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The Temperature Effects on the Mechanical Properties of Pseudo-Ductile Thin-Ply Unidirectional Carbon-Basalt Fibers/ Epoxy Hybrid Composites with Different Stacking Sequences

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Abstract

This study aims to investigate the temperature effects on the flexural and Charpy impact behavior of thin-ply unidirectional (UD) carbon-basalt fibers/ epoxy hybrid composites. The hybrid composites with three stacking sequences of thin-ply UD carbon fibers and basalt fibers were fabricated using hand lay-up method. The samples of [CB6C], [B2CB2CB2], and [B3C2B3] were prepared where B and C are respectively related to the basalt fibers and thin-ply UD carbon fibers and the numbers illustrate the number of composite layers. The flexural test results indicated that the flexural strength and modulus of samples decreased by increasing the temperature to 130 ºC. However, the results indicated that the position of the thin-ply UD carbon fibers in the laminates had a considerable effect on the properties. By placing the thin-ply UD carbon fibers at the top and bottom sides, the flexural properties improved and the negative effects of temperature reduced, compared with other stacking sequences. The reduction percent in flexural strength of [CB6C], [B2CB2CB2] and, [B3C2B3] were respectively about 4.62%, 8.82%, and 7.73% at temperature of 95 ºC. Besides, the temperature and position of the thin-ply UD carbon fibers had major effects on the pseudo-ductile strain of samples. The pseudo-ductile strain of samples increased by placing the thin-ply UD carbon fibers in the center of samples. At a temperature of 95 ºC, the pseudo-ductile strain value of [B3C2B3] sample was respectively about 2 and 6 times higher than that of [CB6C], and [B2CB2CB2] samples. On the other hand, pseudo-ductile strain increased by increasing the temperature up to a certain value. Also, the Charpy impact test results showed a decrease in the absorbed energy values by increasing the temperature. However, the [B2CB2CB2] sample had the higher absorbed energy values due to the occurrence of more delamination.

Keywords: Hybrid composites; Pseudo-ductility; Flexural properties; Impact properties, Thin-ply Carbon

1- Introduction

Polymeric composite materials because of their outstanding properties such as high specific strength [1, 2], high corrosion resistance [3, 4] and high wear resistance [5-7] have found great applications in many industries such as automobile, aircraft, marine, aeronautic, etc. [8-11]. The composite materials during the service life are subjecting to various environmental conditions such as thermal cycling and corrosive conditions. Therefore, evaluating the mechanical properties of the polymeric composites in-service conditions is necessary. Temperature is one of the most influencing factors on the properties of materials; the mechanical and physical properties of materials are different at different temperatures [12-15].

The effects of temperature on the mechanical properties of polymeric composites have been investigated by researchers. Weng et al. [16] investigated the low-velocity impact behavior and post-impact residual strength of carbon fibers reinforced polymer after exposing different temperatures of 20, 150, 230 and 310 ºC. Their results indicated the absorbed energy values of composite decreased as a function of the temperature, at all impact energies. Also, the residual tensile strength values found a decreasing tendency as a function of temperature up to 230 ºC, but the tensile strength value increased again by further increase the temperature to 310 ºC.

Hybrid composites are a type of composite materials that are made by more than one type of fibers to achieve the synergetic properties used fibers [17-20]. Up to now, there are limited papers regarding the temperature effects on the mechanical properties of hybrid composites. The effects of temperature on the impact behavior of the basalt fibers/ epoxy, hemp fibers/ epoxy hemp-basalt fibers/ epoxy composites were investigated by Kumar et al. [21]. The low-velocity impact behavior of samples was evaluated at different temperatures of 30, 50 and 65 ºC. The absorbed energy value of the hemp fibers/ epoxy composites was higher than those of basalt fibers/ epoxy and hemp-basalt fibers/ epoxy composites. Also, their findings indicated that the basalt fibers had higher impact damage resistance than hemp fibers. On the other hand, the absorbed energy values of all samples increased as a function of the temperatures. They also performed the flexural tests on the impacted specimens. Their results indicated that the lowest reduction in the flexural strength was for the hemp-basalt fibers/ epoxy hybrid composites.

In another investigation, Halvorsen et al. [22] studied the temperature effects on the impact behavior of the Glass fiber and Glass/ Kevlar fibers hybrid composites. The different temperatures of -50, 20, 70, and 120 ºC were applied to the samples, in their work. Their study showed that at -50 ºC, the failure mode of samples was nearly brittle while at higher temperatures (i.e. 120 ºC), the samples failed in a ductile manner. In another work, the impact behavior of glass/carbon/epoxy hybrid composites at different temperatures of -20, 0, 20, 40, and 60 ºC was investigated by Sayer et al. [23]. Their results indicated that the energy absorption capability of the hybrid composites at room temperature (20 ºC) was higher than that of other temperatures. Aklilu et al. [24] studied the temperature effects on the mechanical properties of glass-carbon fibers/ hybrid composites. They applied different temperatures of 25, 40, and 55 ºC. Their results indicated that the interlaminar shear strength (ILSS) values of hybrid composites reduced by increasing the temperature from 25 to 55 ºC. However, their study showed that the reduction percentage of the ILSS value of hybrid composites decreased when the carbon fibers were placed at the top layer of composites.

As a well-known fact, the low toughness value of the polymeric composites is their main problem. So, improving the fracture toughness of the polymeric composites has attracted great interest from researchers. Performed studies have indicated that the fracture type of composite materials can be changed from catastrophic to progressive by various approaches such as adding nanoparticles into the matrixes, the use of metallic fibers, and fibers hybridization. In literature, there are extensive works on the fabrication of hybrid composites made up of thin-ply unidirectional (UD) carbon and glass fibers. In the mentioned studies, it has been shown that the fracture type of fabricated hybrid composites is gradual. In these studies, the gradual failure of the samples has been defined as a pseudo-ductility phenomenon [25-28].

Recently, basalt fibers, as a type of natural fibers, have been extensively used as reinforcements in different types of polymeric composites owing to their proper characteristics such as high mechanical strength, high chemical stability and good resistance to high temperature [29-34]. However, to the best of the author's knowledge, there is no investigation on the temperature effects of thin-ply UD carbon-basalt fibers/epoxy composites. This study aims to fabricate the thin-ply UD carbon-basalt fibers/epoxy composites using the hand lay-up method. After that, the flexural and low-velocity impact properties of samples subjected to different temperatures are investigated.

2- Experimental procedure

2-1- Materials

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The basalt fibers (380 g/m^2 sateen woven, ARMBAS, Armenia) and thin-ply UD carbon fibers (38 g/m^2, TeXtreme, Sweden) were used as reinforcements in this study. The epoxy resin (EPL 1012, with hardener EPH 112) was utilized as the matrix for the fabrication of composites. According to the recommendation manufacture, the resin to hardener ratio was 100:13. The most important properties of the used epoxy resin, basalt fibers, and thin-ply UD carbon fibers are presented in Tables 1 to 3, respectively.

Table 1. The main properties of used epoxy resin

Property	Value
Curing time (min)	90
Viscosity (mPa.s)	900-1100
Tensile strength (MPa)	74.62
Tensile modulus (GPa)	2.735
Flexural strength (MPa)	94.14
Flexural modulus (GPa)	3.575

Table 2. The main properties of used basalt fabrics

Property	Value
Density (g/m^2)	380
Thickness (mm)	0.19
Filament diameter (μm)	8-22
Type of sizing	Silane
Operation temperature (ºC)	-260 to +700
Tensile modulus (GPa)	80-95

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Table 3. The main properties of used thin-ply UD carbon fibers

Property	Value
Density (g/m^2)	38
Melting point (ºC)	350
Thickness (mm)	0.1
Tensile modulus (GPa)	294

2-2- Preparation of hybrid composites

For the fabrication of the hybrid composites, the hand lay-up method was used. After lamination of the fibers, the pressure of 0.05 MPa was applied to reduce the void content of composites. Then, the samples were kept at room temperature for 7 days for the curing process. After curing, the fabricated sheets were cut in dimension of 13 × 7 × 1.5 mm for both flexural and Charpy impact tests. The hybrid composites were fabricated with three different stacking sequences of thin-ply UD carbon fibers and basalt fibers. All hybrid composites were fabricated by 6 layers of basalt fibers and 2 layers of thin-ply UD carbon fibers. Fig. 1 presents the schematic image of the hybrid composites with three different stacking sequences of fibers ([CB6C], [B2CB2CB2], and [B3C2B3]). The numbers after B (basalt fibers) and C (carbon fibers) are related to the layer number of basalt fibers and carbon fibers in samples, respectively.

To investigate the temperature effects on the mechanical properties of hybrid composites, the samples were placed in a furnace (Aryasarmayesh, model 7004-37) at different temperatures of 60, 95, and 130 ºC for 2 h. After applying thermal conditions, the furnace was extinguished and the samples were placed in for 5 h for decreasing their temperature to room temperature.

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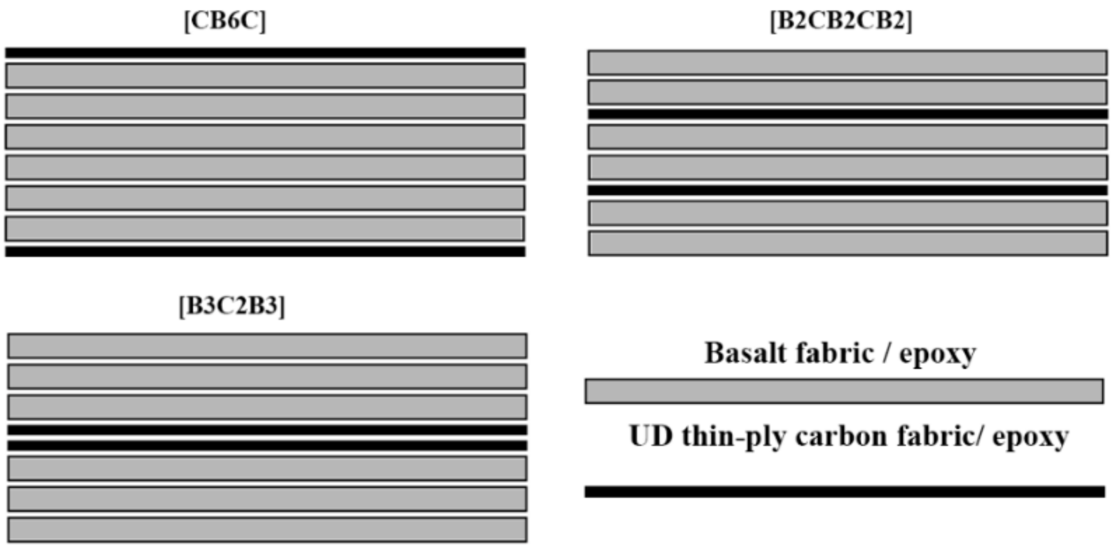

Fig. 1. The schematic image of the thin-ply unidirectional carbon-basalt fibers/ epoxy composites with three different stacking sequences of fibers.

2-3- Characterization

The three-point bending tests and Charpy impact tests were carried out to investigate the effects of temperature on the flexural and low-velocity impact properties of hybrid composite with different stacking sequences. For each type of composite, three samples were tested. The bending tests were conducted at ambient temperature according to ASTM D790 standard [35] using the Hounsfield HK255 universal testing machine. Equations (1-3) were respectively used for calculating the flexural strength, flexural modulus and strain at first failure of the samples.

$$\sigma_f = \frac{3PL}{2bd^2} \quad (1)$$

$$E_b = \frac{L^3 m}{4bd^3} \quad (2)$$

$$\varepsilon_f = \frac{6Dd}{L^2} \quad (3)$$

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Where σ_f is the flexural strength (MPa), E_b is the modulus of elasticity in bending (MPa), ε_f is the flexural strain at the first drop of load. Also, P is the maximum load (N) in the load-deflection curves, L is the support span (mm), b is the width of beam tested (mm), d is the depth of the beam tested (mm) and, D is the deflection at the center of the sample at the first drop (mm). m is the slope of the tangent to the initial straight-line portion of the load-deflection curve (N/mm).

The Charpy impact tests were performed on the samples under constant impact energy of 20 J according to the ASTM D6110 standard [36] using the Santam Charpy SIT200. The specific absorbed energy of samples was measured according to equation (4):

$$Speciefic\ Absorbed\ Energy = \frac{E_1 - E_2}{W} \tag{4}$$

Where E_1 and E_2 are the initial and final potential energy (J), respectively. W is the weight of the sample (g).

The scanning electron microscopy (SEM, TESCAN) were used to characterize the fracture surface of the composites. It is worth noting that for the SEM observations, to remove the contaminations, the samples were cleaned with deionized water. After that, the gold sputtering was done on the surface of samples to prevent the occurrence of the charging phenomenon.

3- Results and discussion

3-1- Flexural properties of samples

Fig. 2 shows the selected flexural stress-strain curves samples as a function of temperature. A pseudo-ductile behavior can be observed for this sample, at all mentioned

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temperatures. The occurrence of the pseudo-ductile phenomenon can be related to the embedding of the thin-ply UD carbon fibers into the laminates. With increasing the temperature from 25 ºC to higher temperatures, the failure behavior has changed considerably. Generally, the [CB6C] samples subjected to different temperatures show the pseudo-ductile behavior. However, the pseudo-ductile strain values of [CB6C] samples at different temperatures are different. As shown in Fig. 2, the pseudo-ductile strain values of the [CB6C] samples at 25, 60, 95, and 130 ºC are about 0.0024, 0.0097, 0.0047, and 0.0044, respectively. This observation indicates that the degree of pseudo-ductility of samples has increased by increasing temperature and the optimum temperature with the viewpoint of pseudo-ductility is 60 ºC. The increased pseudo-ductility of the samples by increasing the temperature can be owing to the occurrence of the softening phenomenon for the [CB6C] samples.

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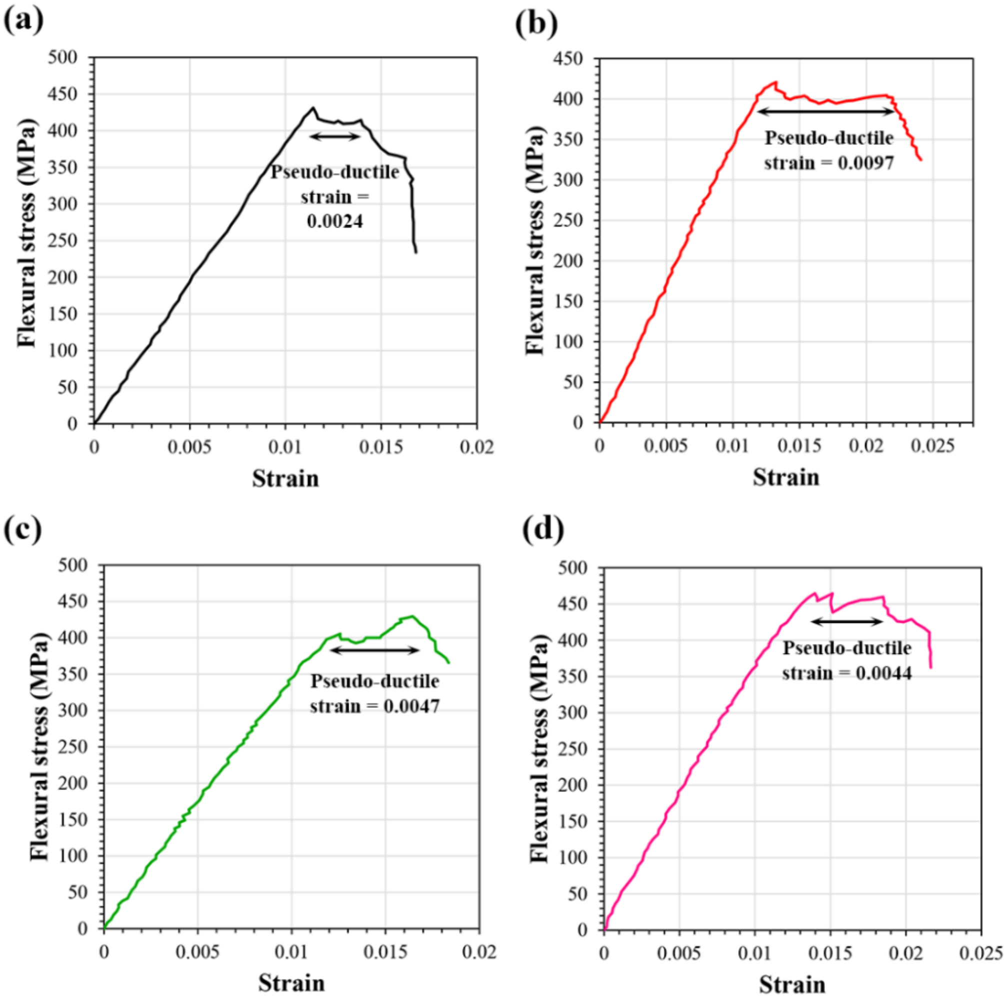

Fig. 2. The flexural stress-strain curves of [CB6C] samples subjected to the different temperatures of (a) 25 ºC, (b) 60 ºC, (c) 95 ºC and (d) 130 ºC.

The calculated flexural properties of samples including the flexural strength, flexural modulus, and strain values of the [CB6C] samples as a function of the temperature are depicted in Fig. 3. A decreasing trend is observed for the flexural strength of [CB6C] samples as the temperature increased. However, it can be seen that by increasing the temperature from 95 to 130 ºC, the flexural strength value has partially again raised. The flexural modulus of [CB6C] samples has found a decrement trend by increasing the temperature, indicating the negative effects of high temperature on the stiffness of samples. The flexural strength of [CB6C] samples subjected to the temperatures of 25, 60, 95, and 130 ºC, are respectively about 451.13, 442.05, 430.27, and 461.76 MPa (Fig. 3a). Besides, the flexural modulus values of the [CB6C] samples are about 37.12, 35.88, 30.72, and 36.62 GPa (Fig. 3b). It can be seen that an increase in the temperature to 60 and 95 ºC has led to the degradation of the flexural properties of [CB6C] samples. For example, the flexural strength and modulus of the samples at 95 ºC are about 4.62% and 17.24% lower than those of the sample at 25 ºC. However, interestingly, as the temperature increases to 130 ºC, the flexural properties of this sample has again improved. On the other hand, generally, the strain values of [CB6C] samples have increased at higher temperatures, compared with the lower temperatures. The increased strain values of

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samples are likely due to the softening occurrence for the epoxy resin (Fig. 3c).

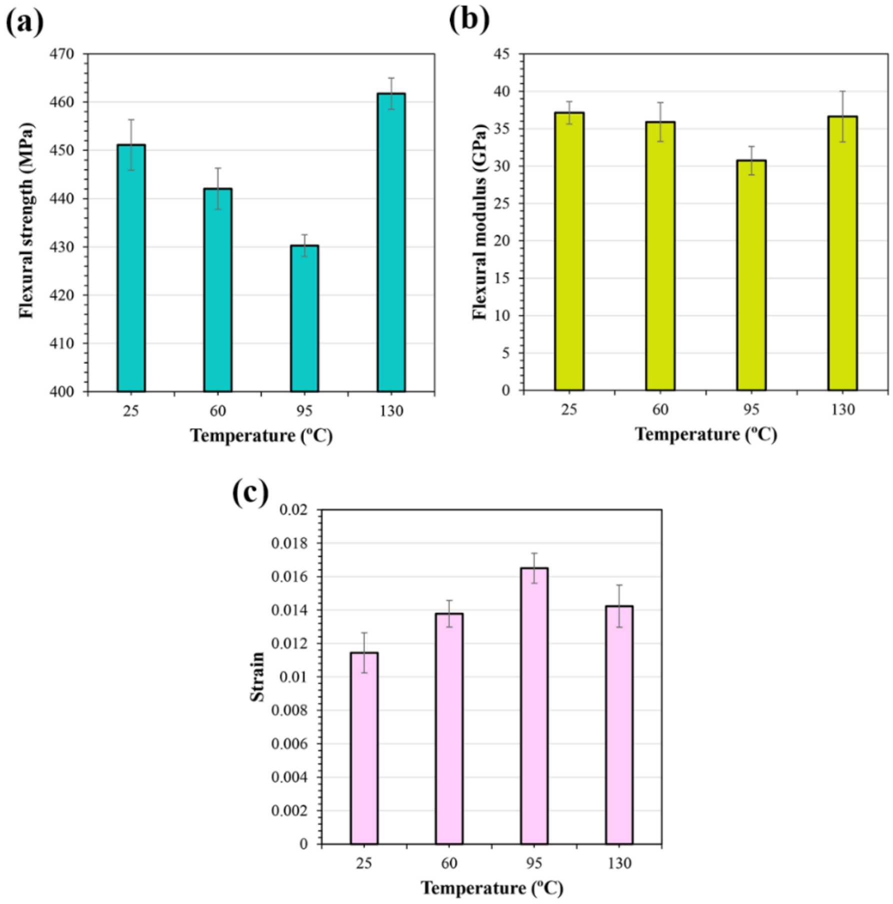

Fig. 3. The flexural properties of [CB6C] samples as a function of temperature, (a) flexural strength, (b) flexural modulus and (c) strain.

As indicated in the literature, temperature has two opposite effects on the properties of polymeric composites [37-39]. At first, an increase in the temperature can enhance the mechanical properties of samples by the occurrence of the post-curing phenomenon. So, the mechanical properties of samples improve owing to the increasing the stiffness of polymer and also adhesion at polymer/ fibers interfaces. On the other hand, the interface of the polymer/ fibers can be weakened owing to the thermal mismatch. As a well-known fact, the coefficient of thermal expansion (CTE) values of components of composites is different. Thereby, the created differences between the CTE values of components of hybrid composites lead to the delamination and so, decreasing the mechanical properties of samples. As reported in the literature, the CTE value of the epoxy resin, basalt fibers, and carbon fibers are respectively about 6-10 × 10^{-5} K^{-1}, 6 × 10^{-6} K^{-1} and -6 × 10^{-6} K^{-1}. So, the expansion rate of fibers is much lower than that of epoxy resin, creating the thermal stresses at fiber/epoxy interfaces [40].

As an example, the effects of thermal cycling on the tensile and flexural properties, and interlaminar shear strength (ILSS) values of carbon/basalt fibers reinforced intra-ply hybrid composites were investigated by Shishevan and Akbulut [39]. The samples were heated to the 120 ºC for 10 min and then were cooled to -40 ºC for 10 min. Their results indicated that increasing the number of thermal cycles up to a certain value led to an increase in both tensile and flexural modulus of samples. Similarly, the tensile and flexural values increased as a function of the number of thermal cycles. However, both tensile and flexural properties of samples began to decrease by a further increase in the number of thermal cycles.

Fig. 4 presents the SEM images of the [CB6C] samples after the flexural test. As can be seen, there is a good adhesion at fibers/ polymer interfaces of [CB6C] samples at 25 ºC. However, as shown by arrows in Figs. 4b to 4d, the weak interface, pull-out, and matrix cracking phenomena can be seen for the [CB6C] samples subjected to the higher temperatures. As mentioned in the experimental section, the samples were heated to the mentioned temperatures for 2 h and then were cooled to the room temperatures. So, weakening the interfaces can be related to the created thermal stresses due to the difference between the CTE values of the components of samples.

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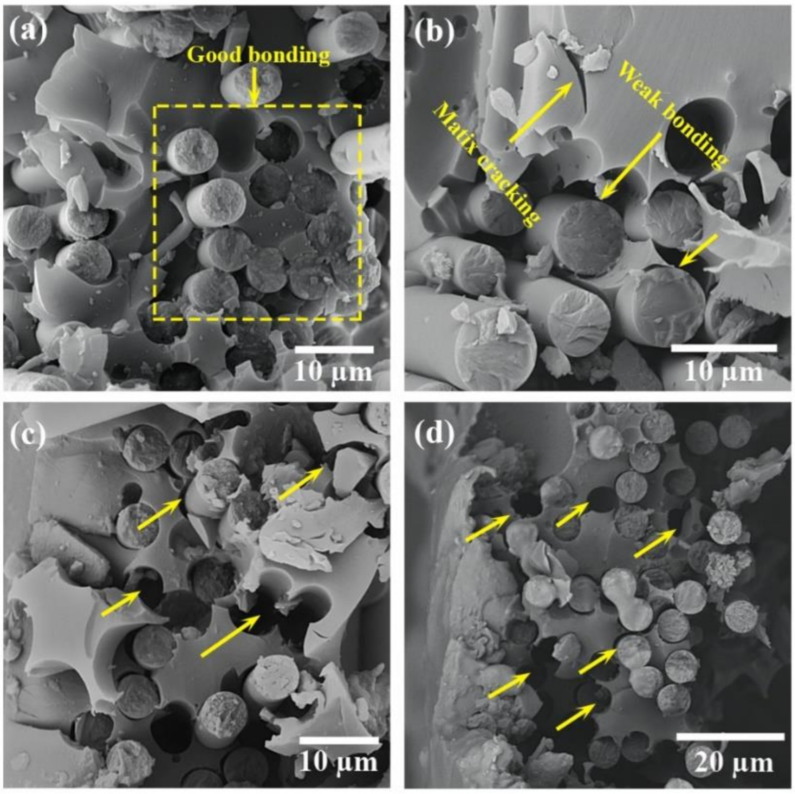

Fig. 4. The fracture surface images of [CB6C] samples subjected to the different temperatures of (a) 25 ºC, (b) 60 ºC, (c) 95 ºC and (d) 130 ºC.

The selected flexural stress-strain curves of the [B2CB2CB2] samples subjected to the different temperatures of 25, 60, 95 and 130 ºC are shown in Fig. 5. Similar to the [CB6C] samples, the pseudo-ductile failure can be observed for the [B2CB2CB2] samples, however, the degree of pseudo-ductility is different for the different temperatures. The pseudo-ductile strain values of the [B2CB2CB2] samples subjected to the 25, 60 and 95 ºC are about 0.0033, 0.0077 and 0.002. This trend roughly is similar to the [CB6C] samples; the degree of pseudo-ductility has increased by increasing the temperature to the 60 ºC but beyond that has decreased. For the [B2CB2CB2] sample at 130 ºC, the failure behavior of samples is different and it can be seen that, at a certain strain value, the modulus of samples has decreased. It can be said that as the temperature

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increases to 130 ºC, the physical behavior of epoxy resin changes from a glassy to a rubbery phase. Comparing the pseudo-ductile strain values of [B2CB2CB2] and [CB6C] samples reveals that although the pseudo-ductile strain of [B2CB2CB2] at 25 ºC is higher than that of [CB6C], at higher temperatures the mentioned values for the [CB6C] are higher. Based on this fact that the occurrence of pseudo-ductility phenomenon during the flexural testing of hybrid composites has rarely been reported in the literature, there is a need for more accurate investigation on this topic.

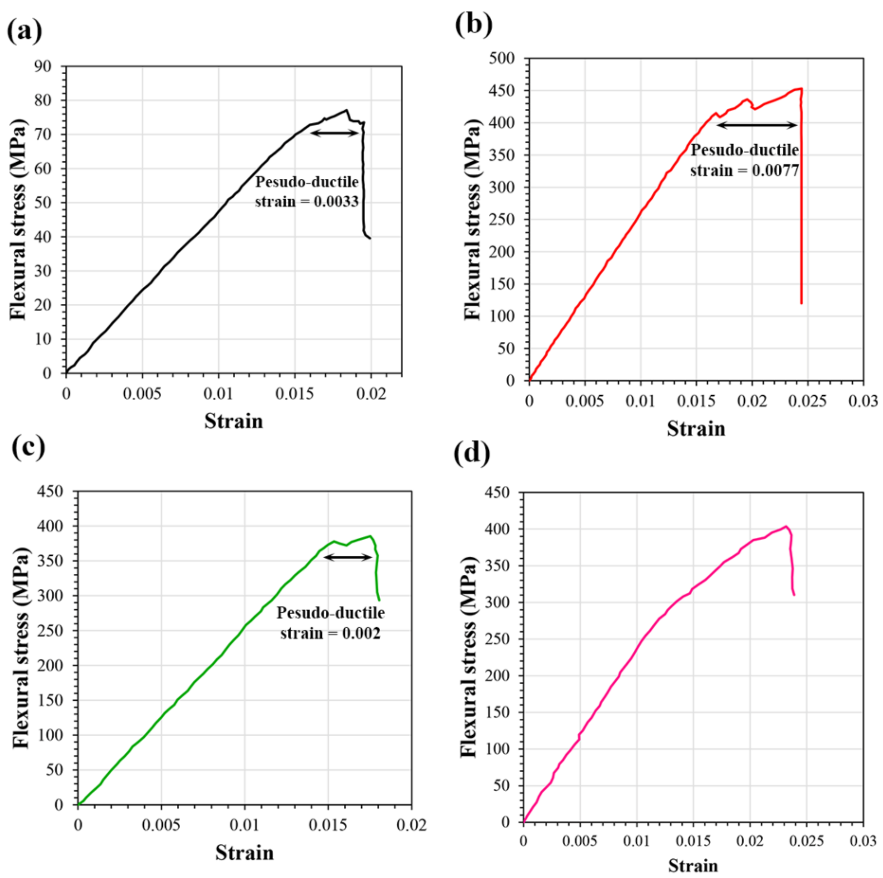

Fig. 5. The flexural stress-strain curves of [B2CB2CB2] samples subjected to the different temperatures of (a) 25 ºC, (b) 60 ºC, (c) 95 ºC and (d) 130 ºC.

Fig. 6 presents the calculated flexural properties of [B2CB2CB2] samples including flexural strength, flexural modulus, and strain values as a function of the temperature. Generally, the flexural strength and modulus of the [B2CB2CB2] samples have decreased by increasing the temperature, compared with the sample at 25 ºC. Similar to the [CB6C] samples, the flexural strength values of [B2CB2CB2] samples have decreased by increasing the temperature up to 95 ºC but beyond that, an adverse tendency is observed. The flexural strength values of the [B2CB2CB2] samples subjected to 25, 60, 95, and 130 ºC are respectively about 422.36, 415.23, 385.01, and 407.26 MPa. The flexural modulus of samples 25, 60, 95 and 130 ºC are about 26.42, 25.64, 24.32 and 22.68 GPa, respectively. The degradation of the flexural strength and modulus of the samples at 95 ºC is 8.84% and 7.94% lower than those of samples at 25 ºC. Comparing the obtained results of [CB6C] and [B2CB2CB2] samples indicate that not only the flexural properties of [CB6C] are higher, but also the degradation effects of temperature on the properties of [CB6C] samples is lower.

In bending tests, the compressive and tensile loads are applied to the samples at the top and bottom sides, respectively. It has been reported that the flexural properties of hybrid composites can be improved by placing the fibers with higher mechanical properties at top (compressive) sides. So, the higher flexural properties of the [CB6C] compared with the [B2CB2CB2] can be attributed to the presence of the thin-ply UD carbon fibers at the top sides. Moreover, it is visible that the presence of thin-ply UD carbon fibers at the bottom sides is more beneficial in lowering the negative effects of the temperature on the properties. With another viewpoint, by placing the thin-ply UD carbon fibers near the central region of composites, more interfaces between the thin-ply UD

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carbon fibers and epoxy resin are created. Consequently, the effects of the difference between the CTE values of thin-ply UD carbon fibers and epoxy resin are more evident and so, the flexural properties more decreases by increasing the temperature by the occurrence of the delamination phenomenon.

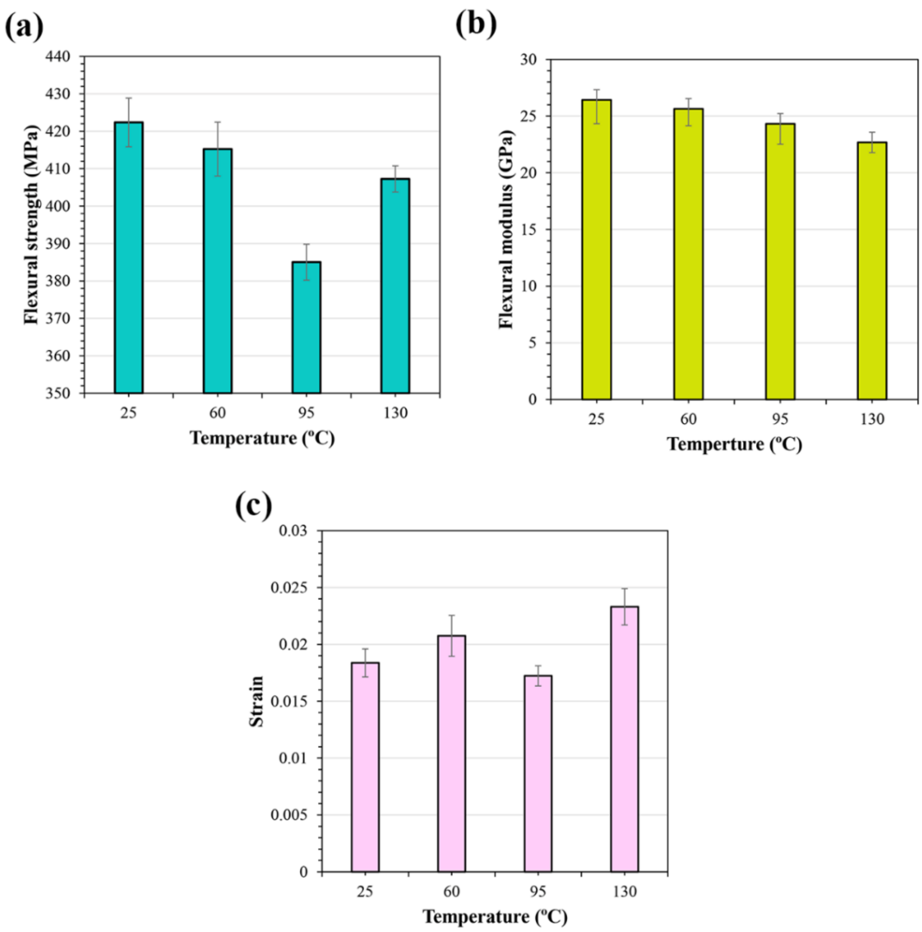

Fig. 6. The flexural properties of [B2CB2CB2] samples as a function of temperature, (a) flexural strength, (b) flexural modulus and (c) strain.

Fig. 7 illustrates the selective flexural stress-strain curves of [B3C2B3] samples. Similar to other presented samples, the pseudo-ductile behavior of [B3C2B3] samples are also visible. The pseudo-ductile strain of the [B3C2B3] samples is higher than the

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previously introduced samples. The pseudo-ductile strain values of 0.0054, 0.0074 and, 0.014 have been achieved for the [B3C2B3] samples subjected to the different temperatures of 25, 60, and 95 ºC, respectively. However, the pseudo-ductile phenomenon is not observed for the sample at 130 ºC. As a comparison, the pseudo-ductile strain value of the [B3C2B3] at 95 ºC is respectively about 2 and 6 times higher than that of [CB6C], and [B2CB2CB2] samples.

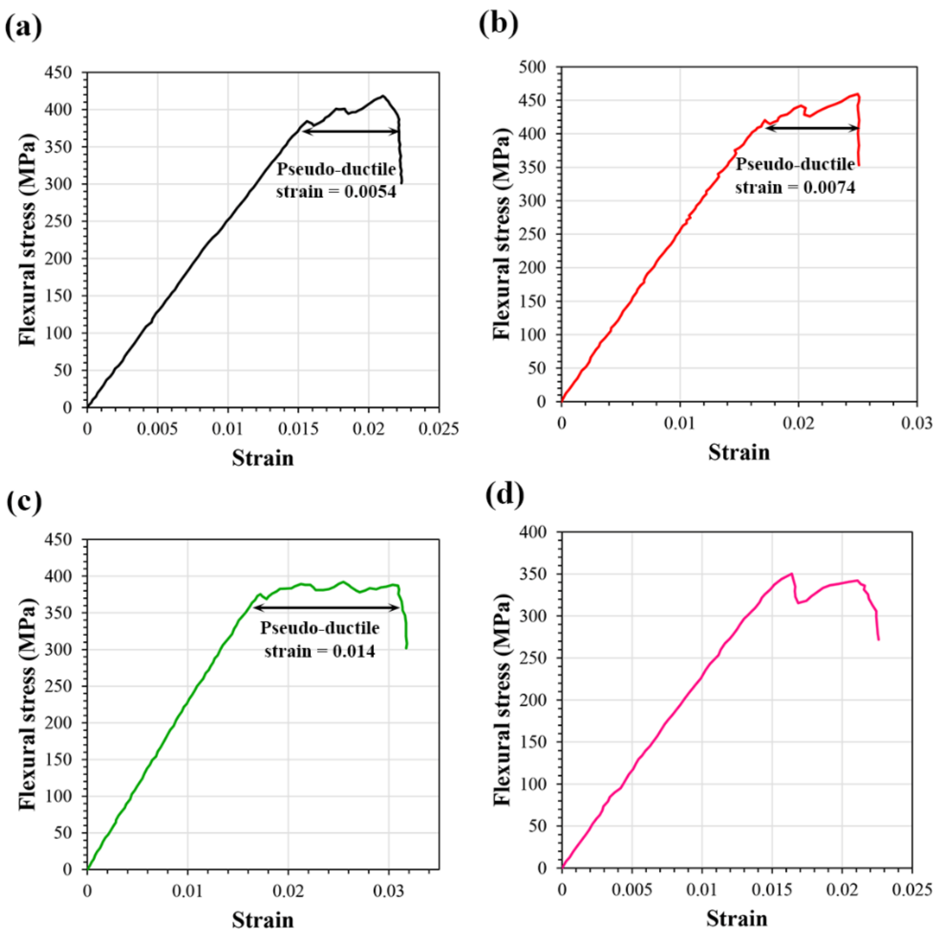

Fig. 7. The flexural stress-strain curves of [B3C2B3] samples subjected to the different temperatures of (a) 25 ºC, (b) 60 ºC, (c) 95 ºC and (d) 130 ºC.

Fig. 8 gives the calculated flexural strength, flexural modulus, and strain values of [B3C2B3] samples as a function of the applied temperatures. Despite the strain values,

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the flexural strength and flexural modulus of samples have decreased as a function of the temperature. The flexural strength values of 422.54, 405.25, 389.88, and 349.37 MPa have been obtained respectively for the samples at different temperatures of 25, 60, 95, and 130 ºC. At similar conditions, the flexural modulus values of the mentioned samples are 26.17, 23.28, 22.38 and 21.44 GPa, respectively. The percentages of degradation of flexural strength and modulus of [B3C2B3] samples at 95 ºC compared with the samples at 25 ºC are respectively about 7.72%, and 14.48%.

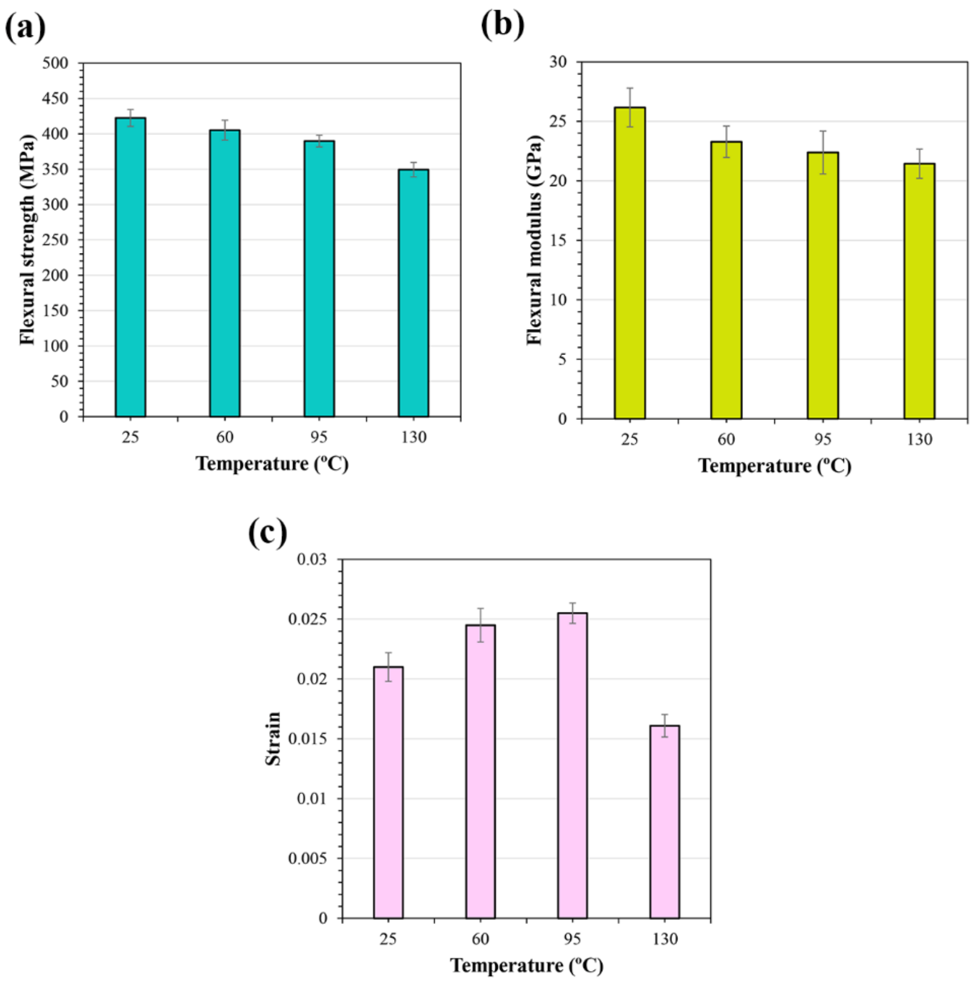

Fig. 8. The flexural properties of [B3C2B3] samples as a function of temperature, (a) flexural strength, (b) flexural modulus and (c) strain.

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The degradation percentages of flexural strength and flexural modulus of all samples compared with the ones at 25 ºC are given in Table 4. In general, it can be seen that the [CB6C] samples had the highest resistance against the degradation caused by temperature. The better performance of [CB6C] samples at higher temperatures can be related to the lower numbers of interfaces with different CTE values. As mentioned earlier, the difference between the CTE values of carbon fibers and epoxy resin is more than basalt fibers and epoxy resin. Thereby, more carbon fibers/ epoxy resin leads to the occurrence of delamination by increasing the temperature. For comparison, the SEM images of samples at two temperatures of 60 ºC and 130 ºC are shown in Fig. 9. The delamination areas have been shown by yellow squares. As can be seen, the degree of delamination phenomenon for the [CB6C] sample is the least but, the [B2CB2CB2] samples have the highest one. The higher degree of delamination for the [B2CB2CB2] can be related to their higher thin-ply UD carbon fibers/ epoxy interfaces.

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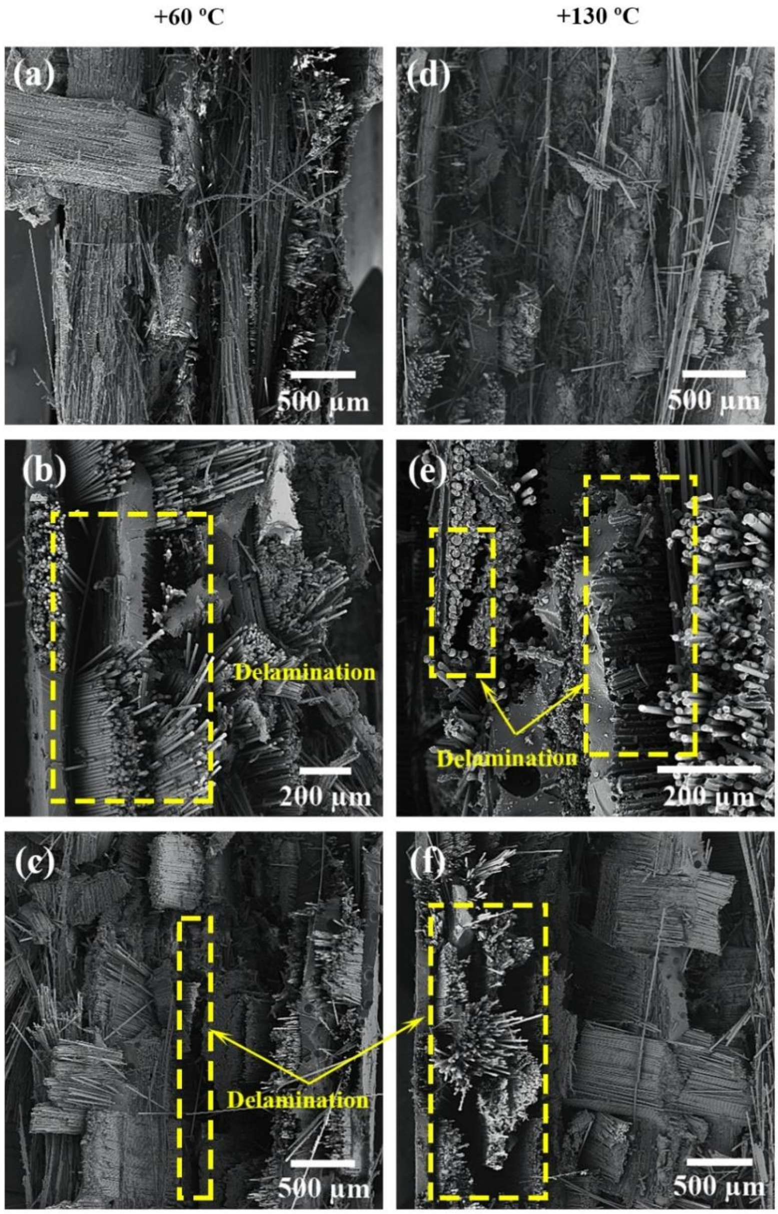

Fig. 9. The fracture surfaces of the samples subjected to temperatures of 60 and 130 ºC, (a) and (d) [CB6C], (b) and (e) [B2CB2CB2], (c) and (f) [B3C2B3].

Table 4. Percent degradation of flexural strength and modulus of samples at different temperatures

Specimen	Temperature (ºC)	Degradation of flexural strength (%)	Degradation of flexural modulus (%)
[CB6C]	60	2.01	3.34
	95	4.62	17.22
	130	-2.35	1.34
[B2CB2CB2]	60	1.68	2.98
	95	8.84	7.97
	130	3.57	14.18
[B3C2B3]	60	4.09	11.04
	95	7.73	14.18
	130	17.31	18.06

3-2- Charpy impact behavior of samples

Fig. 10 shows the absorbed energy values of the samples as a function of the temperature. For the [CB6C] samples, a similar trend to their flexural strength has been achieved (Fig. 10a). In other words, the absorbed energy values have decreased by increasing the temperature up to 95 ºC but further increasing the temperature to 130 ºC has caused the again increment of mentioned value. However, for other samples ([B2CB2CB2] and [B3C2B2]), the absorbed energy values have decreased by increasing the temperature (Figs. 10b and 10c). The decreased absorbed energy values of samples as a function of temperature can be related to the weakening of adhesion of the fibers/epoxy interfaces caused by temperature. Comparing the absorbed energy values of the samples indicates that the position of the thin-ply UD carbon fibers in the laminates have a great influence on the impact properties of samples. At all temperatures, the energy absorption values of the [B2CB2CB2] samples are higher than that of other samples. For example, at temperature of 25 ºC, the absorbed energy values of [CB6C], [B2CB2CB2] and

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[B3C2B3] samples are about 1.02, 1.30, and 1.15 kJ/g, respectively. Also, at temperature of 130 ºC, the absorbed energy values of 1.0, 1.10, 0.84 kJ/g have been respectively obtained for the [CB6C], [B2CB2CB2] and [B3C2B3] samples. There are different mechanisms for energy absorption of polymeric composites during the impact loadings such as delamination, matrix cracking, fiber pull-out, etc. [41, 42]. However, delamination is the most important mechanism for the energy absorption of the samples. As indicated in Fig. 9, the extent of delamination for the [B2CB2CB2] samples was higher than that of other samples, corresponding to their higher energy absorption.

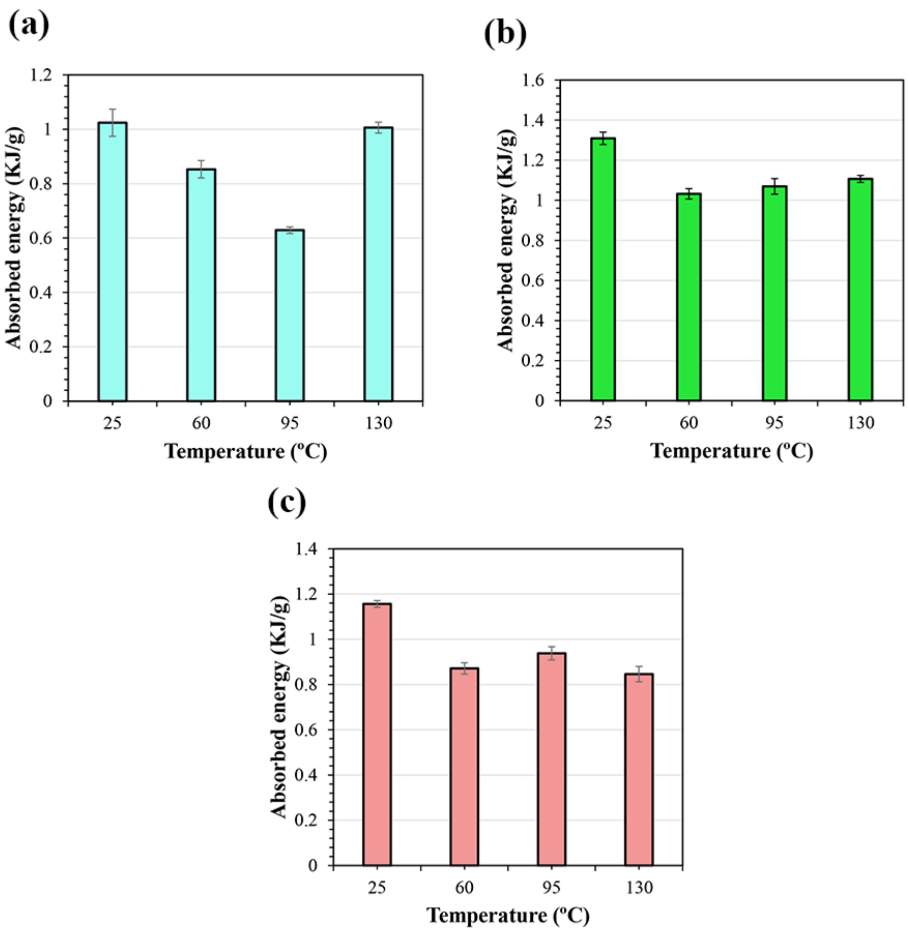

Fig. 10. The absorbed energy values of (a) [CB6C], (b) [B2CB2CB2] and (c) [B3C2B3] samples as function of temperature.

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4- Conclusion

In the present work, the temperature effects on the flexural and impact properties of hybrid composites made up of thin-ply unidirectional (UD) carbon fibers, basalt fibers and, epoxy resin were investigated. The hybrid composites with three different stacking sequences of fibers were fabricated by the hand lay-up method. The specimens with codes of [CB6C], [B2CB2CB2], and [B3C2B3] were fabricated where B and C respectively are related to the basalt fibers and thin-ply UD carbon fibers. To investigate the temperature effects on the mechanical behavior of samples, the fabricated hybrid composites were subjected to different temperatures of 60, 95, and 130 ºC for 2 h. Then, the obtained results were compared also by findings at room temperature. The major findings of this study are as following items:

1- Flexural tests indicated that, generally, all samples were failed in a pseudo-ductile manner. However, the pseudo-ductile strain value of samples was affected by the stacking sequences of fibers and also the temperature. By placing the thin-ply UD carbon fibers in the center of samples, the pseudo-ductile strain increased. The pseudo-ductile strain of [CB6C], [B2CB2CB2] and [B3C2B3] samples at 25 ºC were about 0.0024, 0.0033 and, 0.0054, respectively. On the other hand, the pseudo-ductile strain of samples increased by increasing the temperature to a certain value. As the highest pseudo-ductility, the pseudo-ductile strain of [B3C2B3] at 95 ºC was about 1.6 times higher than that of [B3C2B3] at 25 ºC. In general, the [B3C2B3] showed the highest pseudo-ductility and the [CB6C] samples showed the lowest pseudo-ductility.

2- The flexural strength and modulus of samples were improved by placing the thin-ply UD carbon fibers at the top and bottom sides of samples. At a temperature of 25 ºC, the flexural strength of [CB6C] was about 6.84% and 6.76% higher than that of [B2CB2CB2] and, [B3C2B3] samples, respectively. Increasing the temperature decreased the flexural strength and flexural modulus of samples, however, the [CB6C] had more resistance against temperature.

3- The impact test results showed that the temperature caused the reduction of absorbed energy values. The weakened fibers/polymer interfaces owing to the increased temperature can be introduced as the main reason for this observation. However, among all samples, the [B2CB2CB2] samples owing to the more delamination phenomenon had more absorbed energy values.

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