PREDICTION OF CYCLE SHOE PERFORMANCE IN RELATION TO OUTSOLE MATERIALS BASED ON BIOMECHANICAL TESTING AND FINITE ELEMENT ANALYSIS

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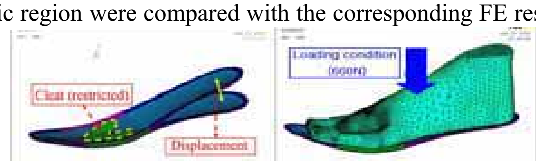
INTRODUCTION

Ultra-stiff carbon fiber composites are now being placed in the outsole of both road and mountain cycle racing shoes. They are intended to transfer energy more efficiently from the legs and feet to the pedals. This is based on the belief that higher the stiffness of the outsole, the greater plantar pressure may be produced in the forefoot [1]. In this study, both finite element (FE) analysis and biomechanical experiment were done to assess the performance of the cycle racing shoes in relation to the material properties of the outsole.

METHODS

Three types of outsole FE models outsole were generated for this study (Fig. 1-a). Type I was entirely made of a carbon composite based on the commercially available model (Shimano R-215, Japan); Type II, with a nylon outsole and the carbon composite insert (50 v/o); Type III, of a 100% nylon outsole. Thus, Type I was the stiffest outsole followed by Type II, and then Type III. Also, a foot model was generated from the CT data of a normal person with material properties from literature [2] (Fig. 1-b). The outsole was directly attached to the plantar surface of the foot. The insole part of the shoe was omitted in modeling for the sake of focusing on the outsole only and also to reflect the riding preference of many professional athletes. The material properties of the carbon composite were computed based on the classic lamination theory [3], which allowed us to convert the material properties of carbon composites from anisotropic to isotropic. Bending test of the carbon composite outsole was done to validate with the FE model results. Here, the cleat region of the outsole was held firmly while the heel part was pushed down until bending failure. Displacements under 30kg·f(294N) and 50kg·f(490N) that were within the elastic region were compared with the corresponding FE results.



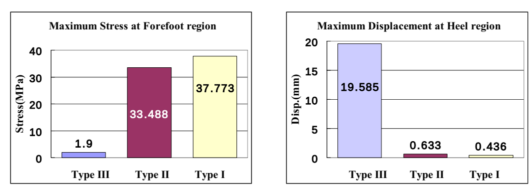
(a) **(b)**

Figure 1: The FE models: (a) outsole, (b) with foot

To obtain the loading conditions for FE analysis, a healthy subject (male, 28 years of age, 735N) rode on a stationary cycle set up (SRM, Germany). In-shoe foot plantar force and pressure were measured with F-scan system (Tekscan Inc., South Boston, USA) while keeping RPM and torque constant during pedaling based on the protocol suggested in the literatures [4]. Maximum force of 660N was recorded and was applied to FE analysis as a loading condition. Performance in relation to different shoe types were assessed by comparing plantar stresses in the forefoot region based on the literature findings on the relationship between the stress-strain and the load transmission and energy absorption at forefoot and heel regions[1, 4]. After applying appropriate loading and boundary conditions based on the experimental data, resulting stresses and displacements were assessed in foot plantar regions of FE models.

RESULTS AND DISCUSSION

The bending test results were in good agreement with the predicted displacements with the FE model, suggesting the validity of our model. The stress at the forefoot was highest with Type I shoes (i.e., the stiffest), followed by Type II and then Type III. It was found that 50 % reduction in carbon composite from Type I resulted in decrease in maximum stress by only 10% in Type II (Fig. 2-a). Corresponding displacement at the heel regions were very small in both Types I and II (Fig. 2-b). However, importance of the carbon composite was clearly shown with significant drop in the maximum stress at the forefoot and leaping increase in the displacement at the heel from Type II to Type III.



(a) (b)

Figure 2: FEA results: (a) Stresses at forefoot, (b) Displacements at heel

CONCLUSIONS

Our results demonstrated that the inclusion of ultra-stiff material such as carbon composite was very crucial for transferring the energy to the pedal through the outsole. More studies on the optimum amount and locations of the carbon composite material will follow using the FE model constructed from this study.

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ACKNOWLEDGEMENT

This study was supported by the grant ATC1007805 from Korea Ministry of Commerce, Industry & Energy.