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Static Structural Analysis of Different Spoke Thickness on Vehicle Wheel Rim

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Abstract: A wheel rim was a very important part for the whole system of a transportation. A lot of impacts and loads acting on them when the vehicle was use on the road. They had to go through the outside force of resistances on the road and hold the pressure for the whole weight of the vehicle. The failure of rim wheel is due to crack initiated near the hole which further gets propagated throughout the rim that leads to fatigue failure. In order to improve the fatigue life of rim, material and design optimization is necessary for which the best material has to be selected by conducting design of experiments to find parametric design which gives higher fatigue life [1]. It is important to design a wheel rim so it can take such impacts and pressure for the safety of the vehicle itself and the passengers inside. That were the main criteria of a wheel rim. For this research, a wheel rim will be designed with three different variants, then analysis of impacts will be conducted to the designed rim. So, there will be three different design of wheel rims with the same material and overall dimensions, but the spokes thickness are different from one another. The rim will be designed using Solidworks 2019 software. The analysis of impacts will be done using ANSYS 2019 R3 software where the method of finite element analysis (FEA) take places. Using the same amount of impacts, there were two type of impacts used that was the force and pressure. Apply on all the three wheels rim designs with the same amount of magnitude at the same exact contact surface. The force apply was 100 Newton and the pressure was 1 MPa. The criteria of the rim simulation involved the total deformation, equivalent elastic strain and equivalent stress. From the results, a comparison of the three wheels rims can be done to see their performance towards the impacts given. From there, it can be determined which design has the best criteria for a wheel rim and the rim with 10.25 mm thickness of spoke had the best criteria based on result and analysis.

Keywords: Wheel Rim, Spokes Thickness, Finite Element Analysis (FEA)

1. Introduction

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A wheel is a very important and crucial components of a vehicle especially for a car because it is the most used type of a vehicle. A wheel consist of a rubber tire and metallic rim. A good wheel should be able to endure a harsh and raspy working condition at an extreme situation [2]. A number of static and dynamic of loads that act on the wheel must be taken during its operational uses [3]. This is for maintaining or protecting other components of the car from damage as well as absorbing impacts and shocks experienced due to collision of potholes and bumpy road. Therefore, it is important to carefully design a wheel rim so that it can be used safely and economically without any hesitation of broken a wheel [4].

Wheel is an important component for a vehicle. There are a vast difference between a wheel and a rim. But still, both of them are very important if working together in making sure the vehicle can move in a very comfortable way and going smoothly without any hesitation from the consumer perspectives. It is not easy to design a rim seem it’s needed a lot of requirements in term of theoretically and mathematically to form a part of a wheel. The main difference between wheel and rim is that rim is not the whole wheel but only a part of the wheel [5]. In a simple word, a rim is the outside edge of the wheel. Without a wheel, there is no rim. These two parts are connected by a spokes. Spokes are another component that are very important for a wheel and rim. It is like a backbone for a wheel. Figure 1 below shows which part is wheel and which is rim.

Figure 1: Part of wheel and rim [5]

1.1 Spokes Rim

Spokes of a wheel rim plays an important role in designing a rim as well the whole vehicle itself. Spokes are the connecting rods between the wheel hub and the rim [6]. Their main purpose is to transfer the loads between the hub and the rim, which are caused by the weight of the whole car, or any outside forces applied on it. Designing the rim especially the spokes must be specific and detail because the whole weight and load of the car depend on the rim spokes. Every size, thickness, density, material, shape and number of spokes must be taken in designing a wheel rim. So, for this research it is important to know which design and the thickness of spokes of a rim is the best in holding a number of loads using the method of Finite Element Analysis (FEA).

1.2 Spokes Construction

Spokes can be made of wood, metal, or synthetic fiber depending on whether they will be in tension or compression. For compression spokes, the original type of spoked wheel with wooden spokes was used for horse-drawn carriages and wagons. In early motor cars, wooden spoked wheels of the artillery type were normally used. In a simple wooden wheel, a load on the hub causes the wheel rim to flatten slightly against the ground as the lowermost wooden spoke shortens and compresses. The other wooden spokes show no significant change. Wooden spokes are mounted radially. They are also dished, usually to the outside of the vehicle, to prevent wobbling. Also, the dishing allows the wheel to compensate for expansion of the spokes due to absorbed moisture by dishing more [7]. For tension spokes, a use of lighter wheels with spokes made of tensioned, adjustable metal wires, called wire wheels replace the previous heavy wooden spokes. The early use of tension spoke was applied in the bicycle. But now,they can be found in today's modern vehicles like motorcycle, automobile, wheelchair and aircraft.

1.3 Spokes Rim Types

Some types of wheels have removable spokes that can be replaced individually if they break or bend [8]. These only include bicycle and wheelchair wheels. High quality bicycles with conventional wheels use spokes of stainless steel, while cheaper bicycles may use galvanized or chrome plated spokes. While a good quality spoke is capable of supporting about 225 kgf (c. 500 pounds-force or 2,200 newtons) of tension, they are used at a fraction of this load to avoid suffering fatigue failures. Since bicycle and wheelchair wheel spokes are only in tension, flexible and strong materials such as synthetic fibers, are also occasionally used. Metal spokes can also be ovalized or bladed to reduce aerodynamic drag and butted (double or even triple) to reduce weight while maintaining strength. These types of rims also can be seen for heavy vehicles like motorcycles and automobiles.

1.4 Rim Size Designation

The wheel specification is as summarized in Table 1. The dimensional model here refers to the CAD model of the rim. For better analysis, the wheel is modeled using a CAD software, Solidworks, using different features ranging from revolve features, sweep features, extrude boss base and extrude cut, fillet and surface features. To model the wheel a picture sketch was used. This was to ensure that the actual shape of the rim is used while modeling so as to reduce errors [9].

Table 1: Wheel Specification [9]

No.	Specification	Value
1	Rim Width	215.9 mm
2	Wheel Diameter	480
3	Offset	128
4	Pitch Circle Diameter (PCD)	110
5	Center Base Diameter (CBD)	70
6	Rim Thickness	7
7	Bolt Diameter	10
8	Number of Bolt Holes	5
9	Ventilation Holes Diameter	60
10	Material	5335MC alloy steel
11	Manufacturing Process	Flow Forming Process

1.5 Finite Element Analysis of Wheel Rim

Using finite element analysis (FEA), it can be determine the correlation between vertical wheel impact energy and can be used as a basis platform to study the parameters for wheel changes such as new material, thickness, size and pattern of spokes. Consequently, more study will provide better solutions for industrial problems involving the production of real parts. There are always a new improvement can be done for the wheel [10].

2. Materials and Methods

This section is to determine how the research is done in term of method and process. From the project objectives, problem identification, literature review, journal or article studies, sketching and designing rim, simulation analysis, how the data obtain and lastly the conclusion. Every aspect of this research is recorded and will be explain in detail like the problem statement, scope, model properties and simulation parameters of impact towards the designed wheel rim with different thickness of spokes.

2.1 Research Method

Figure 2 below is the process flowchart for this research :

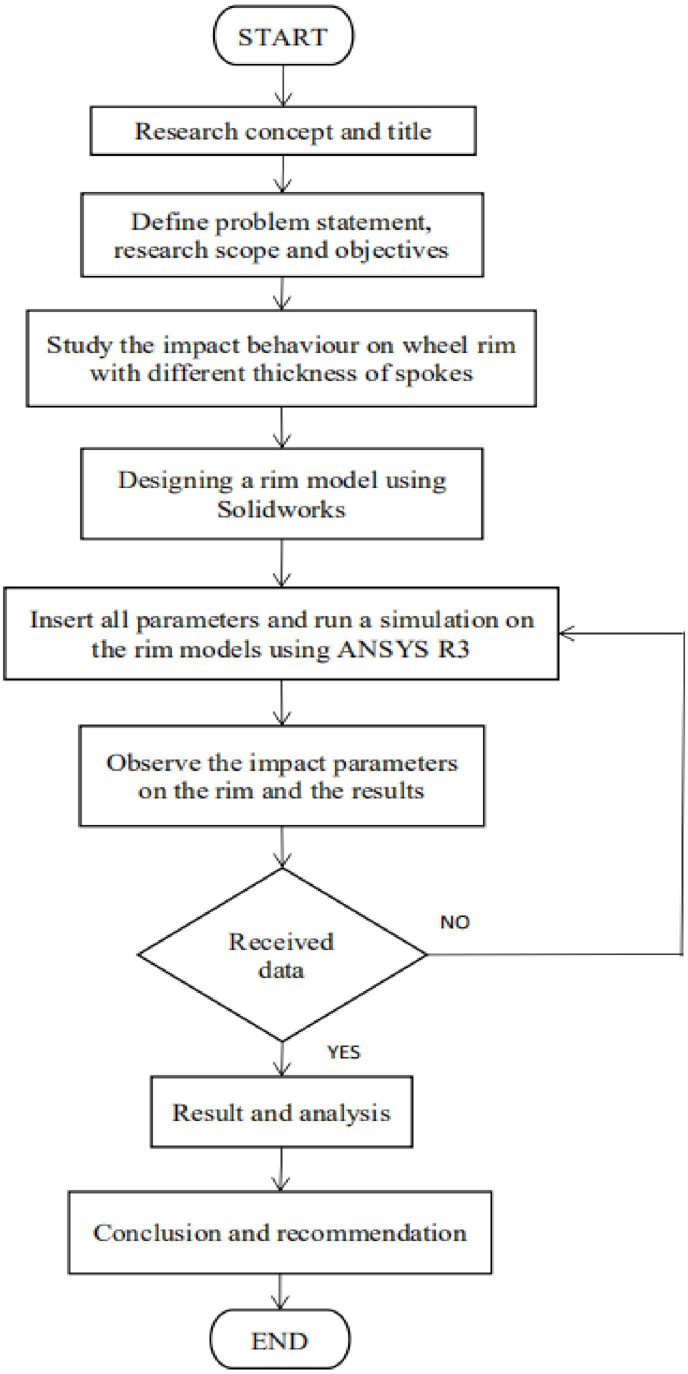


Figure 2: Process Flowchart

2.2 Model Setup

This research will compare three type of rim model. All three rim models has the same basic geometrical structures and dimensions as well as the material. The only different that separates the three rim models are the spokes thickness which is 10.25 mm, 22.25 mm and 28.25 mm respectively. Figure 2.2 below shows the part of the rim model that will determine the different thickness of spokes. Noted that all of the 14 spokes for each rim model is the same as the different value of thickness. The models were designed using Solidworks 2019 software once. And then, changes only the spoke thickness to 10.25 mm, 22.25 mm and 28.25 mm based of that same rim design. Thus, three rim designs are obtained. Table 2 shows the classification of the three rim model of different thickness of spoke.

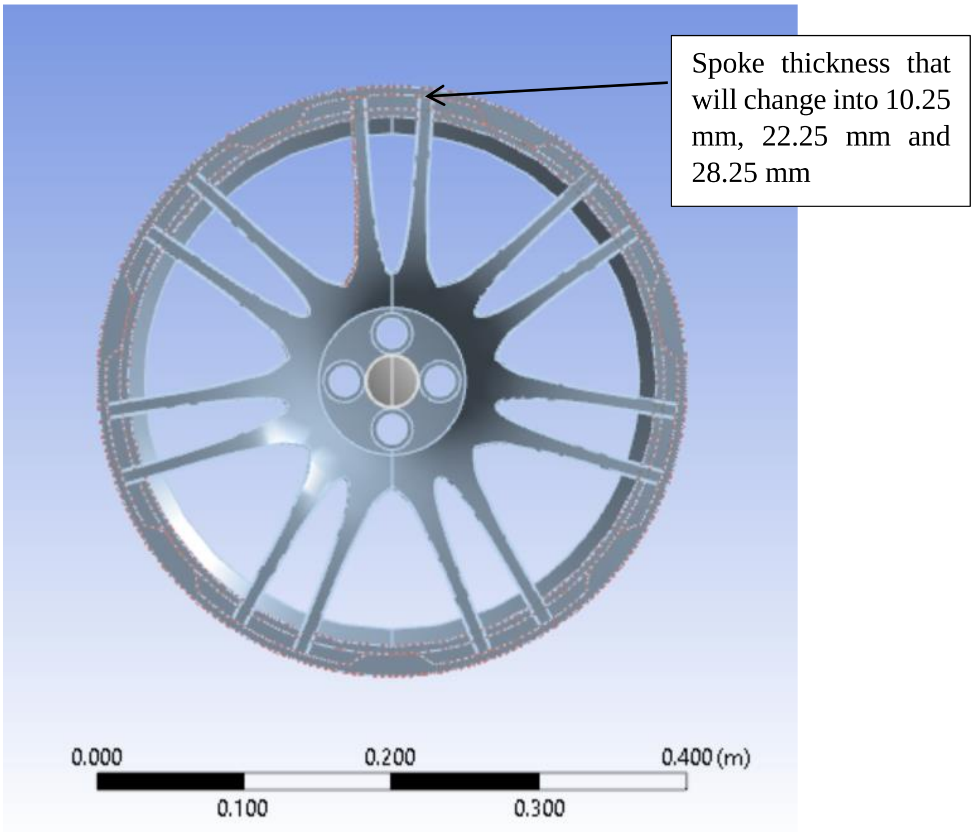


Figure 3: Rim design with part of spokes that differ (all 14 spokes applied)

Table 2: Classification of rim models

Model	Spokes thickness (mm)
A	10.25
B	22.25
C	28.25

2.3 Model Material Properties

The designed wheel rim models from the Solidworks then converted into 'IGS' file format to transfer the computer aided design (CAD) of the models into ANSYS R3 simulation software. From there, aluminium alloy was the material selection for every rim model during the simulation. Table 3 shows the aluminium alloy structural properties.

Table 3: Aluminium Alloy Structural Properties

Density	2770 kg/m^3
Young's Modulus	71000 MPa
Poisson's Ratio	0.33
Bulk Modulus	69608 MPa
Shear Modulus	26692 MPa
Isotropic Secant Coefficient of Thermal Expansion	2.3e - 05 1/^{0}C
Compressive Ultimate Strength	0 MPa
Compressive Yield Strength	280 MPa
Tensile Ultimate Strength	310 MPa
Tensile Yield Strength	280 MPa

2.4 Force and Pressure Appliances Toward the Rim Model

The impacts of force and pressure is directed at the same surface contact for all the rim models with the same number of magnitude. Figure 4 below shows the contact surfaces of force (green) and pressure (red) on the rim models and Table 4 shows the impacts properties.

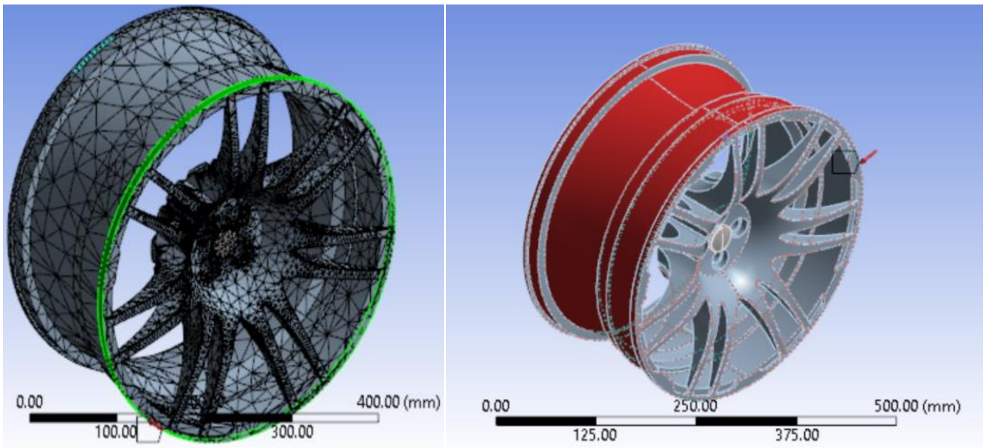


Figure 4: Contact Surfaces of Force (green) and Pressure (red)

Table 4: Impacts Properties

Type	Force	Pressure
Define By	Vector	Normal To
Magnitude	100 N	1 MPa

3. Results and Discussion

This section provided the results and discussion of the static structural simulation on the rim model with different thickness of spokes. All the three designed rim model with same material and geometric properties but with different thickness of spokes are analyzed in this section. The static structural that act on the rim models were the force and pressure. The direction and contact of the force were all the same in geometrical boundary of the rim models as well as the selected pressure. The number of magnitude for both force and pressure were the same for all the rim models with different spokes thickness which was 100 N and 1 Mpa respectively.

3.1 Results of Three Rim Models After the Impacts of Force and Pressure

Table 5 and 6 below shows the results for force and pressure of total deformation, equivalent elastic strain and equivalent stress for the simulation of the three designs of rim models after been applied both the impacts.

Table 5: Results for Force (100 N) Impact

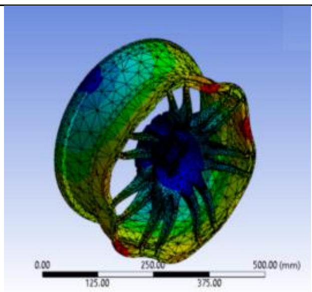
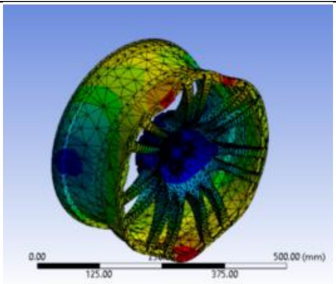
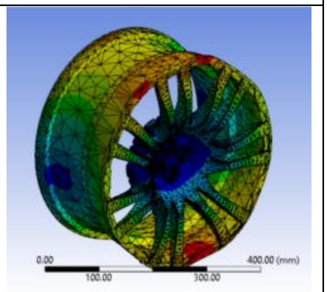
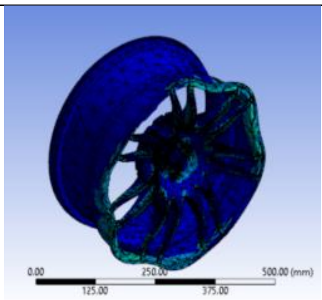
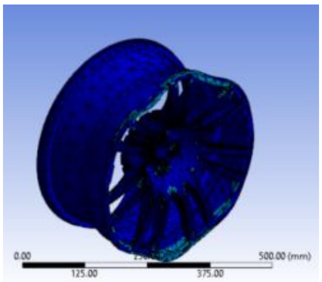
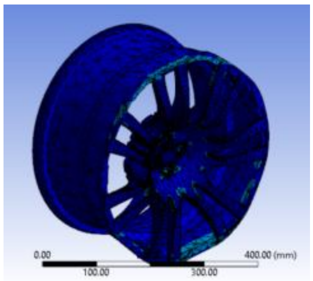
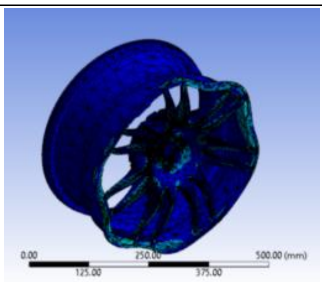
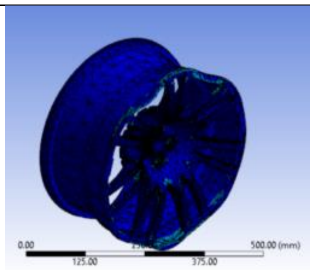
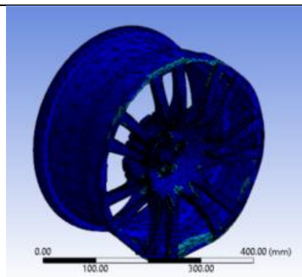
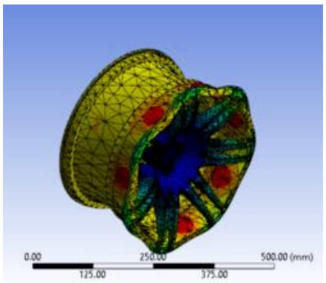
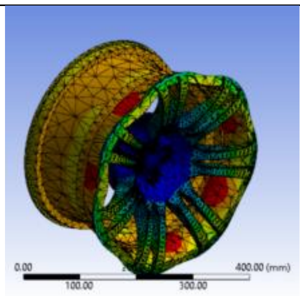
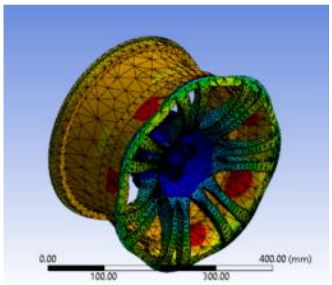
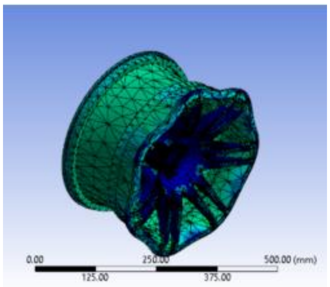
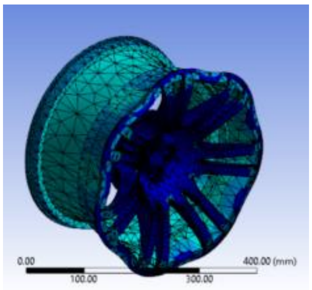
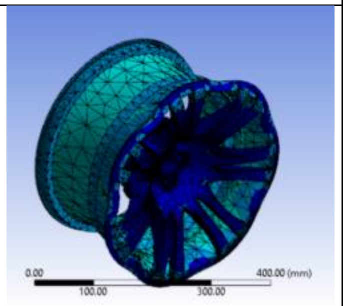
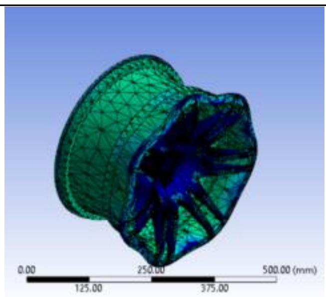
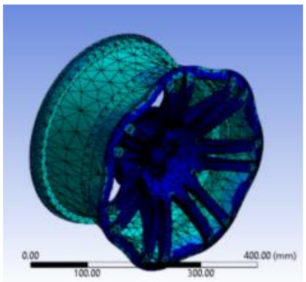
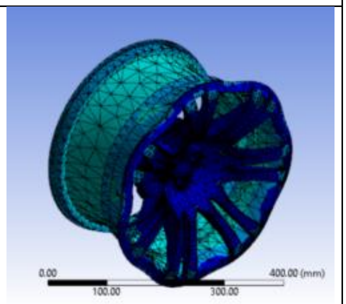
Model	**A**	**B**	**C**
Total Deformation (mm)	 0.00134	 0.00106	 0.00100
Equivalent Elastic Strain (mm/mm)	 0.0000093	 0.0000116	 0.0000110
Equivalent Stress (MPa)	 0.64	 0.77	 0.73

Table 6: Result for Pressure (1 MPa) Impact

Model	A	B	C
Total Deformation (mm)	 0.095	 0.085	 0.083
Equivalent Elastic Strain (mm/mm)	 0.00097	 0.0015	 0.0015
Equivalent Stress (MPa)	 66.92	 101.73	 108.26

3.2 Factor of Safety (FOS)

Factor of Safety is an important criteria for this research in order to ensure whether the wheel rim models was safe to be fully use or not. It can increase the safety of the drivers and passengers besides reduce the risk of failure or cracking on the actual rim wheel. Factor of Safety is being calculated by using the formula : **Factor of Safety (FOS) = Ultimate Strength / Working Stress**

*****Ultimate strength were obtain from the yield strength of material properties of the rim (refer table 2.3) and working stress obtain from the result of equivalent stress.

3.2.1 Force Impact of 100 N

I. Model A :

Factor of safety (FOS) = Yield strength / Working stress

= 280 / 0.64

= 437.50

II. Model B :

Factor of safety (FOS) = Yield strength / Working stress

= 280 / 0.77

= 363.63

III. Model C :

Factor of safety (FOS) = Yield strength / Working stress

= 280 / 0.73

= 383.56

3.2.2 Pressure Impact of 1 MPa

I. Model A :

Factor of safety (FOS) = Yield strength / Working stress

= 280 / 66.92

= 4.184

II. Model B :

Factor of safety (FOS) = Yield strength / Working stress

= 280 / 101.73

= 2.752

III. Model C :

Factor of safety (FOS) = Yield strength / Working stress

= 280 / 108.26

= 2.586

3.3 Comparison Results and Data of Impacts Simulation

Table 7 below shows the results comparison obtain based of simulation been done before. As observe from Table 7, the three rim models had been applied the same amount of force and pressure at the same surface contact showing different amount of results of total deformation, equivalent elastic strain, equivalent stress and safety factor.

Table 7: Results Obtained Comparison

Impacts	Force (100 N)			Pressure (1 MPa)		
Model	A	B	C	A	B	C
Total Deformation (mm)	0.00134	0.00106	0.00100	0.095	0.085	0.083
Equivalent Elastic Strain (mm/mm)	0.0000093	0.0000116	0.0000110	0.00097	0.0015	0.0015
Equivalent Stress (MPa)	0.64	0.77	0.73	66.92	101.73	108.26
Safety Factor	437.5	363.63	383.56	4.184	2.752	2.586

3.4 Discussions of impacts simulation

Figure 5, 6 and 7 below shows the results comparison of three rim designs with different thickness of spokes for the total deformation, equivalent elastic strain and equivalent stress in the shape of bar chart for both force and pressure.

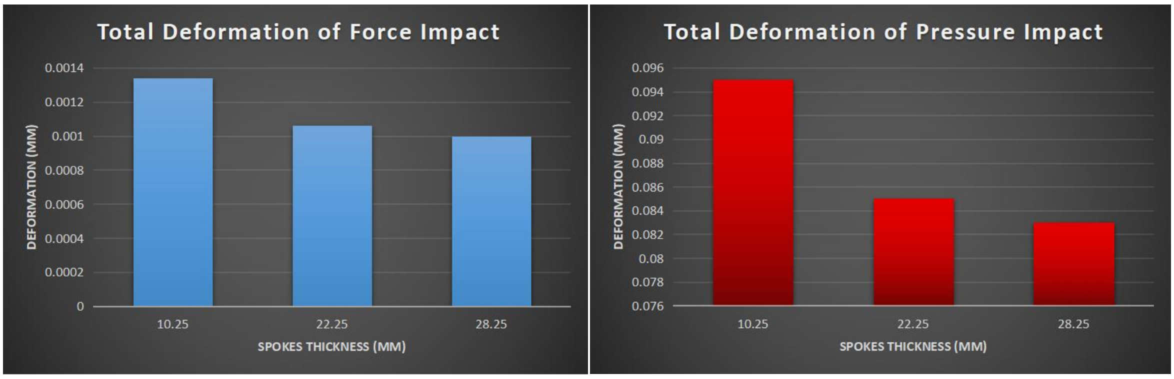


Figure 5: Total Deformation Results Comparison

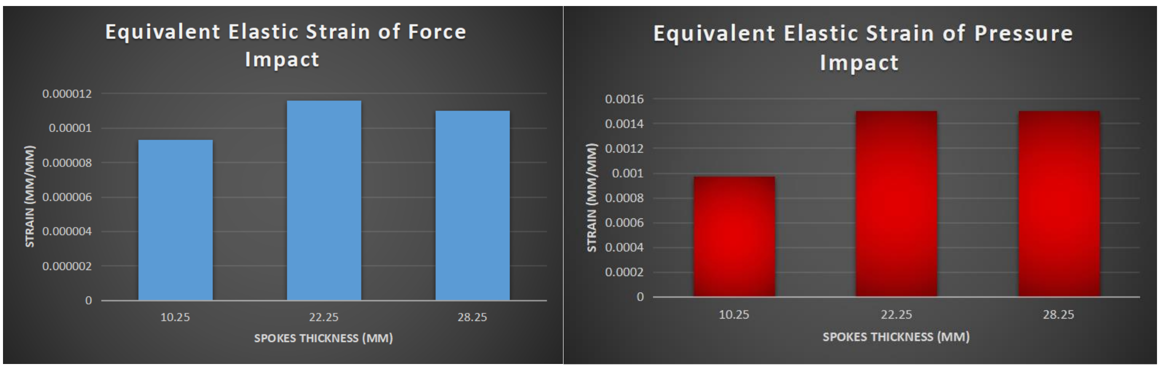


Figure 6: Equivalent Elastic Strain Results Comparison

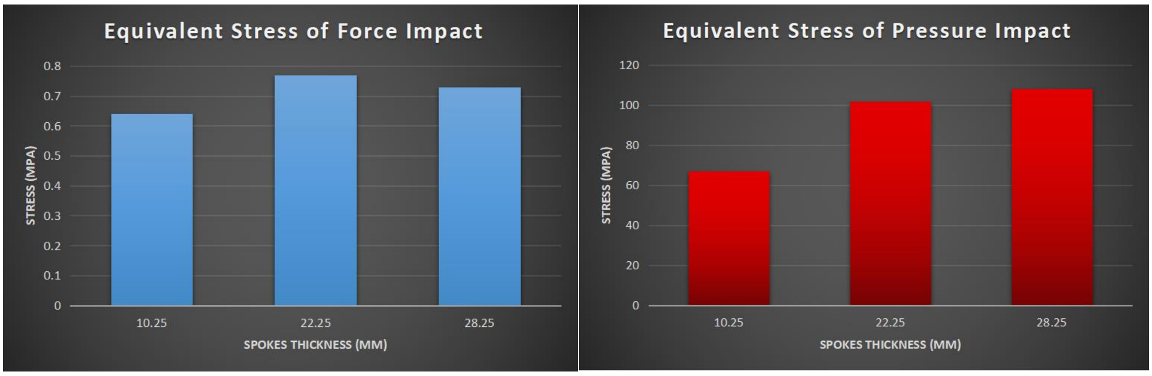


Figure 7: Equivalent Stress Results Comparison

Based on the results and analysis, model A shows the best overall results of total deformation, equivalent stress and safety of factor although the result for equivalent elastic strain was not good enough. But, looking at the point of average results, the design shows the best criteria for a car wheel rim model. So, if an actual car wheel rim need to be manufacture, rim model A is the best choice of design. This shows that thickness of spoke rim plays an important role in designing a wheel rim.

From the results, the rim design plays an important factors that made the rim models had different static structural results analysis. The design factor mentioned was the spokes thickness that are different. The other geometric dimensions of the rim are the same as well as the material. Even a slightly little different of the spokes thickness can effects the performance of the whole rim when applied on them the impacts. Noted that spoke rim plays an important role for the whole design of the wheel rim because all the pressure that come from the outside layer of the rim will be absorb by the spokes to be naturalize towards the centre hub of the rim. So, every analysis of wheel rim design need to be taken, example for this research in term of total deformation, equivalent elastic strain and equivalent stress. Applied on them the impacts of force and pressure and see the rim behaviour after the impacts. From there, a study can be made of what makes a good wheel rim design.

Rim model A was chosen as the best overall rim criteria based of the results and analysis is because the spoke rim has a consistent impacts absorption because of the consistent shape the spoke has. Unlike the spoke rim model B and C where only the top side of the spoke rim is thicker but from the centre until the end of the spoke it becomes thinner. When the impacts occur on the outer layer of the rim, the force and pressure can be absorb by thicker side of the spokes but when it reach towards the thinner part of the spokes, it cannot hold that much of the force and pressure like the thicker top side. So, that are the reasons making the rim become weak and easily deform because lower ability of strain. Unlike the rim model A, the shape of the spokes from top to the end is consistent with almost the same thickness as the top side of the spoke. This will be easier for the force and pressure to be transfer from the outer layer of the rim to the centre hub without any problem because the impacts travel smoothly along the spokes. Lastly, it can be conclude that spoke rim plays an important role in designing the rim.

4. Conclusion

At the end of the research study, based on the results and analysis obtained, it can be concluded that the objectives of the results are achieved where is to test the static structural impacts of force and pressure to three wheels rim design with different thickness of spokes of same material and basic dimensions and to run a simulation of the impacts on the wheel rims using the method of Finite Element Analysis (FEA) of ANSYS R3 software. A comparison of which designs with different thickness of spokes of wheel rim that can hold the highest amount of impacts were obtain. Thus, the wheel rim model A was the best design out of the two other wheel rim designs. It can hold and absorb the most amount of impacts of force and pressure. The maximum total deformation was the highest and the lowest amount of stress in response to the impacts. The safety factor also was the highest among other rim models which means the rim is more reliable and more sustainable. Spoke rim model A has the longest shelf-life based on the result and factor of safety shown. The possibility of the rim to fractured or cracks is low if a large amount of impact strikes the rim compare than the two other rim models. Last but not least, rim model A with 10.25 mm of spokes thickness was the correct choice for a car wheel rim as proved by the research.

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