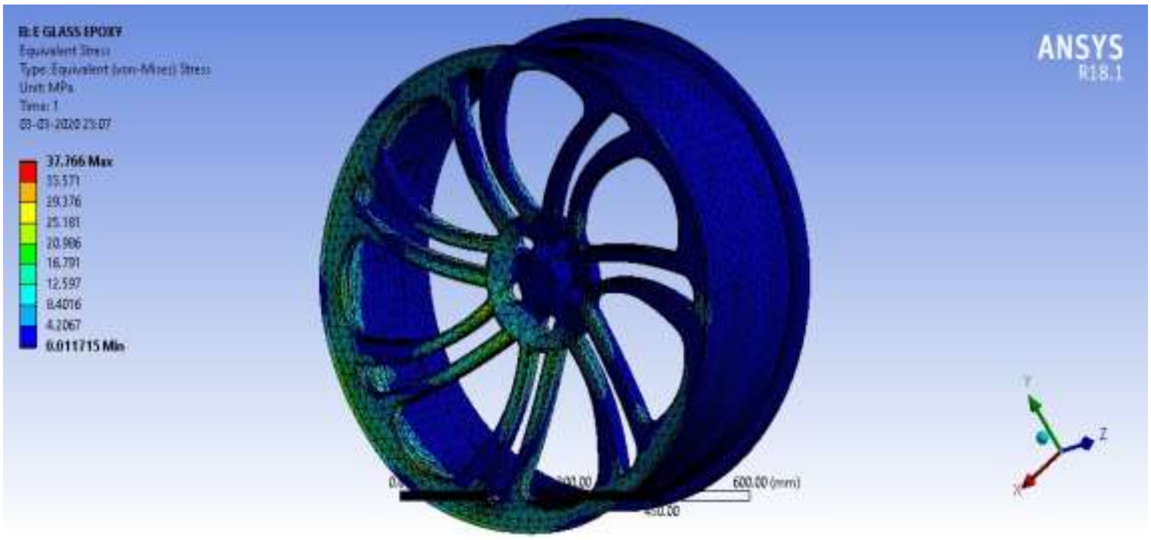

Figure 13 Equivalent Von-mises stress distribution in E-Glass Epoxy wheel rim

5.9 Location wise Distribution of Equivalent Von-mises stress – E Glass Epoxy, S Glass Epoxy and Aluminum Alloy 6061 wheel rim

Location wise distribution of equivalent Von-mises stress accomplished by the E Glass Epoxy, S Glass Epoxy and Aluminum Alloy 6061 wheel rim from minimum level to maximum level have represented with location number in figure.14.

According to the magnitude of the equivalent Von-mises stress, which have attained by the wheel rim during the finite element analysis, location number has allotted in the equivalent Von-mises stress color plot. Minimum equivalent Von-mises stress has established at the wheel rim base and then it has gradually increased with respect to the increasing location number i.e. the innermost surfaces to the outermost surfaces of the wheel rim significantly. Maximum equivalent Von-mises stress has exhibited by the wheel rim at the innermost circumferential area due to the transformation of higher magnitude load.

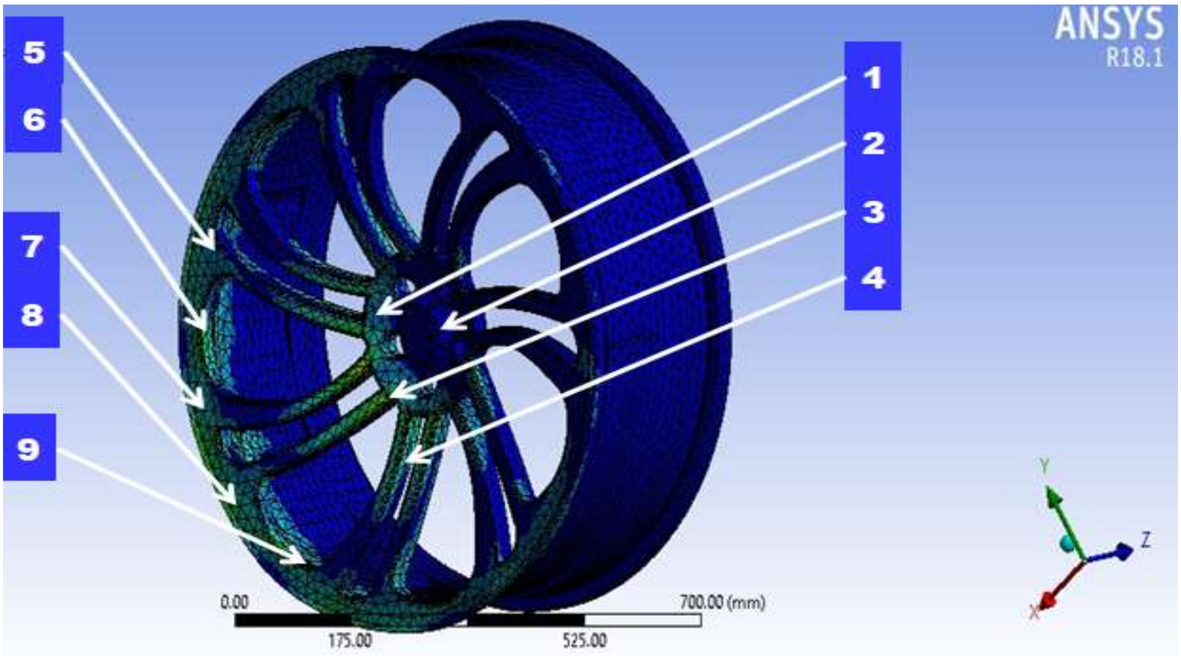

Figure 14 Minimum to maximum equivalent Von-mises stress attained by the wheel rim with corresponding location number

Equivalent Von-mises stress distribution exposed by an unmodified existing automobile wheel rim with respect to the applied dynamic load for the three different materials such as Aluminum Alloy 6061, S-Glass Epoxy and E-Glass Epoxy from minimum to maximum level has represented in figure.15. It has found that an equivalent Von-mises stress distribution of wheel rim has significantly increased from the middle portion to the extreme outermost circumferential surfaces of the rim. An unmodified existing automobile wheel rim, which has analyzed with S Glass Epoxy and E Glass Epoxy have revealed the minimum equivalent Von-mises stress distribution of 37.408 MPa at outermost circumferential area due to the high strength of the corresponding material. On the other hand, maximum equivalent Von-mises stress distribution of 37.776 MPa has revealed by an unmodified existing automobile wheel rim outermost circumferential area, which has analyzed with E Glass Epoxy material.

5.10 Comparison of maximum outermost equivalent Von-mises stress distribution

Comparison of maximum Von-mises stress distribution attained by an unmodified existing wheel rim at its outermost circumferential area for Aluminium Alloy 6061, S-Glass Epoxy and E-Glass Epoxy material have represented in the graphical form in figure.16. Maximum equivalent Von-mises stress distribution for E-Glass Epoxy wheel rim has observed with the magnitude of 37.776 MPa. Wheel rim analyzed with Aluminium Alloy – 6061 has exposed the maximum equivalent Von-mises stress distribution of 37.408 MPa at the outermost circumferential surfaces. Surprisingly, S-Glass Epoxy wheel rim has not produced the maximum equivalent Von-mises stress distribution under the applied dynamic load. S-Glass Epoxy wheel rim has exposed the maximum equivalent Von-mises stress distribution of 37.408 MPa considerably. Compared with Aluminium Alloy 6061 wheel rim and S-Glass Epoxy wheel rim, E-Glass Epoxy wheel rim has exhibited the maximum equivalent Von-mises stress distribution outermost rim surfaces.

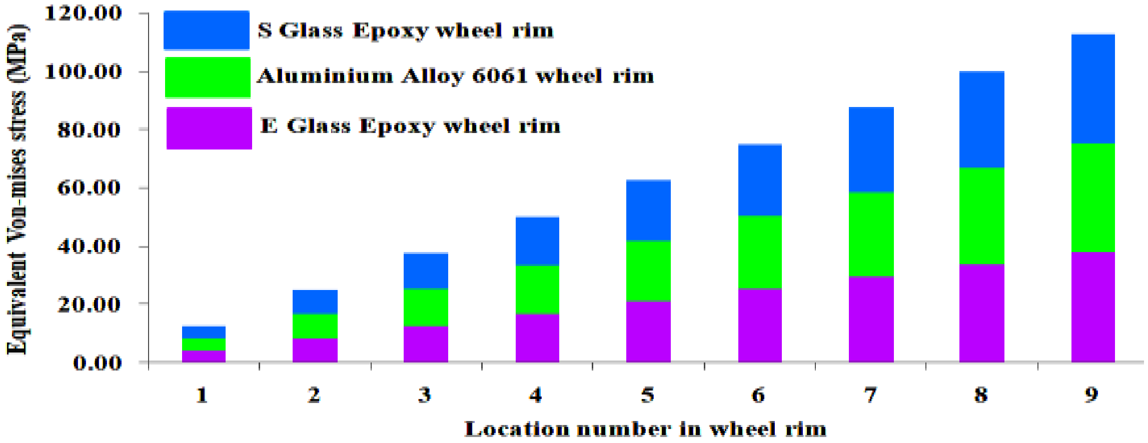

Figure 15 Minimum to maximum equivalent Von-mises stress exposed by S-Glass Epoxy, Aluminium Alloy 6061 and E-Glass Epoxy wheel rim

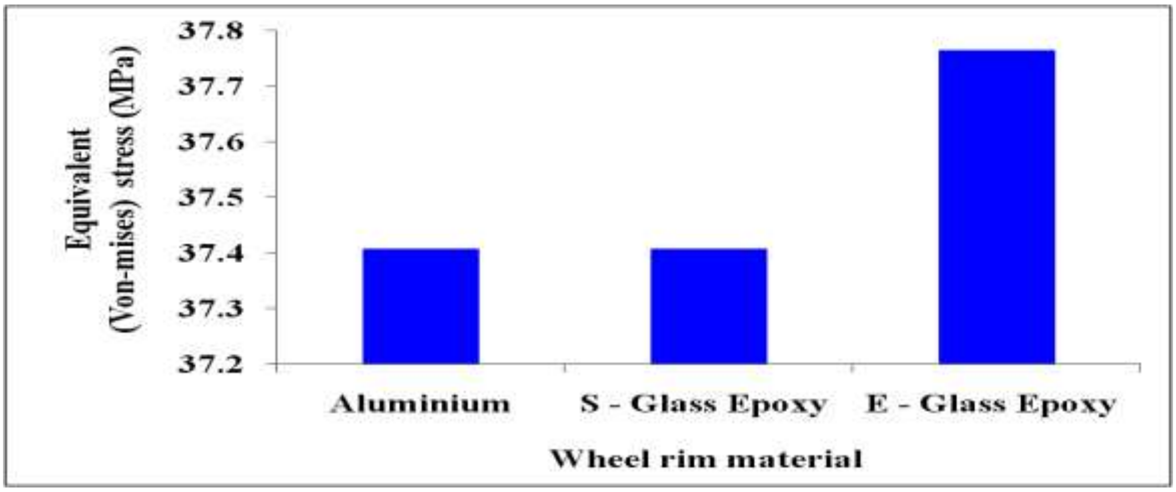

Figure 16 Distribution of equivalent Von-mises stress in Aluminium Alloy 6061, S-Glass Epoxy and E-Glass Epoxy wheel rim

Conclusions

An unmodified existing automobile wheel rim has modeled using modeling software and the structural analysis has been conceded on the wheel rim by changing the material such that Aluminium Alloy 6061, S-Glass Epoxy and E-Glass Epoxy material under the specific dynamic loading condition. Total deformations and equivalent Von-mises stresses distribution behaviour of wheel rim have established for the Aluminium Alloy 6061, S-Glass Epoxy and E-Glass Epoxy. Finite element analyses results revealed that the wheel rim that have analyzed with E-Glass Epoxy material exhibits the better deformation behaviour and have exposed the maximum Von-mises stress distribution over the wheel rim surfaces under the applied dynamic load conditions than Aluminium Alloy 6061and S-Glass Epoxy wheel rim. It has concluded that the E-Glass epoxy material can be used as an automobile wheel rim for the replacement of aluminium alloy and steel wheel rims.

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