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A Study on Structural Fatigue Durability of Automotive Wheel at Driving

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Abstract

The wheels cause mainly fatigue fractures in the situations of applying the random loads. Also, the wheels must pass, without fail, many kinds of performance tests before being used. The fatigue experiments are very important tests among the many kinds of performance tests. In this research, the fatigue tests were realized regarding the wheels through simulations. And, through the fatigue lifetime predictions according to the stresses of the three kinds of aluminum alloy wheels, the stabilities and the strengths of the aluminum wheels were analyzed. With regard to the analysis results, Type 1 showed the most fatigue lifetime and they were in the order of Type 2 and Type 3. Regarding the maximum frequency of the amplitude stress and the average stress and with regard to the Type 1 model, we were able to see that the section of the stress condition in which the frequency occurs was small, thereby being the most stable regarding the fatigue load. And it shows the instability because the section of the stress condition gets larger in the order of the Type 2 model and the Type 3 model. Also, although the Type 1 model is the most stable regarding fatigue, a 1.96% damage possibility is shown in the neighborhood of 300MPa of average stress and 200MPa. Thereby, it is possible to predict that, regarding the Type 1 model, the probability of damage is high in such a stress condition.

Keywords: Amplitude Stress, Average Stress, Fatigue Fracture, Fatigue Life, Wheel

1. Introduction

Recently, with the problem of the safety of the means of transportation getting big, a lot of the developments have been taking place not only with regard to the designs but also the engines and the other, particular parts. Generally, with regard to the strength, there are a lot of the cases in which the damages occur to the interior structures of the machines designed with sufficient room. The destructions take place well at the low stresses that are much lower than the yield stresses. As a result, the many kinds of the researches for investigating this have been taking place with wide range. And, with regard to these, the many kinds of the researches using the fracture mechanics and the statistical methods have been announced[1–3]. With regard to the automobiles and structures, in order to investigate the fatigues and the destructions, the researches on the fatigue cracks, the compressive residual stresses, the optimization designs, etc. have been proceeding vigorously. In this research, the wheels receiving the fluctuating fatigue load that can be easily seen on site were simulated. And the safety and the lifetime relations of the raw materials were interpreted. These wheels are the most important for cars to run. They must be very safe because they are related to life. Because a big accident can take place by being in the situation of the tires ripping due to damage to a wheel, the wheel must have good strength and the durability must be good to avoid damages[4–10]. Due to the continued rotational motions, the wheels of automobiles receive repetitive stresses. And, if this period becomes long-term, a fatigue fracture can take place. But, despite the fact that, generally, cars are run for over 10 years if long, there are even the majority of the people who do not change the wheels until the fatigue durability analyses of the wheels, by kind, of the automobiles to be scrapped. When the car runs, the repetitive stress received by the wheel becomes over millions of times. As such, it is only when the fatigue crack does not take place until this time that the role of

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the wheel can be played functionally and the safety of the driver can be assured[11–12]. As a result, mainly the fatigue cracks of the wheels occur in the situation of applying the random loads. Also, before being used, the wheels must pass many kinds of performance tests without fail. The fatigue experiment is a very important test among the many performance tests. In this research, the fatigue tests regarding the wheels were materialized through simulations. And, through the prediction of the fatigue lifetimes according to the stresses of the three kinds of the aluminum alloy wheels, the stabilities and the strengths of the aluminum wheels were analyzed. The automobile wheels were modeled by using the CATIA. After this, the fatigue analyses were conducted based on the stress values according to the results of the structural analyses of the aluminum alloy wheels by using the ANSYS.

2. The Study Methods

2.1 The Study Models

In this study, a total of three types of wheels were designed. A hole was made in the wheel in the cylindrical shape. After drawing one kind of form inside, the form was arranged in the original form. As in the (a), (b) and (c) of Figure 1, the following appeared: Type 1- The wheel of the starfish shape, Type 2- The wheel of the shape of having many circular axles and Type 3- The wheel which has rotated the axis in the curve form. The structural and fatigue analyses according to the total of the 3 kinds of forms were carried out. And Table 1 shows the numbers of the joints and the elements of the models of this research.

(a) Type 1 (b) Type 2 (c) Type 3

Figure 1. (a), (b), (c) Automative wheels.

Table 1. Property of Material

	Type 1	Type 2	Type 3
Nodes	64270	38552	38765
Elements	38825	21250	21306

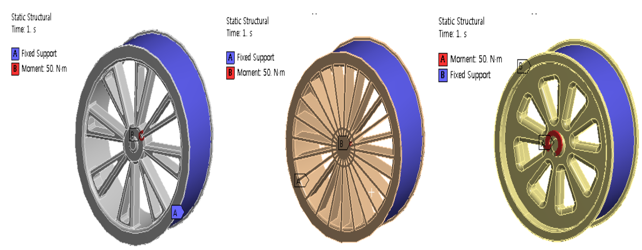
2.2 The Analysis Conditions

Figure 2 consists of the pictures that show the fixing conditions and the loading conditions regarding each of the models in relation to Type 1, Type 2, and Type 3. As in Figure 2, the wheels were fixed. The moments were exerted on the parts that connect the wheels and the axes, 50Nm was made active. The structural analysis was carried out. And the equivalent stresses and the total displacements were examined. Also, aluminum alloys were used for the material of the wheels. Such material properties are shown in Table 2.

3. The Results of the Analysis

3.1 The Results of the Static Analysis

As in Figure 3 and Figure 4, as a result of performing the structural analysis regarding the models of the wheels,

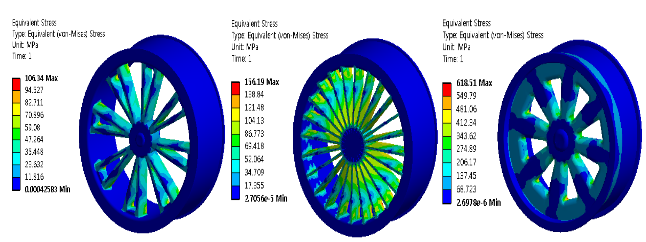


(a) Type 1 (b) Type 2 (c) Type 3

Figure 2. (a), (b), (c) Fixing Conditions and the Loading conditions of Automative wheels.

Table 2. Property of Aluminium Alloy

Density(kg/m³)	2770
Young's Modulus (GPa)	71
Poisson's Ratio	0.33
Tensile yield strength (MPa)	280
Compressive yield strength (MPa)	280
Tensile ultimate strength (MPa)	310



(a) Type 1 (b) Type 2 (c) Type 3

Figure 3. (a), (b), (c) Contours of equivalent stresses.

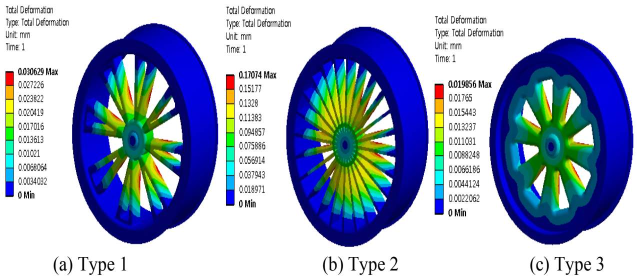


Figure 4. (a), (b), (c) Contours of total deformations.

each of the maximum equivalent stresses regarding Type 1, Type 2, and Type 3 were 106.34MPa, 156.19MPa, and 618.51Mpa, respectively. Also, each of the total displacements of Type 1, Type 2 and Type 3 was 0.0030629 mm, 0.17074 mm and 0.019856 mm. The equivalent stress of Type 1 was the lowest. And by taking a look at the contour picture of the equivalent stress of Type 3, we were able to confirm that, although most of the equivalent stresses were smaller than the yield stresses, the equivalent stress of the small part was bigger than the yield stress and was damaged. Also, in all of the Type 1, Type 2 and Type 3, the maximum amount of transformation was generated in the middle of the spoke.

3.2 The Results of the Fatigue Analysis

Figure 5 is a graph that shows the stress amplitude which becomes a fracture limitation due to the fatigues regarding the aluminum raw materials according to the fatigue cycles that have passed. It shows the stress amplitude according to the fatigue cycles that have passed according to the stress ratios which are the ratios of the minimum stress regarding the maximum stresses. The fatigues that

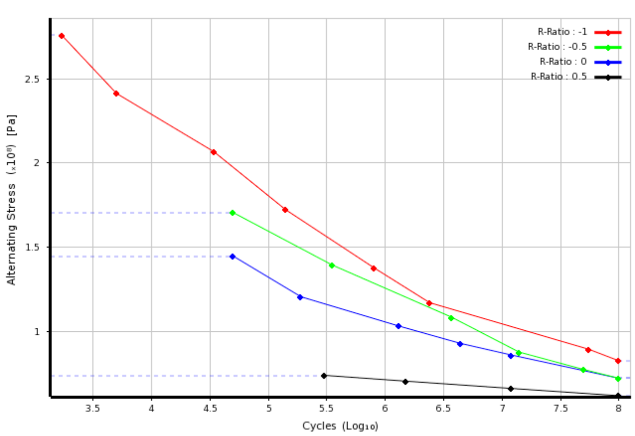


Figure 5. S-N curve in fatigue.

are received by the wheels when the automobiles are actually running are countless.

As in Figure 6, the changes of the loads that can be actually received are 'SAE Transmissions', which are the breakdown of the irregular amplitude loads. The three kinds of the models of Type 1, Type 2 and Type 3 were compared. It shows the changes of the average loads of the periodical fatigue loads that change irregularly in one cycle. The average load in Figure 6 is the same as the load in Figure 2.

Figure 7 consists of the contours of the fatigue lifetimes regarding the models of Type 1, Type 2 and Type 3. It shows the lifespan that can be used according to the types of the wheels. As for the fatigue lifetime, Type 1 showed the most and Type 2 and Type 3 came next in order. Figure 8 is fatigue damage in the contour form. It has divided the design life by the usage-possible life. As in the case of Figure 7, which is on the fatigue life time, the fatigue damage was the smallest in Type 1 and next came Type 2 and

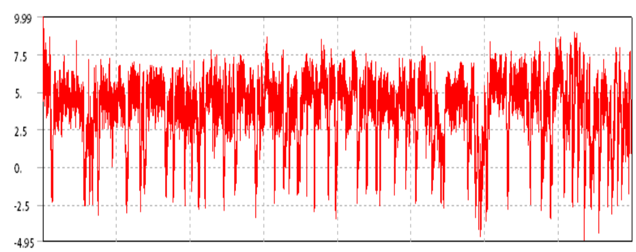


Figure 6. History of SAE transmission.

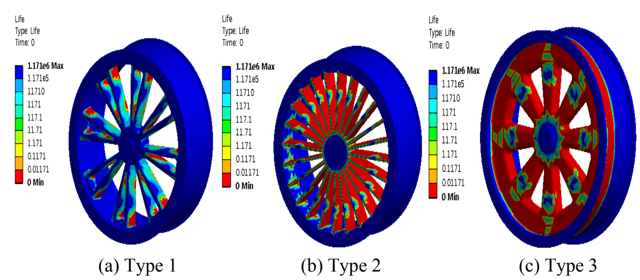


Figure 7. Contours of fatigue lives.

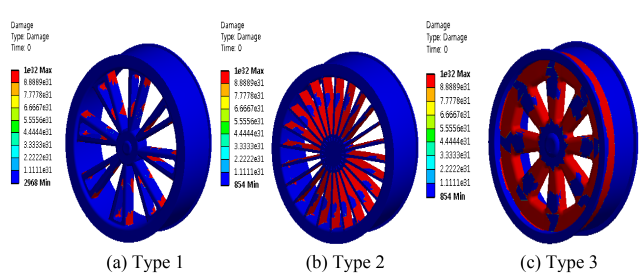
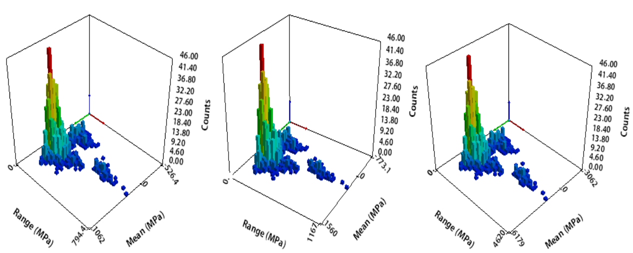


Figure 8. Contours of fatigue damages.

Type 3 in that order. As such, we were able to see that the fracture and progressed considerably in the case of Type 3.

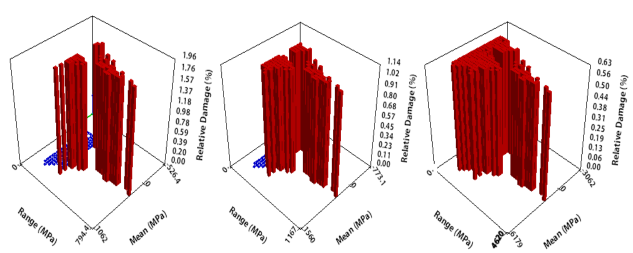
Figure 9 is drawn as the frequency numbers regarding the stress amplitude and the average stress. The z axis pertains to the given stress range and the frequency regarding the average stress. The maximum frequency of the three types of the models is around 46. Except, the average stress range of Type 1 was from −526.4MPa to 1062MPa. The stress amplitude range was from 0MPa to 794.4MPa. The average stress was in the vicinity of 300MPa. The maximum frequency appeared in the vicinity of 100MPa of the stress amplitude. The average stress range of Type 2 was from −773.1MPa to 1560MPa. The stress amplitude range was from 0MPa to 1167MPa. The average stress was in the vicinity of 400MPa. The maximum frequency appeared in the vicinity of 180MPa. The average stress range of Type 3 was from -3062MPa to 6179MPa. The stress amplitude range was from 0MPa to 4620MPa. The average stress was in the neighbourhood of 2000MPa. And the maximum frequency appeared in the neighborhood of 700MPa of stress amplitude. We can see that the Type 1 model is the most stable because the section of the stress condition in which the frequency takes place is much smaller. And the instability is shown because the sections of the stress conditions get larger in the order of the models of Type 2 and Type 3.

Figure 10 consists of the drawings regarding the damage matrices in the critical positions regarding the



(a) Type 1 (b) Type 2 (c) Type 3

Figure 9. Plots of rainflow matrices.



(a)Type 1 (b) Type 2 (c) Type 3

Figure 10. Plots of damage matrices.

damages in the three Types of models. It applies only to the irregular amplitude loads. It shows the relative damage possibilities regarding the limitless lifespans of the 10^9 cycles. Looking at the Figure 10, Type 1 is a case in which, as for the relative damages, the average stress is 300MPa and the stress amplitude is 200MPa. And the range of the maximum relative damages is shown as being about 1.96%. Type 2 is a case in which, with regard to the relative damages, the average stress is 400MPa and the stress amplitude is 300MPa. It shows the range of the maximum relative damages as being about 1.14%. Type 3 is a case in which, with regard to the relative damages, the average stress is 2000MPa and the stress amplitude is 400MPa. It shows the range of the maximum relative damages at about 0.63%. It can be predicted that, through these results, there is a lot of the possibility of the damages in such stress conditions regarding the three types.

4. Conclusion

The prediction of the fatigue lifetimes according to the stresses of the three kinds of the aluminum alloy wheels, the stabilities and the strengths of the aluminum wheels were analyzed in this study as follows;

The maximum equivalent stresses of each of the Type 1, Type 2 and Type 3 were 106.34MPa, 156.19MPa and 618.51MPa. And each of the total displacements of Type 1, Type 2 and Type 3 were 0.0030629mm, 0.17074mm, and 0.019856mm. The equivalent stress of Type 1 was the lowest. And we were able to confirm that, with regard to Type 1, Type 2 and Type 3, all of them generated the maximum amounts of transformations in the middle of the spoke.

As for the fatigue life time, Type 1 showed the most and next came Type 2 and Type 3 in that order. Regarding the maximum frequency related to the stress amplitude and the average stress, with regard to the Type 1 model, the section in the stress condition in which the frequency takes place was very small. As such, we were able to see that the fatigue load was the most stable. Because the sections of the stress conditions get large in the order of the models of Type 2 and type in that order, the instability is shown.

Although the Type 1 model is the most stable regarding fatigue, it shows the damage possibility of 1.96% in the vicinity of 300MPa of the average stress and in the vicinity of 200MPa of the stress range. As such, with regard to the Type 1 model, it can be predicted that there is much possibility of damage in such a stress condition. It is thought that, if the results of this research are aggregated and applied to the wheels of actually running automobiles, the utilizations would be great in examining and predicting the preventions of the fatigue damages and the durabilities.

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