Weight reduction of automobile wheel using topology optimization and 3-D printing production

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ABSTRACT

Recently, environmental regulations for automobiles have been strengthened and the reduction of weight for automobiles is regarded as a crucial research area for solving the air pollution problem as well as saving the energy. In the past, the research for vehicle weight reduction was mainly focused on the material of the parts rather than the design optimization due to the limitations of the production process. However, more research has been recently carried out on the optimized design that overcomes the limitations of the production process by employing the additive manufacturing. In this study, the conventional wheel for automobile is redesigned through the topology optimization and it is manufactured using 3-D printer instead of casting. By redesigning the wheel, the equivalent mechanical stiffness can be maintained and the weight can be reduced. The reduction of weight for automobile parts achieved through the topology optimization and 3-D printing production technology has the potential to be utilized not only in the automobile industry but also in various industries such as portable device and the aerospace industry.

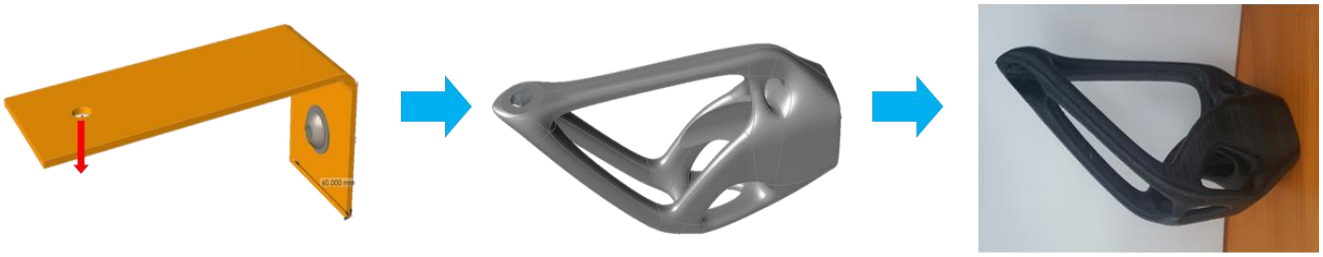
1. INTRODUCTION

Topology optimization represents a class of computational methods for designing weight reduction and high performance structures. However, since the topology optimized shape of parts is complex and it is expensive to manufacture optimized parts, it is not suitable for mass production. Therefore, the topology optimization theory is generally used as a reference shape during designing the component. Recently, the research has been conducted on the integration topology optimization and additive manufacturing in many industries. It is due to topology optimization and additive manufacturing are well suited for each other. Additive manufacturing is manufacturing processes for fabricating parts by adding materials. The growing interest in additive manufacturing stems from its ability to fabricate highly complex parts. Although topology optimization and additive manufacturing have flourished independent of each other, there is significant interest today in integrating them. Figure 1 (a), for example, illustrates a structural design problem that is optimized through topology optimization (Figure 1 (b)), and then fabricated using additive manufacturing (Figure 1 (c)).

From the standpoint of preventing environmental pollution and saving energy, reduction of weight for automobiles is a significant research area. Furthermore, vehicle weight reduction is becoming more important in order to increase the fuel efficiency of electric vehicles and hydrogen fuel cell vehicles. Among the various components of automobiles, weight reduction of wheels is important because the light wheel improves the riding comfort and performance of the automobile. Moreover, the stiffness of the wheel is also important. High stiffness wheels have high durability against road shock and reduce the risk of tires peeling off. Therefore, the objective of this paper is to design the optimized wheel which have a high stiffness and light weigh using topology optimization and additive manufacturing.

2. TOPOLOGY OPTIMIZATION

Topology optimization is used for light-weight, high stiffness, high strength, and safety design. It is a method of setting the mass or stiffness as the objective function and deriving the optimal layout by using the shape density (material density) under the constraint conditions. In this study, in order to design the optimized wheel, the topology optimization was conducted to maximize stiffness on the reference wheel model under the three step weight reduction. (Equivalent, 10 %, and 20 % weight reduction). The topology optimization was done by commercialized software (Altair, INSPIRE 2017).



(a) (b) (c)

Figure 1. (a) Structural problem, (b) Topology optimized design, (c) Additive manufactured part

2.1. Wheel specification & Modeling

The conventional wheel shape was selected for optimization as shown in Figure 2 and its specifications are summarized in Table 1. The modeling of the wheel was done by modeling software (Dassault systems, CATIA V5R19). The aluminum alloy (LM25 alloy) was used as the material of wheel. The alloy mainly consists of 6.5~7.0 % Si, 0.3~0.4 % Mg and aluminum. The mechanical properties of LM25 alloy are summarized in Table 2.

Figure 2. Reference wheel model

Table 1. Specifications of original wheel model

Specifications	Measurements (mm)
Rim diameter	374
Rim width	178
Offset	55
PCD	110
Hub diameter	53

Table 2. Material properties of LM25 aluminum alloy

Material properties	Magnitude with units
Tensile Stress	230 Mpa
Endurance Limit	56 Mpa
Modulus of Elasticity	71 Gpa
Poisson's ration	0.33
Density	2.685 g/cm^3

2.2. Constraint conditions for topology optimization

A force of 2800 N was applied at a point 600 mm away from the center point of the spokes and the load was restrained at the holes of the bolt and the circumferential area was set as the support part as shown in Figure 3. When conducting the optimization, the minimum thickness of the optimized shape was set as 1.8 mm. The design space is the area which the topology optimization is carried out. In order to prevent the functional problem of the part, the design space should be carefully selected. In this study, the design space was selected except for circumferential area of rim where the tire is assembled and the center of spoke where the drive shaft is assembled as shown in Figure 4(a). In addition, the symmetry condition was set to make the shape of wheel spoke as shown in Figure 4(b).

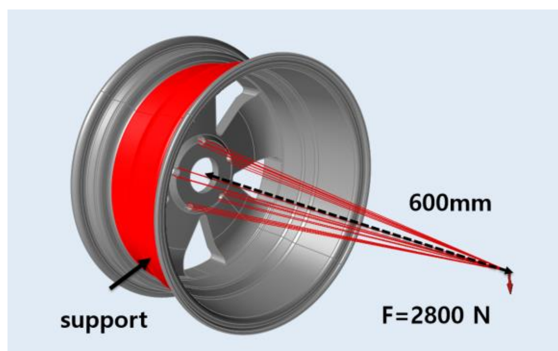
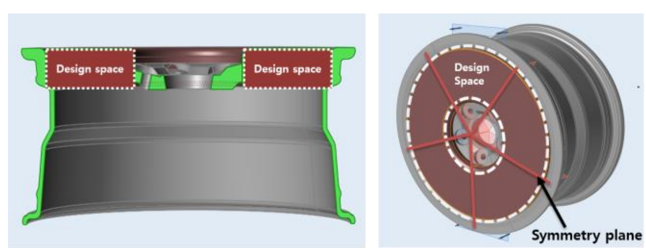


Figure 3. The boundary and loading conditions for topology optimization

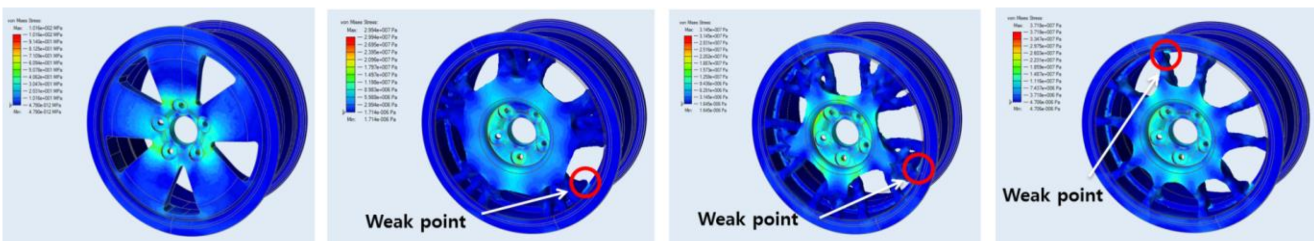


(a) (b)

Figure 4. (a) Design space (b) Symmetry conditions

(a) (b) (c)

Figure 5. The results of topology optimization (a) equivalent mass, (b) 10 % weight reduction and (c) 20 % weight reduction



(a) (b) (c) (d)

Figure 6. The results of von-Mises stress (a) equivalent mass, (b) 10 % weight reduction and (c) 20 % weight reduction

Table 3. The comparison of analysis results.

	Original Model	Optimized model_1 (equivalent mass)	Optimized model_2 (10% weight reduction)	Optimized model_3 (20% weight reduction)
Von-misses stress (Mpa)	49.72	29.94	31.45	37.18
Deformation (mm)	1.60×10^{-2}	1.07×10^{-2}	1.40×10^{-2}	1.52×10^{-2}
Weight (kg)	36.22	36.22	32.76	29.10

3. RESULT & DISCUSSION

The three optimized models were obtained through topology optimization. The shapes of the optimized models are shown in Figure 5. Since the shape is not smooth, it is not suitable for manufacturing. So it is necessary to redesign the surface for manufacturing. In order to evaluate the stiffness of designed wheels, displacement and von-Mises stress are calculated by using numerical calculation. The results of analysis are shown in Figure 6 and summarized in Table 3. Comparing the reference wheel model with optimized models, the von-Mises stress of all models are less than the endurance limit. But optimized models show better performance than reference model. In addition, in the case of the reference model, the maximum von-Mises stress was applied at the center of spokes. But in case of the optimized models, the strength was weakened at the spokes corner and one of them, maximum von-Mises stress was applied at the spokes corner. Hence, it is necessary to redesign the spokes corner in the optimized models to reduce the concentrated stress in this region.

4. CONCLUSIONS

In this study, three optimization models were derived by conducting topology optimization from reference wheel model. The performances of the optimized models were evaluated through analysis of displacement and von-Mises stress using numerical calculation. These results were compared with the reference model. As a result, optimized models with lighter weight and higher stiffness can be redesigned. But it is necessary to verify the simulation through actual experiments. In addition, only one load acting on the holes of wheel is applied as a boundary condition. This can be extended to other forces that act on the wheel rim.

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Dongoh Lee was born in Gwangju, Republic of Korea in 1992. He was graduated in Department of Mechanical Engineering at Konkuk University, Seoul, Republic of Korea. He is a research associate at Reliability based design optimization laboratory of Konkuk University, where his research focuses on additive manufacturing and topology optimization.

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