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# Performance Comparison of Rims of Wheels with Different Materials based on Finite Element Method

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***Abstract:***

In view of the phenomenon of wheel sway, tire burst and steel shortage in process of high-speed driving, this paper aims at analysis the changes of wheel force and displacement under different materials. Wheel rim is the main load-bearing part of the vehicle in process of high-speed driving, the wheel rim will be affected by the axial and radial loads, thus bend and twist deformation of the rim will be produced, in order to select the high performance material of wheel rim. Based on simulation software of Solid Works, the wheel rim of BMW3's wheel was selected, aluminum alloy (Al) and magnesium alloy (Mg) materials were selected for the rim material, and the changes of the force and displacement of the rim which using three materials were compared and analyzed. From the result of radial loading test, the maximum stress of Al and Mg is 64.09Mpa and 64.11Mpa, the maximum displacement is 0.578mm and 0.89mm, which developed at the inner bead seat. And from the result of bending test, the maximum stress of Al and Mg is 78.68Mpa and 78.39Mpa, the maximum displacement is 1.358mm and 1.533mm. If considering the influence of radial loading test, Al has advantages, while in bending test, the stress of Al is bigger than that of Mg, and the displacement of Al is smaller than that of Mg.

***Keywords:*** *Wheel rim, Different materials, Finite element method, Force and displacement.*

## I. INTRODUCTION

Vehicle wheel is an important part and main load-bearing part, it mainly bears vertical load, lateral force, driving and braking torque of wheel. And its quality has a significant impact on the safety, stability, smoothness and economy of vehicle driving [1]. With the rapid development of domestic automobile industry, large-scale foreign automobile companies have joined in the fierce vehicle competition [2]. The speed is getting faster and faster, the performance of the vehicle is getting better and better, and the requirements for wheels are getting higher [3]. The

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phenomenon of deflection、tire burst and bead throw occurs often, and existing tire technology has been unable to meet the rapid development of automobile demand. So a lot of tubeless wheels are used at domestic and abroad, At the beginning, developed countries such as Europe and the United States have fully realized the tubeless wheel, while the penetration rate of tubeless tire in China is not high [4]. Tubeless light-weight wheel, in line with the development of highway direction, is the future development trend [5].

Research on material lightweight, Titanium alloy, a lightweight material, is applied to auto parts, economic type is analyzed through life cycle cost mode by Jones [6], and concluded that titanium alloy can replace traditional steel to manufacture auto parts. Light weight research is carried out by Montalbo through changing the body process and using magnesium aluminum alloy [7], and analyzed the influence of lightweight on the battery capacity by using the dynamic simulation model. The results showed that the battery capacity required for the total weight reduction of electric vehicles was also correspondingly reduced. Das has studied the influence of several lightweight materials on the weight reduction effect of electric vehicles [8]. Through analysis, it is concluded that the application of lightweight materials leads to the decrease of the total cost of electric vehicles. In the whole life cycle, the lightweight vehicle weight will be reduced by 30%, the battery cost will be reduced by 3.5%, the material of the vehicle body will be reduced by 10%, the energy consumption of the whole life cycle will be reduced by 20%, and the carbon dioxide will be reduced by 17%.

The lightweight of automobile means to reduce the quality of automobile as much as possible while ensuring the strength and safety of automobile, so as to improve the power of automobile, reduce energy consumption and exhaust emission. Because the reaction speed of steering, suspension and brake components is related to the wheels. Therefore, the stability of the vehicle can be improved by optimizing the structure and composition of the wheel.

We can reduce the driving resistance by reducing the rim mass, during the analysis, it is assumed that the driving speed is constant, so the power required by the wheel can be expressed in in equation (1) [9] below:

$$F_{wheel}=R_{acceleration}+R_{incline}+R_{air}+R_{rolling} \tag{1}$$

Where the $R_{acceleration}$ is calculated according to the moment of inertia; $R_{incline}$ is the component force of gravity in direction of incline; $R_{air}$ stands for the aerodynamic resistance; $R_{rolling}$ stands for the rolling resistance. The relationship among acceleration resistance, moment of inertia and rim mass can be expressed as follows (equation 2 and 3[10]):

$$I_{wheel}=\frac{1}{2}mr^2 \tag{2}$$

$$T_{wheel}=\alpha\times I_{wheel} \tag{3}$$

According to equation (3), the torque applied to the wheels ($T_{wheel}$) is directly proportional to the moment of inertia and angular acceleration α of the wheel. So if we provide a small moment of inertia, we can reduce the torque output, and the results is reducing fuel consumption.

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In this paper, SolidWorks2016 are used to simulate the load conditions of rim models under different materials (Al and Mg). Finally, comparing results, and the purpose of rim structure optimization, material lightweight and weight lightweight is realized.

## II. MATERIALS AND METHOD

2.1 Candidate Material 1: Al Alloy

Compared with other steels, aluminum alloy has the characteristics of low density, good corrosion resistance and easy processing. Meanwhile the most popular Aluminium alloy is 6061T6 which exhibit both good tensile strength and formability [11]. TABLE I summarized the main properties of this type of Al alloy. It is a lightweight material which has been applied to automobile earlier and technology is increasingly mature, especially on the rim. One of the most realistic choices for automobile lightweight is to improve the aluminum ratio of the whole vehicle.

**TABLE I. Properties of several materials**

| Material name | Aluminium alloy 6061 T6 | Magnesium alloy ZK60A T6 |
|---|---|---|
| Density (Kg/m$^3$) | 2700 | 1830 |
| Tensile strength (Mpa) | 310 | 325 |
| Yield strength (Mpa) | 275 | 270 |
| Elastic modulus (Gpa) | 69 | 45 |
| Thermal conductivity (W/(m*k)) | 166.9 | 120 |
| Elongation (%) | 16 | 11 |
| Specific strength (kNm/kg) | 114.8 | 177.5 |

The wheel rim is mainly obtained by forging, and the precision and uniformity of forged aluminum alloy rim are better than that of casting parts [12]. Aluminum alloy can be distributed along the load path, and the tensile strength can be improved by producing fibrous grain structure.

2.2 Candidate Material 2: Mg Alloy

Magnesium alloy [13] is recognized as the most promising lightweight metal material for automobile. Magnesium has high thermal conductivity, electrical conductivity and non-magnetic. One of the magnesium called ZK60A T6 by Timminco Corporation (1998) is very popular in case of excellent specific strength that superior to Al alloy [14], and parameters are shown in TABLE I. Alternatively, doping additional composition like Ti and Nd can enhance the corrosion resistance of Mg alloy [15].

2.3 Modelling and Static Analysis

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Referring to the standard size of 19 "BWM 3 series 8-spoke wheel pair (online in 2018) [16], a three-dimensional model is established based on SolidWorks, the geometry is shown in Fig 1 below. The axial and radial loads on the rim are calculated by static mechanical calculation respectively. At the same time, the overall displacement and stress distribution of the rim are simulated by the simulation software. Therefore, the comprehensive performance of the new lightweight material wheel can be evaluated according to the simulation results. As is shown in Fig 1 below.

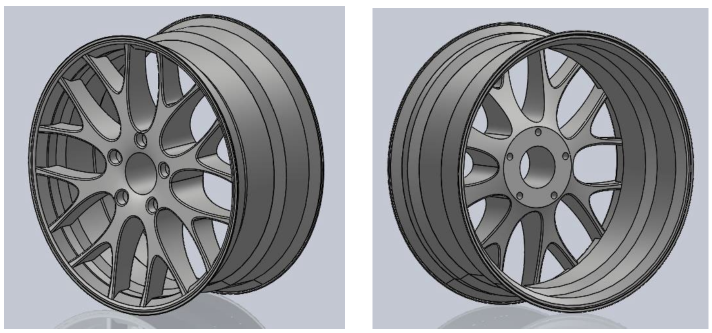

Fig 1: Basic geometry of the model

2.3.1 Radial Load Test

This chapter only considers the influence of three external loads on the rim performance. Firstly, the rim gravity load at the center of mass is assumed to be 4.145kg, the gravity acceleration is 9.81m/s^2, and other parameters are obtained according to the mass properties. Secondly, the external load generated by the tire pressure around the hump is fixed, and the general tire pressure value is 30 psi. Third, the load generated by the support force of tire contact with the ground is the largest. The third load calculation method: according to the relevant literature [17], the effective contact area is set as 1/6 of the side area, and the schematic diagram is shown in Fig 3 and Fig 4.

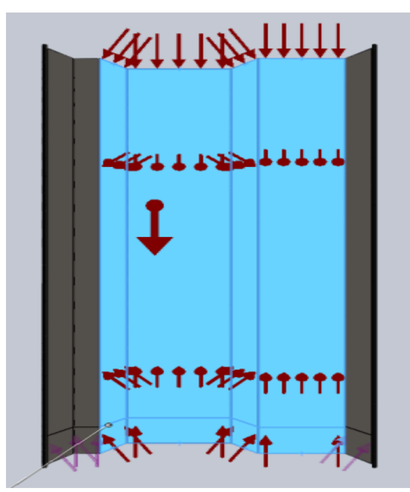

Fig 2: Tire pressure applied at retaining hump

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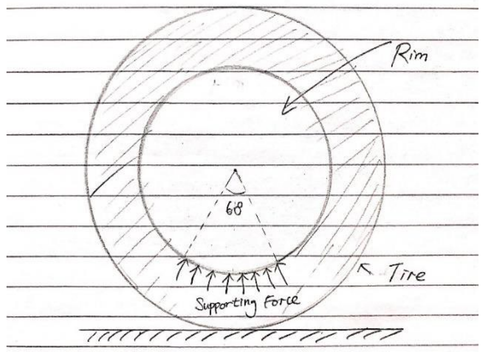



Fig 3: Illustrative figure of supporting force at the rim

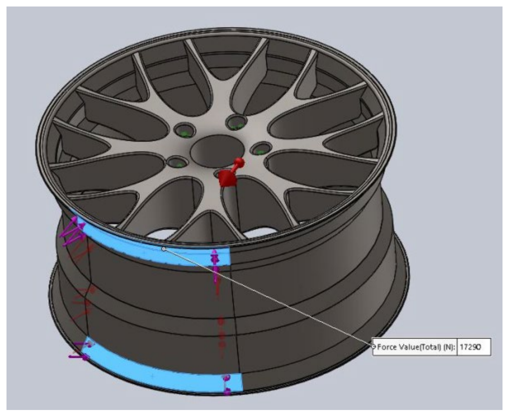



Fig 4: Applying loads at the split bead seats

When the vehicle is static, the force on each rim is 1/4 of the vehicle weight. With the load of 100kg and the total weight of five people, the supporting force of a single wheel can be calculated as Equation (4):

$$F_{support} = \frac{(m_{kerb} + m_{cargo} + 4m_{passenger})}{4} \times 9.81 m/s^2 \tag{4}$$

In the calculation, the load is 100kg, the passenger is 80kg, and the mass of the whole vehicle is 1495kg. The supporting force can be calculated according to equation 4.

$$F_{support} = 4696N \tag{5}$$

In addition, in order to consider the error margin, the experimental coefficient K of radial load is introduced into the applied radial load [18], the value of K will be chosen as 3.49.

$$F_{experimental} = F_{support} \times k \tag{6}$$

$$F_{experimental} = 4696N \times 3.49 = 17290N \tag{7}$$

All loads have been set, and the fixture needs to be set before meshing, the fixtures will be addressed at five bolt holes as shown in green arrows in Fig 5 below. In the radial load experiment, the mesh element size is 10 mm as shown in Fig 6.

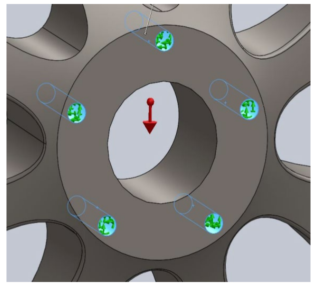


Fig 5: Bolt holes where the fixtures applied

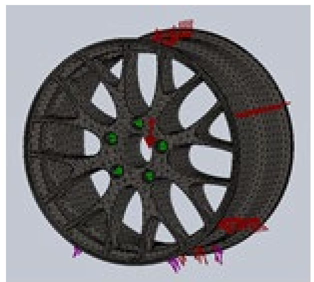
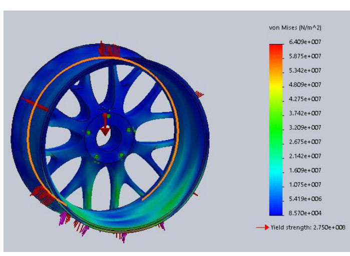
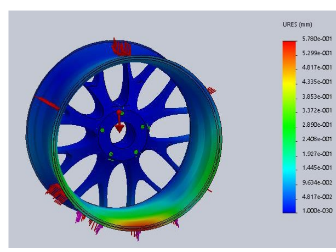


Fig 6: Created mesh

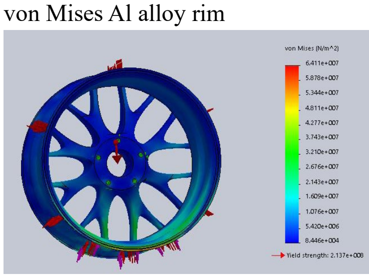
Under the action of radial load, the outputs of stress and displacement are shown in Fig 7 below. For the stress distribution, the significant weak area where developed the maximum stress are labelled in red. The maximum stress of aluminum alloy hub is located at the junction of the two sides of the back cavity spokes near the rim, the maximum stress value is 64.09MPa, the maximum stress of Mg alloy hub is located at the hub center, the maximum stress value is 64.11MPa. The displacement of Al and Mg are 0.578mm and 0.89mm respectively.



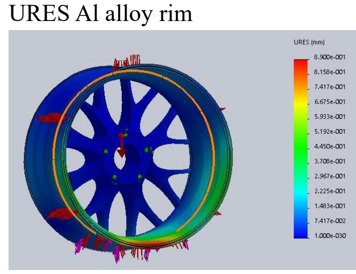
von Mises Al alloy rim



URES Al alloy rim



von Mises Mg alloy rim



URES Mg alloy rim

Fig 7: Von Mises stress and URES

2.3.2 Bending Test

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For simulating the bending load, the fixture was set up in the inner dead corner, and a 0.6m alloy steel axle is assembled to the hub hole. The applied load parallel to the hub at the end of the axle is 5880N as the bending moment at the bolt hole is assumed as 3528Nm, as shown in Fig 8. The bending moment is estimated by Equation (8):

$$M_{bending} = (D_{rim} + d) \times F_{\sup port} \times S \qquad (8)$$

where the diameter of the rim(48.26cm), d refers to the displacement(0.02m) in radial direction under bending moment, the support load(4696N) which has been justified in Equation (4) and S is the test factor(1.6) of bending moment for steel wheel rim.

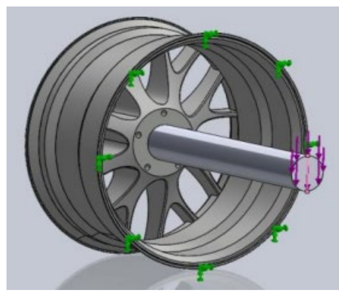
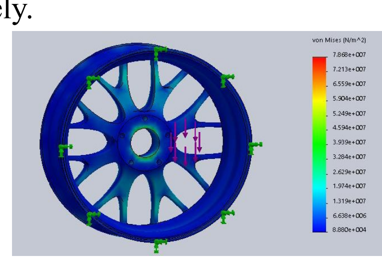
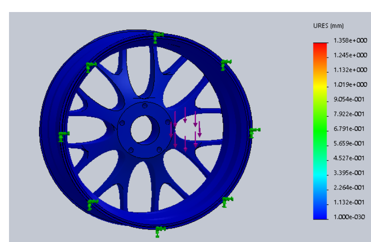


Fig 8: Basic set up of bending test

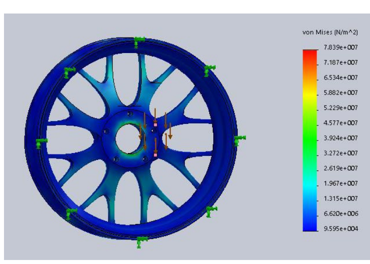
The displacement and miles obtained from the simulation and calculation results are shown in Fig 9 (the axle has been hidden). The maximum stress position of Al alloy hub is that the back cavity spoke near the bolt hole, the maximum stress value is 78.68MPa, and the maximum stress position of Mg alloy hub is that the back cavity spoke near the bolt hole, the maximum value is 78.39MPa. The displacement of Al alloy and Mg alloy are 1.358mm and 1.533mm respectively.



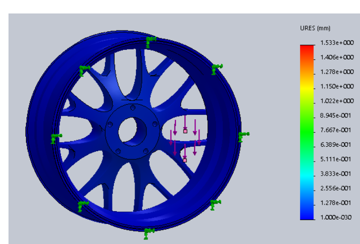
von Mises Al alloy rim



URES Al alloy rim



von Mises Mg alloy rim



URES Mg alloy rim

Fig 9: Von Mises stress and URES

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## III. DISCUSSIONS

Maximum stress and displacement values under radial and bending loads are shown in TABLE II. By comparing the analysis results of the two materials, the maximum stress of bending load is greater than that of radial load, and the maximum displacement caused by bending is greater than that of radial load [9]. Meanwhile, in the radial loading test and bending test, the maximum stress applied to the Al and Mg are almost same. But the displacement of Mg in both test are more significant than Al [9]. According to the property comparison of the two materials, because the elastic modulus of Al is larger than that of magnesium alloy, so the vibration of Al is smaller than that of Mg [19].

**TABLE II. The outputs of two tests**

| Material name | Type of test | Max stress/Mpa | Max displacement/mm |
|---|---|---|---|
| Al alloy 6061-T6 | Radial loading | 64.09 | 0.578 |
| | Bending | 78.68 | 1.358 |
| Mg alloy ZK60A-T6 | Radial loading | 64.11 | 0.89 |
| | Bending | 78.39 | 1.533 |

The results show that the properties of aluminum alloy are better than that of magnesium alloy. However, considering the environmental protection, cost and safety and other factors, because of the high frequency using of automobile rims, impact and fatigue tests should be carried out in the follow-up [20], and more superior materials should be considered to replace the traditional materials.

## IV. CONCLUSIONS

In this paper, firstly, the stress theoretical analysis of rim is carried out, and the model of rim is established in SolidWorks; Secondly, two kinds of lightweight materials (magnesium and aluminum) were selected to analyze the radial and bending load of the hub, and the model analysis was carried out, by comparing the results of the analysis, it can be concluded that the two kinds of light material hubs can meet the strength requirements.

(1) Under the action of radial load, the maximum stress of Al alloy hub is located at the junction of the two sides of the back cavity spokes near the rim, the maximum stress value is 64.09MPa, the maximum stress of Mg alloy hub is located at the hub center, the maximum stress value is 64.11MPa.

(2) Under the action of bending load, the maximum stress position of Al alloy hub is that the back cavity spoke near the bolt hole, the maximum stress value is 78.68MPa, and the maximum stress position of Mg alloy hub is that the back cavity spoke near the bolt hole, the maximum value is 78.39MPa.

(3) The maximum deformation of Al alloy wheel hub is 1.358mm, and that of Mg alloy wheel hub is 1.533mm, which meets the requirements of rigidity and strength of wheel hub.

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If considering the influence of radial loading test, Al has advantages, while in bending test, the stress of Al is bigger than that of Mg, and the displacement of Al is smaller than that of Mg.

## V. CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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