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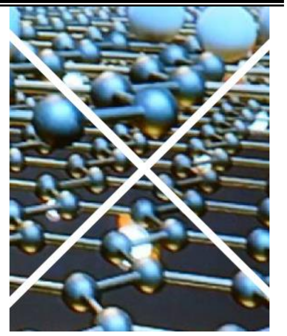

EFFECT OF GLASS FIBER HYBRIDIZATION ON LOW VELOCITY IMPACT BEHAVIORS OF BASALT FIBER REINFORCED COMPOSITE LAMINATES

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Abstract

One of the major drawbacks of fiber reinforced composite laminates is the poor impact damage resistance. Several effective techniques to improve impact damage resistance have been proposed in the literature and among those, fiber hybridization technique takes substantial attention. However, little attention has, as yet, been received for the improvement of impact behavior of basalt fiber reinforced composite laminates by interplyfiber hybridization. The objective of this study is to assess the effect of glass fiber hybridization on Charpy impact behavior of basalt fiber reinforced composite laminates. For this purpose, a series of Charpy impact tests have been performed on composite laminates made of basalt and glass fiber reinforced epoxy resin matrix in five different stacking sequences. Hybrid composite laminates have been fabricated using vacuum assisted resin transfer molding method. The test results show that the absorbed impact energy and impact strength are significantly influenced by the hybridization.

Keyword: Basalt fiber, Glass fiber, Hybridization, Charpy, Impact energy

1. Introduction

In the last few decades, polymer based composites has been gaining a great deal of attention due to demand of use materials with characteristics of the weight saving, higher specific strength and stiffness in engineering applications. They have been now used in many engineering applications ranging from space industry to daily life tools. Even though they are so popular, some deficiencies such as high material costs, very expensive repairs and maintenance have been encountered in the usage of polymer based composites. Furthermore, one of the major drawbacks of fiber reinforced composite laminates is the poor impact damage resistance. Several effective techniques such as nanoparticle enhancement, fiber hybridization, and different designs [1-3] have been developed for eliminating disadvantages of composite laminates. Amongst these options, fiber hybridization considering change in behaviors of reinforcement which is the fundamental load bearing component of composite laminates has been considered as an attractive way.

Several studies devoted to low velocity impact properties of composite laminates are present in the literature [4-9].However, limited number of literature regarding the fiber hybridization influences on the impact and mechanical characteristics of composite laminates are seen [10-12]. Najafi [13] examined the Charpy impact behaviors of hybrid composite laminates. The samples were prepared for various weight ratios of basalt and carbon fibers as 1:0, 0.83:0.17, 0.68:0.32, 0.61:0.39, 0.34:0.66 and 0:1, respectively. In hybrid samples, maximum impact toughness was found to be 219 kJ/m^2 from 0.83:0.17 weight ratios of fabrics. Bozkurt et al. [14] investigated the effects of hybridization on the basalt/aramid fiber reinforced composite laminates. When the basalt fiber/matrix layer was at the impacted surface, the hybrid laminates exhibited lower impact energy due to the restriction in deformation of aramid layers. Ramesh et al. [15] conducted a study on the hybridization of sisal fiber, jute fiber and glass fiber. The results indicated that the incorporation of sisal–jute fiber with GFRP can improve the properties and used as an alternate material for glass fiber reinforced polymer composites. Behnia et al. [16] conducted a study devoted to influences of the stacking sequences and notch angle on the Charpy impact properties of hybrid composites. The results showed that the hybridization can enhance the mechanical performance of composite materials. Alsaadi [17] studied on the hybridization effects of S-glass on Charpy impact characteristics of carbon/aramid fiber reinforced composite laminates. He stated that use of S-glass layers instead of hybrid carbon/aramid layers exhibited the decreasing in the deformation level especially for hybrid carbon/aramid impact side in addition to improve the impact strength of the hybrid composite. Enfedaque et al. [18] examined the glass fiber hybridization on carbon fiber reinforced composites subjected to low velocity impact loading. Glass hybridization resulted with increase up to 10% and 25 % in the maximum load and energy dissipation, respectively. Santhosh et al. [19] investigated E-glass fiber hybridization on the mechanical characteristics of Kevlar and basalt fiber reinforced composite laminates. Differently our study, E-glass was used for hybridization material and hybrid samples were configured sequentially only as $(K\text{-}G\text{-}K\text{-}G\text{-}K\text{-}G)_S$ and $(B\text{-}G\text{-}B\text{-}G\text{-}B\text{-}G)_S$. The laminates of Kevlar/glass exhibited higher impact energy absorption and crack propagation resistance than basalt/glass fiber reinforced laminates.

So far, extensive number of scientific works has been devoted to investigate impact behaviors of composite laminates and most of them have focused on the composites that reinforced with a single fiber type.

Relatively small number of studies has been carried out to assess the impact properties of hybrid fiber reinforced composite laminates. To our knowledge, no work has been reported on Charpy impact behavior of glass/basalt hybrid fiber reinforced composite laminates with symmetrical configuration.

The innovation of this study is to experimentally assess the Charpy impact behavior of basalt fiber reinforced composite laminates with the employment of glass fiber hybridization. To this aim, hybrid and non-hybrid fiber reinforced composite laminates of glass and basalt fibers were fabricated using vacuum assisted resin transfer molding technique. The impact tests were carried out by means of a Charpy impact tester equipped with a 15 J hammer. By comparing the performance of the hybrid and non-hybrid composites, it was displayed that the impact performance of basalt fiber reinforced composite can be tailored with the glass fiber hybridization.

2. Materials and Methods

2.1. Sample Fabrication

Basalt fabric with 300 g/m^2 areal density, is an eco-friendly material obtained from molten basalt rocks in volcanic regions, was procured from Tila Kompozit company, Turkey. S-glass fiber reinforcement with an areal density of 200 g/m^2, epoxy resin (MOMENTIVE MGS L285) and hardener (MOMENTIVE MGS H285) was supplied from Dost Kimya company, Turkey. The matrix component of laminates consists of the resin and hardener mixture with a stoichiometric weight ratio of 100:40, respectively. The thickness, naming and density information of the non-hybrid laminates (G_6 and B_6) and hybrid laminates (G_5B_1, G_4B_2, G_3B_3, G_2B_4 and G_1B_5) were given in Table 1. Density values were found from the ratio of the measured mass and dimensions.

Table 1. The naming, thickness and density information of the composite laminates.

Sample	Naming	Thickness (mm)	Density (g/cm^3)
$(G_6)_S$	GFRP	2.45	1.414
$(G_5B_1)_S$	H1	2.23	1.712
$(G_4B_2)_S$	H2	2.21	1.674
$(G_3B_3)_S$	H3	2.12	1.664
$(G_2B_4)_S$	H4	2.12	1.660
$(G_1B_5)_S$	H5	2.09	1.670
$(B_6)_S$	BFRP	2.05	1.685

All laminates consist of 12 number of fabric layers with (0°/90°) fiber orientations in each one. Two non-hybrid fabric materials (basalt/epoxy and glass/epoxy) were hybridized at five different stacking sequences, as shown in Fig. 1, to examine effectively of hybridization impression. The stacking sequences of laminates were started with basalt fiber/epoxy laminate and were ended with glass fiber/epoxy laminate, by the replacement of inner 2, 4, 6, 8, 10, and 12 basalt fabric layers.

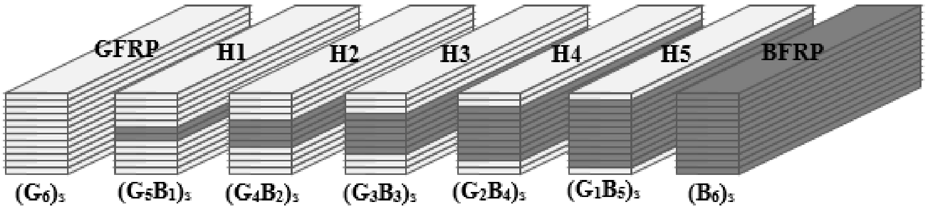


Figure 1. Stacking sequences of glass and basalt fabric layers.

The laminates having 250 mm x 300 mm dimensions were fabricated by vacuum assisted resin transfer molding (VARTM) technique as seen in Fig. 2. The fabrics were firstly put on the process table. Then, necessary preparations such as application of peel ply and resin distribution film were performed to provide closed environment. Prepared resin was impregnated from one end of the system. After whole laminate was wet, the closed system was exposed to 700-mmHg vacuum process for 8 hours. Lastly, curing procedure was conducted at room temperature. After fabrications, CNC router was used to cut Charpy samples with required dimensions.

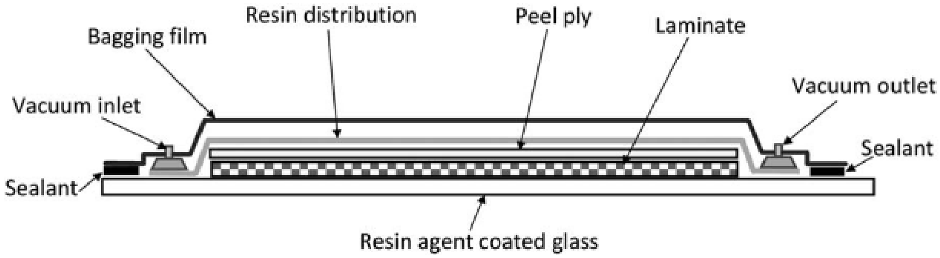


Figure 2. Schematic illustration of vacuum assisted resin transfer molding [11]

2.2. Charpy Impact Test

Charpy impact experiments in accordance with ISO 179/92 standard [20] were performed to investigate the effects of fiber hybridization on low velocity impact characteristics, in terms of energy absorption and impact toughness, of the composite laminates. A Köger 3/70 Charpy test machine with an energy measuring capacity of 15.0 J shown in Fig. 3 was employed for all experiments. The samples were prepared as unnotched and notched types for the flatwise and edgewise impact loadings, respectively.

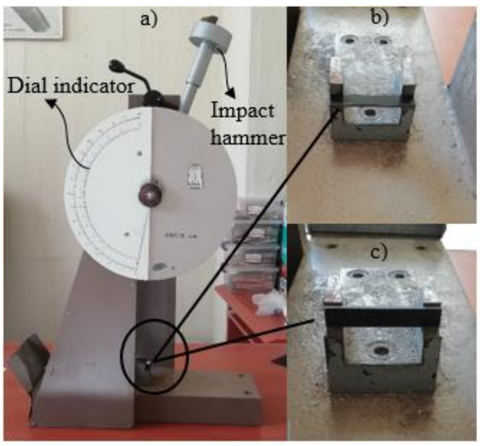


Figure 3.a) Köger 3/70 Charpy impact tester, b) edgewise placement, c) flatwise placement

Impact energy, E was directly measured from the differences of potential energies of pendulum before, E_a and after, E_b impact event as seen in Fig. 4.

$$E = E_a - E_b \quad (1)$$

Impact toughness, a_{cu} which is the absorbed energy per unit area, was calculated from Eq. (2):

$$a_{cu} = E/(bh) \quad (2)$$

where b and h are the thickness and width of the samples, respectively.
At least, five numbers of samples for each configuration were tested to ensure experimental reliability. The dimensions of Charpy samples for flatwise and edgewise loadings were presented in Fig. 5.

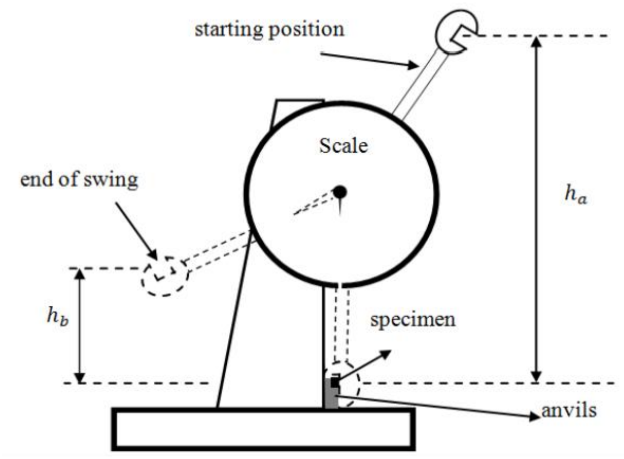
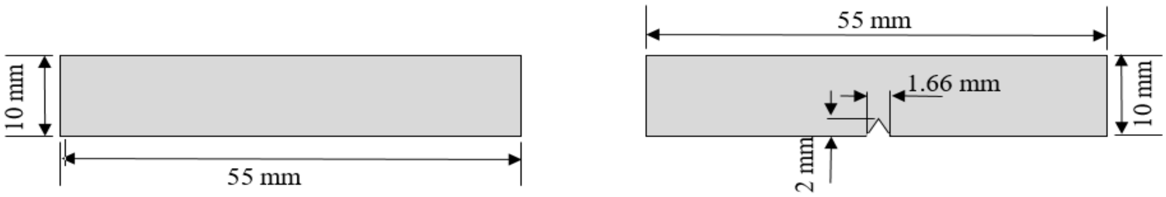


Figure 4. Schematic illustration of Charpy impact test



a) b)

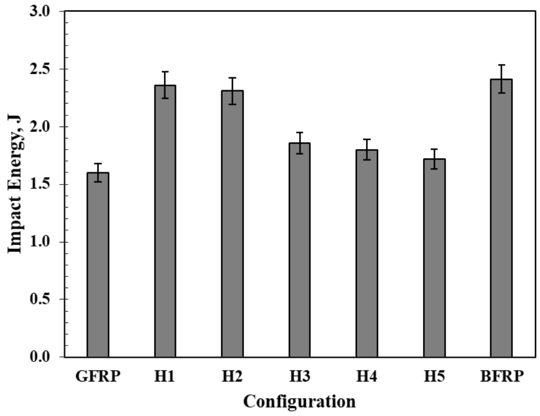
Figure 5. The dimensions of Charpy samples; a) unnotched for flatwise loading, b) notched for edgewise loading

3. Results and Discussion

The absorbed energy and impact toughness of the unnotched samples subjected to flatwise impact loading were presented in Fig. 6. The non-hybrid basalt and the non-hybrid glass fiber reinforced composite laminates were also tested to comparatively scrutinize their impact performance and to establish their contribution on the impact performance of hybrid configurations. The energy absorption and impact strength of non-hybrid basalt fiber reinforced composite laminate were 2.41 J and 4.26 kJ/m^2 which are 71.31 % and 78.28 % respectively higher than non-hybrid glass fiber reinforced composite laminate. Similar results were also observed by Lopresto et al. [21], Santulli et al. [22], and Sarasini et al. [23] in the investigation of low-velocity impact properties under different impact energies. Sarasini et al. [23] also reported that at low impact energies (5 J and 12.5 J) a slight superiority for basalt fiber reinforced laminate is found whereas the difference is not differing much. However, it was marked that at high impact energy (25 J), basalt fiber reinforced composite laminate display remarkable performance relative to the glass fiber reinforced composite laminate. The damage progression of test specimens, shown in Fig. 8, was examined to figure out the difference in energy absorption characteristics of BFRP and GFRP laminates. Fiber failure in the form of fiber pull out together with matrix crack initiation was viewed at the back surface of BFRP.

It was also seen that, in comparison to GFRP, the ductile structure of BFRP leads to more bending in the form of V-shaped geometry formation which point out a large amount of plastic deformation. On the other hand, relatively localized damages in the form of fiber breakage and matrix cracks as contrasted with white color were observed at a small region near around the impacted zone for the GFRP samples. This damage form can be viewed as the result of stiffer and brittle structure of glass fiber reinforced composite laminate which leads to absorption of impact energy at a small region by eliminating the dispersion of impact load to wider regions. Santulli et al. [22] noted that basalt fiber reinforced composite laminate has better damage tolerance capability than glass fiber reinforced composite laminate. The absorbed impact energy and impact strength values of unnotched hybrid composites were found between those of non-hybrid GFRP and BFRP composites. H1 hybrid laminate showed the highest impact energy (2.36 J) and the impact strength (4.09 kJ/m2). The H5 laminate has the lowest impact energy (1.72 J) and impact strength (3.08 kJ/m^2) which are 37.2 % and 24.7 % less than those of the H1 hybrid laminate, respectively. It is clearly shown that volume fraction of basalt layers changes the impact energy of hybrid composites. The damage progressions shown in Fig 6 were examined to analyze the differences in absorbed impact energy of the hybrid composite laminates. At back surfaces of impact point, all hybrid composites displayed matrix cracking, fiber breakages and delamination as the impact damages. Comparing to the non-hybrid GFRP laminate, all hybrid laminates displayed more bending in the form of V-shaped geometry formation. With the increase in basalt fiber volume fraction, there was a decrease in the surface amount of matrix crazing region while the damage in the form of fiber breakage and fiber pull out showed relatively increase in region near around the impacted zone. Also, hybrid composites exhibited delamination between glass and basalt layers and the degree of delamination was increased with the increase in basalt fiber content. It can be attributed to difference in nature of basalt fiber and glass fiber. The ductile basalt layers tend to exhibit more deformation under the impact, however, the stiff glass layers at outer surfaces tend to inhibit higher bending. This forces the formation of delamination between basalt and glass layers and with the increase in number of basalt layers the interfacial force between the basalt and glass fiber layers are formed at the outer layers which exhibited higher values. Weak adhesion between basalt and glass layers can also be considered as another factor for the delamination. At this point, the decreases in hybrid laminates with the increase in number of basalt layers can be viewed as the result of delamination at the outer surfaces which cause premature failure, leading to less energy absorption.

Figure 7 presents the impact energy and impact toughness characteristics of notched composite laminates subjected to edgewise impact loading. Negative effects as deteriorations were detected in hybrid configurations, but the trend was almost same with the unnotched samples. The worse response of hybrid samples compared to non-hybrid ones can be explained weak interfacial adhesion between glass and basalt fabrics. This situation were increasingly seen when basalt fabrics were spreading from inner layers to outer of the laminates. The maximum values in terms of energy absorption and impact strength were obtained from non-hybrid basalt fiber reinforced composite laminates with 3.13 J and 27.71 kJ/m^2. H1 configuration with 2.52 J and 20.61 kJ/m^2 in hybrid laminates showed the 23.77% and 18.9% better results than H5 for the energy and strength, respectively.



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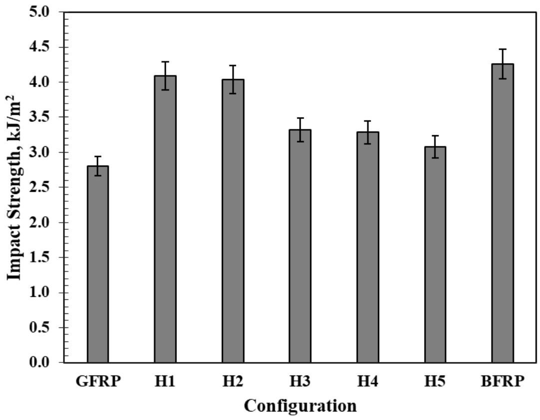
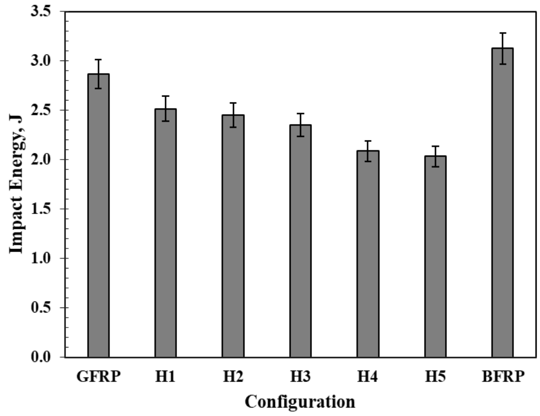


b)

Figure 6. Impact responses of unnotched samples subjected to flatwise loading; a)impact energy, b) impact strength

The damage shapes and failure modes of each configuration were given in Figure 8. The combination of matrix cracking, delamination and fiber breakage were detected on all impacted samples. Basalt fiber reinforced laminate showed the fiber pull out due to higher energy absorption resulted with severe impact. The appearance of hybrid samples after impact showed the easy destruction takes place on samples since weaker bounds between layers.



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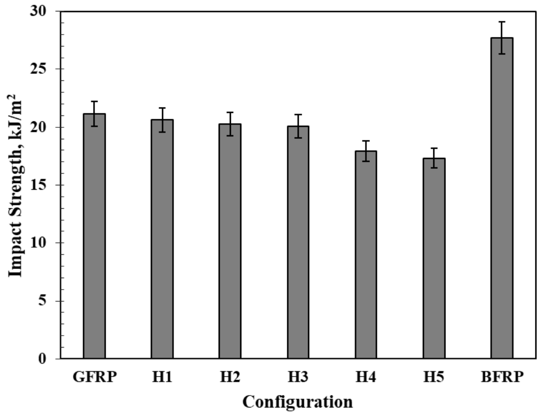

b)

Figure 7. Impact responses of notched samples subjected to edgewise loading; a)impact energy, b) impact strength

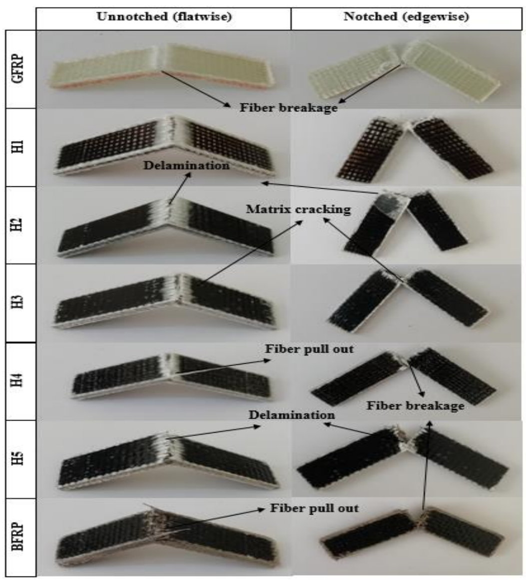

Figure 8. Damage shapes and failure modes of impacted samples

4. Conclusions

In this study, effects of glass fiber hybridization on the low velocity impact behaviors of basalt fiber reinforced composite laminates were investigated. Prepared samples with unnotched and notched structures for flatwise and edgewise loadings, respectively, were impacted on Charpy test machine. Deteriorations in hybrid samples were detected since weak interfacial adhesion between layers caused from ability to fiber debonding. Non-hybrid basalt fiber reinforced composite laminates showed the best impact energy and impact strength characteristics not only for notched configurations but also for unnotched ones. For hybrid samples, H1 or $(G_5B_1)_s$ stacking sequences had the better characteristics than other hybrid ones. The maximum values of unnotched hybrid samples, in terms of energy absorption and impact strength, were obtained from H1 configuration as 2.36 J and 4.09 kJ/m^2 which were 37.48 % and 32.86% higher than H5.Furthermore it showed the 23.77% and 18.9% better results than H5 for the energy and strength, respectively, in samples subjected to edgewise impact loading. The combination of matrix cracking, delamination and fiber breakage were seen as failure modes in mostly. In conclusion, hybridization of basalt and glass fibers was not improved the composite laminates, and so not recommended for related applications.

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