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# Study analysis of car rim design and mechanical properties using CATIA

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***Abstract***

*This study discusses the design of car rims and analyzed its mechanical properties using three different basic materials: aluminum, steel, titanium. The purpose of this study is to reduce production time and to minimize the risk of design failure. In this study, the Catia software is used to design the rims and to conduct simulation of applying force on a component, applying a certain working pressure. This software is also to perform calculations and display the results for analysis. The analytical method used is the Finite Element Method (FEM) of static analysis. The mesh type uses a linear tetrahedron mesh. Provision of clamps or fixed constraints is carried out on the surface of the bolt hole, where this surface is in contact with the wheel holder of car drive system. Then given a circumferential loading of 200 kN/m$^2$. It was found that aluminum material is the best for the manufacture of car rims, which has a low density, so it is lighter than steel and titanium. However, alloys such as lead and magnesium are needed to increase their hardness, and chromium alloys are needed to protect the rims from corrosion due to use in a polluted environment and contain impurities that can trigger corrosion.*

***Keywords****: CATIA; materials strength; mechanical properties; rim design*

## 1. INTRODUCTION

The vehicle rim is the main driving component and is one of the important parts of the vehicle, especially the car. The design and manufacturing process for the rim is certainly not arbitrary, it must be very precise and must meet certain very strict standards (1–4). This is because the quality of the rim has an influence on the acceleration and handling of the car.

There are two important aspects that must be considered in the manufacture of the rim, including the rim design and metal material as the main material for making the rim (5–8). Some of the commonly used materials are steel (an alloy of iron and carbon), aluminum (an alloy of aluminum, magnesium, and nickel), magnesium, and titanium (9–11). Steel rims are often found on thin rims. Aluminum rims are claimed to be the most commonly used because they are easier to shape. Magnesium rims are not very common and are mostly used for racing purposes only, this type of material is prone to corrosion. Titanium rims are found on heavy equipment, this material is known to be very strong but also very heavy.

In the last decade, many durability and reliability analysis have been carried out related to rim design engineering (12,13). For example, braking performance is influenced by parameters such as: rim size (14), rim weight (15,16), rim design (17–19), and rim material (18,20). Rim size is related to how much space is needed between the rim and the brake disc (brake disc). The larger the diameter of the rim (14,21), there is more room for air to flow around the brakes to cool the hot brakes when the brakes work. The weight of the rim is also a special concern, where the car's handling becomes better with lighter rims. Heavy rims have increased rotational inertia, causing the brakes to work harder to stop the car's wheels from turning. Another factor that affects the handling of the car is the strength and flexibility of the rim material. The higher the rim strength, the lower the flexibility. Based on the reasons that have been described, an analysis study of the mechanical properties of a car rim design was carried out by varying the main material forming the rim (21).

## 2. METHODS

The first step is to make a modeling of the rim using CAD software. The software used in this research is Catia. Catia is very powerful for 3D modeling. The flexibility in editing features and the ability to be able to enter material into the sections that we have created are very useful, especially for the engineering profession in designing a three-dimensional design model that is accurate, fast, and satisfying in terms of visualization.

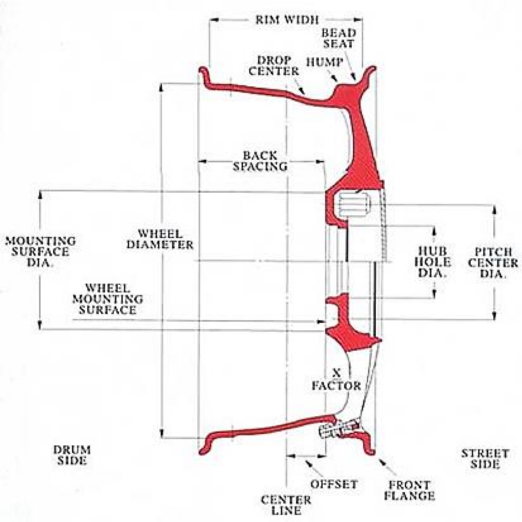



*Figure 1. Geometry of Rim*
Source: https://www.pistonheads.com/gassing/topic.asp?h=0&f=23&t=1165785&p=2

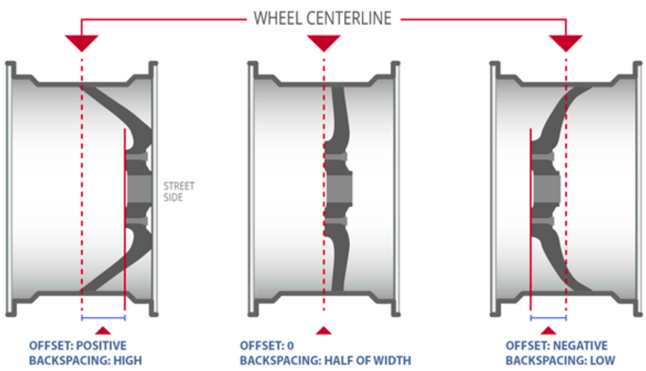



*Figure 2. Rim type based on the position of the hub to the centerline*
Source: https://www.elementwheels.com/custom-wheels-offset

## 2.1 Three-dimensional rim design

The study begins by making a three-dimensional design of the rim to be tested and analyzed. The following is explained in more detail with a systematic sequence or working steps so that it is easy to understand. All units in millimeters.

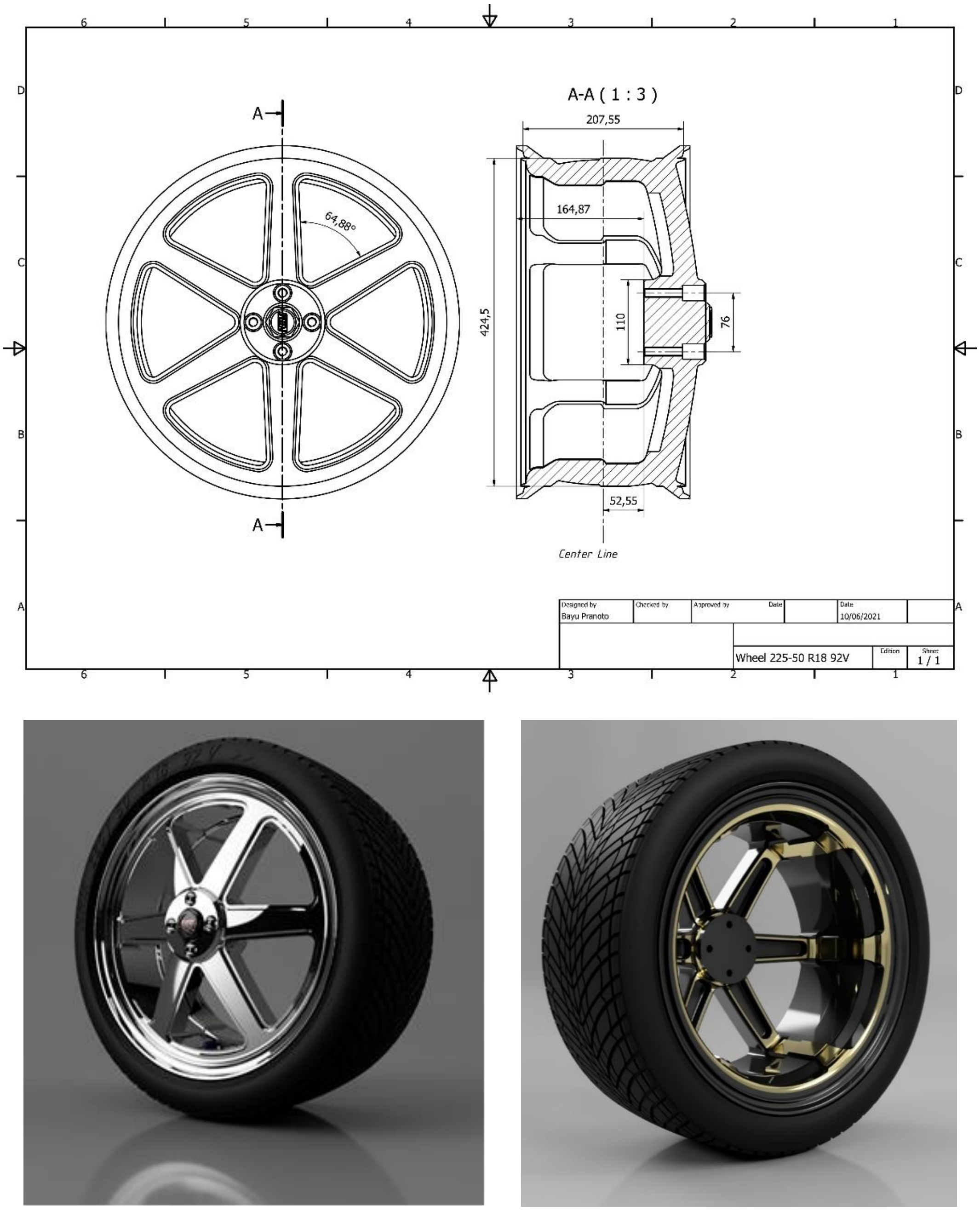



*Figure 3. Three-dimensional rim design*
Source: Drawing and rendering result by author

The specifications for each proposed rim section are shown in Table 1 below. Where each dimension value is designed by the author by taking into account the applicable rules in making rims or other sizes commonly found on a rim.

*Table 1. Dimensional specification of rim purposed*

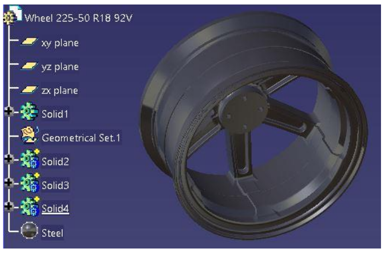
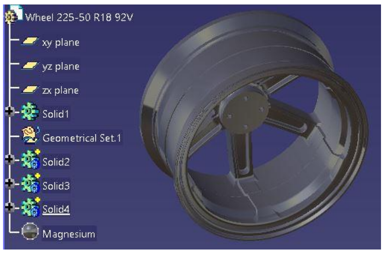
| No. | Part Name | Dimension |
|---|---|---|
| 1. | Wheel diameter | : 424.50 mm |
| 2. | Rim width | : 207.55 mm |
| 3. | Back spacing | : 164.87 mm |
| 4. | Offset | : 52.55 mm |
| 5. | Mount surface diameters | : 110.00 mm |
| 6. | Pitch center diameters | : 76.00 mm |
| 7. | Bolt hole diameters | : 10.00 mm |
| 8. | Wheel type | : Disc wheel |
| 9. | Flange shape | : J |
| 10. | Tire type | : Radial |

Source: Author's design

## 2.2 Apply material

Next, apply the material "aluminum" to the modeling rim, then select "Start" > "Analysis & Simulation" > "Generative Structural Analysis" > "Static Analysis". Do the same thing for another materials variation (steel, magnesium, titanium) for this study that shown in Table 2. Then go to generative structural analysis to carry out the simulation.

*Table 2. Rim material specification*

| No. | Description | Picture |
|---|---|---|
| 1. | Input material : Aluminium<br>Young modulus : 7e+10 N/m$^2$<br>Poisson ratio : 0.346<br>Density : 2710 kg/m$^3$<br>Thermal expansion : 2.36e-5 $^0$K<br>Yield strength : 0.95e+8 N/m$^2$ |   |
| 2. | Input material : Steel<br>Young modulus : 20e+10 N/m$^2$<br>Poisson ratio : 0.266<br>Density : 7860 kg/m$^3$<br>Thermal expansion : 1.17e-5 $^0$K<br>Yield strength : 2.5e+8 N/m$^2$ |   |
| 3. | Input material : Magnesium<br>Young modulus : 4.481e+10 N/m$^2$<br>Poisson ratio : 0.35<br>Density : 1798 kg/m$^3$<br>Thermal expansion : 2.88e-5 $^0$K<br>Yield strength : 2.75e+8 N/m$^2$ |   |
| 4. | Input material : Titanium<br>Young modulus : 11.4e+10 N/m$^2$<br>Poisson ratio : 0.34<br>Density : 4460 kg/m$^3$<br>Thermal expansion : 0.95e-5 $^0$K<br>Yield strength : 8.25e+8 N/m$^2$ |   |

Source: Author's documentation

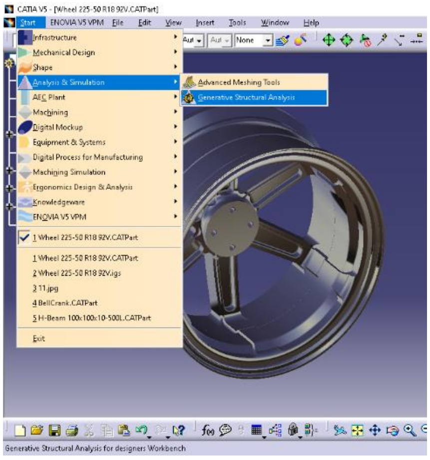


*Figure 4. Generative structural analysis*
Source: Author's documentation

### 2.3 Mesh setting

The next step is setting the mesh, because in this analysis the finite element method is used, we need to do the meshing process for modeling the rim. This mesh setting shown as Figure 5 below.

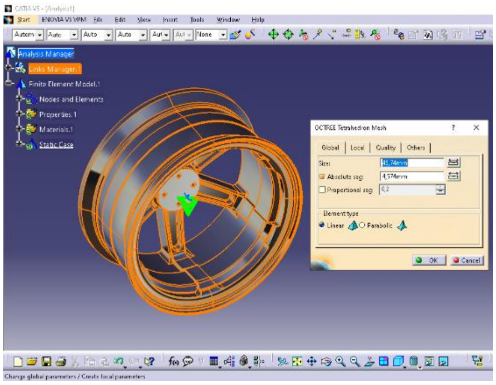


*Figure 5. Mesh setting*
Source: Author's documentation

### 2.4 Clamp setting

Next we lock using a clamp or fixed constraint on the surface of the bolt hole as shown as Figure 6. The selection of this clamping location is based on the surface of the bolt hole makes contact with the stud hub in the actual state.

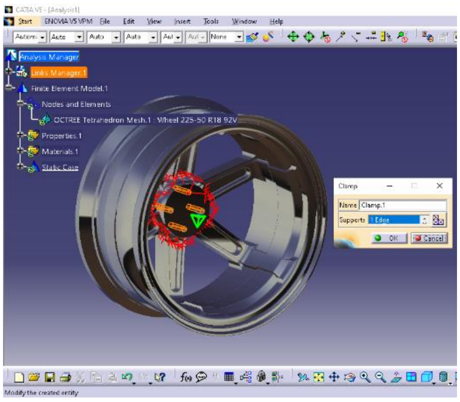


*Figure 6. Clamp setting*
Source: Author's documentation

### 2.5 Load setting

In this analysis, it is simulated that the rim receives a load in the form of pressure from the tire. The pressure from the tire hits the entire circular surface of the rim tread whose direction of pressure is towards the center of the rim. This is called the circumference load, which in this study was 200 kN/m$^2$ as shown as Figure 7 below.

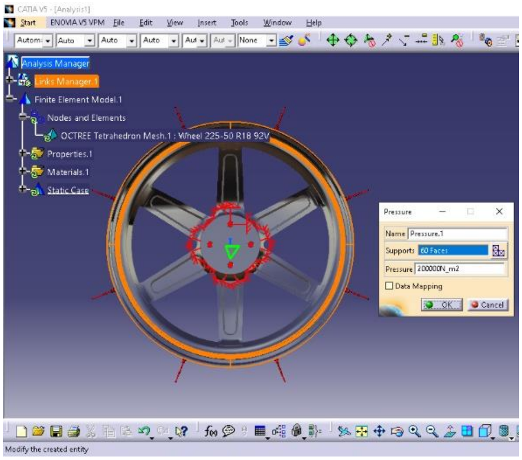


*Figure 7. Circumference load*
Source: Author's documentation

### 2.6 Load setting

Finally, we just run the simulation using the "Compute" feature as shown as Figure 8. Wait a moment until the calculation process is complete. To print the simulation results use the "Generate Report" feature.

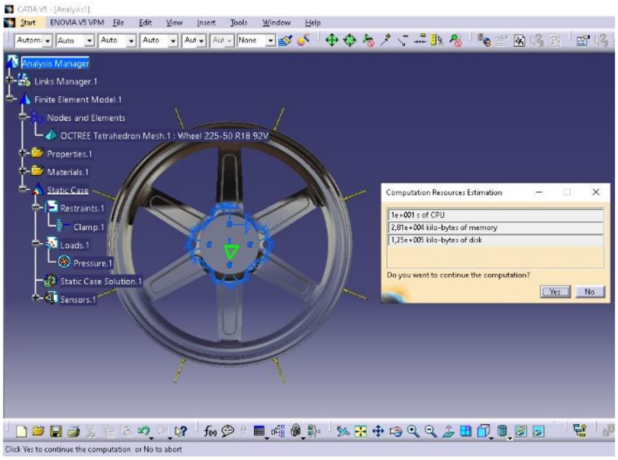


*Figure 8. Computing process*
Source: Author's documentation

After completing the analysis for the "aluminum" material, repeat steps 2-6 using steel, magnesium, and titanium materials. This value represents the characteristics of each tested material.

## 3. Result and Discussion

In Figure 9 and Table 3, based on the simulation results, it is found that for the same rim design modeling, the highest displacement value when subjected to a circumference load of 200 kN/m$^2$ is owned by a rim with magnesium material, which is 0.0202 mm then followed sequentially by the material. aluminum, titanium, and steel which are 0.013 mm, 0.00795 mm, and 0.00451 mm, respectively. These results indicate that magnesium is the softest rim material, while steel is the hardest rim material. When it comes to handling performance for cars, the best is the magnesium material. However, given that magnesium is easily corroded. So that aluminum is proposed as a rim material with the best performance.

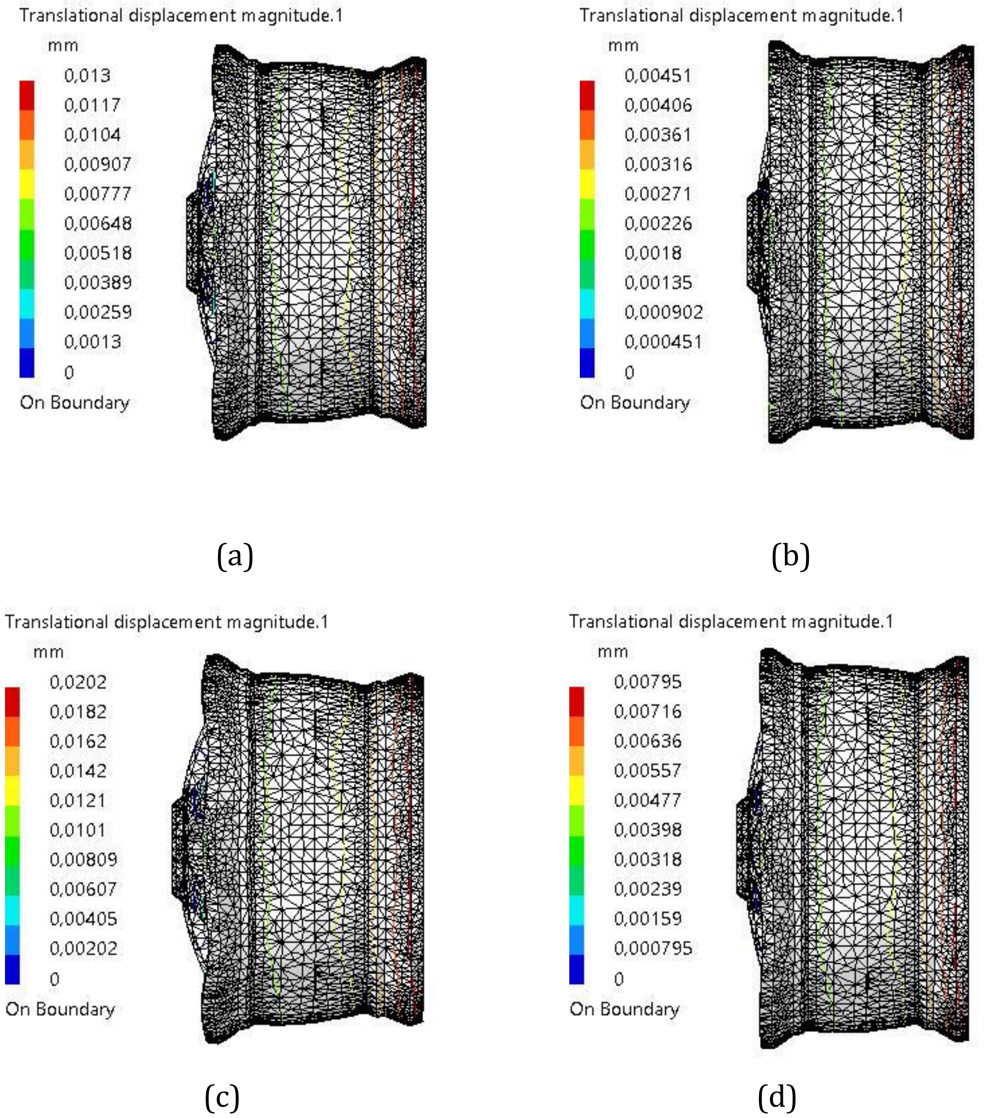



*Figure 9. Translational displacement for each material: (a)Aluminium, (b)Steel, (c)Magnesium, (d)Titanium*
Source: Author's documentation

*Table 3. Transitional displacement value for each material*

| Material | Aluminium | Steel | Magnesium | Titanium |
|---|---|---|---|---|
| Max. Displacement (mm) | 0,013 | 0,00451 | 0,0202 | 0,00795 |

Source: Author's documentation

In Figure 10 and Table 3 it is found that the maximum value of von mises stress is owned by steel material rims, which is 4.27e+6 N/m$^2$, and for aluminum, magnesium, and titanium materials, the maximum von mises stress values are the same, which is 4.24e+6 N/m$^2$. For the minimum value of von mises stress, sequentially from the highest to the lowest value are steel, titanium, aluminum, and magnesium, each of which values are: 4.32e+4 N/m$^2$, 3.47e+4 N/ m$^2$, 3.4e+4 N/m$^2$, and 3.36e+4 N/m$^2$. These results indicate that the softer a material, the lower the stress experienced by the material, because the energy from the outside is partially absorbed by the material grains, this is related to the mechanical properties of the elasticity of the material.

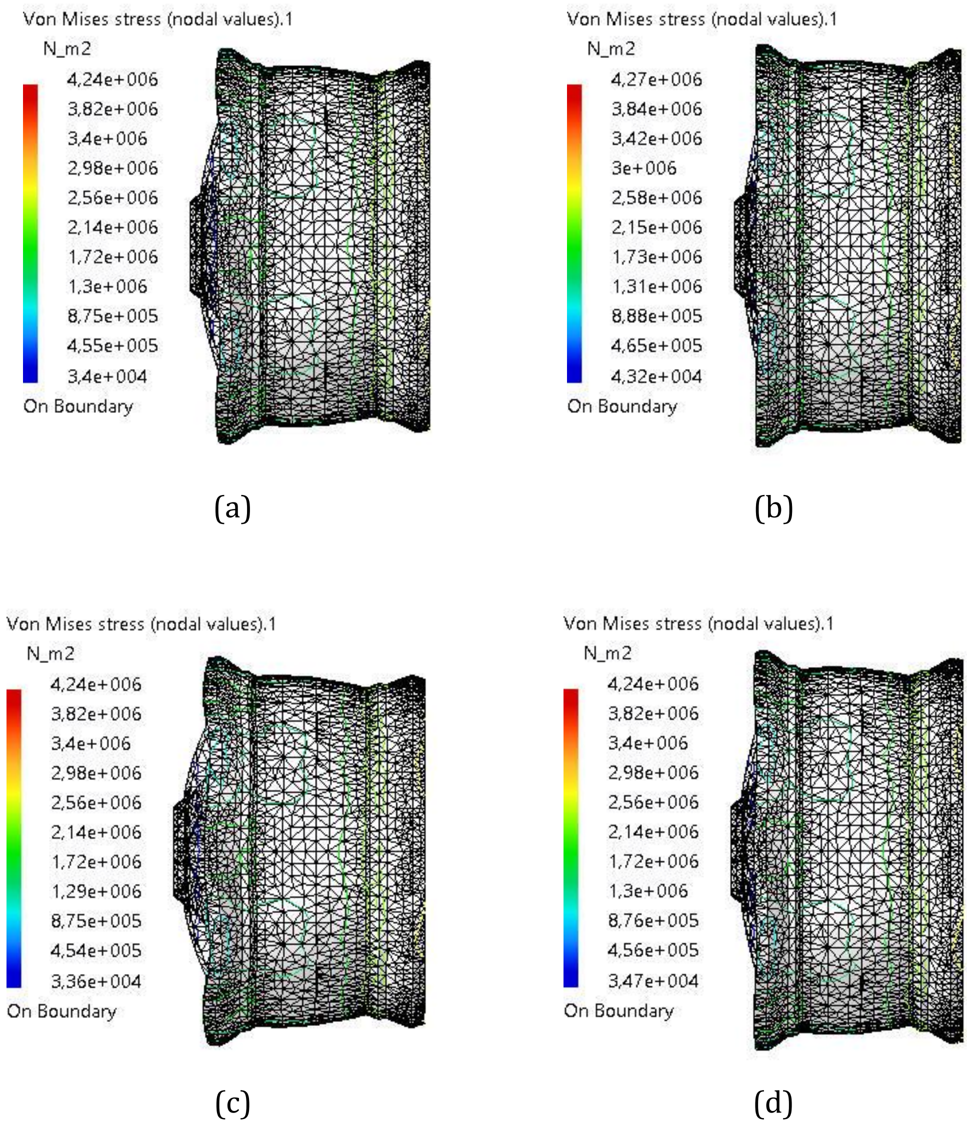



*Figure 10. Von mises stress for each material: (a)Aluminium, (b)Steel, (c)Magnesium, (d)Titanium*
Source: Author's documentation

*Table 4. Von mises stress value for each material*

| Material | Aluminium | Steel | Magnesium | Titanium |
|---|---|---|---|---|
| Max. von mises stress (N/m$^2$) | 4,24e+6 | 4,27e+6 | 4,24e+6 | 4,24e+6 |
| Min. von mises stress (N/m$^2$) | 3,4e+4 | 4,32e+4 | 3,36e+4 | 3,47e+4 |

Source: Author's documentation

Its application to car rims is that if using a soft material, the rim if it experiences a shock load will experience a deflection before it breaks. This is evidenced by the displacement value for soft materials is greater than for hard materials. As for hard materials, when subjected to shock loads, fracture will occur and experience significant deflection. The shock load in this study can be exemplified as when a car passes speed bumps on the road or when a car passes through a pothole in the road.

## 4. Conclusion

Aluminum material can provide optimal car rim design development compared to steel, magnesium, and titanium materials. The good mechanical properties of aluminum have a great impact as the main choice in making car rims.

The results of this study can be further developed by minimizing sharp bends in the rim design. As much as possible the rim is designed by giving a certain radius at points that are prone to stress concentration. The purpose of giving the radius is to distribute the stress on the rim when it receives a force or load from the outside.

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