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A Study on the Load and Deformation of Race Carbon Bicycle Frame for Improved Athletic Performance

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경기력 향상을 위한 경주용 탄소 자전거 프레임의 하중과 변형에 관한 연구

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ABSTRACT

As the industry develops and quality of life increases, the concept of leisure is also changing. Bicycling is a healthy sport for exercising while enjoying nature, facilitating the enjoyment of a healthy life. As a result, the awareness surrounding bicycles has increased, and so has the interest in lighter and more luxurious carbon bikes. The number of domestic companies producing carbon bicycles frames is nil. In this study, we analyze the frames of existing foreign brands and analyze the deformation and stress concentration area according to the load of the frame, using the finite element analysis. In addition, we set up the range of stiffness based on the content of the structural analysis, to localize the carbon bicycle frame and famous foreign products, and compare the prototype with the stiffness by using bicycle molds for track races.

Key Words : Bicycle(사이클), Frame Stiffness(프레임 강성), Athletic Performance(경기력), Maximum Power(최대 파워), Maximum Muscular Strength(최대 근력)

1. Introduction

With industrial development and the increase in quality of life, leisure culture is also changing. Cycling is positioned as a healthy sport through which many riders enjoy nature and that promotes long healthy lives. Accordingly, much attention has been paid to bicycles made from lighter and more luxurious carbon materials.[1-3] The role of the bicycle frame is equivalent to that of the vehicle chassis. That is, it can play a role in maximizing the user's ability. In a bicycle frame, pedaling load, vertical load, and horizontal load are applied.

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Accordingly, a bicycle frame should be able to maintain an appropriate level of stiffness. Although much effort has been made to improve the performance of bicycles for a long period of time, it is still in an early phase.[4-8] In particular, major bicycle companies have long attempted to increase stiffness and higher stiffness has been considered to have better efficiency, but no proof has been made about this.[9-10] To date, no companies in Korea have manufactured a track frame for racing made from carbon materials. As a result, studies on maximum muscle strength and maximum power according to the frame stiffness for improvements of race competitiveness have not been conducted.[10-13]

Thus, this study aims to analyze the stiffness of carbon-made frame bicycles from overseas before the maximum muscle strength and maximum power are studied according to stiffness, and conduct analyses and displacement using commercial structural analysis software. In addition, it aims to set the range of stiffness based on the standards of popular overseas products and structurally analyzed results for the localization of carbon-made bicycle frames and fabricate prototypes by a stiffness level using a bicycle mold for track racing and compare them.

2. Research Method

2.1 Measurement method of frame stiffness

The bottom bracket (BB) stiffness measurement method is used to measure the stiffness of bicycle frames. The BB stiffness measurement method measures level of resistance against frames when a pedaling load is applied to the frame. Generally, the higher the number, the better the characteristic of conversion of rider's power to driving force. The BB stiffness measurement is performed as follows: a frame is tilted to 67° and a load is given to the

Table 1 Stiffness measurement result of sample

	Size	Mass (g)	Stiffness (N/mm)
C Inc.	L	1,575	152
I Inc.	M	1,582	185
B Inc.	L	1,724	175

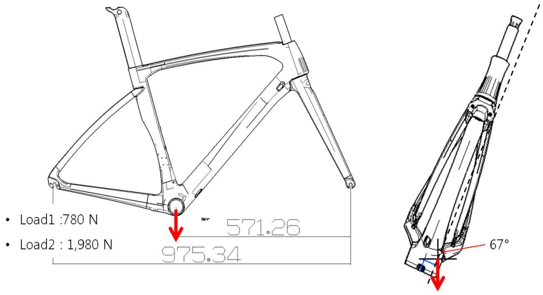

Fig. 1 Stiffness measurement drawing

BB axis while the head tube and rear end are all restrained to measure displacement, thereby calculating the BB stiffness coefficient (k) through

Eq. (1). Distance between the BB center and the weight is fixed to 120 mm.

$$k = \frac{N \times g}{\delta} \, [N/mm] \qquad (1)$$

2.2 Analysis of existing frames

The product of the no. 1 frame manufacturer for cyclists and products of I Inc. and B Inc., two of the renowned brands, were chosen and their stiffness and displacement analyzed. Fig. 1 shows the mimetic diagram of how to measure the BB stiffness of the frames.

Table 1 presents the analysis results.

A frame can be divided into soft, normal, and hard types (by stiffness), fabricated to have 150 - 160 N/mm, 161 - 170 N/mm, and 171 N/mm or higher, respectively.

Table 2 Tensile and flexural test results

	Value
Tensile strength (MPa)	1256.92
Tensile modulus (GPa)	422.22
Flexural strength (MPa)	1464.65
Flexural modulus (GPa)	132.69

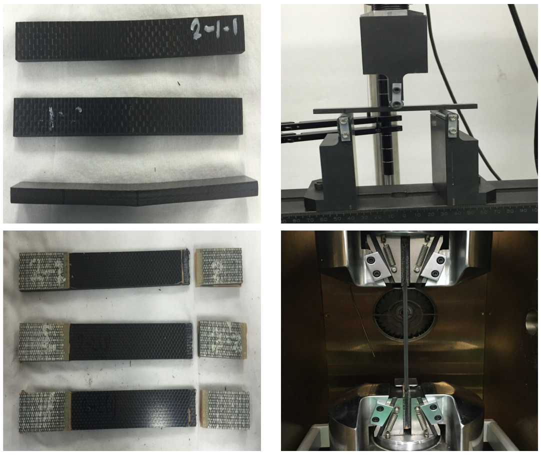

Fig. 2 Test sample and testing machine

2.3 Tension and bending tests of carbon materials

The tension and bending tests were conducted to analyze finite elements and mechanical characteristics of nano carbon, which was the material of the frames. The specimens used in the test were fabricated in accordance with ATTM D790 and ASTM D3039, and tests were conducted through the universal tester. Fig. 2 shows the fabricated sample photo and Table 2 presents the tension and bending test results.

2.4 Finite element analysis of the frame

ANSYS was used to conduct structural analysis to ensure the user's stability through the strain and

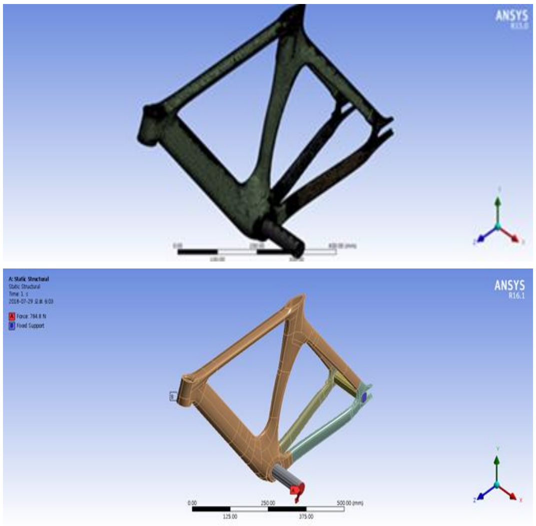

Fig. 3 Mesh and boundary condition

stress analysis of frame's cracks that occurred due to the loads applied during pedaling and through the cyclist's weight and to minimize the weight increase and increase the stiffness through the feedback prior to the product fabrication.

The strain was measured during application of a load in the 67° direction as was done in the frame analysis, and stress-concentration parts were checked to verify the frame's vulnerability. Two loads of 780 N and 1,980 N were applied, and the strains were measured to determine the resultant deformation of the frame.

Fig. 3 shows the frame's mesh and constraints that are analyzed. The number of nodes in the mesh was 1,249,700 and the number of elements was 762,816.

2.5 Finite element analysis results

The maximum strain of the frame when the 780 N load was applied was 3.57 mm, and the maximum stress was 193.21 MPa. The stress concentration part was a rear end, by which the safety was sufficiently ensured considering the tension

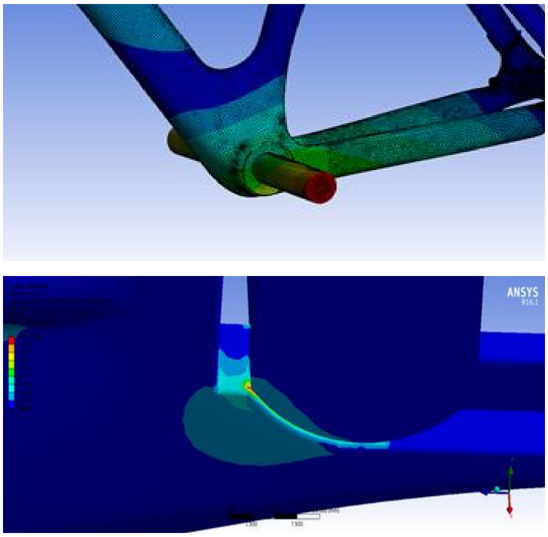

Fig. 4 Total deformation and stress

and bending strength. The BB stiffness was calculated at 218 N/mm. Fig. 4 shows the stress-concentrated part and strain.

The maximum strain of the frame when the 1,980 N load was applied was 8.919 mm, and the maximum stress was 483.02 MPa.

The stress-concentrated part was also the rear end and the measurement result determined that the safety was secured. The BB stiffness was calculated at 219 N/mm. The BB stiffness was found to be constant according to the frame's material regardless of the load.

2.6 Prototype fabrication

The material type and pattern were changed based on the power zone of the frame, thereby fabricating the prototypes of the frame for hard, normal, and soft types. The structural analysis results verified that stress was concentrated in the BB and rear end part. Thus, a layer was added to this part, and the layer in the frame's upper end was reduced to minimize the weight increase and increase the stiffness. Fig. 5 shows the layer's pattern and the part to be added.

Table 3 Stiffness measurement result of prototype

	Mass (g)	Deformation (mm)	Stiffness (N/mm)
Soft	1,233	4.93	157.8
Normal	1,346	4.63	168.05
Hard	1,501	4.09	190.46

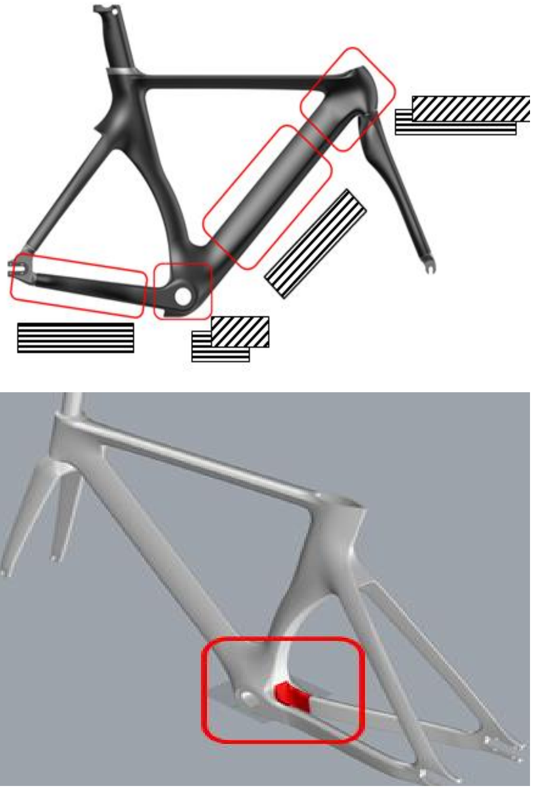

Fig. 5 Frame reinforcement

2.7 Prototype analysis

Three types of prototype were fabricated by changing the layer's pattern. The torsion measurement distance of each product was commissioned to a sport goods testing laboratory.

Table 3 presents the results for each type. First, the weight of the soft type prototype was 1,233 g

Fig. 6 Prototype of normal type

before painting, its deformation distance was 4.93 mm, and the pedaling stiffness was 157.8 N/mm.

Second, the weight of the normal type prototype was 1,346 g before painting, its deformation distance was 4.63 mm, and the pedaling stiffness was 168.05 N/mm. Finally, the weight of the hard type prototype was 1,501 g before painting, its deformation distance was 4.09 mm, and the pedaling stiffness was 190.46 N/mm. Fig. 6 shows a photo of the normal-type prototype.

3. Conclusions

This study analyzed the carbon materials of the pattern used to fabricate a carbon-made bicycle frame. The tension and bending tests were conducted as an analysis method. The finite element analysis for each load on the frame was conducted, and then a frame for each stiffness was fabricated and analyzed, thereby obtaining the following conclusions.

1. The existing products of overseas brands were analyzed, and the results showed that the frames from B Inc. and C Inc. had the hardest and softest stiffness, respectively.
2. The stiffness under each load was analyzed through the finite element analysis before the prototypes were fabricated. The analysis results revealed that when load was 80 kg, the maximum strain was 3.57 mm, the maximum stress was 193.21 MPa, and the stiffness was 218 N/mm. When load was 200 kg, the maximum strain was 8.919 mm, the maxim stress was 483.02 MPa, and the stiffness was 219 N/mm. Based on the above maximum stress, the safety of the frame was confirmed, which was dependent on the characteristics of the material, but the load was not significantly related.
3. Based on the analysis results, three types of frames were fabricated after raising the stability by adding a layer to where the stress was concentrated and removing the layer in the frame's upper end to reduce the weight. The deformation and stiffness of the soft-type frame, which had the smallest number of layers, were 4.93 mm and 157.8 N/mm, respectively, and those of the normal type were 4.63 mm and 168.05 N/mm, respectively. Finally, those of the hard type were 4.09 mm (the smallest) and 190.46 N/mm, respectively.
4. Compared to the overseas frames with excellent stiffness, this study could develop a frame with lighter weight and the same stiffness. This study will significantly contribute to the localization of carbon-made bicycle development in Korea in the future. In addition, it will be helpful for cyclists to select from a wide range of frames.

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