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Investigation of the mechanical properties of carbon and basalt fiber laminated hybrid epoxy composites

Karbon ve bazalt elyaf tabakalı hibrit epoksi kompozitlerin mekanik özelliklerinin incelenmesi

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Abstract

Although carbon fiber reinforced epoxy composites are used in a wide area on structural components, there is a need to increase the toughness of these materials due to their brittle structure. For this purpose, hybrid composites were produced with basalt fibers, which show more ductile behavior than carbon fibers and the mechanical features of the composites were investigated. Layered composites were produced by vacuum infusion method. The effects of hybridization type on mechanical features were studied by producing composites as pure carbon, pure basalt, intercalated and sandwich type hybrids. The mechanical behaviors of the specimens were evaluated by tensile, flexural and Charpy impact tests. At the end of the tests, the mechanical values of the hybrid laminate composites were found between carbon and basalt composites. Adding basalt fiber to carbon fiber, the tensile strength, flexural strength and modulus of elasticity of the composites decreased. However, the impact performance of carbon fiber composites improved with adding basalt fiber.

Keywords: Carbon fiber, Basalt fiber, Laminate composites, Mechanical properties.

Öz

Karbon fiber katkılı epoksi kompozitlerin yapısal komponentlerde geniş bir alanda kullanılmalarına karşılık gevrek bir yapıya sahip olmaları nedeniyle bu malzemelerin tokluklarını arttırmaya gereksinim duyulmaktadır. Bu amaçla karbon fiberlere göre daha sünek davranış gösteren bazalt fiberler ile hibrit kompozitler üretilerek kompozitlerin mekanik özellikleri incelenmiştir. Tabakalı kompozitler vakum infüzyon yöntemi ile üretilmiştir. Kompozitler saf karbon, saf bazalt, ardışık ve sandviç tip hibrit olarak üretilerek hibritleşme türünün mekanik özellikler üzerindeki etkileri çalışılmıştır. Kompozitlerin mekanik özellikleri çekme, eğilme ve Charpy darbe testleri ile karakterize edilmiştir. Testler sonunda hibrit kompozitlerin mekanik değerleri karbon ve bazalt fiberler arasında çıkmıştır. Karbon fibere bazalt fiber ilavesi ile kompozitlerin çekme dayanımı, eğilme dayanımı ve elastisite modülü azalmıştır. Bununla birlikte bazalt elyafın eklenmesi ile karbon fiber kompozitlerin darbe performansları iyileşmiştir.

Anahtar Kelimeler: Karbon fiber, Bazalt fiber, Tabakalı kompozitler, Mekanik özellikler.

1 Introduction

Carbon fiber reinforced epoxy composites have been using in a wide variety of fields, especially in the automotive, aerospace and transportation industries, because of their high specific strength, and specific modulus and high corrosion resistance properties [1],[2]. But, the brittle structure of carbon fiber materials has disadvantages under impact loads. Some methods are used to increase of the toughness of carbon fiber composites to improve the fiber-matrix interface by adding micro and nano additives to the resin, to toughen the resin using liquid rubber or thermoplastic resin, and to produce hybrid composites by using three-dimensional reinforcement, surface modification of the fibers and using more ductile fibers with carbon fiber [3]-[8]. The most efficient method is to produce hybrid composites using fibers that show greater elongation against damage [9]-[11]. The performance of hybrid composites depends on fiber type, orientation angle, hybridization rate, fiber-matrix interface properties [12]. Glass fiber is the most utilized fiber in the hybridization of carbon fiber composites, both more ductile and more economical than carbon fiber [13]-[21]. Today, usage of basalt fiber has begun to increase which is more environmentally friendly and economical as an alternative to glass fiber. Basalt fibers are obtained by melting basalt rocks at temperatures of approximately 1500 °C -1700 °C and are similar to glass fibers with the composition of SiO_2, MgO, CaO, Al_2O_3, K_2O, Na_2O, MnO, TiO_2, Cr_2O_3 and P_2O_5. In addition to being an environmentally friendly and low-cost fiber, it is an alternative material to glass fibers in terms of its ability to work at very low (~ -200 °C) and very high temperatures (~800 °C), high chemical resistance and mechanical properties [22],[23].

In this context, Shishevan et al. [24] investigated the low velocity impact properties of carbon fiber composites and basalt fiber composites. Basalt fiber composites with high toughness showed higher impact absorption than carbon fiber composites. Najafi et al. [25] used the carbon/basalt hybrid composites in a phenolic matrix. Bending and charpy impact behaviors were studied. They stated that the impact behaviours of the specimens were improved with adding basalt fiber. Dorigato and Pegoretti [26] investigated bending and charpy impact behaviors by manufacturing the hybrid composites with basalt-carbon and glass-carbon fiber combinations. Impact absorption behaviours of composites improved with adding glass fiber and basalt fiber. They stated that the effects of glass and basalt fiber reinforcements on flexural and impact strengths were very close to each other in the composites. Sarasini et al. [27] investigated the impact behavior of hybrid

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carbon-basalt woven composites. They produced intercalated and sandwich type composites as the basalt fibers outside and carbon fibers inside and they performed impact tests at different impact energies. Sun et al. [28] studied the tensile and flexural features of carbon/basalt hybrid laminate composites. Basalt provided the progressive damage propagation by preventing sudden damage propagation. Subagia et al. [29], studied the layup sequence effect on the flexural behavior of carbon fiber woven and basalt fiber woven laminate hybrids. They concluded that lay up sequence effected the flexural strength and modulus. Higher flexural strength was reached in hybrid composites with outer carbon layers. Chen et al. [30] studied the effects of hybridization rate and fiber type on flexural behavior of hybrid laminate composites which consist of uni-directional carbon/basalt/glass fibers. The highest flexural modulus was obtained in the symmetrical fiber arrangement where the carbons were in the outer layers. Chen et al. [31] studied the impact behavior of hybrid sandwich type composites which consist of woven carbon/basalt/glass fiber and unidirectional basalt fibers. Sandwich composites with carbon fiber in the middle showed the best impact absorption properties. Woven basalt fibers showed better impact resistance than unidirectional basalt fibers. Glass and basalt fibers showed similar behavior against impact.

In this study, carbon fiber and basalt fiber woven reinforced epoxy composites were manufactured by vacuum infusion method and the effect of hybridization type on the mechanical properties was investigated by manufacturing hybrid composites such as carbon composite, basalt composite and intercalated and sandwich type. In this context, tensile test, flexural test and Charpy impact tests were carried out.

2 Materials and methods

Biresin Sika CR80 epoxy resin and Biresin Sika CH 80-2 hardener were used as the matrix material. The epoxy and hardener mixing ratio was 100:30 by weight. Carbon fiber and basalt fiber reinforcements were selected as the woven type with a weight of 200 g/m^2 (Dost Kimya Company). Laminate composites were prepared in 14 layers. Laminate composites are $[C]_{14}$, $[B]_{14}$ as single fiber type and $[C_4B_3]_s$, $[B_4C_3]_s$, $[C_2B_2]_7$, $[B_2C_2]_7$ as intercalated and sandwich hybrid composites with six different types. Composites manufactured by vacuum infusion method. Stacking sequences are given in Table 1.

Table 1. Stacking sequences of composites.

Composite types	Stacking sequences	Thickness (mm)
$[C]_{14}$	●●●●●●●●●●●●●●	3.08
$[B]_{14}$	○○○○○○○○○○○○○○	2.43
$[C_4B_3]_s$	●●●●○○○○○○●●●●	2.94
$[B_4C_3]_s$	○○○○●●●●●●○○○○	3
$[C_2B_2]_7$	●●○○●●○○●●○○●●	2.68
$[B_2C_2]_7$	○○●●○○●●○○●●○○	2.6

● Carbon fiber, ○ Basalt fiber

The vacuum infusion method consists of the following processes respectively: I. Applying a mold release agent to the mold surface, II. Laying the fibers according to the desired fiber order, III. Laying the peel ply on the fibers and the infusion mesh that provides the flow of the resin to the fibers, IV. Covering the fibers with a vacuum bag to provide a vacuum environment, and V. Absorbing the resin into the fibers with the help of a vacuum motor. After the infusion process, the composites are kept under vacuum for 24 hours. Afterward, the composites were removed from the mold and kept in an oven for post-curing at 60 °C for 4 hours. Composite plates were produced as 400 mm X 400 mm. The plates were cut according to the test coupons by the water jet. The vacuum infusion method is shown schematically in Figure 1.

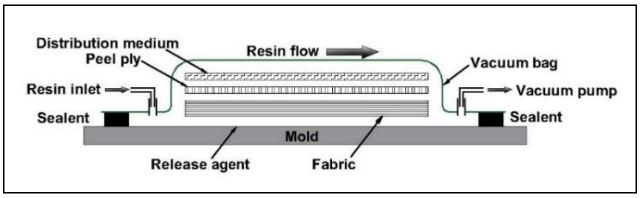

Figure 1. Schematic representation of vacuum infusion method.

Mechanical tests consist of tensile, flexural and charpy impact tests. Tensile tests were performed with a 30 kN capacity DARTEC testing machine with a test speed of 2 mm/min, according to the ASTM D3039 standard. Specimen dimensions were 250 mm X 25 mm. The gauge length was 150 mm. The tab region of specimens were sanded and then glued with metal layers to avoid any damage by the grippers (Figure 2).

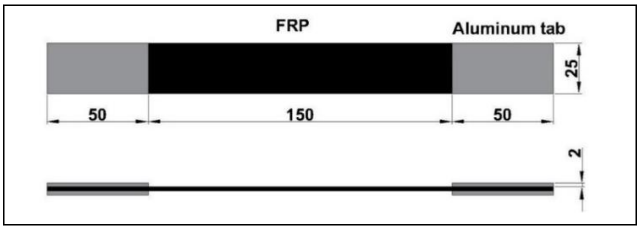

Figure 2. Tensile test specimen size.

Three point bending tests as the flexural tests were performed with a 5 kN capacity SHIMADZU testing machine with the speed of 2 mm/min, according to the ASTM D790 standard. Specimen dimensions were 127 mm X12.7 mm (Figure 3). L is the span distance.

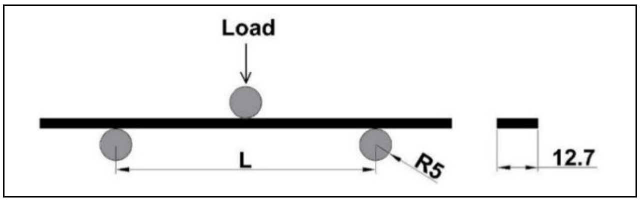

Figure 3. Flexural test specimen size.

Charpy impact tests were carried out according to the ISO 179 Standard with Zwick B5113.300 model pendulum impact tester (15 Joule hammer capacity). Sample dimensions are 80 mm X 10 mm (Figure 4).

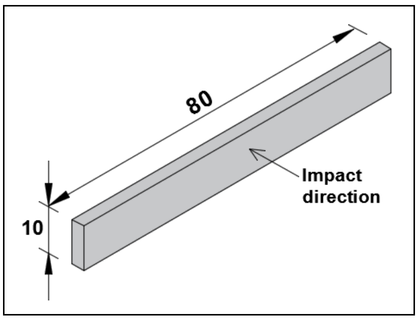

Figure 4. Charpy impact test specimen size.

3 Results and discussions

Figure 5 shows the curves of the tensile tests of carbon and basalt hybrid composites. All curves show a linear behavior. The highest load-bearing ability belongs to carbon fiber. Because of the brittle behavior of carbon fiber, the tensile curve is steeper than other composite structures. The composite consisting of pure basalt has the lowest load carrying capacity. Because of the ductile structure of basalt fiber, it has the highest elongation and shows a horizontal trend. In terms of hybrid composites, composites with outer surface of carbon fiber have higher strength. Composites' tensile strengths decreased with adding basalt. The high-strength carbon fibers in the outer layer absorb the load and transfer it to the basalt fiber. The number of strong fibers determine the mechanical strength of the composites. For this reason, composites with higher number of carbon fibers showed higher tensile strength. On the other hand, intercalated composites showed better strength than sandwich type composites. A similar situation is seen in the literature [28].

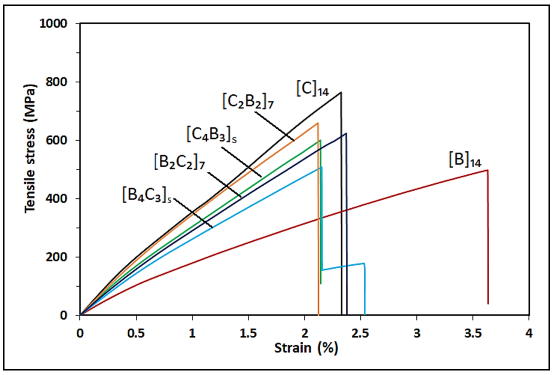

Figure 5. Tensile test curves of composite specimens.

In Figure 6, the tensile strength and elasticity modulus of carbon and basalt fiber composites are given. The highest elasticity modulus belongs to carbon fiber, while the lowest elasticity modulus belongs to basalt fiber. The elasticity modulus of the composites decreases with addition of basalt. Composites with carbon fiber at the outer surfaces have a higher modulus of elasticity among the hybrid composites. As in the tensile behavior, the modulus of elasticity of intercalated sequential composites is higher than sandwich composites. On the other hand, elastic modulus's of composites with more rigid fibers on their outer surfaces is higher.

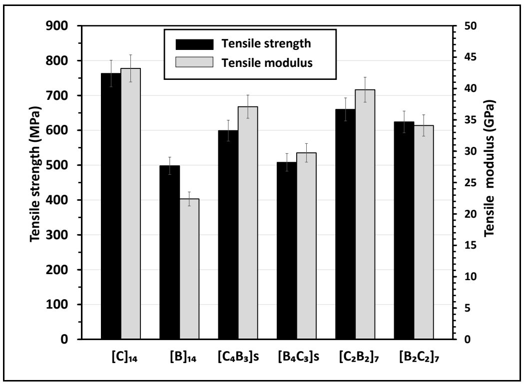

Figure 6. Tensile strength and tensile modulus values of composite specimens.

Flexural load curves of composite specimens are given in Figure 7. Due to the brittle behavior of the carbon fiber, its flexural load curve rises linearly and sudden breakage occurs. Basalt fiber composite has the lowest flexural load bearing capability. In terms of hybrid composites, carbon fibers on the outer surfaces have higher load carrying ability. The more rigid carbon layers absorb the initial load and transmit the load to the basalt fibers [29]. When examined in terms of hybridization type, sandwich type composites with outer surface of carbon fiber have higher load carrying ability than intercalated type composites. On the other hand, when the ductile layers at the outer surface, the importance of the rigid layers distance from the neutral axis to the load bearing capacity has also been seen in the literature [30],[32]. Therefore, flexural performance of $[B_2C_2]_7$ composites is better than $[B_4C_3]s$ sandwich composites.

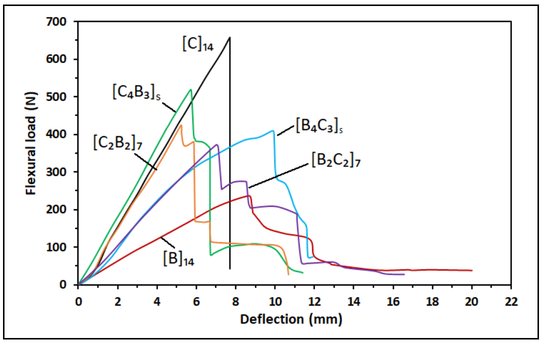

Figure 7. Flexural test curves of composite specimens.

In Figure 8, carbon and basalt composites' flexural strengths and flexural modules are given.

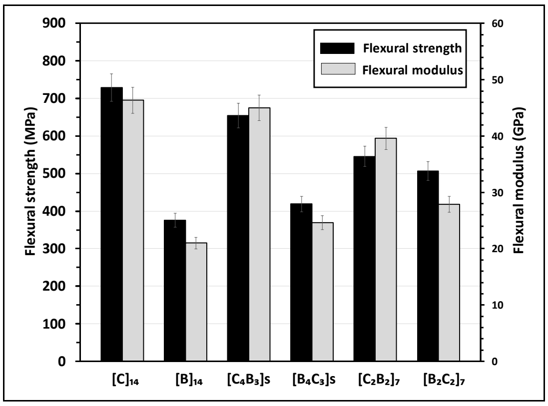

Figure 8. Flexural strength and flexural modulus of composite specimens.

The highest flexural modulus belongs to carbon fiber and the lowest flexural modulus belongs to basalt fiber. The composites' flexural modulus decreases by the addition of basalt. In terms of hybridization type, the flexural strengths and flexural modules of sandwich composites with carbon fibers on the outer surface are higher than intercalated composites. The flexural strength of sandwich composites with outer surface of basalt fibers is lower than intercalated composites. The fact that more rigid layers are on the outer surface increases the load carrying ability. Therefore, by the addition of basalt fiber with low flexural modulus in the outer layers, the load bearing capabilities of the composites decreased. Charpy impact test results of carbon and basalt composite samples are given in Figure 9. The brittle behaviour of carbon fiber causes low impact resistance. Pure basalt fiber has the highest impact strength. Because of the ductile behaviour of basalt fibers, they have high elongation properties against damage. This situation provides high energy absorption capacity to basalt fiber composites. Therefore pure basalt composites performed the best impact strength. By hybridizing carbon fibers with basalt fiber, the impact strength of composites increases with the range of 32% to 59%. Location of basalt fibers at the outer surfaces showed the better impact resistance in the hybrid composites. Similar situations have been seen in the literature [25],[31]. Sandwich type composites showed better impact performance than intercalated type composites as the hybridization type.

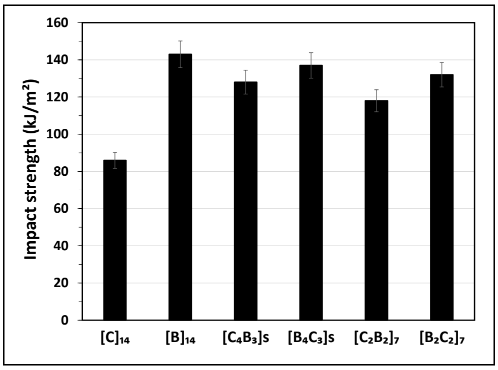

Figure 9. Charpy impact strength of composite specimens.

Figure 10 and 11 show the failures of composite materials after tensile tests top and side view respectively.

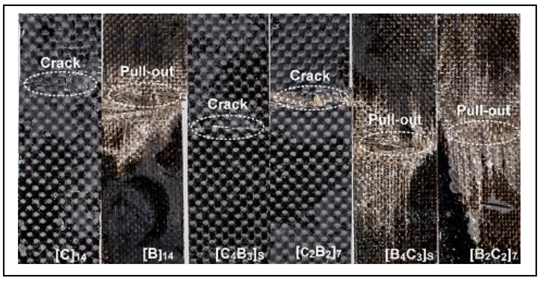

Figure 10. Tensile test failures of composite specimens. (top view).

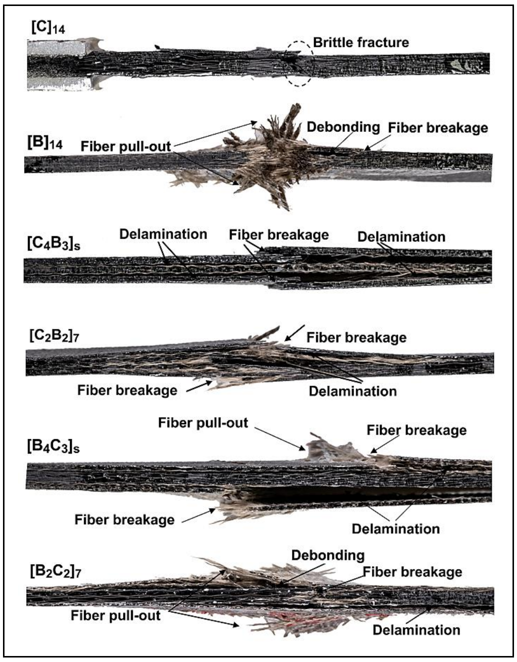

Figure 11. Tensile test failures of composite specimens. (side view).

In tensile test damages, matrix cracking, fiber breakage and delamination failures are seen due to mechanical incompatibilities between different fiber types in hybrid composites [28],[37]. As the damage formation of composites with carbon fiber at the outer surfaces started with matrix cracking, the damage formation of the composites with basalt fiber at the outer surfaces started with the weak bonding of basalt fiber with peeling off the matrix at the increasing load and it caused the fiber pull-out. Due to the brittle behavior of composites consisting pure carbon, a flat structure is observed in the damage regions and the damage is in the form of direct fiber rupture. The damage caused by the ductile behavior of the basalt composites results in the dispersion of the fibers in the fracture zone and also seen in [36]. Delamination is observed between basalt and carbon layers due to different strains and different load carry ability of the fibers. In the transition from carbon fiber to basalt fiber or from basalt fiber to carbon fiber, the difference in elastic modulus and the stress difference caused by the load carrying ability caused the delamination between the carbon and basalt layers. Therefore, the bonding at adjacent interfaces remains weak. A similar situation exists in the literature where hybrid composites are studied [28],[30],[36]. Figure 12 and 13 show the flexural tests failures of composites bottom and side view respectively.

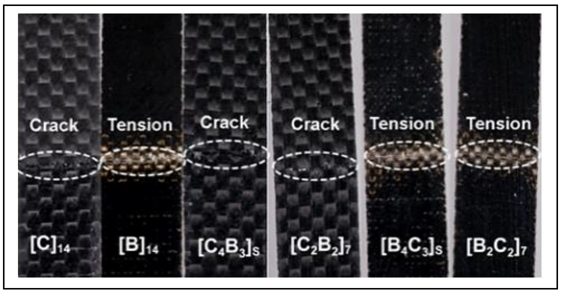

Figure 12. Flexural test failures of composite specimens. (bottom side).

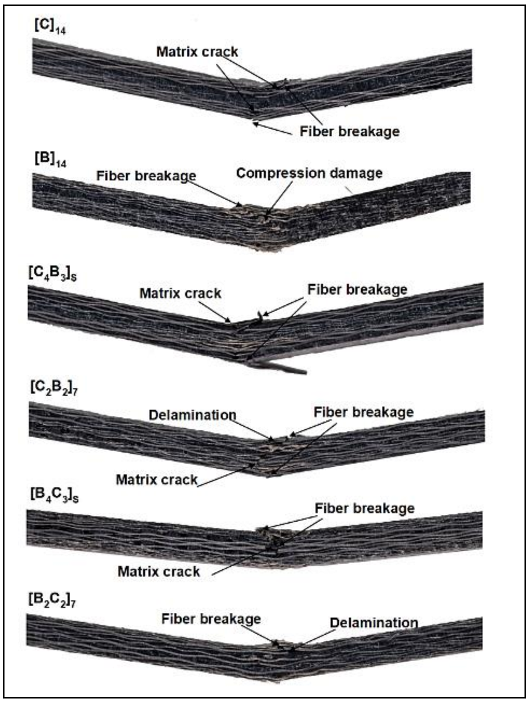

Figure 13. Flexural test failures of composite specimens. (side view).

Laminate composites are encountered compression damage, tensile damage, shear, delamination, matrix cracking and fiber breakages in the flexural tests [29],[30],[33],[38]. High strength and low elongation carbon fibers which wrapped with a brittle epoxy matrix have cracked in the region where the load is applied. A similar situation has been seen in the literature [29]. On the other hand, it has been reported in the literature that cracking occurs with the elongation behavior of high strength carbon fiber bonded with a brittle epoxy matrix [33]. The damage in intercalated type composites with basalt fibers on the outer surfaces is less than sandwich type composites. Basalt fibers, which show lower strength and greater elongation than carbon fibers, show whitening due to stretching of the fibers in the tension surfaces. A similar situation has been seen in the literature [33]. Figure 14 shows the damages of composite materials after impact tests.

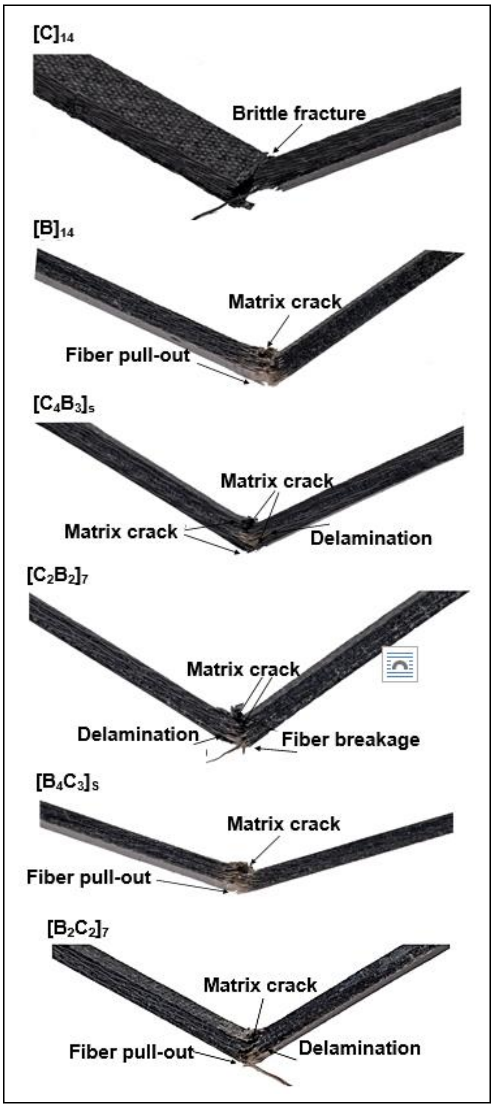

Figure 14. Impact test failures of composite specimens.

Impact behavior of composites depends on fiber type, fiber arrangement, fiber architecture, matrix toughness, impactor geometry and velocity, fiber/matrix hybridization ratio, boundary conditions and environmental conditions [38],[39]. During the pendulum impact tests, damages in the matrix cracking, delamination, fiber-matrix debonding, fiber breakage and fiber pull-out forms occurred in the laminate composites [35],[38]. $[C]_{14}$ composites have a brittle structure, fibers were broken through the thickness and the composite split into two parts. Since direct fracture occurs, energy absorption performance is very low. Due to basalt fibers have a ductile behavior, fibers tend to elongate during the contact with the impactor so the contact time with the impactor was prolonged and basalt fibers have more damaged thus the energy absorption properties of composites improved. In hybrid composites with carbon fiber on outer surfaces, the damage initiation occurred with fiber breakage of carbon ($[C_4B_3]$s and $C_2B_2]_7$). When the basalt fibers at the outer surfaces, basalt fibers were damaged as they absorbing the energy. It is seen in figure 9 that $[B_4C_3]$s composites showed better impact properties than $[B_2C_2]_7$ composites. Matrix crack caused the fiber-matrix debonding and fiber pull out in $[B]_{14}$ and $[B_4C_3]$s composites besides delamination in $[B_2C_2]_7$ composites.

4 Conclusions

Different fiber lay ups with carbon and basalt fibers were prepared and their mechanical behavior was investigated. The results are listed below:

Adding basalt fiber to carbon fiber, the tensile strength, flexural strength and elasticity modulus of the composites decreased.

The tensile strengths, flexural strengths and elasticity modulus of hybrid composites with carbon fibers on the outer surfaces were found to be better than those with basalt fibers on their outer surfaces. With the addition of basalt fiber, the impact strengths of carbon fiber composites improved between an increase of 32% and 59%.

The presence of basalt fibers on the outer surfaces showed the better impact absorption properties than carbon fibers on the outer surfaces. The maximum impact strength in hybrid composites was reached with $[B_4C_3]$s sandwich type composites.

5 Ethics committee approval and conflict of interest statement

"There is no need to obtain permission from the ethics committee for the article prepared".

"There is no conflict of interest with any person / institution in the article prepared"

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