5th International Conference on Materials and Reliability
Jeju, Korea, Nov. 27-29, 2019

Topology Optimization of a Bicycle Crank Arm with Multiple Load Cases

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1. Introduction

Bicycle is one of the most favorite vehicles around the globe. Topics on bicycle discussions apparently arise not only in transportation and sports but also up to safety behavior and even psychology study [1]. Moreover, since the oil price increases rapidly during past decades, non-fossil fuel vehicle like a bicycle has been influencing people to change their preference from riding a car to ride a bicycle, particularly for low distance trip. From gas emission issue, the South Korean government has been initiating an effort to enforce cycling to slash the country greenhouse emissions based on the report by The Korea Transport Institute (KOTI) [2].

Meanwhile, the lightweight structure becomes one of the biggest issues in the bicycle industry since it relates closely to manufacturing cost. Besides that, a lightweight issue also affects bicycle performance considerably. In terms of the design process, lightweight structure often simply defined by reducing the weight of materials or reducing the geometrical size. This is called a design optimization in which many researchers are also interested.

Recently, topology optimization is a well-known method in the design optimization process as discussed by researchers [3]. It is a very powerful method to reduce the material weight of a design part without losing its best performance. Therefore, this paper presents an application of topology optimization on a bicycle crank arm as an attempt to create a lightweight structure of a bike.

2. Methodology

Model

A model of bike crank arm was made in the ANSYS Workbench 2019 R1 as seen in Figure 1. The model was made based on the typical geometry of commercial bike crank arm. The material for this model was AL 7005 Aluminum Alloy which is standard material for bicycle frame and widely used in practice. The properties of the material are briefly shown in Table 1. From the mesh setting, the model has 29748 Nodes and 17449 elements in total. The initial mass of the model was 0.3004 kg.

A static finite element analysis (FE) was conducted with multiple force of 400 N in various angles from 60° to -60° as seen in Figure 1. These various angles represent the distribution of the load and maximum stress along the pedaling cycle of professional cyclist as investigated by Calvo et al [4] during their experimental study using digital goniometer with an accuracy of 0.1. This force also simultaneously created a moment on the crank arm.

Table 1 Model Properties

Material	Aluminum Alloy
Young's Modulus	71,000 MPa
Poisson's Ratio	0.33
Bulk Modulus	69,608 MPa
Shear Modulus	26,692 MPa

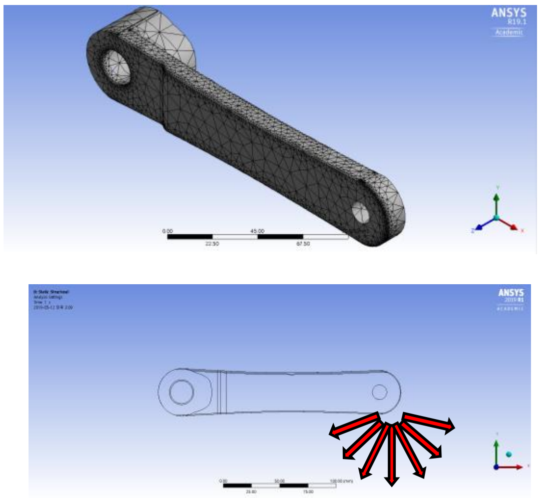

Fig.1 Bicycle crank arm model in ANSYS

Topology Optimization

The objective function for topology optimization with multiple load case is given by the following equation :

$$\min \sum f_i^T u_i \qquad (1)$$

Where *i* indicates the multiple force sequence (*i* = 1, 2, 3…7), *f* is the applied force and *u* is the displacement.

The constraint for this objective function is the retained mass should be 50%. Using ANSYS Workbench 2019 R1 topology optimization, the optimized design was generated using curve fitting in the SpaceClaim software and the final design can be obtained.

3. Optimization Results and Discussions

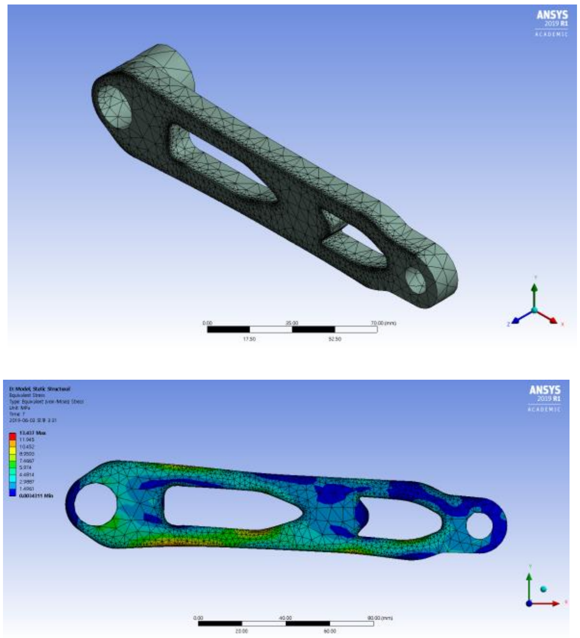

Fig.2 Topology optimization and stress distribution result.

Table 2 Comparison result

Parameter	Original Design	Optimized Design
Mass	0.3004 kg	0.1711 kg
von Misses Stress [Max]	13.849 MPa	13.437 MPa

Figure 2 shows the optimized design of the crank arm from the topology optimization result. It also shows the stress distribution of the crank arm. It clearly shows that the optimization method gives significant mass reduction shown by the presence of holes on the crank arm. The holes surely reduce the initial mass of the crank arm that is seen in Table 2. The total mass reduction is achieved roughly by 0.13 kg from its original mass 0.30 kg turns into 0.17 kg. The mass reduction occurs mainly at the area with low-stress distribution which is the center of the crank arm in this case. This phenomenon is typical with the previous study for thin-walled structures [3].

Meanwhile, from the stress distribution of the optimized design, it is found that the multiple loads give non-symmetrical stress distribution. This is caused by the direction of the multi-forces are mostly in the negative *y*-direction. Additionally, the moment also moves towards the negative *y*-direction. This makes the lower part of the crank arm experiencing higher stress than the upper part. The lower part of the crank arm experiences compression stress while the upper part experience tension stress. From the result, we can see that the compression stress occurs almost throughout the lower part of the crank while the tension stress occurs only up to the middle part of the crank arm.

It can also be seen that the optimized design gives slight differences in von Mises stress compared to the original design. The stress has been reduced from 13.849 to 13.437 MPa. Unlike the previous result from Hu et al [5], the narrowing cross-sectional area does not increase the stress concentration in this case. This can be optimized by setting the maximum von Mises stress constraint in the future.

The experimental study will be carried out to validate this optimized design using strain gauge measurement of the crank arm during rider's wheeling.

Acknowledgment

This work was supported by the National Research Foundation of Korea (NRF) grant (No. NRF-2018R1D1A1B07050370) and the Human Resources Development Program (grant no. 20174010201350) of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grants by the Korea government.

References

[1] B. Höchli, A. Brügger, R. Abegglen, and C. Messner, "Using a goal theoretical perspective to reduce negative and promote positive spillover after a bike-to-work campaign," *Front. Psychol.*, vol. 10, no. MAR, 2019.

[2] H. C. Shin, D. Kim, J. Y. Lee, J. Park, and S. Y. Jeong, *Bicycle Transport Policy in Korea*. 2013.

[3] K. D. Tsavdaridis, E. Efthymiou, A. Adugu, J. A. Hughes, and L. Grekavicius, "Application of structural topology optimisation in aluminum cross-sectional design," *Thin-Walled Struct.*, vol. 139, no. March, pp. 372–388, 2019.

[4] J. A. C. Ramos, C. lvarez-Caldas, A. Quesada, and J. L. S. Román, "Determining the Stress Distribution in a Bicycle Crank Under In-Service Loads," *Exp. Tech.*, vol. 40, no. 2, pp. 885–890, 2016.

[5] Z. Hu, V. K. Gadipudi, and D. R. Salem, "Topology Optimization of Lightweight Lattice Structural Composites Inspired by Cuttlefish Bone," *Appl. Compos. Mater.*, vol. 26, no. 1, pp. 15–27, 2019.