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Research Article

LOW VELOCITY IMPACT BEHAVIORS OF BASALT/EPOXY REINFORCED COMPOSITE LAMINATES WITH DIFFERENT FIBER ORIENTATIONS

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ABSTRACT

The current study aims to explore the effects of fiber orientation angle on the low velocity impact behaviors of the basalt fiber reinforced composite laminates. Samples with four different orientation angles (0º/90º, 15º/-75º, 30º/-60º and 45º/-45º) fabricated by vacuum assisted resin transfer molding have being tested on the Charpy impact test machine. Furthermore, failure modes of notched/unnotched samples subjected to impact loadings in the flatwise and edgewise directions have been examined to detailly understand fracture behavior. The results showed that the fiber orientation angle has substantial effects on the energy absorption capability and impact toughness of the samples. The increment in fiber orientation angle was led to increases in impact energy and toughness, and the reduction in impact damage. The best values as 3.07 J and 34.82 kJ/m^2 for impact energy and impact toughness, respectively, are obtained from the notched samples in edgewise impact loading that having (45º/-45º) fiber orientation angle. Almost all of the samples exhibited failure modes as matrix fragmentation, delamination, fiber cracking and fiber pull-out, respectively. The most destructive results were observed as laminate fracture on the samples having (0º/90º) fiber orientation angle.

Keywords: *Basalt Fiber, Charpy, Fiber Orientation Angle, Energy Absorption, Impact Toughness*

1. INTRODUCTION

With the awareness of industrialization that is growing faster than ever on a global scale, engineers and scientists are strictly working in many industrial fields to facilitate life and meet the increasing consumption demands of humans. As a result of these efforts, materials science has been making great progress by persistently dealing with the development or derivation of new materials in terms of affordability, productivity and design flexibility compared to the conventional engineering materials. In this context, polymer based composite materials by exhibiting higher specific strength and durability, longer service life and fatigue behavior compared to the classical metallic materials (Zhong & Joshi, 2015) have been derived. The ease of production, tailorability, resistance to corrosion, better damping behavior and excellent fatigue resistance are also some of the other advantages of composite materials.

Polymeric composites are composed of a reinforcement phase, generally in the form of fiber or particle, and a matrix phase. Due to their superior mechanical and dynamic performance, fiber reinforced polymeric composites have found application areas in a wide variety of industry fields including domestic, sports, transportation, military and aerospace industries. Carbon fiber with its high specific strength and specific stiffness, and the glass fiber with its high chemical resistance, impact toughness and low cost, have become the most widely used fiber types in the polymeric composites. Despite all their good properties, the search for new promising fiber types, in terms of organic, inorganic, synthetic or natural, that do not possess the weaknesses of carbon and glass fibers are also continued.

In today's world, the use of natural materials in engineering applications has an increasing trend to meet the stringent environmental regulations enforced by public policies. In that sense despite its wide use in other fields, the use of basalt as fiber reinforcement in polymeric composites are relatively new compared to glass and carbon fiber (Jamshaid *et al.*, 2017). Basalt, obtained from molten volcanic rocks, is an eco-friendly, natural, harmless and recyclable material. Furthermore, with its considerable properties such as good mechanical strength, non-flammable, high temperature resistance, biological stability, and high resistance to chemicals, have been attracted the attention of the researchers. In the literature, there are many studies that investigated the physical, mechanical and dynamic properties of basalt fiber reinforced polymeric composites (Amuthakkannan *et al.*, 2013; Zhang *et al.*, 2012;, Botev *et al.,* 1999, Czigany *et al.*, 2008; Colombo *et al.*, 2012, Demirci *et al.*, 2014; Bozkurt *et al.*, 2016; Bozkurt *et al.*, 2018; Sim & Park, 2005). Elmahdy *et al*. (2019) examined the effect of strain rate on the tensile characteristics of woven basalt fiber reinforced composite laminates using a split Hopkinson tension bar. They stated that poison's ratio, stiffness, tensile strength and tensile strain of the samples increased with higher strain rate for both warp and fill directions. Amuthakkannan *et al*. (2013) studied the tensile, flexural and impact properties of short basalt fiber reinforced polymer composites and showed that the length of basalt fiber has significant effect on tensile, flexural and impact properties together with the fiber weight fraction. Zhang *et al*. (2012) examined the variation in tensile, flexural, impact and fracture behaviors of basalt fiber reinforced poly(butylene succinate) composites with respect to basalt fiber content. An increase in tensile, flexural and thermal properties with an increase in basalt fiber loading up to 15vol% were reported. Botev *et al*. (1999) assessed viscoelastic properties of untreated short basalt fiber reinforced polypropylene composites. Deterioration in tensile and impact properties of PP matrix were shown with the inclusion of untreated short basalt fiber reinforcements. However, after the addition of poly(propylene-g-maleic anhydride) significant increases in those properties were revealed. Zhao *et al*. (2019) researched the effect of temperature on the static and tension-tension fatigue properties of basalt fiber reinforced polymers. The life time, stiffness degradation, displacement behaviors of samples exposed to five different temperature environment as -20, 0, 20, 40 and 60 °C were investigated. Czigany *et al*. (2008) explored the crack propagation response of basalt fiber reinforced polypropylene composite. The results outlined that basalt fiber reinforcement provides increase in fracture toughness of polypropylene (PP) matrix. Colombo *et al*. (2012) investigated the mechanical properties and fatigue behavior of basalt fiber reinforced composites. Improvements in tensile and compressive strengths were presented as a result of basalt fiber reinforcement. Demirci *et al*., (2014) researched the fracture toughness characteristics of the basalt and glass fiber reinforced having arc shaped samples. Charpy impact experiments were conducted to examine the effects of the different notch depth ratios on the energy characteristics of the samples. Increasing in the considered ratios resulted with the decreasing in impact energy and fracture toughness values. Also, basalt fiber reinforced samples showed the better features than glass ones. Less *et al*. (2019) carried out the effects of fiber length and compatibilizing agents on mechanical and thermomechanical behaviors of basalt fiber reinforced polyamide composites. It was found that the stiffness of long fiber basalt composites are much higher. Bozkurt *et al*. (2016) examined the effects of the different fiber orientation angle on the vibration and damping behaviors of the basalt fiber reinforced composites. They stated that the higher fiber orientation angle resulted in decrease of natural frequency and increase of damping ratios. Subagia *et al*. (2014) conducted a study about the effects of hybridization of basalt and carbon fibers on the flexural characteristics. They pointed out the hybridization process gave the new materials with less cost compared to carbon fiber reinforced samples and comparable flexural strength and improved ductility.

The aim of this work is to investigate the effects of the fiber orientation angle on the energy absorption characteristics of the basalt fiber reinforced composite laminates. The samples with four different orientation angles ((0º/90º), (15º/-75º), (30º/-60º) and (45º/-45º)) were prepared using the stack of eight basalt fabric layers and subjected to low velocity impact tests. The fracture surface of samples were examined to explore the effect of fiber orientation on fracture mechanism.

2. MATERIALS AND METHOD

2.1. Sample Preparation

The bidirectional basalt fiber fabrics procured from

Tila Kompozit, Turkey, were used for reinforcement component. For matrix system, epoxy resin (MOMENTIVE MGS L285) and hardener (MOMENTIVE MGS H285) which were supplied from Dost Kimya, Turkey, were mixed with a stoichiometric ratio of 100:40 in weight basis, respectively. The physical properties of raw materials were given in Table 1.

Table 1. The physical properties of raw materials

Material	Density	Thickness
Basalt fabric	200 g/m^2	0.17 mm
Epoxy	1.18 g/m^3	-
Hardener	0.94 g/m^3	-

Basalt fiber reinforced composite laminate was fabricated by vacuum assisted resin transfer molding technique (VARTM) seen in Figure 1. The fabric preforms having dimensions of 250 mm x 300 mm were stacked over the mold plate. Then, the fabric stackings were covered by a peel ply to easily remove composite laminates from the mold after the fabrication. A resin distribution medium was placed over the peel ply to ensure a uniform resin system injection to fabric stacks. The resin system was injected into mold structure with the help of vacuum. Following the soak of fabrics, the mold structure was held under 700 mm-Hg vacuum at 40ºC temperature for 8 hours to complete curing process. By the completion of curing, the laminate was left to cool at room temperature for the next 24 hours. The thickness of the laminate, shown in Figure 2, was measured as 1.6 mm. The test coupons were removed from the composite laminates using the CNC router in accordance with ISO 179/92 test standard.

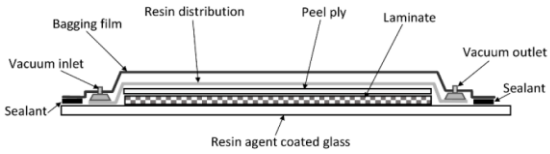


Fig. 1. Vacuum assisted resin transfer molding (VARTM) (Bozkurt *et al.*, 2018)

Fig. 2. Basalt/epoxy fiber reinforced composite laminate

2.2. Low Velocity Impact Tests

Charpy impact tests were performed to determine the effects of fiber orientation angle on the impact energy and toughness characteristics of the basalt fiber reinforced composite laminates. ISO 179/92 standard was used for reference guide for the sample preparation and testing procedure. A Kögel 3/70 Charpy impact tester with 15.0 J impact energy capacity, shown in Figure 3(a), were employed for the experiments. The samples having 55 mm x 10 mm in length and width were prepared as notched and unnotched configurations subjected to edgewise and flatwise impact loading as seen in Figure 3(b) and 3(c), respectively. At least five samples were tested to ensure experimental reliability.

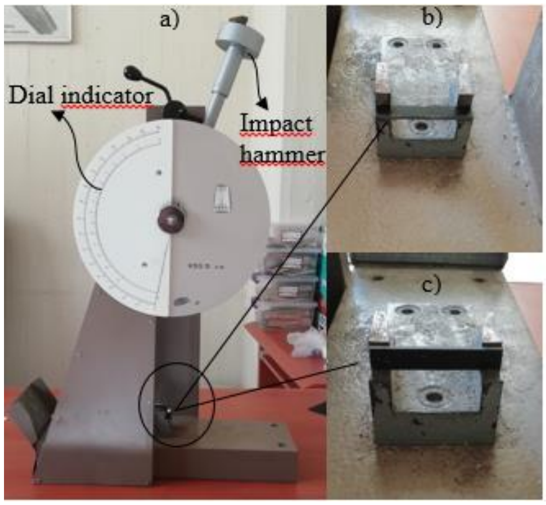


Fig. 3. a) Köger 3/70 Charpy impact tester, b) edgewise impact, c) flatwise impact

Impact energy, E, was directly measured from the dial on the machine using potential energy lost after breaking the sample as shown in Eq. (1).

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

where E_a and E_b represent the pendulum energy before and after impact event, respectively. 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. Figure 4 also presents an illustration of Charpy impact test machine.

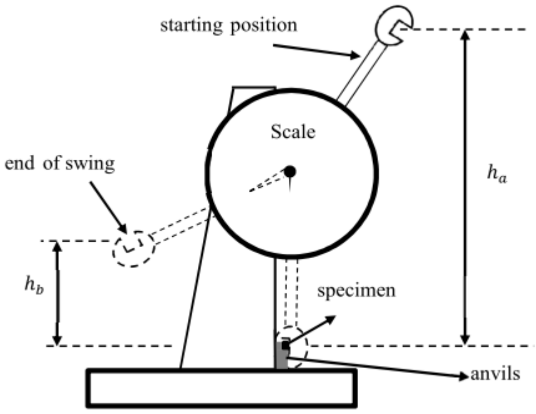


Fig. 4. The schematic illustration of the Charpy impact test

3. RESULTS AND DISCUSSIONS

Charpy impact test is a practical and an economic method to comparatively determine the failure characteristics of composite laminates (Bozkurt *et al*., 2018). In this section, the results of the Charpy impact tests in terms of the energy absorption capability, impact toughness and impact damages were summarized to detailly analyze the influence of the fiber orientation on low velocity impact response. The impact damages were also examined by taking photos with a manual camera to monitor fracture characteristics of basalt fiber reinforced composite laminates.

Impact energy and impact toughness values of the samples subjected to the impact loadings in the flatwise and edgewise directions were presented in Figure 5 and Figure 6, respectively. The edgewise impacted samples had the better response than flatwise impacted ones due to exhibition of more resistance behavior in edgewise direction. This appears to be compatible with the findings of Dhar's study (Dhar *et al*., 2018) who reported that higher fracture energy is necessary for the crack initiation phenomenon in edgewise direction of composite laminates. Furthermore, laminate impact position had the larger width in edgewise orientation as reported in literature (Dhar *et al*., 2019).

It was proved that fiber orientation angle had the significant effects on laminates, experimentally. The results showed that an increase in fiber orientation angle resulted with an increase in both absorbed energy and the impact toughness of the material. This can be explained by the easier pull out failure mode (Flasar, 2018) happening in smaller orientations. Additionally, this situation may be explained by the findings of a literature study (Sharma *et al*., 2019) indicating the first cracking energy was higher for composite laminates with (45º/-45º) fiber orientation angle accumulating lower impact damage. For the notched samples, the maximum absorbed energy and impact toughness as 1.73 J and 3.09 kJ/m^2 was obtained from the (45º/-45º) fiber orientation angle. When compared to (0º/90º) fiber orientation, 22.7% and 23.1% increase were achieved in impact energy and toughness values, respectively.

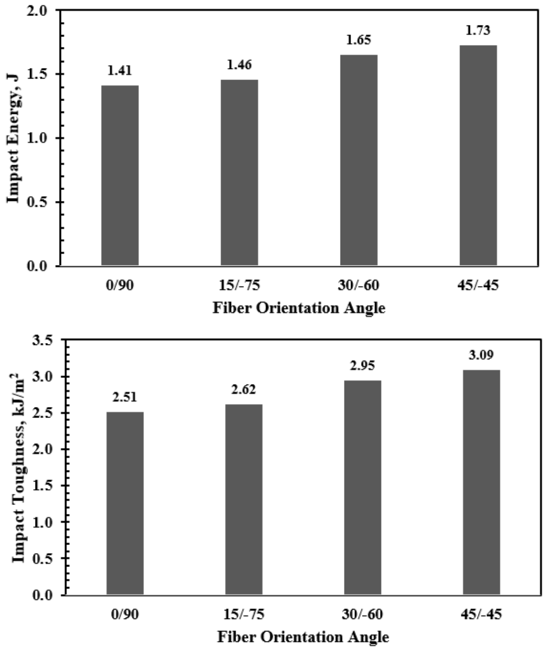


Fig. 5. Absorbed energy and impact toughness of the unnotched samples subjected to flatwise impact loading

With the increase in fiber orientation angle, the samples subjected to edgewise impact loadings showed an increasing trend, in impact energy and toughness, like the flatwise impacted samples. Compared to (0º/90º) fiber orientation, the (45º/-45º) fiber orientation angle exhibited 2.03 times higher values in both impact energy and toughness. Maximum absorbed impact energy and impact toughness values were found as 3.07 J and 34.82 kJ/m^2.

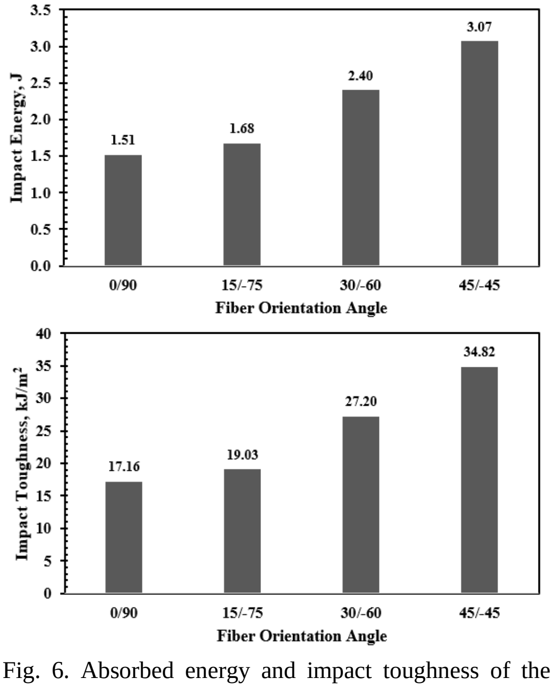
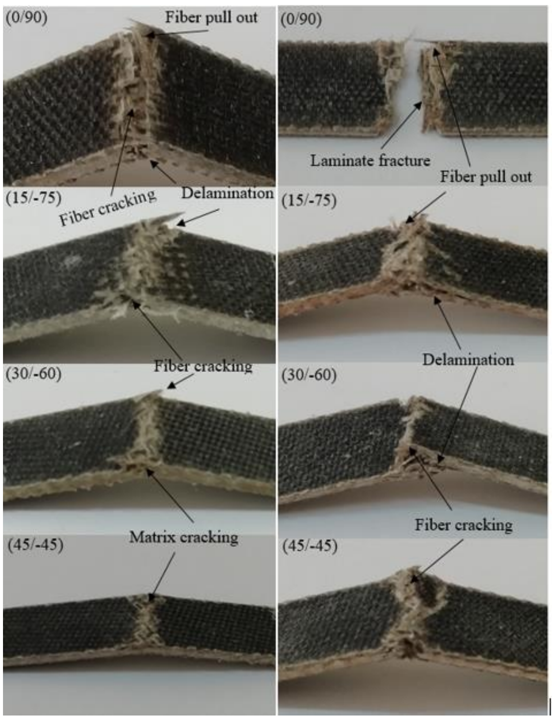


Fig. 6. Absorbed energy and impact toughness of the notched samples subjected to edgewise impact loading

The failure modes and damage types of the flatwise and edgewise impacted samples after Charpy impact tests were given in Figure 7(a) and Figure 7(b), respectively. It was obvious that higher fiber orientations showed the less damage. This is explained by the higher resistance to first crack initiation formation in damaged areas of the samples. Also, edgewise impacted samples showed more destruction compared to flatwise impacted ones since required higher fracture energy.

It was observed that the failure modes were started with matrix cracking and followed by delamination, fiber breakage and fiber pull out as the fiber orientation angle decreased in unnotched samples. However, failure mode as fiber breakage was triggered by matrix cracking and delamination caused from matrix-fiber decomposition, especially in (15º/-75º) and (30º/-60º) fiber orientations of edgewise-notched samples. The sample of (0º/90º) fiber orientation showed matrix fragmentation followed by fiber breakage, causing irregular fiber placement on the damage surface. An irregular matrix cracking was shown for the sample of (0º/90º) fiber orientation.



(a) (b)

Fig. 7. Damage types for; (a) unnotched samples subjected to flatwise impact, (b) notched samples subjected to edgewise impact

4. CONCLUSIONS

In this work, the effect of fiber orientation angle on the low velocity impact behavior of the basalt fiber reinforced composite laminates were experimentally investigated. The composite samples having four different orientation angles (0º/90º, 15º/-75º, 30º/-60º and 45º/-45º) were prepared using VARTM technique and subjected to Charpy impact tests to determine the impact energy and toughness. The unnotched and notched samples were subjected to flatwise and edgewise impact loadings, respectively. An increase in fiber orientation angle resulted with the increase in energy absorption and impact toughness for all samples. Maximum increases in impact energy and impact toughness were obtained from (45º/-45º) fiber orientation as 22.7% and 23.1% for notched samples. Also, unnotched samples with (45º/-45º) fiber orientation exhibited 2.03 times of energy absorption and toughness values of the samples having (0º/90º) fiber orientation. It was shown that the failure modes were started with matrix cracking and followed by delamination, fiber breakage and fiber pull out as the fiber orientation angle decreased. As seen in the results, the effect of fiber orientation on energy absorption characteristics was very significant. It can be a reference guide for in the usage of related applications.

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