DESIGN AND ANALYSIS OF ROTATING WHEEL: ALLOY WHEELS

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ABSTRACT

The design and analysis of wheel rims have drastically improved for the last two decades. Research works have shown the possibility of using a wide range of materials that gives out maximum efficiency for the user. Alloy wheels are practically the mixtures of metal and other elements. Their unique properties over the conventional ones have made them the most favoured. The project involves modelling a newly designed wheel rim using the CreoParametric software. The design aims to improve the alloy wheel spokes and manufacturing feasibility. The designed model is further imported to ANSYS Workbench 2021 R1 for analysis work. The model is subjected to static structural analysis by selecting alloys such as A6061-T6, ASM ZE62, PEEK-90 HMF 20% Carbon fibre as the base materials and their relative results are noted accordingly. The modal analysis is further carried out while carefully observing the necessary outputs. Further, the results from the analysis are carefully observed and the best material is selected for manufacturing an effective wheel rim.

Keywords: Alloy wheels, ANSYS, CreoParametric

INTRODUCTION

The primary motto of wheel design and analysis is that it should not fail during the service. Either alloy or conventional wheels must have high strength and fatigue life. Design for long life and better strength to weight ratio wheels are necessary to develop a better wheel rim. The actual product design uses a rotary fatigue test to determine the strength and fatigue life of the wheel [1]. The wheel manufacturing industry explores the possibility of selecting materials that give maximum efficiency such as mileage, wheel control, etc. Without compromising the vehicle build quality [2]. The wheel enables efficient movement of an object across a surface where there is a force pressing the object to the surface [3]. Material selection and precise manufacturing are necessary for the wheel rim as being the highly stressed component of the vehicle [4].

A wheel's performance can be severely affected by overdesigning and adding unwanted materials which in turn increases the mass and rotational inertia, having a negative impact [5]. The design of the wheel rim must be efficient and innovative. Being the outer edge of the wheel, holding the tire it must be able to support the vehicle despite the weight and withstand the effects from normal operations [6]. Lightweight wheel rim designs are needed as they keep the un-sprung weight to a minimum [7,8]. Alloys can produce many lightweight designs compared to the steel versions. Out of the selected materials for the project Al6061 is one of the most common and universally used alloys for wheel manufacturing and other applications [9]. Al alloys took over steel rims due to lower density and able to withstand more forces comparatively [10]. There are two variants for this grade alloy which are undergone solution heat treatment and aged, T4 variants are naturally aged while T6 variants are artificially aged for maximum strength. T6 variants are superior in yield and tensile strength, along with a similar modulus of elasticity. Al6061 has 97.9%Al composition. It is noted that Al6061 contains a maximum of 0.35 chromium which may increase the fatigue life of the wheel just like the Mg AZ31B [11]. AZ31 is a well-established wrought alloy in a multitude of applications. Al6061 falls under the same wrought alloy category [12]. Apart from the cast alloys, these alloys are also able to produce lightweight designs accordingly but through the forging process collectively. Wheel rims produced by this method are usually of higher ductility and toughness than steel wheels, although it is very costly in manufacturing [13]. The lightweight designs of Al-Mg alloys give better handling and control over the vehicle also they have good heat absorption properties which improve the braking system and reduces the chance of failure [14]. Alloy wheels face a backlash in their replacement issues, even though they are strong and tough, they are not impervious to crack and bends. Once the wheel is damaged the replacement cost is high compared to steel but the features such as fuel economy, better performance, etc. vehicles prefer alloy wheels.

Die-Cast alloy wheels were widely preferred in elite vehicles such as Formula One, World Superbike, etc. until the mid-90s when the forged wheel technology became preferred. Magnesium alloy Mg-AZ31B was proved to be efficient in manufacturing commercial vehicle wheels also provided better corrosion resistance and improved fatigue life due to the 0.35% chromium present in it but Mg alloy wheels have their share of disadvantages [11,15]. Due to Mg wheels being lighter than aluminium they are easily flammable and hard to extinguish also once the corners of Mg wheels bend they can't be straightened again. These problems were resolved to a great extent when a global service organization Allite, Inc. introduced the super magnesium to the public in 2006. In the development stage, it has only been authorized for classified military applications until now. It can be used in a variety of applications, from high-tech smartphone case architecture to high-powered locomotive engine components. Being the lightest structural metal, magnesium has a density only slightly higher than that of plastics and glass/carbon fibre reinforced polymers along with all the properties necessary for an ideal alloy wheel [15].

ASM ZE62 one of the four super magnesium introduced by Allite, Inc. has been designed to deliver a superior combination of elongation and strength. It's a high-performance alloy that enables shapes and structures never before possible, primarily through forging processes. They use a bath-based method of producing ceramic layers on the surface of light alloys know as Plasma Electrolytic Oxidation (PEO). This process gives a hard and dense coating for the alloys optimized to provide important properties and benefits such as Corrosion protection, Wear resistance, Improved hardness, Improved fatigue performance, etc. Magnesium being 100% recyclable, 75%lighter than steel, 50%lighter than titanium, and 33%lighter than aluminium, ZE62 contains the composition of rare earth elements which makes the alloy superior [15].

Recent researches showed the introduction of composite material wheels in motorbikes as well as cars [16]. Composites are the combination of two materials relatively called the matrix phase and reinforcing phase. Carbon fibre is 40 to 50% less weight compared to alloys of Al & Mg. Composites are known for their very high strength-to-weight ratio. When given the same loading condition for composites and Al alloy wheels there's a reduction in the strain of 70% -75%, the stress of 35%-40%, and displacement up to 70% [3,17]. Many composites that were currently chosen for the wheel show high internal damping capacity which leads to better vibration energy absorption within the material structure. The combination of strength and modulus are almost equal to the traditional metal used in wheels. Due to their modulus and strength-to-ratio along with low specific gravities certain composites are superior to metal alloys [17]. Carbon fibre can be an excellent replacement for the metal alloys concerning the failure techniques, the manufacturing process involved, and determination of materials. Conservation of natural resources is also aimed through recent developments. There are various combinations available in the market but limitations such as strength, cost, and endurance compared to certain alloys and steels do not make them favoured [6,18]. Developments in the composites also lead to the introduction of PEEK (Polyether ether ketone) which has shown great promise as a material for current and future industrial, automotive, and aerospace applications. Composites are developed mainly as a lightweight material but it has inadequate consistency for best strength and heat. Still, PEEK replaces steel, aluminium, and other high-performing materials due to its ideal combination of mechanical and thermal properties which provides excellent resistance to oil, acids, grease, and all other automotive fluids [18]. Today replacing 40-50% metal in wheels using plastic material PEEK (Polyether ether ketone) has shown better strength and fatigue life to the wheel. Plastic materials are relatively cheap and efficient than aluminium alloys [19,20].

Future scopes in the wheel rim design will be able to develop materials that will be both economical and efficient.

CLASSIFICATION OF ALLOY WHEELS:

In the automotive industry, alloy wheels are made from an alloy of aluminium and magnesium. Alloys are mixtures of one or more metals and other elements. They generally provide greater strength over pure metals, which are usually much softer and more ductile. Alloys of aluminium or magnesium are typically lighter for the same strength, provide better heat conduction, and often produce improved cosmetic appearance over steel wheels. Although steel, the most common material used in wheel production, is an alloy of iron and carbon, the term "alloy wheel" is usually reserved for wheels made from nonferrous alloys. There are currently various types of alloy wheels available for two-wheelers.

- Light alloy wheels: These wheels use light metals such as aluminium and magnesium These wheels were introduced in Europe in the 1960s and rapidly become popular for the original equipment vehicle and in the United States in the 1970s for the replacement tire. Most of the alloys at the time were magnesium-based, but the low ductile, brittle nature and poor casting issues removed these alloys from the market and were replaced by aluminium alloys and took the place of magnesium as low cost, high-performance wheels for motorsports.

- *Aluminium alloy wheel*: Aluminium alloy wheels fall under the category of light-alloy wheels. It has a wide range of physical and chemical properties that makes it suitable for manufacturing wheels. Excellent lightness, corrosion resistance, thermal conductivity, low temperature, characteristics of casting, machine processing, and recycling. Due to its reduced weight, high accuracy, and design choices of the wheel, alloy wheels are widely preferred also its recycling feature makes it useful for energy conservation.

- *Magnesium alloy wheels*: While compared to aluminium, Magnesium is about 30% lighter, along with excellent impact resistance and size stability. Recent developments lead to improved casting, forging, and corrosion resistance of the magnesium. Due to the renewed interest in energy conservation magnesium is receiving special attention. The strength-to-weight ratio of the precipitation-hardened magnesium alloys is comparable with that of the strong alloys of aluminium or with the alloy steels. Magnesium alloys are used when great strength is not necessary, but where a thick, light form is desired. The strength of magnesium alloys is reduced at somewhat elevated temperatures; temperatures as low as 200Fproduce a considerable reduction in the yield strength.

- *Composite Material Wheel*: These wheels are different from the above-mentioned alloy wheels and are developed mainly for low weight. It is generally a thermoplastic resin that is composed of glass fibre reinforcement material. Carbon fibre which is used nowadays is a composite material that shares similar properties to thermoplastic resin, but due to their high manufacturing cost, they are restricted to sports vehicles.

MATERIAL SELECTED:

- Aluminium alloy A6061-t6
- Magnesium alloy ASM ZE62
- PEEK-90 HMF 20% carbon fibre

- AL6061-T6

Table 1

Density	2.7 g/cm^3
Melting point	650 °C
Tensile strength	310 MPa
Yield strength	275 MPa
Modulus of elasticity	69 GPa
Poisson's ratio	0.33
Shear modulus	26 GPa

- AL6061 composition by mass%

Table 2

Al	95.85-98.56
Mg	0.8-1.2
Si	0.4-0.8
Fe	0.0-0.7
Cu	0.15-0.4
Cr	0.04-0.35
Zn	0.0-0.25
Ti	0.0-0.25
Mn	0.0-0.15
Remainder	0.05 each, 0.15 total

- ASM ZE62

Table 3

Density	1.84 g/cm^3
Melting point	635 °C
Tensile strength	350 MPa
Yield strength	303 MPa
Modulus of elasticity	45 GPa
Poisson's ratio	0.315
Shear modulus	26 GPa

- PEEK-90 HMF 20% carbon fibre

Table 4

Density	1.37 g/cm^3
Melting point	343 °C
Tensile strength	290 MPa
Compressive Yield strength	270 MPa
Young's modulus	22000 MPa
Poisson's ratio	0.45
Shear modulus	7.557*10^8 Pa

OBJECTIVE

The objective of the project is to design a wheel rim and analyze alloys AL606-t6, ASM ZE62, PEEK-90 HMF 20% Carbon Fibre used for wheel manufacturing. Once the analysis is done the results from the selected materials are observed in terms of deflections, stresses, strain, and other properties, to choose the best suitable one for two-wheelers.

METHODOLOGY

A five spoke wheel rim with "X" shape is designed using CreoParametric for the research work. Each spoke has been combined with dual spokes that forms the intersection at the base which gives the "X" shape. The intersection at the lower base side gives strength to the hub surroundings as well as the whole wheel design. The more number of spokes reduces the load put on individual spoke. However, if the number of spokes are increased it also increases the overall weight in turn which also affects the aesthetics. A five spoke wheel is aesthetically improved and lighter in design.
The model is imported to ANSYS Workbench and subjected to static structural analysis to determine the total deformation and equivalent stress for the selected material under equally given loading condition. To find the dynamic characteristics of the wheel rim under vibrational excitation it is subjected to modal analysis.
The results from the following analysis are tabulated and compared accordingly to find the best suitable material for the wheel manufacturing with all the necessary parameters as strength, weight, corrosion resistance, economical, longevity etc.

Table 5: geometric values of the wheel rim

GEOMETRIC PROPERTIES	VALUE
Wheel diameter	383.84mm
Spoke length	145.59mm
Width of rim	58mm
Width of hub	20mm
No: of spokes	5
Inner hub diameter	35.84mm
Outer hub diameter	92.66mm

LOADS TO BE APPLIED

Dead Weight of Bike =143kg

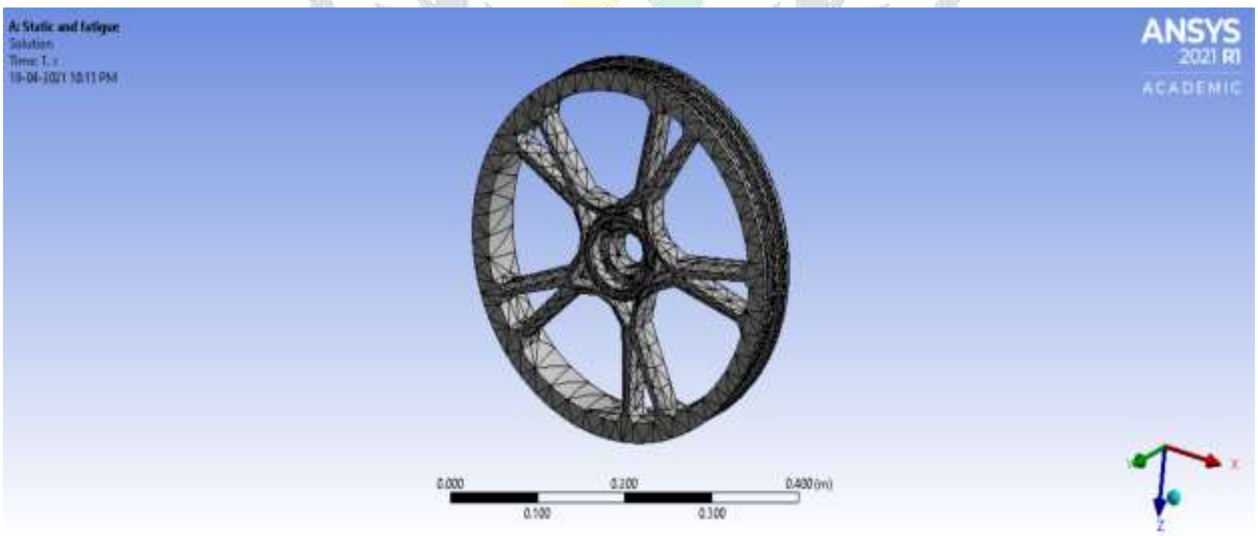
Other Loads = 20 Kg, Total Gross Weight =143 + 20 = 163 Kg = 163X 9.81N

Tires and Suspension system reduced by 30% of Loads

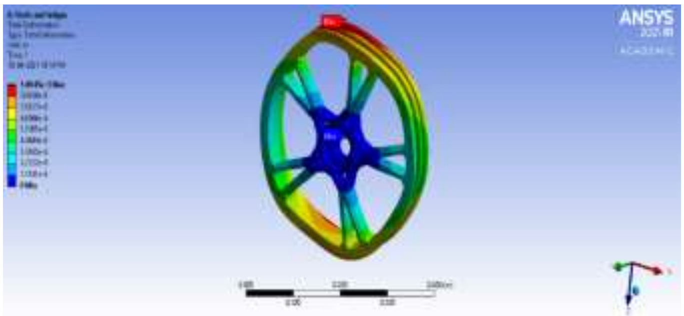
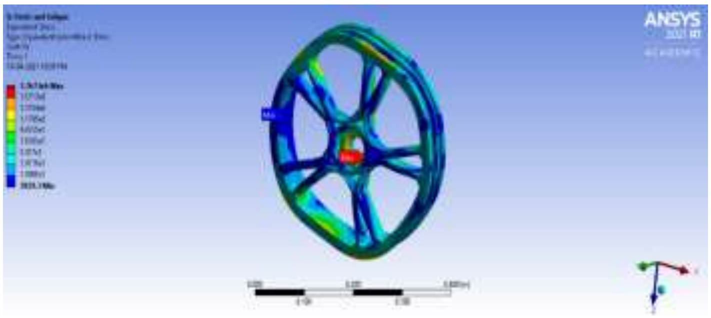
W_{net} = 163 X 9.81 X 0.7 N = 1119.32N

Reaction Forces On Bike=N_r = 1119.32N

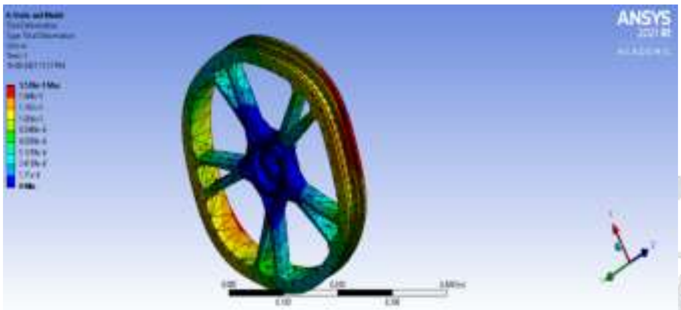
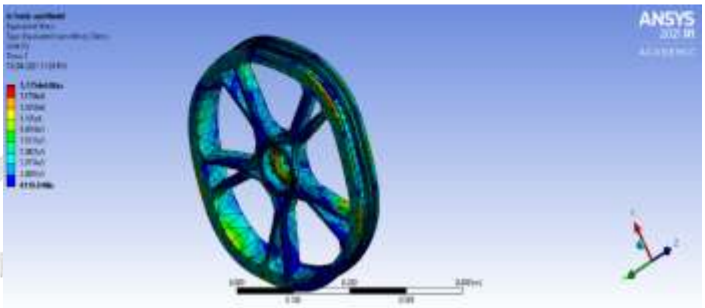
STATIC AND MODAL ANALYSIS



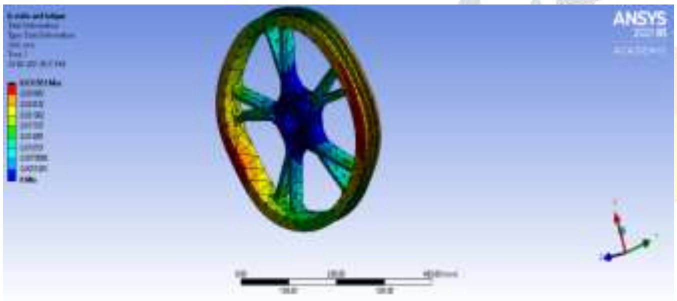
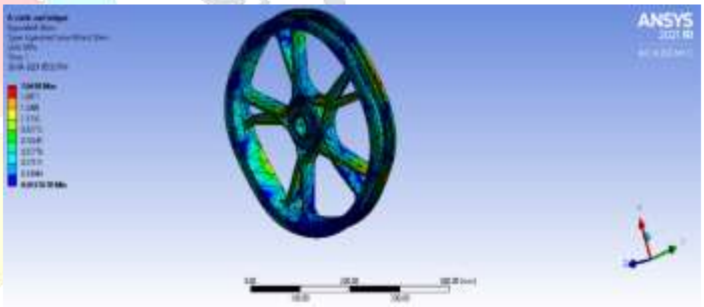
Meshed view

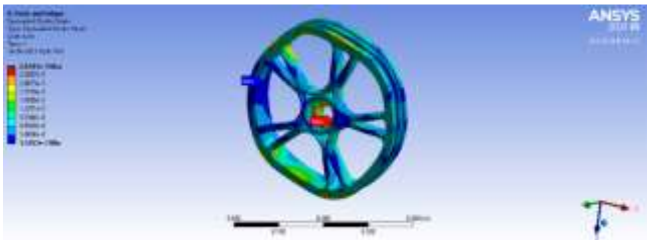
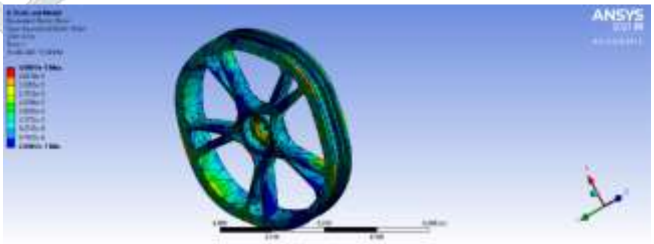
Total deformation and stress for AL6061-T6

Total deformation and stress for ASM ZE62

Total deformation and stress for PEEK-90 HMF 20% carbon fibre

Equivalent elastic strain for AL6061-T6, ASM ZE62, PEEK-90 HMF 20% carbon fibre respectively

Table 6

AL6061-T6

Results	Minimum	Maximum	Units	Time (s)
Total Deformation	0.	1.0045e-002	mm	1.
Equivalent Elastic Strain	1.3457e-007	2.6541e-005	mm/mm	1.
Equivalent Stress	3.9293e-003	1.7673	MPa	1.

Table 7

ASM ZE62

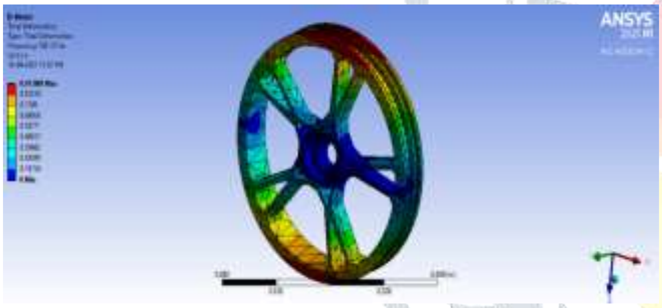
Results	Minimum	Maximum	Units	Time (s)
Total Deformation	0.	1.539e-002	mm	1.
Equivalent Elastic Strain	2.0987e-007	4.0897e-005	mm/mm	1.
Equivalent Stress	4.1199e-003	1.7754	MPa	1.

Table 8

PEEK-90 HMF
20% carbon fibre

Results	Minimum	Maximum	Units	Time (s)
Total Deformation	0.	3.1503e-002	mm	1.
Equivalent Elastic Strain	3.8401e-007	7.9555e-005	mm/mm	1.
Equivalent Stress	3.7678e-003	1.6658	MPa	1.

- Modal analysis for AL6061-T6



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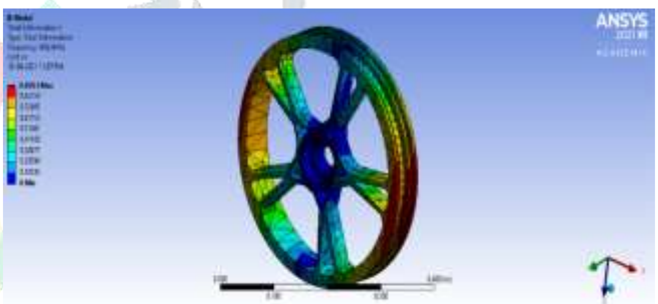

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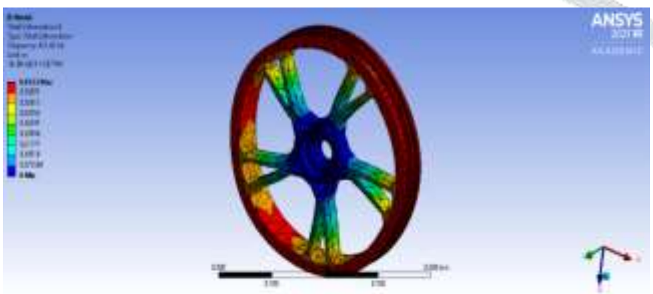

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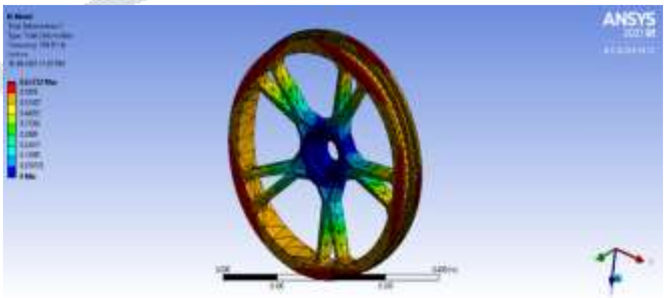

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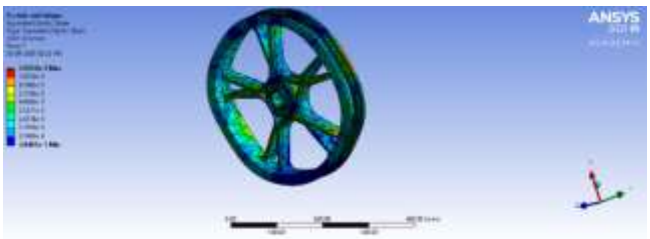
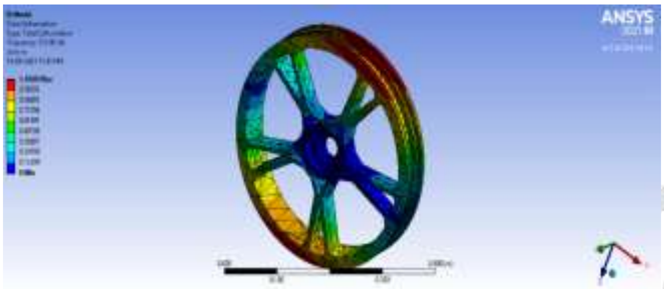


Table 9

Results	Min.	Max.	units	Reported frequency(Hz)
Deformation 1	0	**0.91388**	m	365.15
Deformation 2	0	**0.9263**	m	368.24
Deformation 3	0	**0.6533**	m	431.43
Deformation 4	0	**0.67252**	m	584.91

➢ Modal analysis for ASM ZE62



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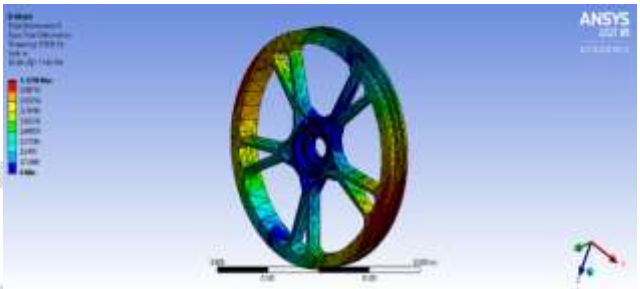

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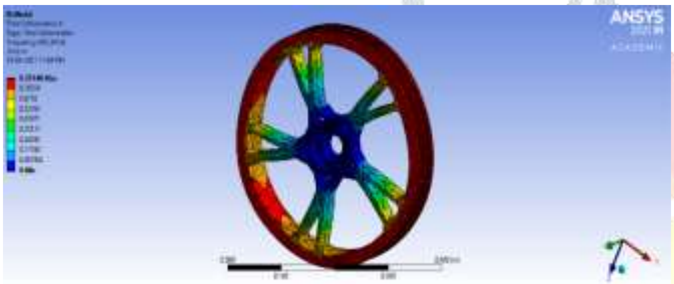

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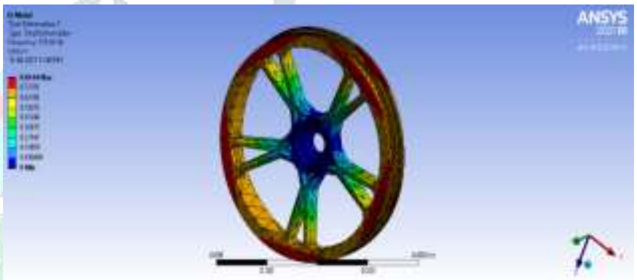
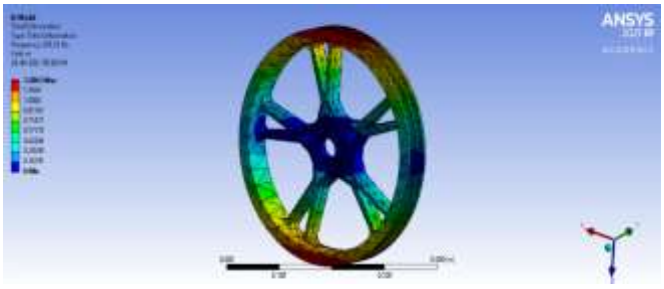


Mode 4

Table 10

Results	Min.	Max.	units	Reported frequency(Hz)
Deformation 1	0	**1.1069**	m	357.05
Deformation 2	0	**1.1218**	m	359.92
Deformation 3	0	**0.79148**	m	422.24
Deformation 4	0	**0.8144**	m	571.42

- Modal analysis for PEEK-90 HMF 20% carbon fibre



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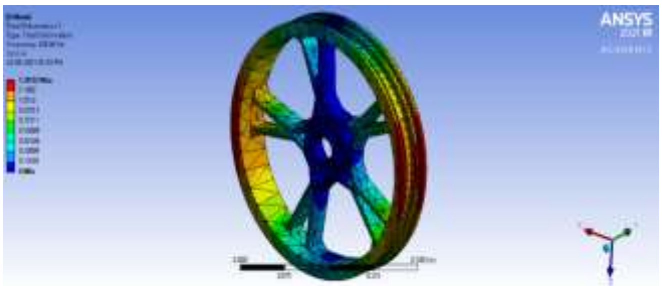

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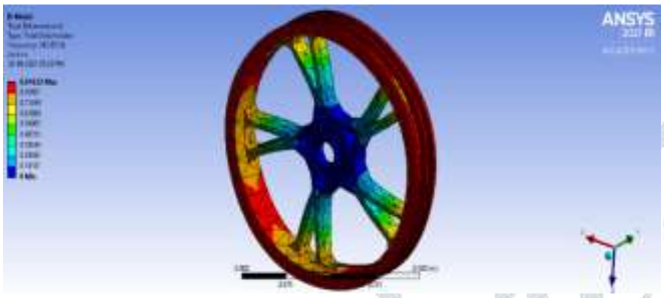

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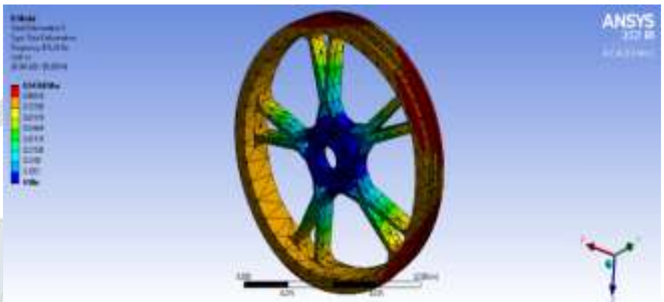

Mode 4

Table 11

Results	Min.	Max.	units	Reported frequency(Hz)
Deformation 1	0	**1.2865**	m	293.32
Deformation 2	0	**1.3052**	m	298.06
Deformation 3	0	**0.91632**	m	343.05
Deformation 4	0	**0.94768**	m	478.28

CONCLUSION

- The result of static structural analysis is recorded in table 6,7,8. From the table, we can observe that all the 3 materials have almost the same Von-Mises stress of 1.7 MPa for AL6061-T6 & ASM ZE62, 1.6 MPa for PEEK-90 HMF 20 with different deformation values. The highest stress is for ZE62 (1.77 MPa) and the least value is for PEEK-90 HMF 20 (1.66 MPa). From the above results for max. deformation PEEK-90 HMF 20 has the least stress value that can replace the rest of the two.
- A maximum of 4 modes was taken for each of the materials for analyzing the modal frequencies tabulated in table 9,10,11. From the modal analysis, the least frequencies are obtained for PEEK-90 HMF 20% carbon fibre as compared with other alloys.
- From the analysis result, we can conclude that **PEEK-90 HMF 20 carbon fibre** is the best alloy material with less deformation, equivalent stress, and less frequency for all modes compared to AL6061-T6 and ASM ZE62. This material can be a better replacement for the conventional alloys as well as future manufacturing, but further extensive study testing is required before total replacement.

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