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Numerical simulations of equivalent stress of a motorcycle wheel by using ANSYS

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ABSTRACT

The design of a motorcycle wheel contains several complexes and attempt has been made to meet the requirements of original equipment manufacturers (OEMs). By using UNIGRAPHICS (NX 7.5), it involves with the drawing requirements and design of a motorcycle wheel. The design in 6 degree of freedom (DOF) for characteristics and durability has been developed. After designing of wheel, the material should be selected and to go through several analysis test on ANSYS software. By applying different loads in existing Aluminium alloy wheel and analyze the bending stresses, the material has been changed from Aluminium alloy to Polyether-ether ketone, PEEK150GL30, PEEK90GL30 and PEEK150CA30 for the study. In the same design the materials has been changed one by one and applying different loads, and analyze the bending stresses. It is concluded that the existing design is suitable for plastic material. Plastic material will deform at a maximum load of 2452.5N (250Kg). So change the design and the materials and analyze the bending stresses and finally conclude that Aluminium alloy can be replaced by plastic material.

Keywords— *Unigraphics, ANSYS, Al alloy, Peek150GL30, Peek90GL30, Peek150CA30*

1. INRODUCTION

The design is the creation of new and better machines and improving the existing ones. A latest or better design is one which is more economical in the overall cost of production and operation. The process of design is a long and time consuming one. From the study of existing ideas, a new idea has to be conceived. In the preparation of these drawings, care must be taken of the availability of resources i.e. money, men and material required for the successful completion of the new idea into an actual reality. A large number of wheel tests are required in designing and manufacturing of wheels to meet satisfactory requirement. Since the rims on which vehicle moves are the most vital element in a vehicle they must be designed carefully. Safety and economy are particularly of major concern when designing a mechanical structure so that the people could use them. The wheels are made of either steel or cast/forge aluminium alloy. Automotive manufacturer have been developing safe, fuel efficient and light weight vehicular components to meet governmental regulation and industry standards.

1.1 Aluminium Alloys

The alloy used smooth road wheels today is a blend of aluminium and other element. Magnesium alloy is generally not suitable for road usage due to its brittleness and susceptibility to corrosion. In market mostly aluminium alloy wheel is used. Pure aluminium is soft, ductile, and corrosion resistant and has a high electrical conductivity. Due to this it is widely used for foil and conductor cables, but alloying with other elements is necessary to provide the higher strength needed for other application. The aluminium may be alloyed with one or more other material like, magnesium, manganese, silicon, copper and nickel. The addition of small quantities of alloying element converts the soft and weak metal into hard and strong metal, while still retaining its light weight. The main aluminium alloys are discussed below:

Table 1: Mechanical Properties of Aluminium Alloy

Modulus of Elasticity	72.4GPa
Poisson's Ratio	0.33
Density	2770kg/m^3
Yield Stress	218MPa
Ultimate Stress	283MPa
Specific Gravity	2.7
Melting Point	658 ^{0}C
Tensile Strength	283Mpa

1.2 Introduction about PEEK

The linear aromatic polyether ketone family consists of several variations on the theme of repeated monomers of ether and ketone. The first one produced in the laboratory in 1977 was the polymer polyether ether ketone B (now simply known as PEEK). The structure of PEEK is shown below:

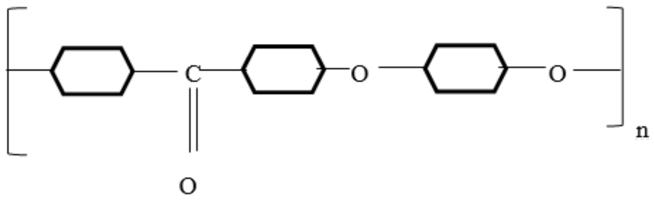

Fig. 1: Structure of Polyetheretherketone

The diagrammatic representation of PEEK may appear daunting at first but this is nothing compared to the word description where the repeat unit can be described as:

[-oxy-1,4-phenylene-oxy-1,4-phenylene-carbonyl-1,4-phenylene-]

ICI realized the potential for the outstanding properties of PEEK and test marketing was conducted in 1978, only one year after the first preparation of the material. ICI sold the PEEK business in 1993, via a management buyout, to Victrexplc (the original brand name for the PEEK product), and for many years Victrex remained the only commercial manufacturer and supplier of PEEK.[10]

The annual production capacity of Victrex® PEEK is approximately 2800 tonnes (6.2 million lbs.) but demand is rising rapidly as applications increase. This means that not only is Victrex installing more capacity but also other manufacturers are starting production of PEEK to meet the market needs.

PEEK (Polyether etherketone) is a high strength alternative to fluoropolymers with an upper continuous use temperature of 2500 C. (4800 F). PEEK having excellent mechanical and thermal properties, creep resistance at high temperature, chemical inertness, low flammability, hydrolysis resistance and radiation resistance. These properties make PEEK a preferred product in the aircraft, automotive, semiconductor and chemical processing industries.

1.3 Different grades of PEEK

PEEK is available in a variety of grades for specific applications, and the main grades available are the following:

- **Standard unfilled powder grades:** This is the form of PEEK a general-purpose grade, which has the highest elongation capacity at break and also the lowest general mechanical properties (tensile strength, flexural strength and flexural modulus) at a given temperature. Unfilled PEEK also has the best impact properties of the PEEK range.
- **Glass filled grades:** The addition of glass fibre reinforcement greatly increases the general mechanical properties at a given temperature (tensile strength, flexural strength and flexural, Modulus), and reduces the elongation at break and impact strength at low temperatures. Glass fibre filled grades of PEEK also show reduced thermal expansion rates and are ideal for high temperature structural applications.
- **Carbon filled Grades:** The addition of 30% carbon fibre reinforcement further increases the general mechanical properties at a given temperature (tensile strength, flexural strength and flexural modulus), and further reduces the elongation at break and impact strength at low temperatures. Carbon fibre filled grades of PEEK also have much reduced thermal expansion rates and greatly improved thermal conductivity.[14]
- **Lubricated (Friction and wear Polymer grades):** The addition of 30% carbon/PTFE improves the tribological properties (friction and wear) of PEEK. The additives also improve the machinability and make this grade ideal for machined bearing parts.

1.4 Properties of PEEK

PEEK has good mechanical properties, including impact resistance; low wear rate, and a low Coefficient of friction, but more importantly, these properties are also retained over a wide temperature range.

Table 2: Physical and Mechanical Properties of PEEK

Property	Approximate Value		
	Unfilled	PEEK150GL30	PEEK150CA30
Tensile strength	100MPa	150MPa	240MPa
Tensile Modulus	3.4GPa	11.4GPa	22.3GPa
Elongation at Break	34%	2%	1.5%
Flexural Strength	163Mpa	212MPa	40GPa
Notched Impact Strength	7.5kJ/m^2	10.3kJ/m^2	0.5J/m^2
Specific Heat (Melt)	2.16kJ/$^{kg\ 0\ C}$	1.7kJ/kg ^{0}C	1.8kJ/kg ^{0} C
Glass Transition Temperature	143 ^{0}C	143^0 C	143^0 C
Heat Deflection Temperature	152 ^{0}C	315^0 C	339
Coefficient of Thermal Expansion	<Tg 4.7x10-5/^{0}C >Tg 10. x10-5/^{0}C	<Tg 2. x10-5/^{0}C	<Tg 1.5x10-5/^{0}C
Specific Gravity	1.30 g/cm^3	1.51 g/cm^3	1.40 g/cm^3

1.5 Advantages of PEEK

- Excellent high temperature electrical performance
- Excellent abrasion resistance at high temperatures
- Excellent chemical resistance at high temperatures
- Excellent gamma radiation resistance
- Excellent hydrolysis resistance at high temperatures

1.6 Modeling of Motorcycle wheel

CAD Modeling is the base of any project. Finite Element software will consider shapes, whatever is made in CAD model. Solid modeling is the first step for doing any 3D analysis; it gives 3D physical picture for the products. FE models can easily be created from solid models by the process of meshing. CAD modeling software's are dedicated for the specialized job of 3D-modeling. Commercially available solid modeling packages are: AutoCAD, PRO-E, UNIGRAPHICS, and CATIA etc.

CAD model designs with conventional and plastic materials of motorcycle wheel are created in UNIGRAPHICS NX6. UNIGRAPHICS contains special tools in generating typical surfaces, which are later converted into solid models. For modeling the aluminium alloy wheel, the dimensions of an existing wheel of a light commercial vehicle are chosen.

1.7 Finite Element Analysis

Finite element analysis (FEA) is a tool used for the evaluation of system and structures. It is needed to analyze complex structures, whereas very simple ones, for example a beam can be analyzed using hand calculation. FEA is capable of performing parametric studies in which different geometries, material and loading conditions like thermal, structural and vibratory can be evaluated. A typical analysis evaluate the deflection and stresses which result and compares these against acceptable defined limits. The finite element analysis (finite element method) is a numerical technique for finding approximate solutions of partial differential equations as well as of integral equations. Thus the element equation cannot be solved alone to render the solution over each element. This task can only be performed by computer. It is noteworthy that as the structure is broken into a larger number of elements a greater number of simultaneously equations need to be solved. Thus typically results for more complex structure requires more computing power. Function of the FEA are a very accurate tool used for failure analysis purposes used to quantify design defects fatigue, buckling and code compliance can be used to distinguish between failure due to design, deficiencies material defects, fabrication error and abusive use provide quantified results previously based on metallurgical testing and excellent visual aids and animation easily understood.

1.8 Design and modification of wheel

The design of a motorcycle wheel contains several complexes and attempt has been made to meet the requirements of original equipment manufacturers (OEMs).The actual motorcycle wheel design is made by using **NX 7.5,** Author tried and ultimately succeeds with the drawing requirements and draws a complete design of motorcycle wheel. The developed design in is 6 degree of freedom (DOF) for characteristics and durability to fine tune the designs.

The whole design took about 4-5 weeks. The concept design of the component by using **NX 7.5** reduces our lead time by 2-3 weeks as well as 6 DOF validation expenses.

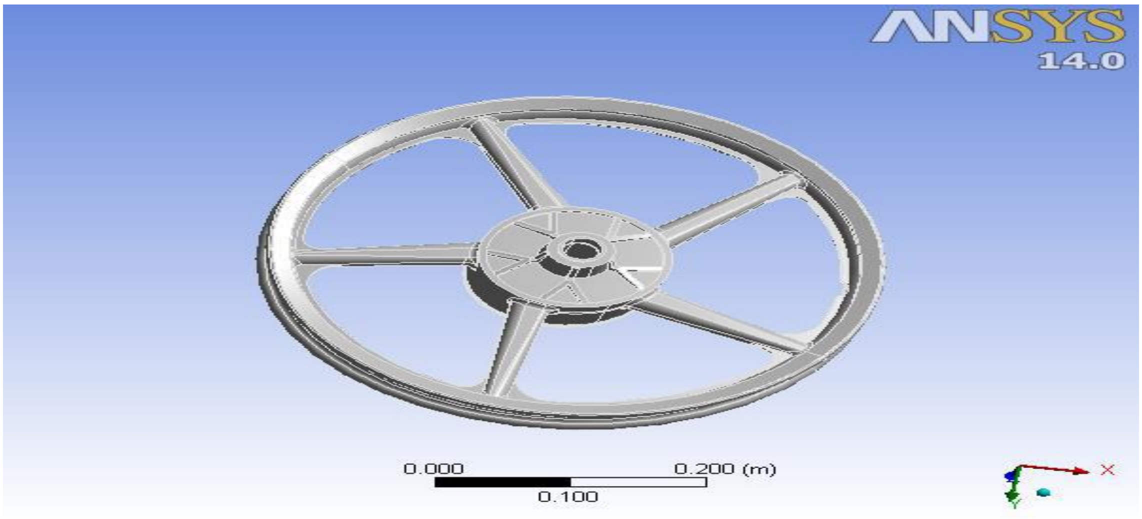

Fig. 2: Three Dimensional design of alloy wheel

Table 3: Design Parameters of Aluminium Alloy Wheel

Rim outer diameter	462mm
Rim width	57mm
Hub diameter	144mm
Spokes length	121mm
Angle between two spokes	76.51^0

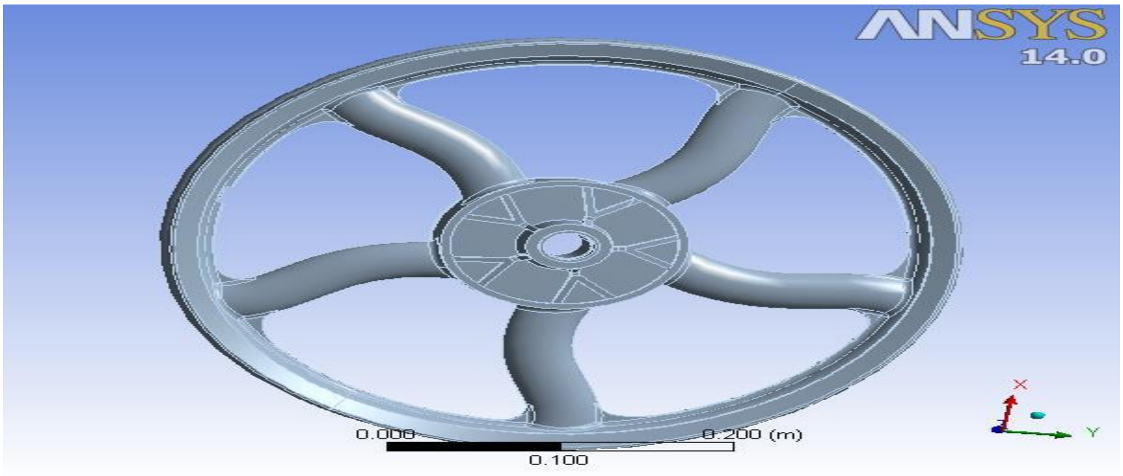

Fig. 3: Modified 3D design of alloy wheel

Table 4: Design Parameters of Modified Wheel

Rim outer diameter	462mm
Rim width	57mm
Hub diameter	144mm
Spokes length	121mm
Angle between two spokes	76.51^0
Spokes thickness	44mm

2. MATERIAL APPOINTMENT

Several materials have been chosen which could meet the requirements of motorcycle wheel. By evaluating many of the components, the material finally appointed is Polyether- ether ketone (PEEK), PEEK150GL30, PEEK90GL30, PEEK150CA30.

2.1 Properties of PEEK

Table 5: Properties of PEEK

Temperature *C	Young's Modulus Pa	Poisson's Ratio	Density	Bulk Modulus Pa	Shear Modulus Pa
23	3.6×10^6	0.39	1320 kg/ m^3	5.4×10^6	1.295×10^6

2.2 Properties of PEEK150GL30

Table 6: Properties of PEEK150GL30

Temperature *C	Young's Modulus Pa	Poisson's Ratio	Density	Bulk Modulus Pa	Shear Modulus Pa
23	4.06×10^6	0.45	1.3533×10^6	1520 kg/ m^3	1.4×10^6

2.3 Properties of PEEK90GL30

Table 7: Properties of PEEK90GL30

Temperature *C	Young's Modulus Pa	Poisson's Ratio	Density	Bulk Modulus Pa	Shear Modulus Pa
23	2.2×10^6	0.455	1370 kg/ m^3	8.2383×10^6	7.557×10^6

2.4 Properties of PEEK150CA30

Table 5: Properties of PEEK150CA30

Temperature *C	Young's Modulus Pa	Poisson's Ratio	Density	Bulk Modulus Pa	Shear Modulus Pa
23	4.5×10^6	0.48	1450 kg/ m^3	3.75×10^6	1.5203×10^6

3. RESULTS

3.1 Stress analysis of Modified wheel

Basic Steps to perform Finite Element Analysis for Modified Wheel:

CAD Modeling: Creation of CAD Model by using CAD modeling tools for creating the geometry of the part/assembly of which we want to perform FEA.

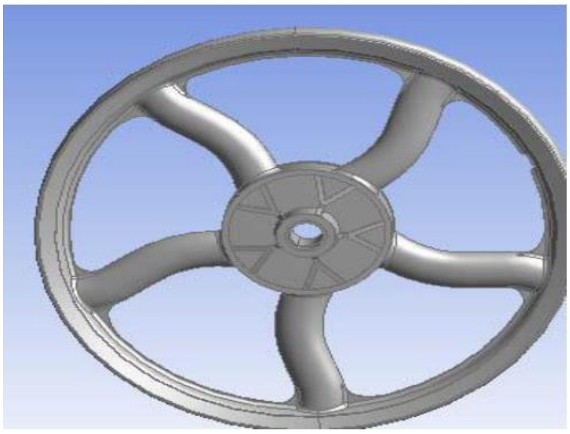

Fig. 4: 3D Model of Modified wheel

Meshing: Meshing is a critical operation in FEA. In this operation, the CAD geometry is divided into large numbers of small pieces. The small pieces are called mesh. The analysis accuracy and duration depends on the mesh size and orientations. With the increase in mesh size, the finite element analysis speed increase but the accuracy decrease.

Meshing includes following Steps

- **Element Selection**: Select the element according to dimensionality like 1d, 2d, 3d
- **Defining Material Properties:** First the material should be select in the material list of FEA package for the given part or assembly. By this process tell modulus of elasticity, poissions ratio and all other necessary properties require for the FEA
- **Mesh Size**: Define the Mesh size i.e. Element edge length, No. of Division.

Defining Boundary Condition

- Fix the wheel from bottom
- Apply load of 250Kg at the center of the wheel
- Compression only support on rim circumference.

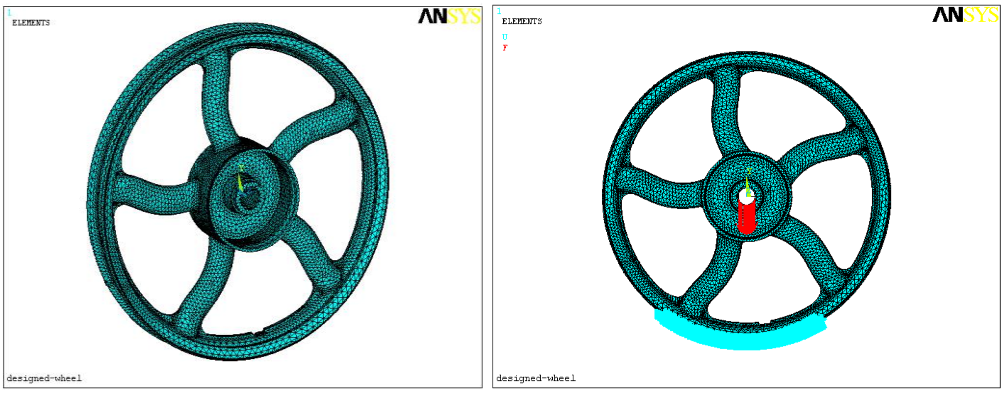

Fig. 5: Meshing of modified wheel and boundary condition for modified wheel

3.2 Solution or Analysis

Solve: In this step tell the FEA package to solve the problem for the defined material properties, boundary conditions and mesh size.

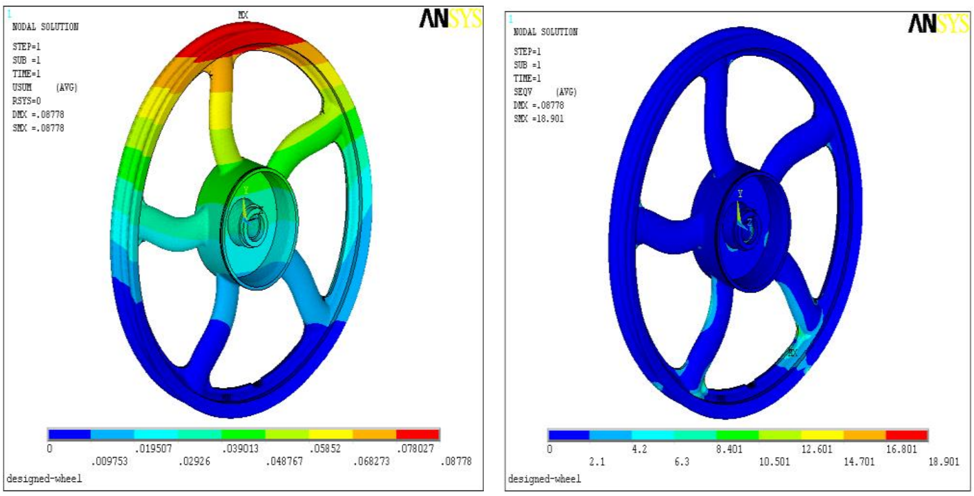

Fig. 6: Total deformation and equivalent stress of Aluminium alloy wheel in modified design at250Kg (2452.50N)

Table 6: Result analysis of Aluminium alloy wheel in modified design

Results	Total Deformation	Equivalent Stress
Minimum	0.078027mm	16.801MPa
Maximum	0.08778mm	18.201MPa

3.3 Analysis Procedure for PEEK

3.3.1 Boundary Conditions for Static Analysis of PEEK

(a) Maximum load of 250Kg (2452.5N)
(b) Fix the wheel at the bottom
(c) Apply load at the center

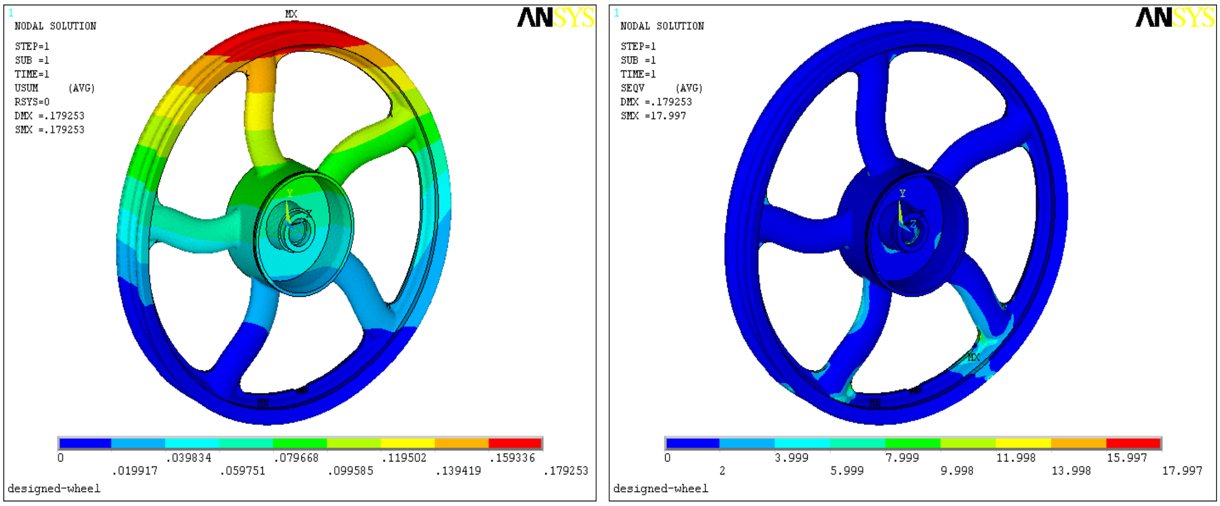

Fig. 7: Total deformation and equivalent stress in modified wheel of PEEK at maximum load of 250Kg (2452.5N)

Table 7: Result Analysis of PEEK Material in Modified Design

Results	Total Deformation	Equivalent Stress
Minimum	0.159336mm	15.997MPa
Maximum	0.149253mm	17.497MPa

3.4 Static structural analysis of PEEK150GL30 in modified design

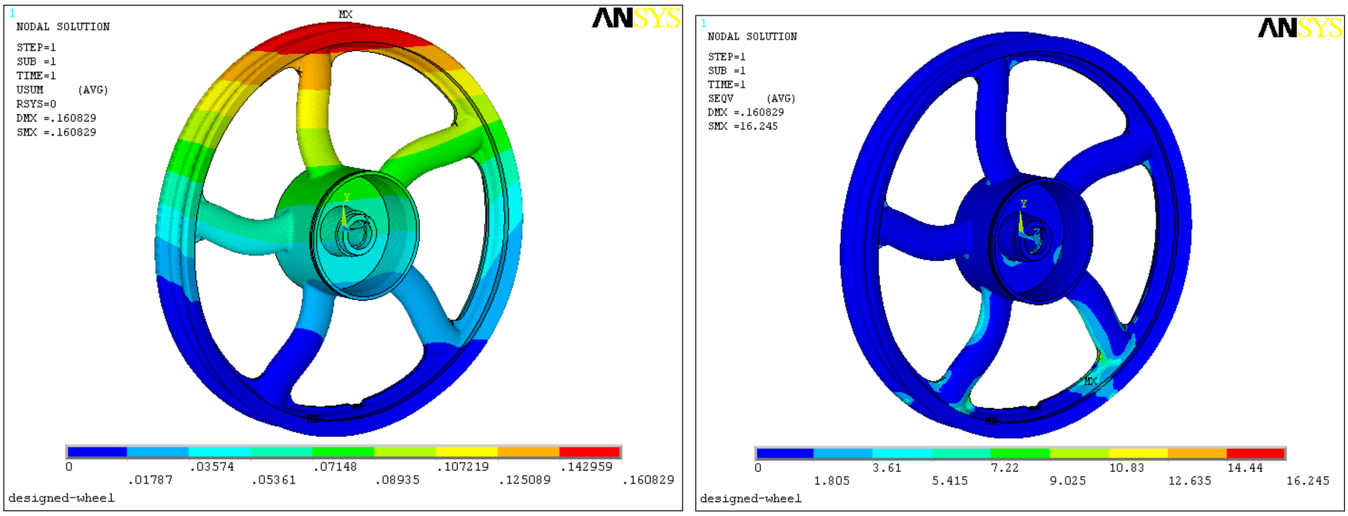

Fig. 8: Total deformation and equivalent stress in PEEK150GL30 modified wheel at maximum load of 250Kg (2452.5N)

Table 8: Result Analysis of PEEK 150GL30

Results	Total Deformation	Equivalent Stress
Minimum	0. mm	14.44MPa
Maximum	0.120829mm	15.215MPa

3.5 Static Structural Analysis of PEEK 90GL30 in Modified Design

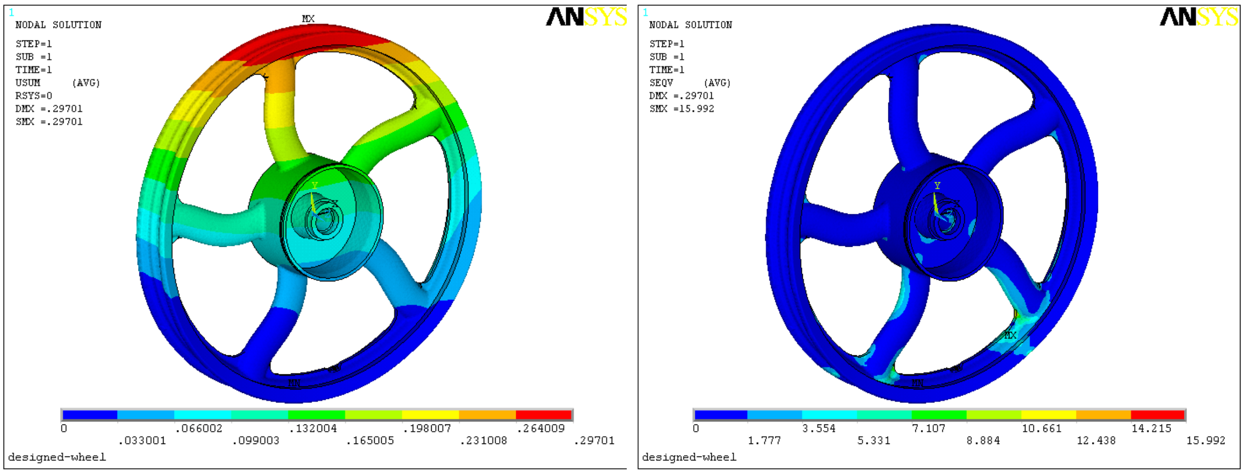

Fig. 9: Total deformation and equivalent stress in PEEK90GL30 modified wheel at maximum load of 250Kg (2452.5N)

Table 9: Result analysis of PEEK90GL30 material

Results	**Total Deformation**	**Equivalent Stress**
Minimum	0. mm	14.215MPa
Maximum	0.19701mm	15.112MPa

3.6 Static Structural Analysis of PEEK150CA30 in Modified Design

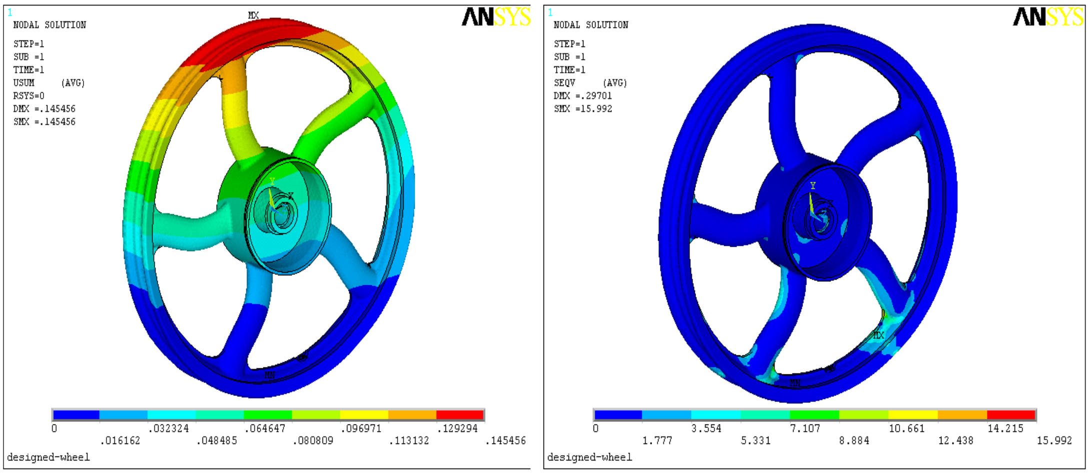

Fig 10: Total deformation and equivalent stress in PEEK150CA30 modified wheel at maximum load of 250Kg (2452.5N)

Table 10: Result Analysis of PEEK150CA330 Material

Results	**Total Deformation**	**Equivalent Stress**
Minimum	0. mm	12.621MPa
Maximum	0.095456mm	15.992MPa

4. RESULT AND DISCUSSION

4.1 Comparison Analysis Data of Different Material

In the following table the comparison analysis of Equivalent Stress and deformation has been done.

Table 11: Comparison Analysis Data of Different Material

Material		**Analysis Data of Actual Wheel**		**Analysis Data of Modified Wheel**	
		Total Deformation	**Equivalent Stress**	**Total Deformation**	**Equivalent Stress**
Aluminium Alloy	Minimum	0.032467mm	22.008MPa	0.07802 mm	16.801MPa
	Maximum	0.036525mm	25.76MPa	0.08778mm	18.201MPa
PEEK	Minimum	0.066219mm	20.579MPa	0. mm	15.997MPa
	Maximum	0.074496mm	24.132MPa	0.14925mm	17.497MPa
PEEK150GL30	Minimum	0.059457mm	17.689MPa	0. mm	14.44MPa
	Maximum	0.066899mm	21.941MPa	0.12082mm	15.215MPa
PEEK90GL30	Minimum	0.109829mm	17.26MPa	0. mm	14.44MPa
	Maximum	0.123558mm	20.516MPa	0.19701mm	15.112MPa
PEEK150CA30	Minimum	0.053907mm	16.766MPa	0. mm	12.621MPa
	Maximum	0.060645mm	18.964MPa	0.09545mm	15.942MPa

5. CONCLUSION

The project finally designs the motorcycle wheel for plastic material (Polyether ether ketone, PEEK) which provides better strength and fatigue life to the wheel. Project also got succeed in minimizing the cost and weight of motorcycle wheel. When load decreases on the vehicle its efficiency increases, as the result shows Plastic wheel is lighter than Aluminium wheel it increases the overall efficiency of motorcycle.

5.1 The Equivalent stress analysis of the component to define stresses on the assembly

The fatigue life of the motorcycle wheel by using ANSYS 14.0 has been done successfully by which the various Equivalent stress level have been tested which helps us to locate the point of stresses and shear of the motorcycle wheel, the loads and the structure's response are assumed to vary slowly with respect to time. A static structural load can be performed using the ANSYS 14.0 software.

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