Advanced Materials Research Vols 69-70 (2009) pp 631-635 *Online: 2009-05-05*

doi:10.4028/www.scientific.net/AMR.69-70.631

Magnesium Alloy Material Substitution Redesign Method for Wheels of Electric Bicycle

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Keywords: Magnesium Alloy, Wheel, Redesign

Abstract. For the excellent characters such as lightweight, high ratio-strength, high rigidity and reuse, magnesium alloy is used widely in vehicle lightweight redesign. Selecting AM60B as material, the process of magnesium alloy material substitution redesign for wheels of electric bicycle is advanced. The structure of aluminum alloy wheel is chosen as prototype structure for magnesium alloy wheel according to the similarity between the properties of aluminum alloy and magnesium alloy. The structure redesign optimized parametric model is put forward by the stimulation analysis of static load test and dynamic bending fatigue test. The inspection of samples shows that the structure redesign is feasible, and the target of wheels lightweight redesign is achieved.

Introduction

Wheels play an important role when the electric bicycle is running, whether the electric bicycle is in security, stability, balanced status depending on the wheels. Wheels also make a notable impact on the energy consumption and lifetime of tyre[1]. Magnesium alloy has a series of particularly properties, and applied in many kinds of industry, especially in automobile, motorcycle and information industry. The research on wheels is to reduce the weight based on the demand of strength and rigidity, and also to promote the economization and balance-stability of the whole vehicle [2].

The traditional product design approaches with material substitution show as follows: "Design → Trial-Manufacture → Test → Improving Design →Trial-Manufacture again→Test again→ Improving again [3]", and it is a process that should be done round and round. Selecting wheels of electric bicycle as object, aluminum alloy wheel structure is chosen as research prototype, and the structure of magnesium alloy wheel is optimized by simulation and analysis using FEM analysis tools.

Redesign Process of Magnesium Alloy Material Substitution for Wheels of Electric Bicycle

With the well toughness and plasticity, AM60B magnesium alloy is fit to be applied in the situation of the demand for the impactive loading and high safety. AM60B magnesium alloy is chosen as the new material for substitution redesign. The tensile strength and the yield point of magnesium alloy are much lower than steel, just a little lower than aluminum alloy [2]. Due to the similarity of mechanical property between magnesium alloy and aluminum alloy, on the assumption that the structure of aluminum alloy wheel can satisfy the requirement of strength, it is chosen as the prototype structure of magnesium alloy wheel, and material substitution redesign is carried out. Redesign process of magnesium alloy material substitution for electric bicycle wheel includes 6 steps:

Step 1: The structure of aluminum alloy wheel is chosen as redesign prototype structure of magnesium alloy material substitution.

Step 2: 3D geometric model of magnesium alloy wheel is constructed.

Step 3: Static loading test simulation and dynamic bending fatigue test simulation for magnesium alloy wheel are carried out.

Step 4: If the results are not satisfied during the strength checking, the structure parameters of magnesium alloy wheel should be redesigned, return to step 2.

Step 5: If the results are satisfied during the strength checking, then move into developing the forming technology optimization design of magnesium alloy wheel, then trial- manufacture.

Step6: The magnesium alloy wheel samples are checked. The design is finished if the results are ok, or returns to step 2.

Structure redesign of Magnesium Alloy Material Substitution for Wheels of Electric Bicycle

Dynamic Bending Fatigue Test Simulation for Wheels of Electric Bicycle. The geometric shape of wheel is relatively complicated which induces the analysis of force is difficult. Stress concentration of wheel brings stress higher in some areas. It has proved that the fatigue failure occurs in these areas[4]. In running of electric bicycle , wheels bear varietis of alternating load. Wheels receive radial load from the ground when the vehicle is running straight. During the vehicle turning, it receives centrifugal effect and brings wheel a bending moments. While the vehicle is to start, brake, accelerate and deceleration, wheels stand the torsion moment , etc. [5]. It is bending fatigue and radial fatigue mainly that causes the fatigue failure of wheel. A large number of facts show that the rates of bending fatigue failure is larger than radial fatigue failure [6]. The test is that sets up a finite element model according bending fatigue experiment and analyses high stress areas and the numeric value of the wheel . Then the numeric value is checked by strength principles.

Dynamic bending fatigue test of wheels of magnesium alloy material and of aluminum alloy have been simulated respectively for their same structure, then will analyses the results of them.Their stress distribution are showed as follow Fig.1 and Fig.2.

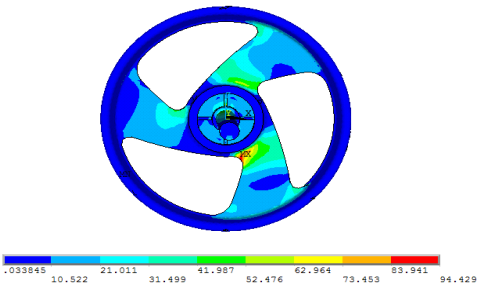


Fig.1 Stress distribution of electric bicycle wheel by A356

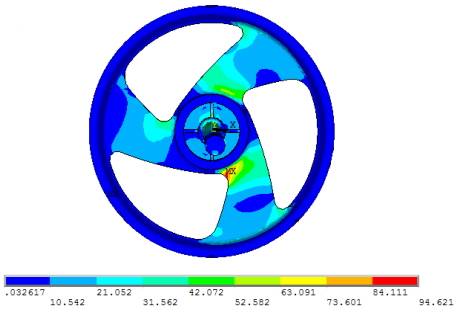


Fig.2 Stress distribution of electric bicycle wheel by AM60B

In order to analyse further the states of stress which the aluminum alloy wheel and magnesium alloy wheel are under the moment, a graph about the change of stress in local which the value is maximum in a cycle is drawn . From the curves in the Fig.3, it can be seen that the trend of stress change is similar between these two materials. Therefore, if the strength of magnesium alloy wheels meet the strength conditions after checking through ,the structure of magnesium alloy wheel can be designed based on aluminum alloy structure model.

It can be seen from Fig.3 that the point in maximum stress of wheel in the rotation is subject to non-symmetrical cyclic stress and maximum stress occurred at the corner of 180° position. The biggest of alternating stress appears in this position in the process of wheel rotation. The phenomenon about failure and fracture will occur earlier in the point of maximum stress. This point determines the life of wheels[7]. Therefore, in order to determine the magnesium alloy wheels strength performance, the stress of maximum value is be checked by he strength criterion. Taking into account the impact about a variety of accidental or difficulty to accurately analyze, the factor of safety is considered. Strength criterion express as follows:

$$\sigma \le \frac{\sigma_{-1}}{S} \tag{1}$$

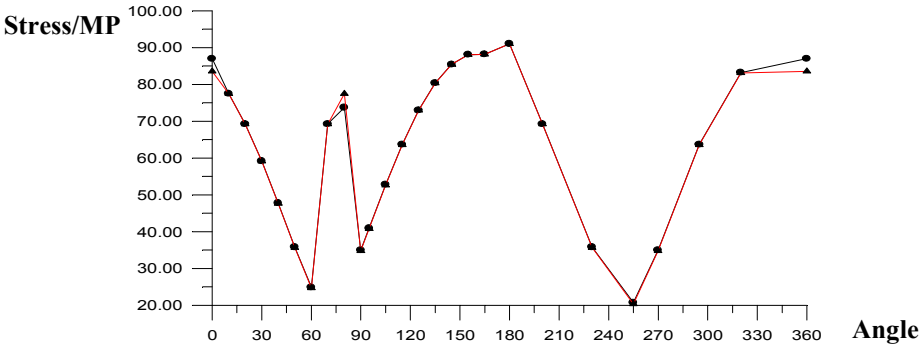


Fig.3 Stress value of Mg-Al at the point 9154

As the aluminum alloy wheels have been widely applied and the strength performance is ideal, the structure of aluminum alloy wheels should be safe and reliable during normal driving life. It can be made using the safety factor to check bending fatigue strength of magnesium alloy wheels. It takes estimation method to calculate the bending fatigue limit σ_{-1} of wheel about these two materials . Its estimation formula express as follows [8]:

$$\sigma_{-1} = f\sigma_b \tag{2}$$

f: fatigue ratio, the recommended data is 0.44[9]

Aluminum alloy：σ_{-1} =115.28 MPa， Magnesium alloy：σ_{-1} =99 MPa

According to the formula (2)**, t**he safety factor of aluminum alloy wheels can be caculated. The value is about 1.27. Then the strength of magnesium alloy wheel to be checked according to the coefficient.

$$91.002 \le \frac{\sigma_{-1}}{S} = \frac{99}{1.27} = 77.95 \tag{3}$$

Obviously, the structure for magnesium alloy wheel based on the aluminum alloy wheel is not meet the requirements of the dynamic bending fatigue strength. so the structure of magnesium alloy wheel should be redesigned.

Redesign of the Wheel Structure. Wheels of magnesium alloy are formed in die-casting filling process in the project. So increasing arc methods are adopted to improve the design of wheel structure. Spoke is the major region of the stress concentration. So change the spokes sizes then analysis the stress distribution. Fig.4 shows the arc structural parameters of the spokes, and Table 1. shows the spokes arc structural parameters redesign schemes and simulation analysis result.

Scheme 1 and Scheme 2 are based on the Scheme 0. Increasing the R1, R2, R3 at the same time, results show that the stress at the location 2 is decreased as the R2 increased, at the location 1, it is increased after firstly decreased, and the stress at the location 3 is increased as the R3 is increased. Compared with Scheme 0, in three arc location maximum stress values are all declined, but the law is not clear. And these two schemes are unable to satisfy the strength requirements. As is shown in Fig.5, with the R1, R2, R3 value increased, the width of spokes gradually reduced, the width of local areas, also narrowed. It can be seen that increased maximum stress results from the reducing of the width of spokes. Therefore it can not reduce the maximum stress only by increasing spoke's radius without changing other parameters.

Scheme 3 and Scheme 4 analysis the wheel's stress distribution when increasing the width of spokes and R2, R3 at the same time. Result shows that maximum stress and stress at the R2, R3 arc location are all declined by increasing the width of spoke and R2, R3 simultaneously, but not obviously.

Compared Scheme 4 with Scheme 5, all the stress values decreased obviously by increasing R1 and decreasing R4, from Fig.5, it can be seen that the stress concentration region become smaller.

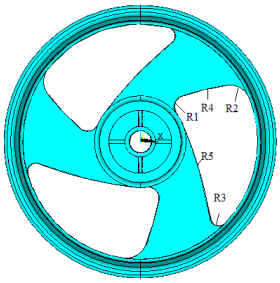


Fig.4 Spokes arc parameters of the electric vehicle wheel

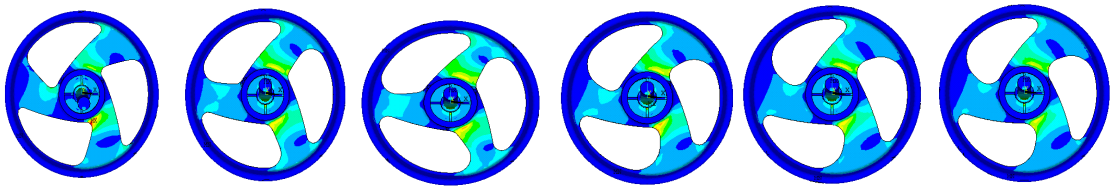
Table 1 Spokes arc structural parameters redesign schemes and simulation analysis result

Scheme	R1/mm	R2/mm	R3/mm	R4/mm	R5/mm	Stress/MPa			
						1	2	3	Max
0	13.2	25	10	334.9	471.7	91.002	67.504	24.732	91.002
1	16	27	13	334.9	471.7	62.2154	25.484	25.8968	80.23
2	20	30	16	334.9	471.7	68.212	25.302	31.431	82.069
3	16	35	13	334.9	471.7	68.798	25.095	21.517	83.000
4	16	45	15	334.9	471.7	74.546	24.443	19.945	82.986
5	25	45	13	324.9	471.7	62.405	20.242	18.679	80.881
6	25	45	13	324.9	350	62.932	20.161	16.942	80.881

Note: "0" is the original scheme

Compared Scheme 6 with Scheme 5, the value of stress does not change obviously. Comparing these two situations in Fig.5, the area of stress concentration in the Scheme 6 is relatively small, but the change are not very obvious. Totally, the stress of wheels has not much relationship with the change of R5.

From the analysis of the Scheme 3, 4, 5, 6, it can be concluded that when the width of spoke is increased, then the stress concentration of the wheels change furthest by decreasing R4, but only a little change by decreasing R5. If the other three values are increased, while R4 is decreased, then the local stress value is decreased.



Scheme 0 Scheme 1 Scheme 2 Scheme 4 Scheme 5 Scheme 6

Fig.5 Dynamic bending fatigue stress distribution of the wheel spoke arc structure parameters redesign scheme

It can be concluded that to reduce the maximum stress about magnesium alloy wheel of electric bicycle, two sides of spoke structure must be improved. One is increasing the width of spoke, the other is changing the arc radius of spoke. While increasing the width of spoke, it should be ensured that local place mustn't too narrow. From the analysis result, it can seen clearly that the changes of R2, R4 influent the total stress mostly. So when these two parameters are fixed, it would be gotten an ideal

structure of wheel by increasing R1 and R3 properly. In this way, the optimized parameters of spoke arc for wheel structure redesign is received.The value is R1=24.45mm, R2=13mm, R3=13mm，R4=307.5mm and the value of R5 is still.Through the analysis of wheel bending fatigue experiment simulation, the stress of wheel is improved obviously and the max value of stress is also decreased to 65.612Mpa. The stress is also decreased in the other thress locations and the values are 24.1MPa,8.3Mpa and 4.68Mpa in the position of 1,2,3. In addition, the stress distribution in wheels becomes symmetric, as is shown in Fig.6.

The strength is checked in order to verify whether the structural strength is to meet the strength condition, the result is as follows:

$$65.612 \le \frac{\sigma_{-1}}{S} = \frac{99}{1.27} = 77.95 \tag{4}$$

From the result, the strength of the structure is to meet the requirements. The quality of being improved magnesium alloy wheel is 1.436kg while the quality of aluminum alloy wheel is 2.007kg. The weight is decreased nearly 0.6kg, reaching 29.9%. The purpose of lightweight is achieved.

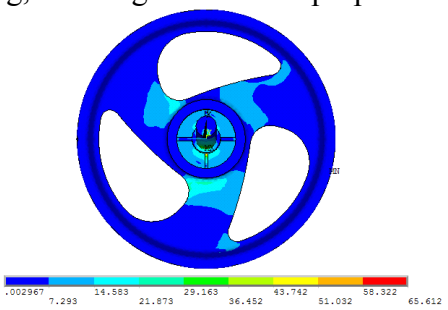


Fig.6 Dynamic bending fatigue stress distribution (after improvement)

Summary

AM60B magnesium alloy has been selected as the new materials in the process of material substitution redesign. The structure of aluminum alloy wheel is chosen as prototype structure for magnesium alloy wheel according to the similarity between the properties of aluminum alloy and magnesium alloy. The structure redesign optimized parametric model is put forward by the stimulation analysis of static load test and dynamic bending fatigue test.Weight of the model is decreased approximately 30% throught substituting material. The aim with lightweight redesign of wheel is achieved. In this project, the samples of magnesium alloy material for wheels of electric bicycle have been produced,and these samples reach the standard requirement by checking.

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Ultra-Precision Machining Technologies, CJICUPM2008
10.4028/www.scientific.net/AMR.69-70

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