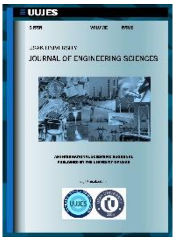

Usak University

Journal of Engineering Sciences

An international e-journal published by the University of Usak

Journal homepage: dergipark.org.tr/uujes

Research article

INVESTIGATION OF THE WATER ABSORPTION PROPERTIES OF PULTRUDED HYBRID COMPOSITE PROFILES

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Received: 10 April 2019 Revised: 7 May 2019 Accepted: 13 May 2019 Online available: 30 June 2019
Handling Editor: Kemal Mazanoğlu

Abstract

Pultrusion is a continuous process for the manufacture of fiber reinforced polymer matrix composite products having a constant cross section, such as rod stock, structural shapes, beams, channels, pipe and tube. Pultruded profile products have high structural integrity and mechanical properties. The water absorption characteristics of composite materials give serious concern, especially for their potential outdoor applications. It is also known that having a high water absorption tendency has negative effects on the mechanical, physical, chemical and optical properties of composite materials. This is why; it is undesirable that the polymer matrix, which is used in the production of the composite profiles by the pultrusion method, has high water absorption values. Fiber content is also a leading parameter and has a significant influence on the mechanical properties of composite materials. In this study; the water absorption characteristics and fiber contents of pultruded glass-carbon fiber reinforced polyester and vinylester hybrid composite profiles were experimentally investigated. Water absorption tests were performed by immersing composite specimens into water conditions according to ASTM D 570 standard. The fiber contents of composite specimens were determined by calcination method according to TS 1177 EN ISO 1172 standard. The results obtained from the experiments were analyzed and explained with necessary comments.

Keywords: *Water absorption; pultrusion; polyester and vinylester resin; hybrid composite profiles.*

1. Introduction

Composite materials have been widely used in space and aviation industry, marine applications, civil engineering applications, renewable energy applications, defense industry, automotive industry and etc. because of their properties such as durability, rigidity, corrosion resistance, thermal - electrical resistance and aesthetic appearance [1].

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Fiber reinforced polymer matrix composite profiles are preferred due to their certain features like low cost producibility and good mechanical properties in industrial applications. I profiles are one of the most commonly used bearing element to support the engineering applications. Polymeric composite materials consist of two main substances which are the matrix (resin) and reinforcement element (fiber types). The matrix element which directly penetrates into the fibers and provides good support has one of the most important role on the physical and mechanical properties of composite materials [2]. The inevitable exposure of the composite materials to moisture and liquid contact in their working environments or environmental conditions adversely affects their physical and mechanical properties in time. In the literature and previous studies; it was seen that moisture would cause the matrix to swell, break and the material to deteriorate [1]. Absorbing the moisture into composite materials causes the matrix to show plasticization behavior and debonding at the fiber-matrix interface. Hydrolysis reaction of unsaturated groups within the polyester causes the fibre-matrix interphase debonding. Due to the reasons stated, physical and mechanical properties such as modulus of elasticity, tensile and flexural strength, electrical and thermal resistance are adversely affected by the increase of moisture [3-8]. Considering the aforementioned studies, it seems to know the water absorption characteristics of composite materials has great importance in order to predict their long term behavior [6,9].

Calcination process is like a purification method for the fibers from the volatile substances of polymeric composite materials and also the first step to determine the fiber content or reinforcement ratio of composite materials by weight. Fiber content and modification of fibers has a significant effect on the properties of composite materials [10]. It is a known fact that the moisture affects the properties of the composite materials in two ways as reversible and irreversible. Reversible effects are restored by removing the moisture from the composite material by drying such as material strength. Irreversible effects are the permanent effects which are not restored by removing the moisture such as weakening of interfacial strength, initiation of microstructural defects and hydrolysis of polymeric matrix [11]. Therefore, it is also significant to know about the fiber content effects on water absorption characteristics of composite materials.

Although there has been considerable research devoted to the water absorption properties of polymer matrix glass fiber or organic fiber reinforced composite materials [1-9], there are not enough experimental data about the water absorption properties of pultruded polymer matrix hybrid glass-carbon fiber reinforced composite materials.

In this study; the water absorption properties and fiber contents by weight of composite materials which are produced in different configurations by pultrusion method were experimentally investigated with the accordance of ASTM D 570 standard and TS 1177 EN ISO 1172 standard respectively. The obtained results were examined and the water absorption performances of the composite materials with different configurations were compared among each other.

2. Materials and methods

Pultrusion is a continuous process for manufacturing composite materials with constant cross-section that consist of immersing the fibres into a resin pool and pulling through a heated die which have the cross-section geometry of the certain profile to cure the composite materials. Fig. 1 shows the pultrusion line and manufacturing process of the composite profiles.

In this study, four types of I-section beam with the certain configurations were manufactured by pultrusion method. Glass fiber, carbon fiber, glass fiber continuous strand mat and carbon woven roving mat configurations were used as reinforcement elements and polyester, vinylester resin preferred as matrix because of its certain properties in production of profiles. Configuration information about I beams is given in Table 1 and the structure of I beam is shown in Fig. 2. As seen in Fig. 2, web and flange regions are named as A, B, C. Inner mats and outer mats are numbered as 3,6,7 and 1,2,4,5 respectively.

Fig. 1 Pultrusion line and manufacturing process of the composite profiles.

In Fig. 2 red line shows the overlapping length and region of the outer mats. After the manufacturing of profiles, three numbers of specimens were taken by cutting from the (c) region (web) of the four pultruded I beams with different configurations. The test specimens are cut with the dimensions of 76.2 mm length, 25.4 mm width, and 6 mm thickness. Fig. 3 shows the prepared specimens in accordance with the ASTM D 570 standard.

Table 1 Configuration of the specimens and their content.

Specimen type	Fiber type	Mat type	Resin type
1	Glass fiber	Glass continuous strand mat	Polyester
2	Glass fiber	Inner mats: glass continuous strand mat Outer mats: carbon woven roving	Polyester
3	Glass – carbon fiber	Glass continuous strand mat	Polyester
4	Glass – carbon fiber	Glass continuous strand mat	Vinylester

Specimens are subjected to the twenty-four hours water immersion according to ASTM D570 standard. Firstly, three specimens for each type of the configuration and totally twelve specimens are conditioned at 50 °C in a vacuum oven for twenty-four hours. After the cooling process, specimens are immediately weighed by the accuracy of 0.001 g by an analytical balance. Fig. 4 shows the water immersed specimens.

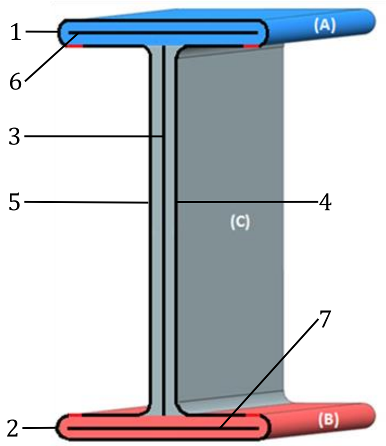
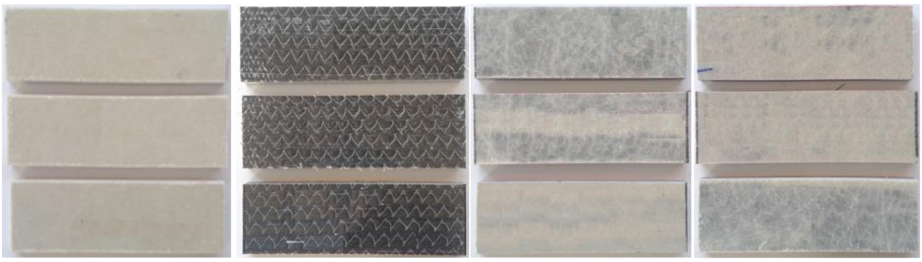


Fig. 2 Configuration schematic of the I beam.



(a) (b) (c) (d)

Fig. 3 Sample photos of prepared specimens in accordance with the ASTM D570 standard (a) Type 1 specimens, (b) Type 2 specimens, (c) Type 3 specimens and (d) Type 4 specimens.

Fig. 4 Photos of the water immersed specimens.

Twelve specimens were immersed into the distilled water at a temperature of 23 °C and rested for twenty-four hours. At the end of the twenty-four hour water immersion, surfaces of specimens were wiped from water by a dry cloth and their weight were immediately measured by the accuracy of 0,001g. After conducting weight measurements, water absorption percentage or percentage increase in weight during immersion were calculated by using the following Eq. (1).

$$W_a = \frac{W_w - W_{co}}{W_{co}} \times 100\ (\%) \qquad (1)$$

Where, W_a is water absorption percentage (%), W_w denotes wet weight of the specimen (g), and W_{co} is conditioned weight of the specimen (g).

Filler contents of the composite specimens were determined with the accordance of the TS 1177 EN ISO 1172 standard. Three Specimens were prepared from nearby regions of flange of the profile (C region) parallel to each other by cutting with the rectangular shape and weight between 2 g to 10 g as seen in Fig. 5(a). The crucibles were conditioned and their weights were measured with the analytical balance. Specimens were dried within a vacuum oven and their weights were measured with crucibles after the conditioning process (Fig. 5(b)). Solid volatile substances of the composite materials (resin and its additives) were uniformly heated by using a muffle furnace, as seen in Fig. 5(c), at 625 °C temperature for a certain period of time approximately 45 min to 55 min. After the calcination process, weight measurements of the specimens with crucibles were conducted again by analytical balance. Fig. 6 shows the calcinated composite specimens and their reinforcement configuration.

(a) (b) (c)

Fig. 5 Photos of (a) Type 1 calcination specimens, (b) Type 1 conditioned specimens and (c) muffle furnace.

Fiber contents of the composite materials were determined by using obtained data from the experimental study and calculated by using the following Eq. (2).

$$M_f = \frac{m_3 - m_1}{m_2 - m_1} \times 100\ (\%) \qquad (2)$$

Where, M_f: fiber content or reinforcement ratio of the composite (%), m_1: initial weight of the dry crucible (g), m_2: initial weight of the specimen and crucible (g), m_3: final weight of the specimen and crucible (g).

Fig. 6 Photos of calcinated specimens and their reinforcement configurations (a) Type 1 specimen, (b) Type 2 specimen, (c) Type 3 specimen and (d) Type 4 specimen.

3. Results and discussions

Measured specimen weights and calculated water absorption percentages according to Eq. (1) are given in Fig.7. The water absorption values show that Type 3 carbon fiber reinforced composite materials have more water absorption tendency than the others. Type 1 glass fiber reinforced composite materials have the second lowest water absorption percentage values. Type 2 carbon mats and glass fiber reinforced composite materials show water absorption percentage values between the Type 1 and Type 3 specimens. It can be explained by the void content of the composite materials.

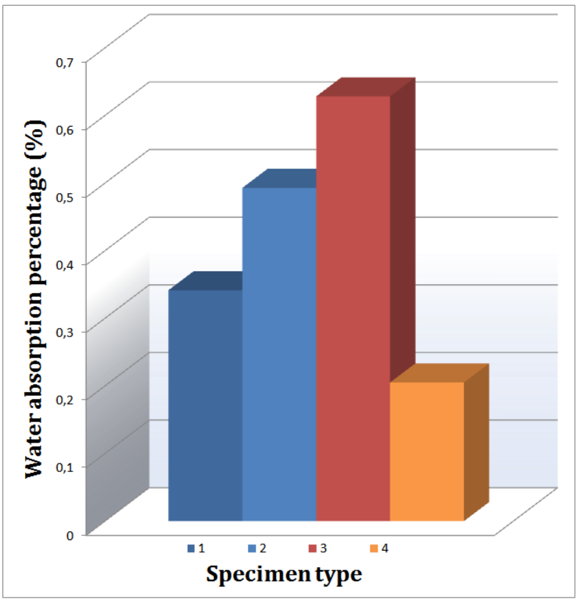


Fig. 7 Water absorption percentage comparison of composite specimens.

Due to the voids that are caused by the poor penetration of the polyester resin into the carbon fibers give rise to increases of the water absorption percentages. It is a known fact that resin penetration capability is getting harder when the filament is getting thinner and since carbon filament thickness is between 5~10 μm , resin impregnation is harder than the glass fibers. So that water absorption percentages of carbon fiber reinforced polyester matrix composite materials were found to be higher than glass fiber reinforced materials. Using an agent that can increase the penetration capability of the polyester to the carbon fiber during the curing process can eliminate this obstacle. It is seen that the water absorption percentage increases as the carbon fibre ratio increases. Type 4 glass-carbon fibre vinylester matrix composite specimens have the lowest water absorption percentage values. This situation shows that vinylester resin can penetrate into carbon fibres better than polyester resin and also void content of the vinylester composites is lower than that of polyester composites. This is the reason for why vinylester resin composites are preferred in marine applications.

Calculated fiber content values according to Eq. (2) and weight measurement values were given in Fig. 8. Type 1 specimens have the highest fiber content values and the carbon woven roving mats showed its effect in terms of weight on Type 2 specimens as seen in Fig 8. Carbon fiber reinforced specimens Type 3 and Type 4 showed close fiber content values. Resin type is the only difference between Type 3 and Type 4 specimens. Polyester resin density is 1.12 g/cm^3 and vinylester resin has 1.05 g/cm^3 density value. Therefore, Type 4 specimens showed higher fiber content values than that of Type 3 specimens. Type 1 and Type 2 specimens have the same glass fiber roving configuration, relatively close fiber content values and only difference between them is the carbon woven roving mats. It is seen that carbon woven roving mats cause to increase the water absorption tendency of the composite materials with close fiber content values. As previously mentioned, resin type is the only difference between the Type 3 and Type 4 specimens and this clearly shows that difference between the water absorption characteristics of the polyester and vinylester resins has a significant role on the water absorption behavior of composite materials.

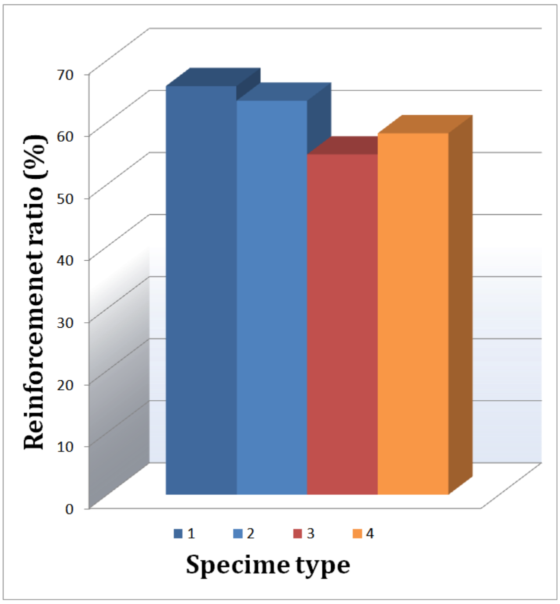


Fig. 8 Reinforcement ratio comparison of the composite specimens.

4. Conclusions

In this study; the water absorption characteristics of glass-carbon fiber reinforced polyester and vinylester pultruded hybrid composite profiles were investigated. The following main conclusions can be drawn from this study:

i. Type 3 glass-carbon fiber reinforced polyester matrix composite materials have the most water absorption tendency than the other specimens and Type 1 glass fiber reinforced polyester matrix composite materials have the second lowest water absorption percentage values. This situation is caused by the void content of the polyester matrix.

ii. It is observed that the water absorption percentage increases as the carbon fibre ratio increases. Voids that are caused by the poor penetration of the polyester resin into the carbon fibers are the reason of the situation.

iii. Type 4 glass-carbon fiber reinforced vinylester matrix composite materials have the lowest water absorption percentage values because of better penetration capability of vinylester. Although Type 3 and Type 4 have the same reinforcement configuration and close fiber content values, it is clearly seen that matrix has the vital role on the water absorption characteristics of composite materials.

iv. Fiber content values, which were obtained from calcinations experiments, clearly showed that carbon woven roving mats cause to increase the water absorption tendency of composite materials with same fiber content; and resin type has the significant role on the water absorption behavior of the composite materials.

Acknowledgements

We would like to thank Pul-Tech FRP Company for their support in production of the composite materials.

This study was supported by TUBİTAK 1505 project with the number of 5150016 and partially based on a PhD. Thesis studies by Önder YEŞİL.

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