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# Characteristics of golf shafts produced by carbon and basalt fibers

**Young Chyul Choi[a], Doo Na Chung[b], Hyun Mi Kim[c], Bong Geun Choi[c], Bong Arm Choi[d], Sun-Min Park[e] and Kwang Bo Shim[c,*]**

[a]*Division of Sports and Well-being, Hanyang University, Ansan-City, Gyeonggi-do 426-791, Korea*
[b]*Dumina Inc., Munjeong 2-dong, Songpa-gu, Seoul 138-961, Korea*
[c]*Division of Advanced Materials Science and Engineering, Hanyang University, Seoul 133-791, Korea*
[d]*Department of Golf Industry, Dae Gu University, Gyeongsan-si, Gyeongsangbuk-do 712-714, Korea*
[e]*Korea Institute of Ceramic Engineering and Technology, Gasan-dong, Geumcheon-gu, Seoul 153-801, Korea*

**Basalt fibers have been applied for the conventional carbon golf shaft manufacturing process. The woven basalt fiber layer has been replaced for one carbon layer among 7 ~ 8 carbon layers, partially and wholly in the length direction of the shaft, during the rolling process of carbon pre-preg. General shaft characteristics, including the mechanical and microstructural features, have been evaluated and human test by golf players was also performed. The replacement of basalt fiber for carbon fiber brought about the microstructural change and therefore different swing feelings by many golf players. It could be concluded that the introduction of advanced materials processing into conventional shaft manufacturing technique could be beneficial for the economical production of personally customized golf shafts.**

**Key word: Carbon fiber, Basalt fiber, Golf shaft.**

## Introduction

Among all sports, golf play has become popular rapidly in the world. Desire of most golf players is how to get toward the low-handy. Basically, the best performance for golf play is how to hit a golf ball by a golf shaft with an accurate direction toward the desired position. Since the golf shafts were made from the hickory wood firstly, the materials for golf shaft have been developed rapidly in a sequence of wood, steel, and composite. Now a day, advanced materials and new processing technology have been researched for the higher performance of golf club, even carbon nanotube (CNT) based on the nanotechnology (NT), which was initiated only fifteen years ago, has been considered as a material for the club head. [1, 2]

Golf club is composed of the three parts; grip, shaft and head. Generally, the characteristic properties of golf club depend mainly on the shaft and head which affect the airborne distance and directionality. The development of golf club has greatly contributed to golf play and therefore major club manufacturers have focused on the enhancement on characteristic variables affecting on the performance [3]. The golf shaft is a unique part which contacts directly with human hands and therefore it makes most critical role in the golf swing that delivers the club head to the ball with a wide range of shots depending on the club types from drivers to putters. The golf shaft is attached a club head and will be subjected to swing speeds depending on the individuals [4]. The variety of dynamic swing motion, head mass and swing speed will induce differently the deformation of the shaft and ball, resulting from the stresses and torques on the impact moment. The enhanced characteristics can deliver the longer airborne distance, accurate direction, and effective swing motion; however these variables should be well-adapted with a swing tendency depending on the physical feature, age, distinction of sex, and etc. of an individual person. Therefore, the selection of golf shaft is very important for satisfied golf play.

Graphite golf shafts is most popular in these days because they are more lightweight, needed less force to swing the club and can be useful for longer airborne distance. Therefore, they would be more suitable for high handy players, in particular those with a slower swing speed. Graphite shafts are typically made from carbon fiber reinforced polymers (CFRPs) and can be either sheet-wrapped or filament-wound [5, 6]. Graphite shafts typically consist of several layers of carbon fibers and would exhibit different properties with the variation of the angle between load direction and fiber orientation. Many golf shaft manufacturers have tried to change the shaft design in order to enhance the shaft characteristics including weight, flex, torque, bend point, and balance point. Ideally, all players should hold the golf club with the best combination of these

*Corresponding author:
Tel : +82-2-2220-0501
Fax: +82-2-2291-7395
E-mail: kbshim@hanyang.ac.kr

**Table 1.** Mechanical and physical properties of basalt fiber, compared with glass and carbon fiber [10].

| Properties | Continuous Basalt fiber | Glass fiber (E-glass) | Carbon fiber |
|---|---|---|---|
| Breaking Strength (MPa) | 3,000 ~ 4,840 | 3,100 ~ 3,800 | 3,500 ~ 6,000 |
| Modulus of Elasticity (GPa) | 79.3 ~ 93.1 | 72.5 ~ 75.5 | 230 ~ 600 |
| Breaking Extension (%) | 3.1 | 4.7 | 1.5 ~ 2.0 |
| Fiber Diameter (μm) | 6 ~ 21 | 6 ~ 21 | 5 ~ 15 |
| Linear Density (tex) | 60 ~ 4,200 | 40 ~ 4,200 | 60 ~ 2,400 |

parameters for the satisfied golf play. In this work, we have considered to find out another variable to change easily the shaft characteristics and suggest the use of different material. Our selection is a basalt fiber because this material possesses many different properties compared with those of metal, e-glass, and carbon fiber [7].

Basalt is an aphanitic igneous rock with less than 20% quartz and less than 10% feldspathoid by volume, and where at least 65% of the feldspar is in the form of plagioclase. It has typically a composition of 45 ~ 55 wt% $SiO_2$, 2 ~ 6 wt% total alkalis, 0.5 ~ 2.0 wt% $TiO_2$, 5 ~ 14 wt% FeO and 14 wt% or more $Al_2O_3$. Contents of CaO are commonly near 10 wt%, those of MgO commonly in the range 5 to 12 wt%. Basalt fiber is a material made from extremely fine fibers of basalt rock. [8, 9]The production of basalt fibers is similar to the production of glass fibers. Basalt is quarried, crushed and washed and then melted at ~ 1500 °C [8]. The molten rock is then extruded through small nozzles to produce continuous filaments of basalt fiber.

Basalt fiber has several excellent properties such as good mechanical strength, excellent sound and thermal insulator, non-flammable, biologically stable, etc. Table 1 show the mechanical properties of several fibers which are considered as golf shaft materials. Basalt fiber possesses the ratio of strength to weight 2.5 times higher than alloyed steel and 1.5 times than glass, respectively. It also is highly resistant toward corrosive mediums, such as salts and acids solution and especially alkalis. Above all, it is very technologically important that it is really cheap since it is made of natural rock.

This work is aimed to investigate the possibility of basalt fiber as golf shaft materials. Weaved basalt fiber has been partially applied for conventional shaft manufacturing process instead of carbon fiber. The mechanical and microstructural properties of the produced shaft were evaluated and shaft swing feelings have been tested indoor and outdoor (golf field) by the amateur and professional players. The relationship between the characteristics and swing feelings of the shafts has been discussed.

**Table 2.** The typical properties of Tansome carbon fiber (H2550).

| Filament Diameter | 7.0 μm |
|---|---|
| Tensile Strength | 4,400-4,900 MPa |
| Tensile Modulus | 240-250 GPa |
| Tensile Strain | 2.0% |
| Fiber Density | 1.76-1.78 g/cm$^3$ |

**Fig. 1.** Photo of woven basalt fibers. SEM micrograph in the center shows the woven pattern.

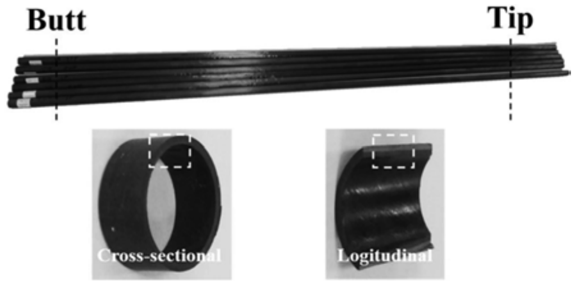


**Fig. 2.** The shafts manufactured for this study and the cutting direction for the microstructural evaluation.

**Table 3.** Load method of basalt fiber on the steel mantle.

| Nomination | Load method |
|---|---|
| B@B300 | 30 cm from Butt End |
| B@T300 | 30 cm from Tip End |
| B@Full | Whole shaft length |

## Experimental and Test

The pre-pregs carbon sheets (H2550 Tansome carbon fiber, Hyosung, Korea) and woven basalt fibers (74TEX woven basalt fiber, YJC, Korea) have been used as starting materials. The typical properties of pre-pregs carbon sheets are illustrated in Table 2. Fig. 1 shows the woven basalt fibers and is composed of 200 filaments with 13 μm diameter and its weight is 74 tex (g/km). The details can be seen in the SEM micrograph in the center of Fig. 2.

The graphite shafts were produced by the conventional manufacturing technique through the carbon fiber reinforced polymers (CFRPs). Graphite shafts were ini-

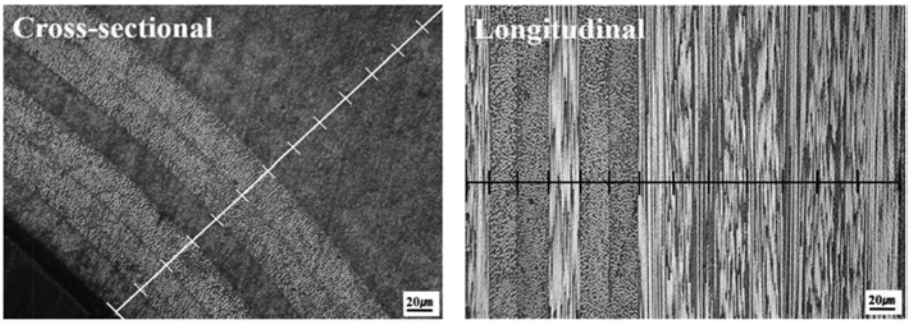


**Fig. 3.** The cross-sectional and longitudinal optical micrographs of graphite golf shaft which was produced typically by Dumina Co.

tially made from the sheet-wrapped process. The sheet wrapping process is as follows. The pre-pregs are cut into the sections (flags) with different fiber angles. These pieces of pre-pregs are rolled around the tapered steel mandrels to form the shaft, resulting in a total number of approximately six or seven layers. In this stage, the woven basalt fiber was applied in various ways for this research work, as listed in Table 3. Usually, each flag is rolled around the mandrel more than once. After all pre-pregs are wounded on the mandrel, it is covered with tape providing the necessary pressure during the curing process. After the curing process, the mandrel is removed, and the outer surface of the shafts is lapped and polished to finish.

The manufactured shafts were initially weighed and their CPM (cycle per minute) measured using the CPM measuring machine (Golf Fitting Solution, GFOSS, Korea). The cross-sectional/longitudinal microstructure of the shafts was evaluated using optical microscope and scanning electron microscope (SEM, JSM-5900LV, Jeol, Japan). Fig. 2 shows the shafts manufactured for this study and the sectioned direction for the microstructural evaluation. The specimens was sliced cross-sectionally and longitudinally with the shaft and then cold-mounted with an epoxy resin. The polished samples were prepared in the sequence of cutting, lapping, and polishing (3 μm, 1 μm, 0.25 μm). For human test, the swing feelings of the manufactured golf shaft by several golf players (amateur and professional) at indoor and outdoor has been collected and then compared with those of the conventional carbon fiber golf shaft.

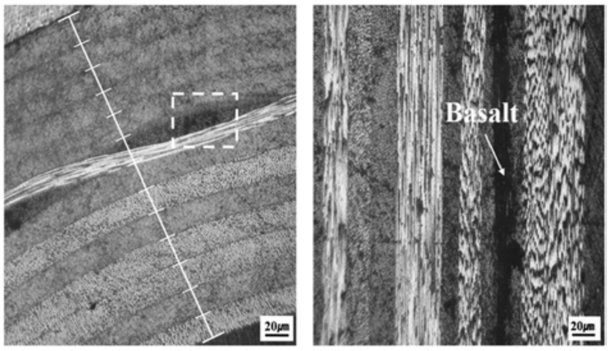


**Fig. 4.** The cross-sectional and longitudinal optical micrographs of the golf shaft which is replaced by a basalt fiber layer instead of one middle carbon layer among eight layers.

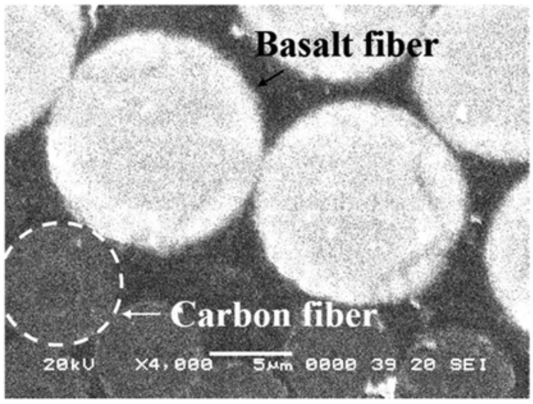


**Fig. 5.** SEM of the cross-sectional view of carbon and basalt fibers.

## Results and Discussion

### Microstructural features of the shafts with the addition of basalt fiber layer instead of a carbon layer

Fig. 3 shows the cross-sectional and longitudinal optical micrographs of graphite golf shaft which was produced typically by Dumina Co. Each carbon layers are about 20 μm with an uniform thickness and the layer boundaries at the outer regions were indicated with the dotted lines. The different contrasts are occurred from the loading direction of carbon pre-pregs, namely the carbon fiber direction. The reason why the layer thickness cannot be differentiated in the some parts is because that the carbon prepreg's rectangular pattern was loaded with a different direction during a sheet wrapping process. From the view point of shaft manu-facturing process, Dumina's shafts are composed of a close-packed micro-structure without any cavities (or defects), indicating a good bonding between the carbon layers and epoxy resin. These microstructural features are very important for the shaft quality and lifetime.

Fig. 4 shows the cross-sectional and longitudinal optical micrographs of the golf shaft which is replaced by a basalt fiber layer instead of one middle carbon layer among eight layers. It seems that a basalt layer was curved. This feature is attributed by a larger diameter

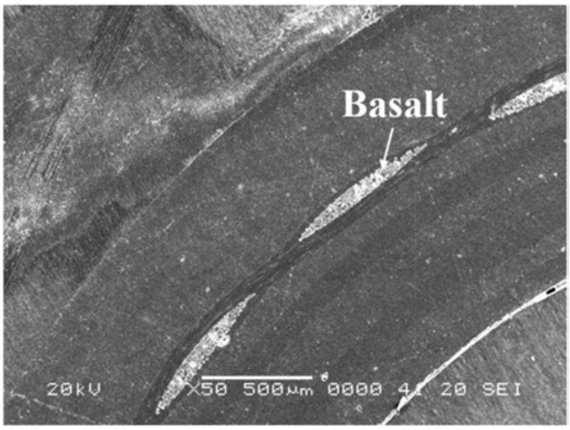


**Fig. 6.** Cross-sectional SEM of woven basalt fibers.

**Table 4.** The general characteristics of the iron shafts with different materials.

| | Carbon + Basalt | Carbon | Steel 950 (NSPro) |
|---|---|---|---|
| Weight | 378 g | 378 g | 420 g |
| CPM | 302 | 302 | 299 |
| Shaking on impact moment | acceptable | a little unstable | acceptable |

of the basalt fiber (13 μm) compared with that of carbon fiber (7 μm), as shown in Fig. 5, therefore basalt fibers are difficult to be close-packed during the woven process. The curved white region and twisted dark region represent the upper and under part of basalt layers, respectively. Sometimes, this feature appears as a broken curve depending on the loading direction of woven basalt fibers as shown in Fig. 6. It is shown that the uniformity of layer thickness becomes blunt near the basalt layer (see the dotted rectangular in Fig. 4).

### Human test of the shafts with the replacement by basalt fiber layer instead of a carbon layer among

The shaft weight should be fixed during the polishing process depending on the shaft specification. Therefore, the change of shaft weight due to the density difference between carbon (0.4 to 0.5 g/cm$^3$) and basalt (1.76 to 1.78 g/cm$^3$) could be ignored. Table 4 shows the general characteristics of the shafts manufactured by different materials. In order to evaluate the effect by the basalt addition, the shaft weight was fixed as 378 g and those shafts (carbon+basalt and carbon) were compared with commercially available steel shaft (Steel 950, NSPro). The addition of basalt fiber did not change the CPM value. During the human test, it was found that the addition of basalt fibers brings the stability of the shaft shacking on impact moment and could be competed with the stability of steel shaft. Many players say that they feel a little higher weight from the basalt-added shaft at the moment of shaft swing. This means that an addition of basalt fiber increase a swing weight of the shaft. In case of the iron shaft, it was said that the basalt-added shaft decreases the shaking at the impact moment on the ball, compared with the only carbon shaft. This means that the softness of shaft decreased but its stiffness increases by the addition of basalt. This change of swing feeling can give the variation of shaft characteristics.

For drive shaft, the basalt fiber was applied differently on the part of drive shaft. In the case of the tip-loaded case (B@T300), there are no practical changes of weight, CPM and twisted shaking feel, however the ball-running became longer. With the comparison with only-carbon shaft, the shaft stability increased but the softness reduced during shaft swing. Therefore, this basalt-load application may be suitable for female-professional or senior golf players. In the case of whole-loaded case (B@Full), the CPM value of shaft increased about 10, the weight 2 ~ 3 g, and the shaft shaking decreased. From the viewpoint of the commercial shaft specification, it can be expected that if the basalt fiber is applied on the carbon 60 R Spec., it becomes SR Spec. but S Flex in the swing feeling. This kind of basalt application may be suitable for the male professional players including the player who can withstand a power swing.

It is very difficult that the microstructural change of the golf shaft is correlated directly with the human swing feeing. However, it is clear that the shaft quality, which can be represented qualitatively to the player's feeling during swing, can be changed depending on the methods of the replacing application of the basalt fiber instead of carbon fiber. This means that any kind of shaft spec. can be produced and the personally customized golf shaft can be easily manufactured by the microstructural control. There were sometimes found relatively large-sized cavities near the basalt fiber applied regions. This kind of problem could be overcome from the adaption of new material processing methods or the use of advanced materials such as CNT (carbon nano tube).

## Conclusions

The application of basalt fiber in the conventional carbon golf shaft has been studied. The introduction of woven basalt fiber in to carbon fiber layer induced the microstructural change and this change could be helpful for different golf players because various swing feelings can be brought about, as confirmed by the human test results. The use of basalt gives also economical advantage, because of its cheap price and can be effective as the replacement of steel iron shafts especially for female-professional, amateur and junior players. Its application could be expanded for the replacement for driver, wood, hybrid shafts, and even iron shafts of professional players.

## Acknowledgments

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