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Design and Simulation of Mg and Ti Alloy-based Wheel Nuts for Formula One Cars

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Abstract

Formula One is the highest level of globally recognised auto racing for single-seater formula racing vehicles, as sanctioned by the Federation of International Automobiles (FIA). In the Formula One World Championship, the word formula refers to the set of rules that all competing cars must obey. Formula cars are developed with outstanding attributes to survive in high-speed racing. However, issues such as wheel nut failure are common in these vehicles. The wheel nut has to hold the wheel to the car and must resist braking and lateral forces. Titanium alloys are commonly utilized in the manufacture of wheel nuts for Formula One cars, while magnesium alloys are also considered for high-end automobile wheel nuts. In this study, the design of a wheel nut with titanium and magnesium alloys is analyzed using Ansys under uniform and variable stress situations. The results of the analysis showed that titanium alloy is the best-suited material for F1 racing cars. The reasons for the nut failure are also discussed in this paper. The paper contributes to the automotive industry by providing insights into the design and material selection for wheel nuts in high-speed racing cars, specifically Formula One vehicles.

Keywords: *Ansys, Formula One, Magnesium Alloy, Titanium Alloy, Wheel Nut Failure*

1.0 Introduction

In 1981, the FIA Formula One World Championship replaced the legendary World Drivers' Championship. Since its first season in 1950, this has been one of the world's most prestigious forms of racing. A Formula One season consists of a series of races known as the Grand Prix that take place on purpose-built tracks and closed public roads across the world each year. Due to extremely high cornering speeds obtained by the development of massive quantities of aerodynamic downforce and outstanding build quality, Formula One vehicles are the fastest controlled road-course racing cars on the planet. Even though F1 cars are manufactured to a higher standard, they are susceptible to a limited number of flaws. One of these is wheel nut failure. Valtteri Viktor Bottas, a Finish racing driver who presently competes in Formula One for Mercedes, had the identical problem at the Monaco Grand Prix. When his crew brought him into the pit lane on lap 30, Bottas was only five seconds behind the race leader. However, they failed to properly remove the wheel nut to remove the car's right front wheel. As a result of this simulation, we are attempting to identify and compare some different wheel nut materials.

Formula One is the pinnacle of technological achievement in all of racing. It's also the world's wealthiest, most intense, most challenging, most charged, and most international racing championship[1,2]. It is critical in the car business to manufacture low-weight assemblies to improve vehicle performance[3,4]. The formation lap is

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the first lap of a Formula One race, and the pit lanes are opened for this purpose 30 minutes before the race starts[5]. The FIA Formula One World Championship, which is the FIA's property and includes two World Champion titles, one for drivers and one for constructors, will be organised by the FIA. MSC/NASTRAN finite element software is used for structural analysis of automotive vehicle wheels and optimization of wheel designs subject to both NVH and fatigue-related limitations[6]. The engine collaborates with ERS to deliver a considerable gain in efficiency and horsepower. The engine in Formula One vehicles is a turbocharged direct fuel injection unit with 700 horsepower. The gearbox in all Formula One vehicles is the same, an 8-speed semi-automatic sequential unit. This gearbox has been in service since 2014 when it was introduced to replace the previous 7-speed gearbox. The F1 regulations allow Pirelli to pick three tyre compounds for each race, a popular rule change in 2016 that offered up strategy choices for each race weekend. Cast iron is now utilized as a wheel hub material. It has higher capabilities when compared to recommended model materials such as Nylon and Molybdenum Disulphide[7,8]. The finite element analysis of the hub was performed to investigate the distribution of stresses, which were discovered to be larger around the holes in the hub. It was determined that the combined impact of bending, torsional shear, and axial loads resulted in the development of a crack that progressed during the car's testing, eventually leading to the catastrophic fracture of the hub[9-11]. The operational loads and fatigue characteristics are the critical factors for design and durability. This is dependent on the material and production technology[12-14]. These test techniques are intended to describe the toughness of plastics during fracture initiation in terms of the critical-stress-intensity factor and the energy per unit area of the crack surface, or critical strain energy release rate[15,16]. The size of the specimen obtained is a crucial variable in fracture toughness testing, and it is also impacted by crack length and thickness. An electron microscope can be used to do microstructural testing[17-23]. All dimensions and limitations are subject to the Society of Automotive Engineers' guidelines[24]. Pressure die-casted aluminium may also be utilized as an alternate material for wheel hubs. According to the FEA results, the upright assembly is capable of performing safely under real-world track conditions[25]. Materials selection and wheel design are scrutinized to reduce the goal of reducing weight while maximizing efficiency in all aspects of functionality[26-31].

2.0 Variables to be Addressed Before Designing the Wheel Nut

In an automobile, there are two types of mass: sprung and unsprung mass. The sprung mass refers to when the spring dampens the entire mass of the automobile. When the spring does not dampen the mass of the wheel assembly, it is classified as unsprung mass. It is important to note that the sprung mass is greater than the unsprung mass and that it should be as low as possible to offer optimal vehicle driving stability and load balance. When doing so, make sure that the mass of the wheels, tyres, and wheel assembly is sufficient to prevent the car from lateral toppling during cornering. In both static and dynamic conditions, forces acting on the wheels must be considered. All of these forces eventually influence the design of the wheel assembly since it is directly related to the wheels. The forces of acceleration, braking, turning, and tilting on the wheel assembly must all be taken into account. A perfect wheel assembly will be able to handle all of these forces for a longer period.

During the pitstop condition, very high instantaneous torque is applied over the driving faces of wheel nuts, which leads to rounding off. The main objective of the comparative study is to suggest a better material to be used in the current wheel nut design. Titanium alloys are usually used as wheel nut material for F1 automobiles while certain magnesium alloys are also considered for high-end cars. Titanium is a long-lasting metal for structural applications because it resists corrosion and is both strong and light. It is roughly 40% lighter than steel yet has the same strength as high-strength steel. It's Naturally Resistant to corrosion and reaction with chemical agents, so it can be used in high-stress and speed applications like Formula One automobiles.

2.1 Designing of Wheel Nut

SOLIDWORKS, a robust 3D CAD software tool with integrated analytical tools and design automation, is used to model physical behaviour for a wide range of applications, including kinematics, dynamics, stress,

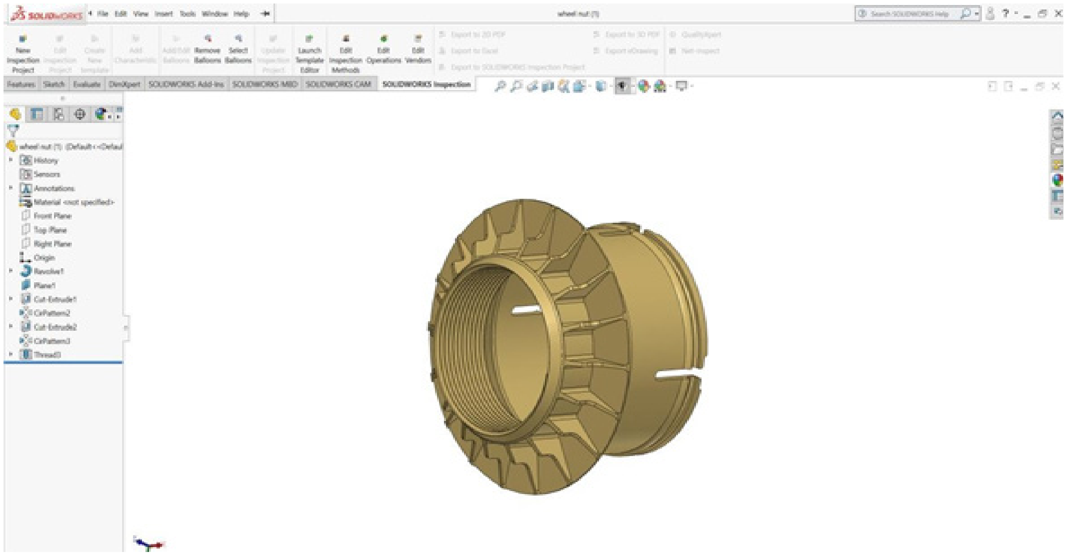

Figure 1. Depict the three-dimensional computer-aided design model of the wheel nut suggested in 1st view.

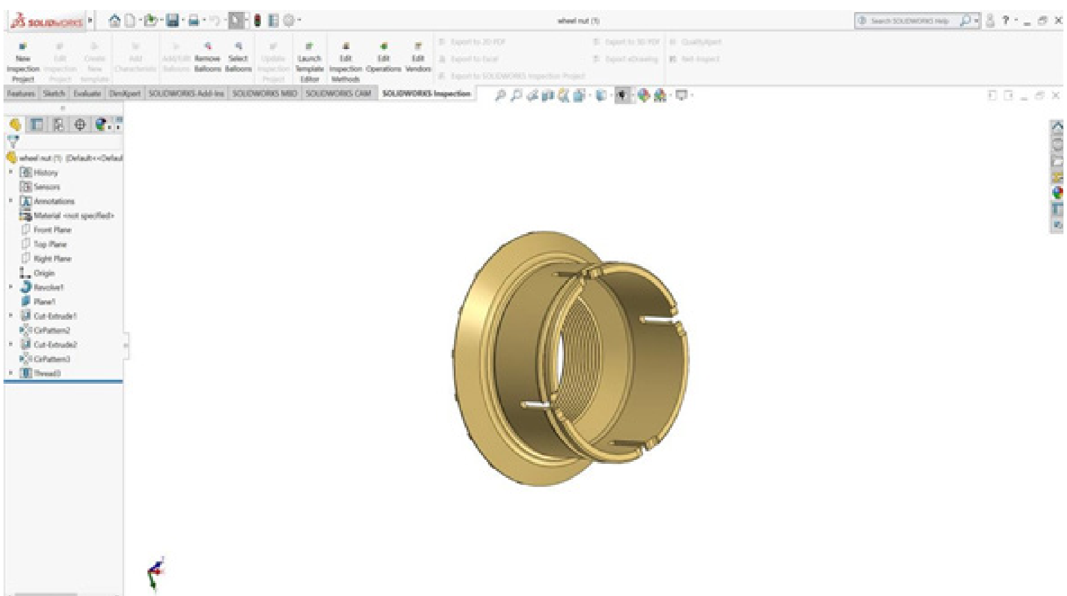

Figure 2. Depict the three-dimensional computer-aided design model of the wheel nut suggested in 2nd view

vibration, temperatures, deflection, and fluid flow. The ANSYS workbench software is used for simulation. Ansys workbench is a finite element analysis software that analyses the strength, temperature, toughness, elasticity, distribution, electromagnetism, fluid flow, and other properties of computer models of structures or machine components.

3.0 Static Load Analysis

Calculation on the clamping force,

T – Torque required (Nm)

K – Torque coefficient (0.15-0.2)

D – Nut Diameter (M60)

Calculation,

$$Fcl = \frac{T}{KD}$$
$$= 3000/.2 \times 0.06$$
$$= 250000N$$

Hence, the clamping force is 250KN.

The clamping torque is assumed to be 3000 Nm in the load calculation. This is because the torque wrench used in an F1 car for wheel nut clamping requires that much torque in a relatively short time to clamp the nut. A static load of 250KN is applied to each vertical face of the wheel nut in the Ansys workbench (Figure 3), followed

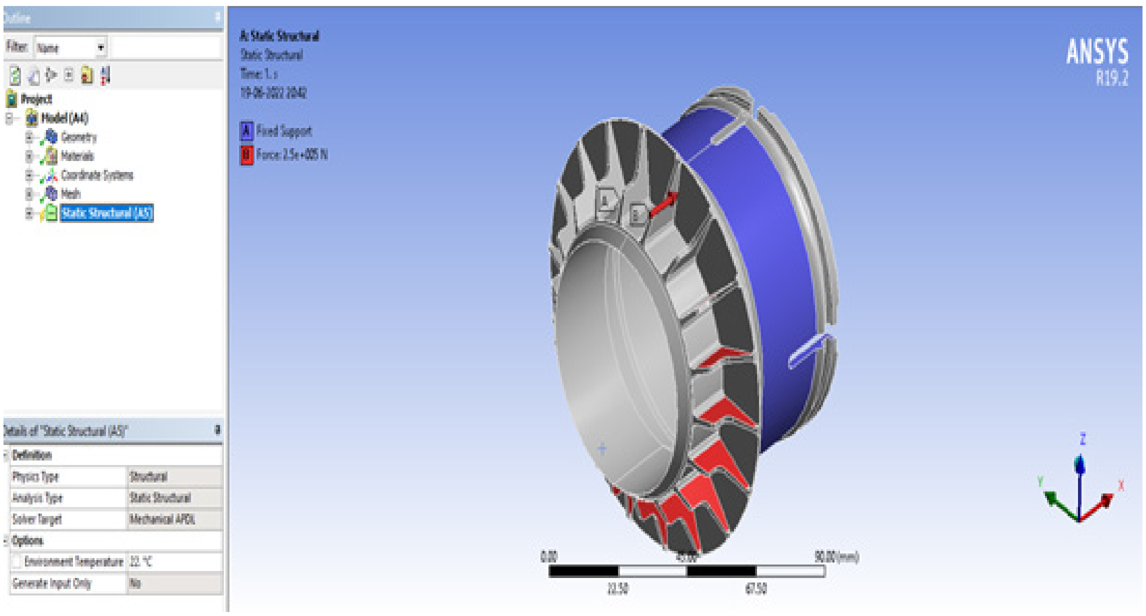

Figure 3. Wheel nut applied with the static load.

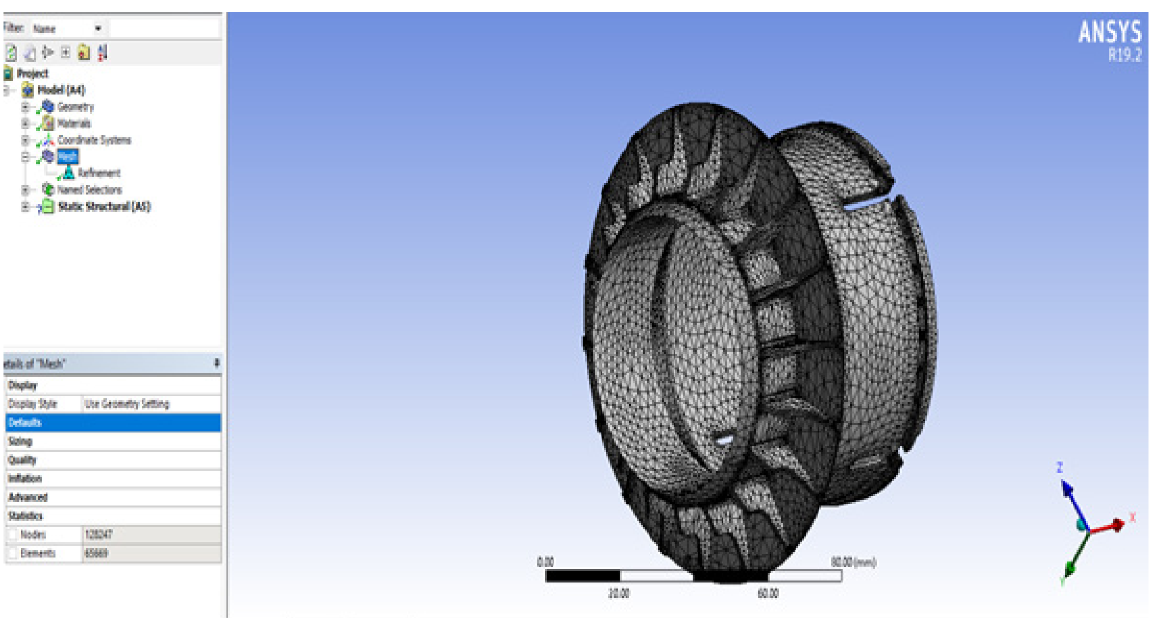

Figure 4. Meshing of the component.

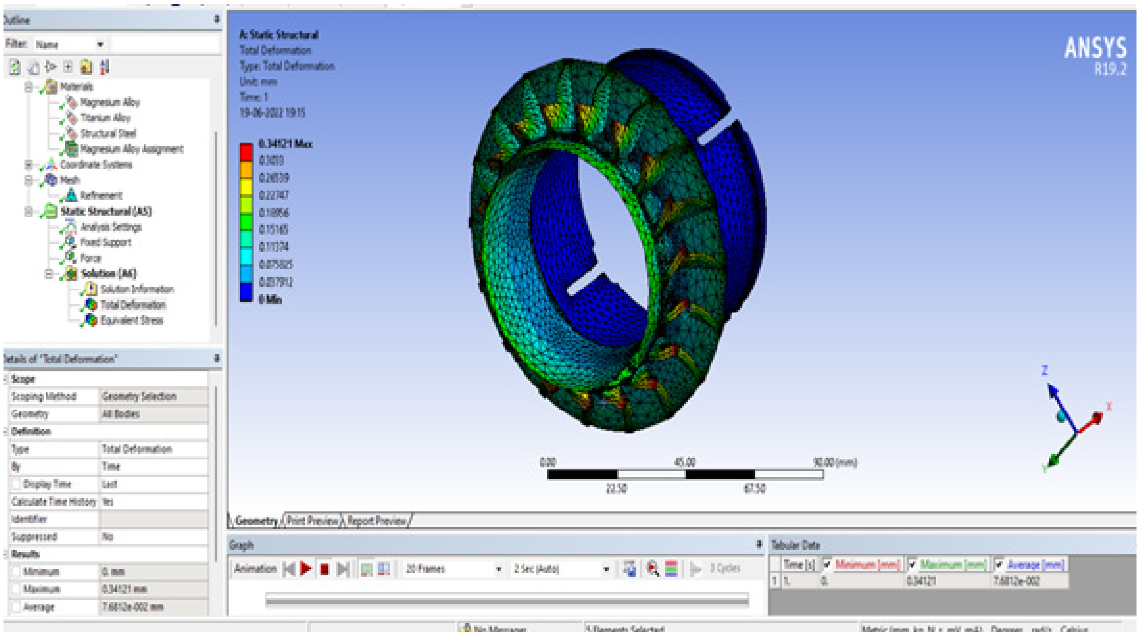

Figure 5. Deformation in magnesium alloy.

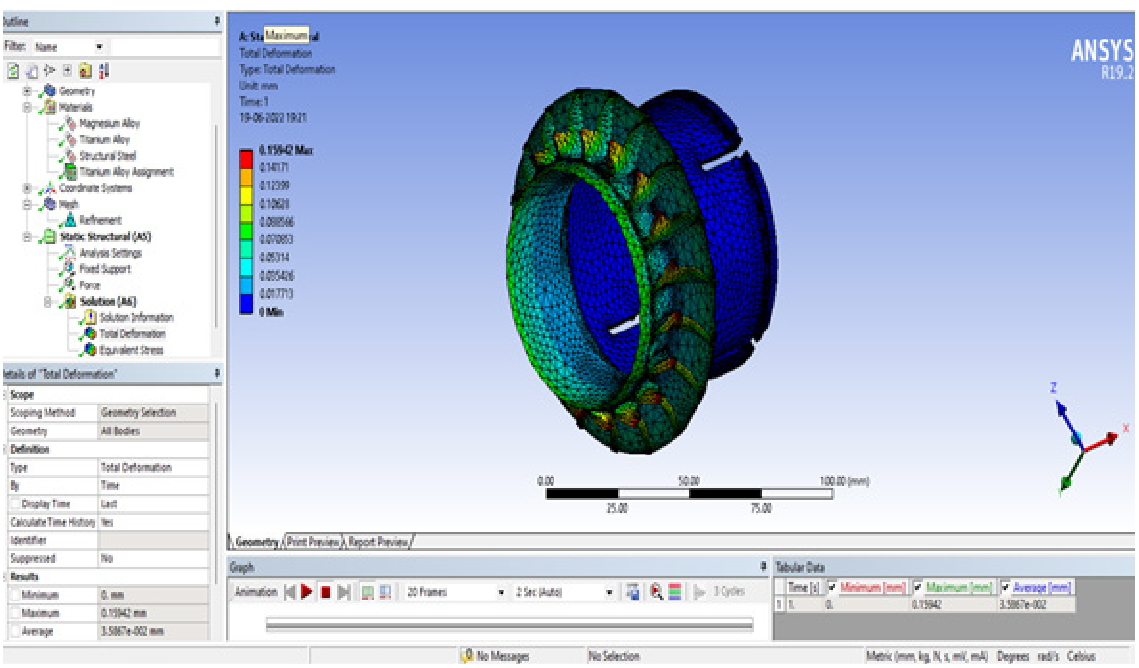

Figure 6. Deformation in titanium alloy.

by tetrahedron meshing with refinement (Figure 4). A mesh with 65669 elements and 128247 nodes is used in the analysis. The deformation in Titanium alloy (Figure 5) and Magnesium alloy (Figure 6) is simulated via Ansys software and the results are noted. Deformation in Magnesium Alloy (Figure 7) with uniformly varying stress distribution as well as Deformation in Titanium Alloy (Figure 8) with uniformly varying stress distribution

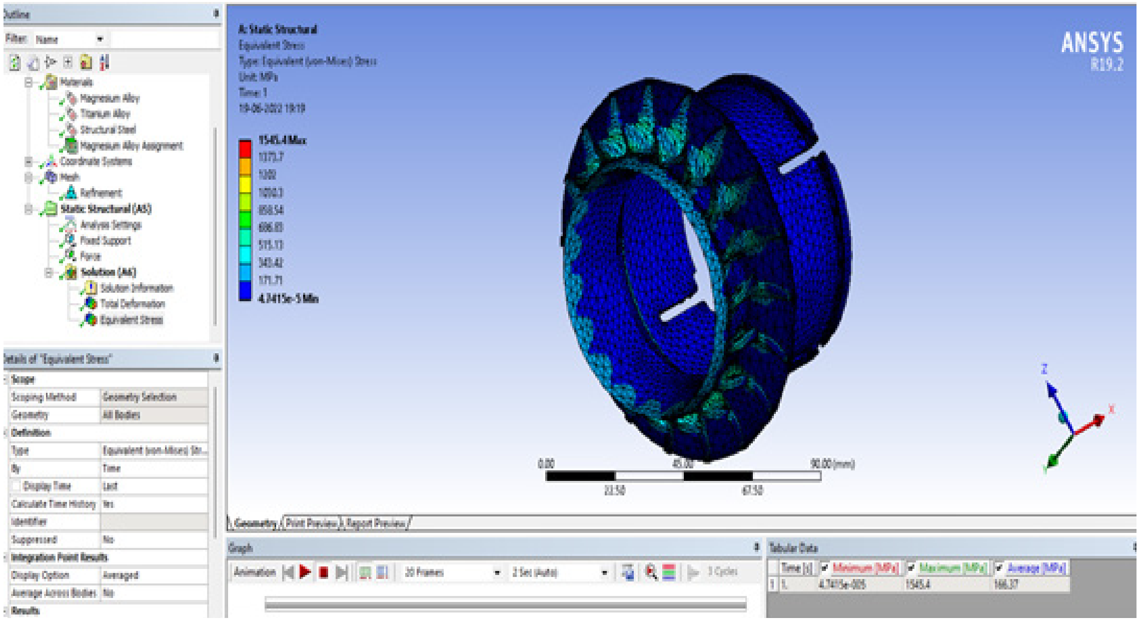

Figure 7. Equivalent stress distribution in magnesium alloy-based wheel nut.

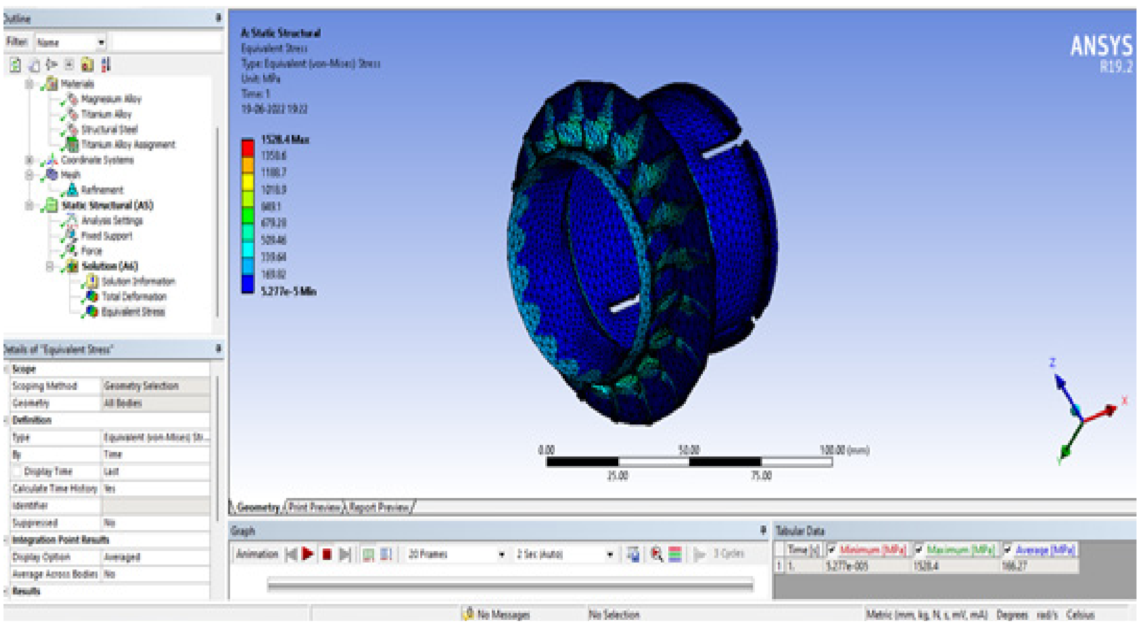

Figure 8. Equivalent stress distribution in titanium alloy-based wheel nut.

is simulated with the aid of the same software. Results from the analysis concluded that the Titanium alloy has better structural properties for these constraints than the considered type of Magnesium alloy. This result can be justified as evidence of better functional capabilities of titanium alloy compared to magnesium alloy for Formula One car wheel nuts.

3.1 Reasons for the Wheel Nut Failure

3.1.1 Deviation of Camber Angle Due to the Improper Positioning of the Wheel in the Pitstop

Camber angle is defined as the angle of the wheel concerning the vertical axis. The front view of the Formula One car will reveal the camber angle. It normally varies between 2 and 4 degrees. When the wheel cannon is used to remove the tyre at the pitstop, a minor change in angle causes the whole nut to be broken. The machining effect was generated by a tiny misalignment between the wheel gun used for removing the wheel and the wheel nut, making it difficult to remove the wheel. As a result, one of the key valid reasons for wheel nut failure for Formula 1 racing vehicles at these international racing events is the variation of camber angle owing to poor wheel alignment in the pitstop.

3.1.2 Cross-Threading

Cross-threading is one of the most common reasons for failure when working with threaded fasteners. When a threaded fastener is placed into a hole or threaded nut with the threads not aligned properly, Cross threading occurs. Cross threading occurs when the applied fastener is put at an angle to the suitable site and firmly forced into the bolt. The threads on a bolt and nut are wedges wrapped around a small cylinder. Wrapped wedges pull objects closer together in the same manner as wedging pulls them apart. The nut and bolt must have the same diameter and thread pitch and be threaded together at the same angle, or the threads will cross. The insertion angle changes when more than one is used.

4.0 Conclusion

According to the findings, titanium alloy outperforms magnesium alloy in terms of performance. For Formula One cars, titanium alloy is often utilized as the wheel nut material, but various magnesium alloys are also considered for high-end vehicles. From the Ansys software analysis, it is evident that titanium is best suited for this application under both static and uniformly variable loading conditions. Ansys employs tetrahedral meshing because it provides information on even minor deviations. Under static load conditions, the titanium alloy deformed only 0.15942 mm, while the magnesium alloy deformed up to 0.34121 mm. The Elastic von-mises stress of the titanium alloy showed a stress value of 1528.4 N/mm^2, and the magnesium alloy showed a stress value of 1545.4 N/mm^2. Therefore, the results of the deflection and stress values make it clear that titanium is the ideal material for wheel nuts in F1 cars. The comparative study aims to suggest a better material for the current wheel nut design, with titanium alloys being commonly used for F1 cars and certain magnesium alloys considered for high-end automobiles. The paper contributes to the automotive industry by providing insights into the design and material selection for wheel nuts in high-speed racing cars, specifically Formula One vehicles.

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