

The Effect of Moisture Absorption and Gel-coating Process on the Mechanical Properties of the Basalt Fiber Reinforced Composite[†]

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Abstract

Generally, strength degradation is caused by the absorption of moisture in composites. For this reason, a fracture is generated in the composites and traces of glass fiber degrade human health and physical damage is generated. Therefore, in this research, we studied the mechanical properties change of composites by moisture-absorption. The composites were manufactured with and without the Gel-coating process and were immersed in a moisture absorption device at 80°C for more than 100 days. The mechanical properties of the moisture-absorption composites and the composites which dry after moisture-absorption were compared. The mechanical properties degradation of basalt fiber composites according to the result of the measurement of moisture-absorption was smaller than that of glass fiber composites by about 20%. In addition, the coefficient of moisture absorption was lower for the case of Gel-coating processing than the composites without the Gel-coating process by about 2% and it was deduced that Gel-coating did not have a significant effect on the mechanical properties.

Keywords: Absorption, Basalt fiber, Composites, Gel-coating, Glass fiber

1. Introduction

Recently, the dispute about the harmful effects of glass fiber to humans and the environment continues and because of the current situation where the limit for industrial application is internationally discussed, the demand for the development of a new inorganic fiber increases.

In terms of basalt fiber, in the production process the fiber is produced through a single production process without another annex. The manufacturing process is consequently simple, the production cost is low, and the material is environmentally-friendly. The property of basalt fiber is superior to that of glass fiber. Because of this, basalt fiber is known as a material which is suitable for high-fidelity industrial use.

In the fiber reinforced composite, the degradation of the mechanical property can be generated from not only long-term load but also special environmental conditions. However, the investigation of the mechanical property of basalt reinforced composite reveals that it is weakened in severe environmental conditions such as excessive moisture and ultraviolet light and so on.

Generally, the principal reason why the composite material structure is degraded by the environment is the change of many conditions such as the surrounding temperature, humidity, and ultraviolet light etc.. That is, the absorbed moisture causes plasticization of the resin at the same time and causes volume expansion and generates cracking. The moisture also diversifies the internal stress condition, while, in the interface of the resin between the fibers, the swollen moisture separates the chemical combination of the composites and degrades the bond strength. The interface

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between the fiber and resin is degraded by this damage and the mechanical property of the composites is thus degraded. In this research, a test specimen of the basalt fiber reinforced composite was made and was immersed in distilled water of 80°C for 100 days. The specimen dries after immersion and the mechanical property due to the moisture of the basalt reinforced composite was examined. In addition, the moisture-absorption mechanism of the composites with the Gel-coating process on the test piece surface is compared with the mechanical property of the composites which are not processed with Gel-coating and a study is carried out of this comparison.

2. Manufacturing of Specimen and Experiment Method

2.1 Manufacturing of specimen

For the basalt fiber, plain woven fiber manufactured by the SECOTECH Company was used. The properties of the fiber are presented in table 1. A plain woven fiber is used for the glass fiber, in which the diameter is the same as the basalt fiber for an accurate comparison. The chemical composition of the basalt fiber used in this experiment is shown in table 2. Epoxy resin (RIM135/137) was used for the resin, which is a thermosetting resin with an excellent mechanical property and a large-scale adhesive strength during hardening. The Gel-coat used is a product manufactured by the In-Sung industry and has the model name of AC200 product, having thermal resistance and water resistance. The specimen was made by using the VaRTM method of construction.

Table 1. Physical properties of the basalt fiber and glass fiber used for experiments

Physical properties	Basalt fiber	Glass fiber
Tensile Strength (MPa)	3100~4840	2000~3500
Modulus of Elasticity (Gpa)	85~95	70
Density (g/cm ³)	2.8	2.5
Elongation at Break (%)	3.15	2.5

Table 2. Chemical contents of the basalt fiber and glass fiber used for experiments

Compositions Contents	Basalt fiber (weight %)	Glass fiber (weight %)
SiO ₂	56	54
Al ₂ O ₃	17.4	15
Fe ₂ O ₃	11.8	-
MgO	3.2	5
CaO	9.9	17
Na ₂ O+K ₂ O	1.7	0.6
Others	-	8

2.1 Experiment and method

Four types of specimens were made, including the basalt fiber composites, glass fiber composites, composites with the Gel-coating process and composites without the Gel-coating process. The test was progressed using 7 specimens and in order to improve the reliability of the research the average of the return value of the other 5 specimens, except the maximum value of the measured return value and minimum value, were taken. All the tensile test specimens and the short beam specimens were sufficiently immersed into the distilled water in the moisture absorption device at a constant temperature of 80°C for more than 100 days after which a tensile test and short beam test were conducted according to each water absorption rate. The tensile strength test was based on ASTM D638 and the cross head speed was 5.00mm/min. The short beam test was based on ASTM D2344 and the cross head speed was 1.00mm/min. By using the classification of 10 for monitoring the specimen, the water absorption rate was measured every day. Also, this specimen was used as the grounds for the judgment of time of the coefficient of moisture absorption. The calculation of the water absorption rate applied to the test was produced by the following mathematical formula (1).

$$W(\%) = \frac{W_t - W_d}{W_d} \times 100 \quad (1)$$

Here, W is the water absorption rate and W_t is the specimen weight after the moisture absorption. And W_d is the initial sample measured value with the former specimen weight of the moisture absorption.

3. Experimental result and consideration

3.1 Moisture absorption behavior for each specimen

In all specimens, a rapid increase in the water absorption rate showed up until the 20th day, after which the water absorption rate showed a slow increase. This can possibly be explained by Fick's law; the moisture absorbent behavior of the specimens in this research follows the Fick's law well. After immersion for more than 100 days, the increase and reduction were repeated and the water absorption rate of each specimen increased and it is considered that the coefficient of moisture absorption is saturated. The result of the analysis of the coefficient of moisture absorption behavior showed that the water absorption rate of the basalt fiber composite had a measured value of about 2% lower than the water absorption rate of the glass fiber composite. It is thus determined that the interface coherence between the basalt fiber and resin was superior to the interface coherence between the glass fiber and resin and the penetration of the water molecule was relatively small. It is also confirmed that the water absorption rate increased on the fiber reinforced composite surface with the Gel-coating more than that on the specimen without the Gel-coating process. The moisture-absorption on the composites is also progressed by the moisture diffusion. However, moisture penetration is prevented due to the processing of the Gel-coating. For this reason, the role of the Gel-coating prevents the swelling phenomenon and prevents the separation of the resin interface and fracture because of the fracture of the three dimensions network structure of the resin. The coefficient of moisture absorption behavior according to the time of immersion for the 4 types of specimens is shown in figure 1.

3.2 Tensile strength and short beam strength property due to moisture-absorption

When moisture-absorption occurs on the composites, the swelling phenomenon is generated and the interface between the resin and fiber is separated and the strength is degraded. In addition, the interface between the resin and fiber is completely destroyed by the fracture of the three dimensions network structure of the resin and this creates a condition where recovery is impossible. The mechanical property change due to the moisture-absorption is shown in Figure 2. On the whole, the tensile strength and short

beam strength reduced as the time of immersion passed. In particular, a rapid reduction was displayed up until the 20th day. This seems to be caused by the weakening of the adhesive strength between the interfaces in which the moisture penetrates and is generated into the interface between the fiber and the resin. The reduction of the tensile strength according to the time of immersion for the basalt fiber composite was 39.58% and that for the glass fiber composite was 59.67%. The tensile strength decrease rate of the basalt fiber composite was smaller than that for the glass fiber composite. And the decrease rate of the tensile strength of the specimen with the Gel-coating process was 29.92% and the decrease rate of the specimen without the Gel-coating process was 55.74%. It can therefore be confirmed that in the case of the specimen with the Gel-coating process, the decrease rate of the tensile strength is small. As mentioned above, the Gel-coat prevents the penetration of the moisture in the case of the composite with the Gel-coating process. For this reason, the decrease rate seems to have a small effect on the water absorption rate. For the Short beam Strength, the basalt fiber composite was 46.70% and the glass fiber composite was 59.24%. This showed that the decrease rate is similar to the tensile strength. And in the case of the specimen with the Gel-coating process, the basalt fiber composite was 34.64% and the glass fiber composite was 54.69%. Similarly, it could be confirmed that the decrease rate of the tensile strength did not differ. The mechanical property due to the moisture-absorption was tested.

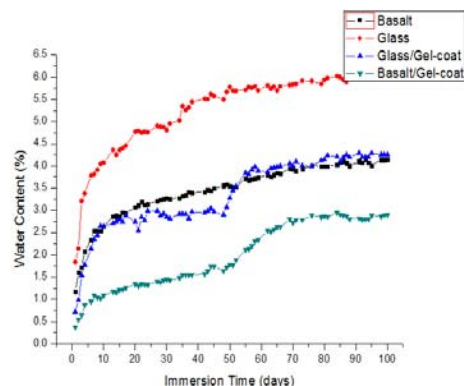
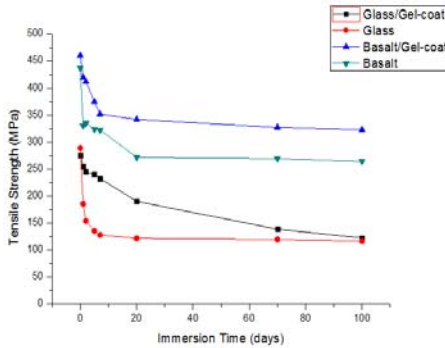


Fig. 1. The time of immersion moisture-absorption behavior.

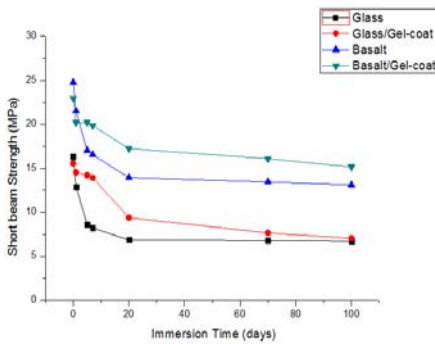
Consequently, the increase in the water absorption rate according to the time of immersion is considered to weaken the adhesive strength between the interfaces and has an effect on the degrading of the mechanical material property.

3.3 The tensile strength and short beam strength recovery by the drying

In terms of the reduction of the tensile strength and short beam strength due to the moisture-absorption according to the time of immersion, recovery is possible through the drying process. However, as the time of immersion passes, if the water absorption rate increases and permanent damage is caused because of the interface combination part of the fracture between the resin and fiber, the recovery is then impossible. This can be illustrated by dividing the material property degradation mechanism due to the moisture absorption into 3 steps. In terms of the material property degradation mechanism, if the fiber reinforced composite has moisture-absorption, the moisture penetrates into the polymer resin whereby the network structure is entangled by the long chain due to diffusion. Due to this, it was assumed that the moisture had an effect on the coherence between the molecules and degrades the properties of matter. The material property degradation mechanism due to the moisture absorption of the fiber reinforced composite is shown in 3 steps in figure 3. In step 1, it is assumed that the water molecule penetrates into the resin portion and while the fiber reinforced composite is exposed to the water environment it degrades the properties of matter. In this step, the moisture does not have a direct effect on the interface combination part and the properties are mostly recovered if the composite dries. In step 2, it is assumed that the water molecule penetrates into the interface between the resin and fiber and increases the swelling phenomenon and weakens the interface coherence. The recovery of the properties is possible if the composite dries similarly to that in step 1. In step 3, it is assumed that the water molecule penetrated into the interface between the resin and fiber, the swelling phenomenon deepened, the moisture weakened the interface coherence and the interface between the fiber and resin was completely destroyed causing permanent damage. In this step, recovery by drying is impossible. Figure 4 shows the tensile strength and short beam strength recovery by drying. In the case of the basalt fiber composite, the section in which the tensile strength is recovered through drying by 90% of the initial value was accomplished in step 1. And the section that was recovered by 80% was accomplished in step 2 and the section which is 65% not recovered was accomplished in step 3. After immersion, the composite recovers



(a) The tensile strength behavior by the moisture-absorption



(b) The short beam strength behavior by the moisture-absorption

Fig. 2. The mechanical property change by the moisture-absorption.

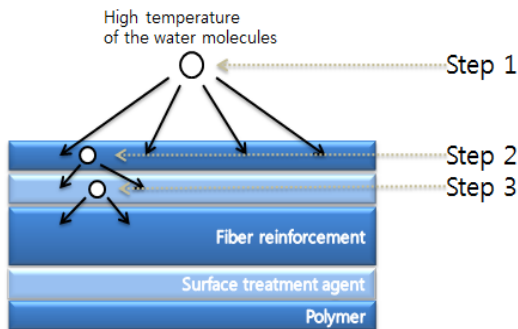
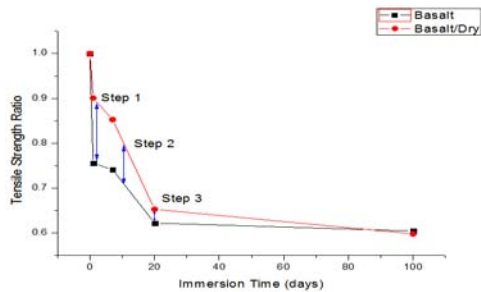
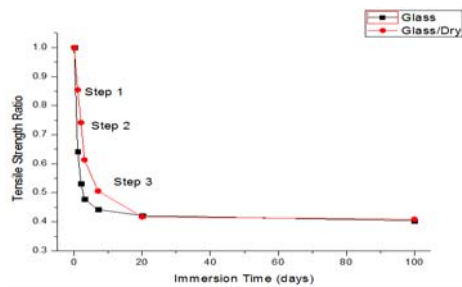


Fig. 3 Material property degradation mechanism because of moisture absorption of fiber reinforced composite.

mostly through the drying process and as the time of immersion passes, the recovery rate can reduce and it can be confirmed in the 3 steps that due to the tensile strength degradation, recovery is nearly impossible. In the case of the glass fiber composite, the section similarly recovered through drying by 85% of the initial value in step 1. And in step 2 the section recovered by 75% and, in step 3 the section did not recover by 50%. In terms of the recovery rate of the glass fiber composite, it was about 5% higher than the basalt fiber composite. In the case of the glass fiber composite, the water absorption rate is high and the material property degradation is serious. Consequently, the amount of moisture in the water absorption rate in which the recovery is possible and which is high in steps 1 and 2 is removed. Therefore, it is determined that the recovery rate is enhanced. The result showed that the recovery rate of the short beam strength is similar to the recovery rate of the tensile strength.



(a) The dry tensile strength recovery



(b) The drying Short beam Strength recovery

Fig. 4 The tensile strength recovery and short beam strength recovery by the drying.

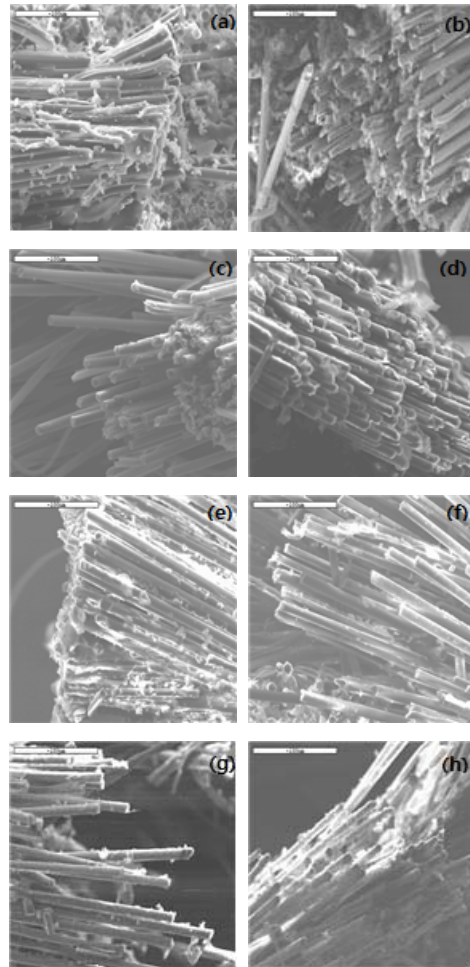


Fig. 5 The immersed fracture shape by period about the glass fiber composites and basalt fiber composites: (a) The first stage glass fiber composites specimen (b) The moisture absorption glass fiber composites specimen for 7 days (c) The moisture absorption glass fiber composites specimen for 100 days (d) the glass fiber composites which is on 1st dry after humidity-absorb (e) The first stage basalt fiber composites specimen (f) The moisture absorption basalt fiber composites specimen for 7 days (g) The moisture absorption basalt fiber composites specimen for 100 days (h) the basalt fiber composites which is on 1st dry after humidity-absorb

3.4 Fracture surface analysis

The tensile test was carried out and in order to observe the fracture shape in the interface between the resin and fiber, the fracture surface was observed with SEM. Figure 5 shows the fracture surface

according to the time of immersion for each specimen. Generally, the brittle fracture, which is the inherent fracture aspect of the fiber reinforced composite, did not occur. As the time of immersion increased, for both the basalt fiber composite and glass fiber composite, the resin was unable to play a proper role due to the water molecule penetrating into the specimen. Consequently, it can be confirmed that the pull-out phenomenon, in which the fiber is lengthened, is generated. On the other hand, the brittle fracture was displayed in the case of the specimen where the time of immersion was short, due to the powerful coupling between the resin and fiber. In addition, the immersed specimen was dried in the drying machine at a high temperature (80°C) for one day.

Subsequently, while the water molecule that penetrated inside the resin was completely removed, the pull-out phenomenon could confirm the recovery of the decreased strength. And it was confirmed that the resin that adhered to the fiber surface increases by a trace amount. As the time of immersion passes, the fiber with the pull-out phenomenon is lengthened and the amount of resin in the fiber surface is decreased. This is determined to be generated by the interface coherence weakening between the resin and fiber. In addition, it is considered that the increase in the interface coherence between the resin and the fiber through the drying is caused by the properties of matter recovery.

4. Conclusion

In this research, a fiber reinforced composite was made by using glass fiber and basalt fiber with epoxy resin. In addition, the composites were divided into those with the Gel-coat process and those without the Gel-coat process and were then immersed into distilled water at 80°C in a moisture absorption device and the change of the water absorption rate was observed. A drying test chart was then created after immersion with the immersion test. The mechanical property change was examined through the test and the following conclusion was obtained.

(1) The water absorption rate of the basalt fiber and glass fiber displayed a rapid increase up until the 20th day. A slow increase was subsequently shown. After a time of immersion of more than 100 days, the water absorption rate is determined and the increase and reduction is repeated until near saturation. The water

absorption rate of basalt was lower than the water absorption rate of the glass fiber composite with the analyzed result showing about 2% coefficient of moisture absorption behavior. Consequently, it can be determined that the interface coherence between the resin and the fiber of the basalt fiber composite is superior to the interface coherence of the glass fiber composite and it is determined that the penetration of the water molecule was relatively small.

(2) The water absorption rate of both the basalt fiber composite and glass fiber composite showed about 2% reduction through the processing of Gel-coating. Thus, water molecule penetration is prevented due to the processing of Gel-coating within the composites. And the fracture of the three dimensions network structure of the swelling phenomenon and resin is prevented. Therefore, it is considered that the Gel-coating plays a role in preventing the interface coherence weakening between the resin and fiber and it moreover prevents the interfacial delamination and fracture. However, the increase in the water absorption rate and mechanical material property degradation was unable to be completely prevented. The reason why the water absorption rate increases in spite of the processing of Gel-coating is as follows. It is determined that this is because the moisture was penetrated and generated by the minute air hole which disabled the mechanical processing of the coating. In addition, after 50 days, the reason why the water absorption rate again increases drastically is as follows. It is determined that while the coating is being processed, due to the immersion continuing at the high temperature (80°C), the moisture penetrates between this coating and the composite and the moisture-absorption is progressed. However, because the Gel-coat itself is vulnerable to the high temperature, although the perfect processing of coating is made, the partial fracture of the Gel-coat will be generated in the test if the high temperature is maintained every day. Therefore, it is considered that further research on the water absorption rate behavior should be carried out.

(3) In the tensile test and short beam test, the mechanical material property degradation of the basalt fiber composite was smaller than the mechanical material property degradation of the glass fiber composite. Consequently, it could be confirmed that the basalt fiber composite showed a superior mechanical property. The reason why the interface coherence is excellent is determined to be the strong chemical

combination between the fiber and resin. In addition, it is considered that the properties are degraded due to the degradation of the glass fiber absorbing too much moisture.

(4) The analyzed result of the fracture surface shows that as the time of immersion passed, the brittle fracture, which is the inherent fracture shape of the fiber reinforced composite, did not occur and the pull-out phenomenon showed instead. The penetration of the water molecule by the diffusion causes the swelling phenomenon and pull-out phenomenon and degrades the properties of the material. However, while the water molecule penetrated into the resin, more than 80% recovery was seen through the drying process. But the interface combination part is destroyed by the interface coherence weakening between the resin and the fiber because the time of immersion passed. Then, the permanent damage is generated. And it could be confirmed that the recovery of properties through drying was impossible.

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