Designing optimal material selection for manufacturing car wheel rims

Thiết kế lựa chọn vật liệu tối ưu cho việc chế tạo mâm bánh xe ô tô

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Abstract: The selection of suitable material for manufacturing wheel rim is essential to address the issue of weight reduction while ensuring the load-bearing capacity of the wheel rims during vehicle movement on the road. In this study, the research team designed a 3D model of the wheel rim using Solidworks software. Afterwards, a numerical simulation model using Ansys Workbench software was constructed to calculate the load-bearing capacity of the wheel rim under two conditions: stationary and moving, using four different materials including steel alloy, aluminum alloy, magnesium alloy, and titanium. From the calculated results, the research team concluded that aluminum remains a suitable material for manufacturing wheel rims. This is due to its appropriate mechanical properties, ease of fabrication, cost-effectiveness, and the significant weight reduction achieved when wheel rims are manufactured using aluminum material.

Keywords: *Wheel rim, numerical simulation, steel alloy, aluminum alloy, magnesium alloy, titanium.*

Tóm tắt: Việc lựa chọn vật liệu phù hợp cho việc chế tạo mâm bánh xe là yếu tố quan trọng để giảm trọng lượng đồng thời đảm bảo khả năng chịu tải trong quá trình xe vận hành trên đường. Nghiên cứu này tập trung vào việc thiết kế một mô hình 3D của mâm xe với phần mềm Solidworks và xây dựng một mô hình mô phỏng số với phầm mềm Ansys Workbench để đánh giá khả năng chịu tải dưới trong hai trường họp với điều kiện xe đứng yên và di chuyển. Bốn vật liệu gồm hợp kim thép, hợp kim nhôm, hợp kim magiê và titan đã được tính toán và đánh giá kết quả mô phỏng. Kết quả chỉ ra rằng nhôm vẫn là vật liệu phù hợp nhất do tính chất cơ học phù hợp, dễ gia công và hiệu quả về chi phí, và đạt được sự giảm trọng lượng đáng kể cho mâm xe khi mâm bánh xe được chế tạo bằng vật liệu nhôm.

Từ khóa: *Mâm bánh xe, mô phỏng số, hợp kim thép, hợp kim nhôm, hợp kim magiê, titan.*

1. Introduction

The wheel rim is a load-bearing rotating component. The tire is mounted on the outside of the wheel rim and situated between the vehicle's axles. Its function is to securely attach the tire to the vehicle while transmitting and bearing various types of forces and moments between the tire and the vehicle's axle. The wheel comprises the rim, hub, and spokes. Commonly used materials for manufacturing wheels nowadays include aluminum alloy and steel, with magnesium alloy and titanium alloy being introduced later. Based on current manufacturing technologies, wheels can be made using various methods such as stamping, welding, casting, or forging.

Being a structure subjected to large loads and harsh environments, wheel rims must be designed to withstand high loads with a high safety factor; however, current trends are optimizing wheel rims for weight reduction to achieve lighter weights. Therefore, to meet these criteria, wheel rims are aimed to be manufactured from optimized materials that still ensure load-bearing capacity in harsh working environments while having overall lighter weight. In this study, the research team applied numerical simulation models under the same boundary conditions for four different types of materials to find the most suitable material for manufacturing optimized wheel rims.

In this study, Solidworks was utilized in designing the 3D wheel rim and numerical simulation models were conducted with mesh models and boundary conditions in two situations: when the vehicle is stationary and when it is moving on the road. Along with the computational conditions, the research team applied four types of materials: aluminum alloy, steel alloy, magnesium alloy, and titanium. The aim was to find the most suitable material for the load-bearing structure of the wheel rim and to reduce its weight.

2. Design of wheel rim

Solidworks is a powerful tool in 3D design, thus it has been utilized in this study to create the wheel rim model. The rim specifications were carefully calculated and selected to align with commercial products, ensuring accuracy prior to simulation. The ongoing trend in wheel design heavily emphasizes weight reduction through material substitution, mass reduction, and structural optimization. Despite the complex loading conditions and high-stress environments experienced during vehicle operation, lightweight design remains a top priority. Nevertheless, it also guarantees compliance with industrial standards and achieves exceptional load-bearing capacity.

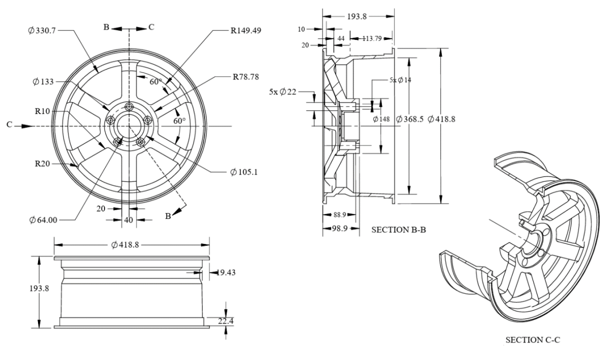

Figure 1. 03 projections of the wheel rim

Figure 1. presents detailed specifications of the wheel rim, with all units measured in millimeters. Meanwhile, Table 1. displays the computed values derived from the wheel rim calculation basis.

Table 1. Technical specifications table of the wheel rim.

Content	Value	Unit
Type of tire	Radial	-
Type of wheel	Disc type	-
Type of rim	Casting	-
Rim diameter	418.8	mm
Wheel width	193.8	mm
Diameter of the bonding surface	148	mm
Bolt hole diameter	14	mm
Diameter of the bolt hole seating surface	105.1	mm
Number of spokes	6	-
Spoke width	40	mm

3. Material and boundary conditions in calculation

3.1. Material

Four common types of materials commonly used for wheel rims are aluminum alloy, steel alloy, magnesium alloy, and titanium. The properties of the 04 aforementioned types of materials are presented in Table 2 [1]. In which, the weight of the wheel rim corresponding to magnesium alloy is the lightest at 6.9kg, aluminum alloy is 11.1kg, titanium is 19kg, and the heaviest is steel alloy at 31.6kg. Furthermore, aluminum alloy stands out for its cost-effectiveness compared to other materials. Not only does it boast excellent resistance to corrosion, but its ease of machining and fabrication makes it a preferred choice for a wide range of vehicles [2].

Table 2. Specifications of materials commonly used for wheel rims.

Material	**Aluminum alloy**	**Steel alloy**	**Magnesium alloy**	**Titanium**	**Unit**
Young modulus	7.00E+10	2.00E+11	4.48E+10	1.14E+11	Pa
Poisson ratio	0.346	0.266	0.35	0.34	-
Density	2710	7860	1798	4460	kg/m^3
Thermal expansion	2.36E-05	1.17E-05	2.88E-05	9.50E-06	^{0}K
Yield strength	0.95E+08	2.50E+08	2.75E+08	8.25E+08	Pa

3.2. Boundary conditions in calculations

a)The load on the wheel rim is calculated when the vehicle is stationary

In the case of the vehicle being stationary on a level road, one wheel rim is mainly influenced by tire pressure and 1/4 of the vehicle's weight if the vehicle's center of gravity is between the two axles. But in the case where the vehicle is stationary while turning uphill at the tipping angle of the vehicle, one rear wheel rim bears half of the entire vehicle's load [3].

Total weight of the vehicle: 2500 kg

Load placed on the rear wheel rim when the vehicle is stationary turning uphill at the tipping angle: 2500/2 = 1250 kg

The force applied on the rear wheel: 1250 × 9.81 = 12262.5 N

The maximum tire pressure exerted on the wheel rim: 40 × 6894 = 0.27576 MPa

b) The load acting on the wheel rim when the vehicle is in motion

When a vehicle moves on a flat road, besides the pressure exerted by the tires, the weight of the vehicle is placed on each wheel; the wheel rim also experiences additional torque from the engine along with the engine speed transmitted [3]. Table 3. presents the calculated parameters for the wheel rim load-bearing capacity in the case where the vehicle moves through the theoretical calculation basis.

Table 3. Calculated parameters of the wheel rim in the moving vehicle condition

Maximum torque of the engine	260	Nm
Engine speed at maximum torque	2400	rpm
Power at maximum torque of the engine	65	kW
Torque at the wheel output shaft	1497.37	Nm
Total vehicle weight	2500.00	kg

Load placed on each wheel	625	kg
Force applied to each wheel	6131.25	N
Maximum tire pressure acting on the wheel rim	275760	Pa

4. Numerical Simulation and Results

4.1. Numerical Simulation

a) Stationary vehicle on slope at vehicle's rollover angle

After selecting the material and importing the 3D Solidworks model of the wheel rim into Ansys Workbench in the "Geometry" dialog box, the next step is to set up the mesh in the "Model" dialog box, as finite element method is used in this problem [4], [5]. Figure 2a illustrates the mesh model of the component.

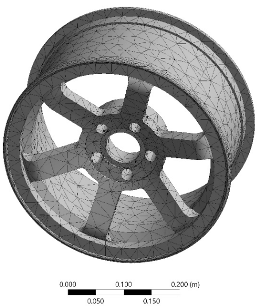

Figure 2a. Mesh model of the wheel rim

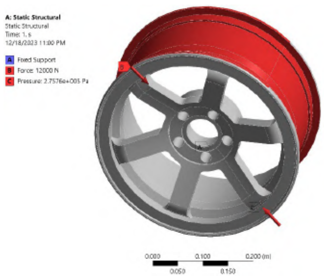

Figure 2b. Boundary conditions

Next, the fixed constraints on the surface of the bolt hole and the component acting on the rim are illustrated in Figure 2b. The selection of these fixed positions is based on the surface of the bolt hole contacting the center of the rivet in the actual state [3], [6].

b) Case when the vehicle is moving on the road

The steps of material selection, model placement, and mesh generation are repeated as in the static case. Through calculations, the boundary conditions have been established and are illustrated as shown in Figure 3. In addition to bearing loads from the vehicle, the surfaces of the bolt holes also experience additional shear moments from the bolts as the vehicle moves, while the fixed positions are placed on the wheel rim [3], [6].

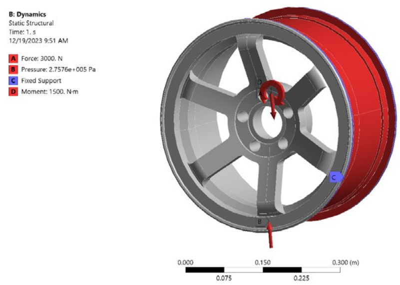

Figure 3. Force application model when

4.2. Simulation Results

a) Results when the vehicle is stationary

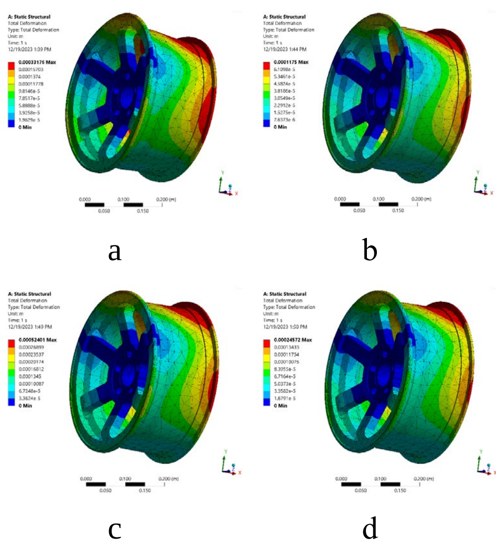

Figure 4. Total deformation of the wheel rim under stationary vehicle conditions with materials a) Aluminum alloy, b) Steel alloy, c) Magnesium alloy, d) Titanium.

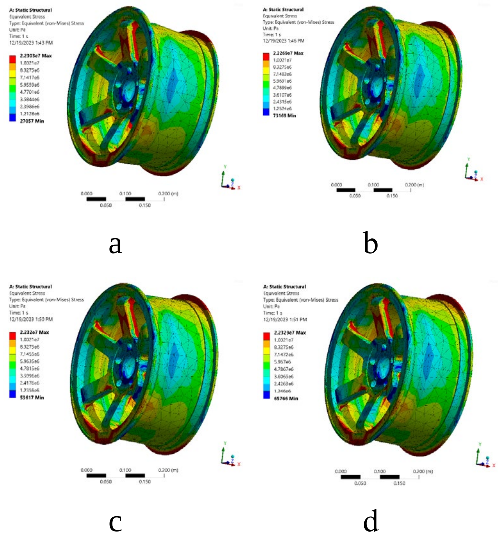

Figure 5. Results of Equivalent Elastic Strain under stationary vehicle conditions with materials a) Aluminum alloy, b) Steel alloy, c) Magnesium alloy, d) Titanium.

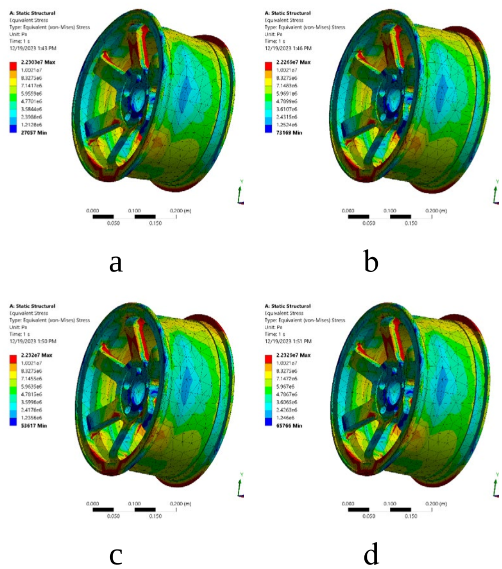

Figure 6. Results of Equivalent Stress under stationary vehicle conditions with materials a) Aluminum alloy, b) Steel alloy, c) Magnesium alloy, d) Titanium.

b) Simulation Results in the Case of Vehicle Movement

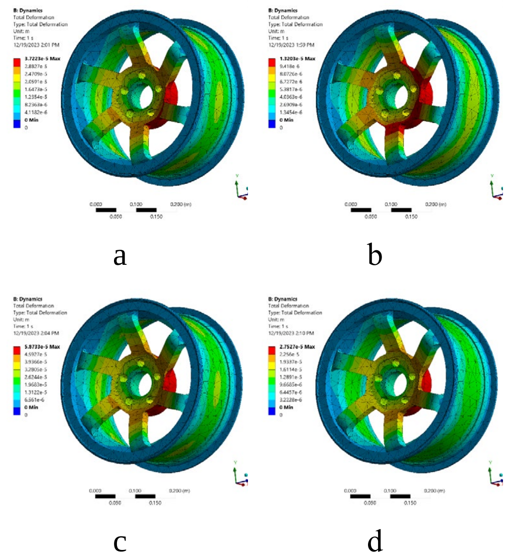

Figure 7. Total deformation of the wheel rim in the case of a moving vehicle with materials a) Aluminum alloy, b) Steel alloy, c) Magnesium alloy, d) Titanium.

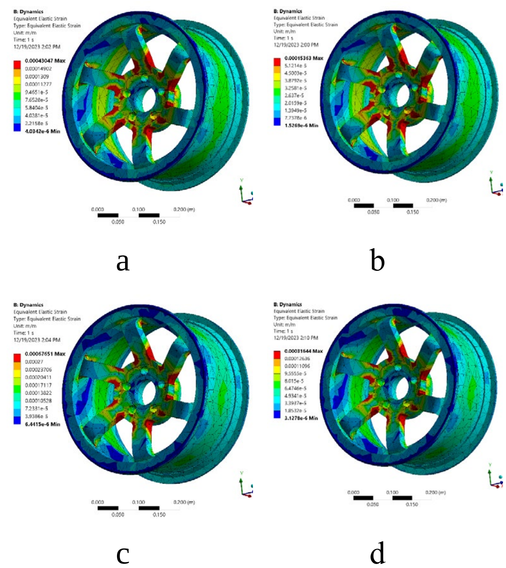

Figure 8. Results of Equivalent Elastic Strain in the case of a moving vehicle with materials a) Aluminum alloy, b) Steel alloy, c) Magnesium alloy, d) Titanium.

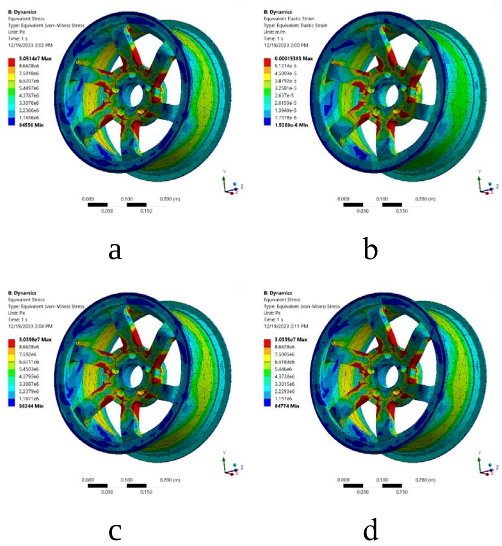

Figure 9. Results of Equivalent Stress of the wheel rim in the case of a moving vehicle with materials a) Aluminum alloy, b) Steel alloy, c) Magnesium alloy, d) Titanium.

4.3. Summary of Results

In Figures 4, 7, and Table 4, based on simulation results, it can be observed that for the same wheel rim design model, the maximum displacement values in the two simulated cases belong to an alloy wheel with Magnesium material, at 0.05873 mm followed sequentially by aluminum, titanium, and steel materials at 0.03722 mm, 0.02753 mm, and 0.01320 mm, respectively.

Table 4. Comparison of deformation values of the wheel rim corresponding to each material type.

Result		**Aluminum alloy**	**Steel alloy**	**Magnesium alloy**	**Titanium**	**Units**
Deformation result under stationary vehicle condition	Maximum	3.318E-04	1.175E-04	5.240E-04	2.457E-04	m
	Minimum	0	0	0	0	m
	Medium	6.738E-05	2.392E-05	1.063E-04	4.978E-05	m
Deformation result under moving vehicle condition	Maximum	3.722E-05	1.320E-05	5.873E-05	2.753E-05	m
	Minimum	0	0	0	0	m
	Medium	1.001E-05	1.984E-06	1.580E-05	7.409E-06	m

Table 5. Displacement values of the wheel rim for each type of material

Result		Aluminum alloy	Steel alloy	Magnesium alloy	Titanium	Units
Displacement result under stationary vehicle condition	Maximum	3.418E-04	1.243E-04	5.301E-04	2.463E-04	m/m
	Minimum	9.025E-07	4.623E-07	1.358E-06	7.633E-07	m/m
	Medium	8.053E-05	2.866E-05	1.269E-04	5.941E-05	m/m
Displacement result under moving vehicle condition	Maximum	4.305E-04	1.536E-04	6.765E-04	3.164E-04	m/m
	Minimum	4.034E-06	1.527E-06	6.442E-06	3.128E-06	m/m
	Medium	2.774E-05	2.370E-05	1.047E-04	4.904E-05	m/m

Table 6. Stress values of the wheel rim for each type of material

Result		Aluminum alloy	Steel alloy	Magnesium alloy	Titanium	Units
Stress result under stationary vehicle condition	Maximum	2.230E+07	2.227E+07	2.232E+07	2.233E+07	Pa
	Minimum	27057	73169	53617	65766	Pa
	Medium	5.064E+06	5.072E+06	5.059E+06	5.057E+06	Pa
Stress result under moving vehicle condition	Maximum	3.051E+07	3.067E+07	3.040E+07	3.034E+07	Pa
	Minimum	9.456E+04	1.052E+05	9.624E+04	8.477E+04	Pa
	Medium	4.027E+06	4.036E+06	4.021E+06	4.018E+06	Pa

In Figures 6, 9, and Table 6, it can be observed that the maximum von Mises stress values belong to the steel alloy material, which are 3.067E+07 Pa, and for aluminum alloy, magnesium alloy, and titanium materials, the values are 3.051E+07 Pa, 3.040E+07 Pa, and 3.034E+07 Pa respectively. For the minimum value of von Mises stress, in sequence from the highest value to the lowest value, for steel, magnesium, aluminum, and titanium, each value is: 1.052E+05 Pa, 9.624E+04 Pa, 9.456E+04 Pa, and 8.477E+04 Pa.

5. Conclusion

Based on the simulation process involving four different materials, the following are the main conclusions drawn from the results obtained:

- In both cases, the stresses of the chosen materials in this study are lower than the yield stresses of the materials.

- The wheel rim deforms the most with the magnesium alloy material, while the steel alloy deforms the least.

- The application of materials in wheel rims is such that if soft materials are used, the rim will deform before breaking under shock loads. This is evidenced by larger displacement values for soft materials compared to hard materials. For hard materials, when subjected to shock loads, cracking and fracture are more likely to occur, leading to significant damage [7].

- Aluminum material can offer optimal development in wheel design compared to steel, magnesium, and titanium because of its cost-effectiveness and excellent mechanical properties, which have a significant impact on the primary choice in wheel manufacturing.

- The results of this study have indicated that aluminum is the preferred material for making wheel rims. Its performance can be further improved by minimizing sharp bends in the rim design. More specifically, rims are designed to incorporate specific radii at stress concentration points. The purpose of introducing these radii is to distribute stress across the rim when it experiences external forces or loads.

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