IJE TRANSACTIONS A: Basics Vol. 31, No. 7, (July 2018) 1139-1145

International Journal of Engineering

Journal Homepage: www.ije.ir

Mechanical Characterization of Glass-Basalt-Carbon/Polyester Hybrid Composites

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PAPER INFO

Paper history:
Received 21 December 2017
Received in revised form 26 February 2018
Accepted 9 March 2018

Keywords:
Stacking Sequences
Hand Lay-up Procedure
Fracture Surface
Mechanical Properties

ABSTRACT

Influence of the stacking sequences of hybrid composites on the tensile strength, flexural strength, inter-laminar shear strength (ILSS) and impact energy was investigated. The hybrid glass-basalt-carbon/polyester composite laminates were processed by hand lay-up procedure at room temperature. The fracture surface of the composite laminates after the tension and flexural test was examined by scanning electron micrograph (SEM). The results show that the best mechanical properties were obtained for the composite laminates S5 at stacking sequences [C/B/C/B/C]; where the tensile strength, flexural strength, and ILSS were 148 MPa, 448 MPa, and 25 MPa, respectively. This decline in mechanical properties attributed to the good interfacial bonding between the fibres and the matrix in this configuration. On the other hand, the largest impact strength (43.70 kJ/mm^2) was clearly observed for laminates S2 at the stacking sequences [C/G/C/G/C] compared to other laminates simply due to the high stiffness and strength of the carbon fabrics.

doi: *10.5829/ije.2018.31.07a.19*

1. INTRODUCTION

Composites materials have a high stiffness and strength without increasing in the weight, but the toughness was low beside the high processing cost. The fabrication techniques which used to processed the polymeric composites include, hand layup, spray up, filament winding, lamination and pultrusion. The hybrid composites have been produced to obtain a good balance between the toughness, strength, and stiffness depending on the different types of fibers such as carbon, E-glass, and basalt [1]. Glass fiber is considered the traditional reinforcing phase for polymeric composites [2]. Carbon fibers were utilized as reinforcement materials due to the high modulus of elasticity, strength, and low density [3]. Basalt fiber has a good attention over than the glass and carbon fibers in composites [4]. Hybrid composite was used in many fields such as aerospace, Helicopter rotor blades**,** exhaust stacks, humanoid skin**,** dental implants, and automotive partsand electronics applications such as printed circuit boards, lids and interlayer dielectrics [5-8].

Al-Saadi [9] studied the effect of stacking sequence on tensile properties of hybrid composite materials using different stacking sequence. It was observed that there is an enhancement in the tensile properties of the hybrid composites with stacking sequences (C-C-F) compared to other stacking sequences. Also, Subagia and Kim [10] have investigated the flexural properties of the hybrid composites with different stacking sequences. Flexural properties depend on the stacking sequence of the hybrid composites laminates. For the hybrid laminates, with stacking sequences (C-B-C-B-C) indicated higher flexural strength and flexural modulus compared to the other fiber configurations. Also, Lim et al. [11] investigated the flexural and fracture properties of two groups of the carbon/basalt/epoxy hybrid composites but in the form of sandwich shape such as basalt skin-carbon core (BSCC) composites and carbon skin-basalt core (CSBC) composites. It was obvious that the flexural strength of the carbon skin-basalt core hybrid composite with stacking sequences (CSBC) was approximately increased with 32% greater than that the basalt skin-carbon core hybrid composites with stacking sequences (BSCC). In addition, the effect of the stacking sequences

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on the mechanical properties and microstructure of basalt-glass/epoxy hybrid composites was studied by Amuthakkannan et al. [12]. It was observed that the combination (4B/4G/4B) gives the largest tensile strength compared to the other stacking sequences of different layers of basalt and glass. The effect of uniaxial basalt fabric layers on the mechanical properties of a glass mat /epoxy composite was investigated experimentally and numerically. It is observed that the tensile modulus of the hybrid laminates with a basalt layer increased 16 % for code B4 structure [8]. Influence of fiber orientation on compressive strength of basalt-carbon/polyester hybrid composite laminates was demonstrated. Best compressive strength was occurred at stacking sequences (2C/4B/2C) compared to the all the stacking sequences [13]. E-glass-carbon/polyester hybrid composites were manufactured by the hand lay-up process. Theflexural properties of these hybrid composites were investigated experimentally and by finite element analysis (FEA). It was found that span-to-depth ratio influence on the flexural modulus and flexural strength of hybrid composites. The flexural strength increases with span to-depth percent. It was observed that the highest flexural strength ocured at Span to depth ratio (S/h = 64) for the all stacking sequences [14]. Effect of stacking sequence on the mechanical properties of basalt-jute -flax with E-glass/epoxy was investigated [15]. Best strength and flexural modulus were found at stacking sequence (2G/3B/2G) and (2G/3F/2G), respectively. Also, Jusoh [16] demonstrated the effect of stacking sequences of glass/basalt, glass/jute and glass/flax-epoxy resin hybrid composites on flexural behavior. Matrix cracking and fiber pull-out were founded on the fracture surfaces of Glass/jute hybrid composites with stacking sequences [G/F/G/F]s, which leads to the poor interfacial bonding between the matrix and glass layers. Flexural properties of the glass fiber and recycled GFRP waste (rGFRP) laminates were studied. The hybridization proved to increased composites. It was found that the flexural stress of kenaf/rGFRP laminates was enhanced with 47.3% compared to kenaf/glass composites [17]. The tensile strength, flexural strength and impact strength of the carbon/glass unsaturated polyester hybrid composite were studied [18]. It was concluded that the mechanical properties increased as the carbon fiber content increases. Jagannatha and Harish [19] studied the mechanical properties of carbon/glass-epoxy hybrid composites. The glass fiber percent varies from 15 to 60 wt.% and the percent of carbon fiber was 40% of the epoxy matrix. It was found that an improvement in the mechanical properties of the carbon/epoxy composites compared to the other hybrid composites. The mechanical characteristics of carbon- glass/polyester hybrid composite were studied by Kumar et al. [20]. It was observed that the hybrid composites give best mechanical properties compared to conventional GFRP composites. Impact response and damage process of glass-carbon/epoxy hybrid composite and conventional composites plates were investigated. For CG hybrid, the impact energy was higher than that other conventional composites and hybrid composite plates. Also, fiber failures increased as the impact energy increase [21]. Kanthraju et al. [22] studied the effect of filler loading on the mechanical properties of glass-basalt hybrid composite. It was found the increase in the tensile and flexural strength was 5 and 35%, respectively over the unfilled traditional composite. Flexural properties of basalt/E-glass/ epoxy composites were studied by Carmisciano et al. [23]. The basalt/epoxy composites give higher flexural modulus compared to with E-glass/epoxy. Majzoobi et al. [24] investigated the ballistic response of the Kevlar fabric and kevlar/epoxy Composite. It was observed that the Kevlar/epoxy composite gives higher strength compared to Kevlar fabric.

The objective of this paper was focused on the mechanical characterization of carbon-basalt-glass/ polyester hybrid composite laminates manufactured by the hand layup procedure at various stacking sequences up to 5 layers. Fracture surface of the composite laminates was analyzed by using SEM.

2. EXPERIMENTAL PROCEDURE

2. 1. Materials and Manufacturing

The laminate specimens were processed from glass-basalt-carbon-/unsaturated polyester hybrid composites using the hand layup procedure. Unsaturated polyester (HTC-667C) was used as matrix and the carbon fabric (C120-3K, Hyun Dai Fiber Co.) E-glass (biaxial weave 300 g/sqmt.) and basalt fabric (EcoB4-F210, Seco-Tech), were the reinforcements to produce the hybrid composites laminates. The fabric weight of the carbon and basalt fabrics was 200 and 210 g/sqmt., respectivally. Mechanical properties of the unsaturatedpolyester resin and the three types of reinforcements are listed in Table 1 [1].

TABLE 1. Properties of resin matrix and reinforcements

Properties	Polyester	Carbon	Basalt	E-glass
Density [gcm^{-3}]	1.26 ±0.01	1.74 ±0.01	2.58 ±0.01	2.65 ±0.01
Elastic modulus [GPa]	2.4±0.01	201±20	64.0±4	69.0±14
Shear strength [MPa]	50± 2	1527±643	1587±433	2400±402
Poisson's ratio	0.35	0.21	0.3	0.2

The total weight of all fabric reinforcement, unsaturated polyester resin (UP) and hardener were 60, 17.70 and 22.3 wt. %, respectively.The setup of the hand lay-up technique and any more details about the specification of fabrics reinforcement and preparing the hybrid composite laminates was reported in the previous work [26]. The carbon, E-glass, and basalt fabric reinforcements were distributed in the UP resin matrix in the form of five different layers as shown in Figure 1. The designations of composite laminates are given in Table 2.

2. 2. Mechanical Characterization

2. 2. 1. Tensile and Inter-Laminar Shear Test

Tensile test on composite specimens wasmodelled according to ASTM standered, with dimensions (165*19*5 mm) to evaluate the tensile strength of this laminate specimens at variuos stacking sequences. The test was performed on the universal testing machine (UH-F1000kN) at cross head speed of 5 mm per minutes at room temperature. The tension test specimens and testing setup are shown in Figure 2.

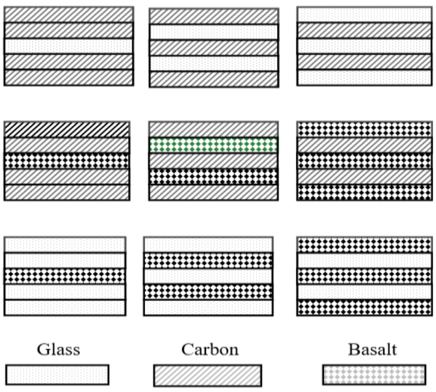

Figure 1. Configurations of composite laminates

TABLE 2. Designationsof composite laminates

Code	Stacking	Percentage of reinforcements
S1	[C/C/G/C/C]	48 wt. % Carbon + 12 wt. % Glass
S2	[C/G/C/G/C]	36 wt. % Carbon + 24 wt. % Glass
S3	[G/C/G/C/G]	24 wt. % Carbon + 36 wt. % Glass
S4	[C/C/B/C/C]	48 wt. % Carbon + 12 wt.% Basalt
S5	[C/B/C/B/C]	36 wt. % Carbon + 24 wt. % Basalt
S6	[B/C/B/C/B]	36 wt. % Basalt + 24 wt. % Carbon
S7	[G/G/B/G/G	48 wt. % Glass + 12 wt. % Basalt
S8	[G/B/G/B/G]	36 wt. % Glass + 24 wt. % Basalt
S9	[B/G/B/G/B]	36 wt. % Basalt + 24 wt. % Glass

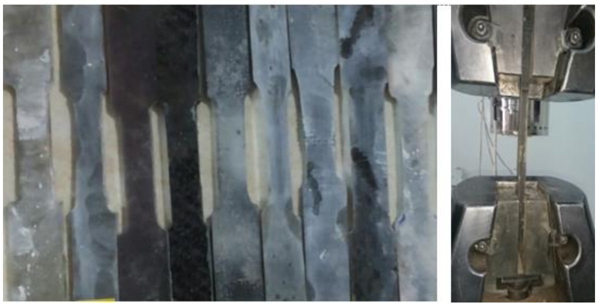

Figure 2. Tension test specimens and testing setup

Flexural characteristics such flexural strength and ILSS of composite laminates specimens were evaluated by the three point bending test. ILSS test was performed according to ASTM on specimens with dimensions (80*10*5 mm), at a cross-head speed of 5.0 mm/min. The maximum load of the composite laminates was evaluated from the typical load displacement curves of specimens from laminates S1 to S8; also the flexural strength and ILLS were determined from the following equations [25]:

$$\sigma_{flex}=\frac{3Fl}{2wt^2} \quad (1)$$

$$\tau_{ills}=0.75\frac{F}{w.t} \quad (2)$$

where, σ_{flex} and $\boldsymbol{\tau}_{ills}$ are the flexural strength (MPa) and ILLS (MPa), while the parameters F, l, w, t are the breaking load (N), the span length (mm), width of specimen (mm) and specimen thickness (mm), respectively. Five composite specimens were examined for each stacking sequences and recorded the average value.

2. 2. 2. Impact Test

The impact test was utilized to evaluate the impact energy using the impact tester (JBW-500 N, PIT Series: 030829, 150 J). Impact test was carried according to ASTM D256. Five specimens were recorded for each stacking sequences and take the averaged value.

3. RESULTS AND DISCUSSIONS

3. 1. Tensile and Flexural Strengths Behavior

The variationin tensile strength and flexural properties with the stacking sequences of the composite laminates are represented in Figures 3 to 5. It was observed that the maximum tensile strength (128.46 MPa) was obtained for the hybrid composites with stacking sequences [C/B/C/B/C] while the minimum tensile strength was 59.08 MPa for the stacking sequences [B/G/B/G/B]. Addition of two layers of basalt fabrics interlaminate between the carbon layers clearly enhanced the balance of the tensile properties and the ductility of the hybrid composite with fiber configuration [C/B/C/B/C]. Also, the strong interfacial bonding between the basalt and carbon fibers and polyester matrix leads to the improvment in the tensile properties, where the basalt fiber has good strength and better strain to failure over than the carbon fiber. On the other hand, for stacking sequences [B/G/B/G/B], the basalt layers were placed in the core and the external layers, so the tensile strength was decreased.

For laminates S8 with stacking sequences [G/B/G/B/G], the tensile strength increased by 8.32, 16 % compared tolaminates S7 and S9 with stacking sequences [G/G/B/G/G], [B/G/B/G/B], respectively.

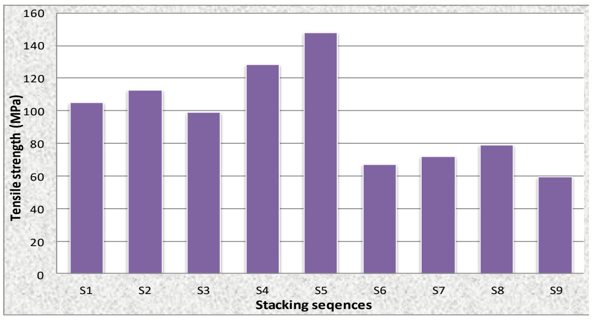

Figure 3. Effect of stacking sequences on the tensile strength of composite laminates

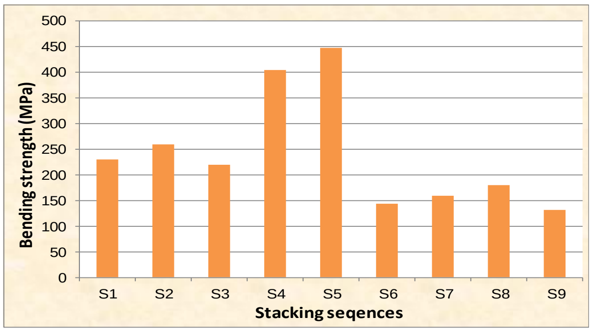

Figure 4. Effect of stacking sequences on the bending strength of composite laminates

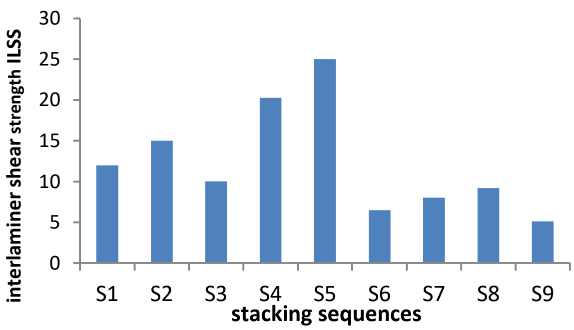

Figure 5. Effect of stacking sequences on ILLS of composite laminates

The tensile strength of the stacking sequences [B/C/B/C/B] was clearly decreased by 55.23% compared to the fiber configurations [C/B/C/B/C] but increased 10.72% over than the stacking sequences [B/G/B/G/B]. On the other hand, the tensile strength of the stacking sequences [C/C/B/C/C] was 128.46 MPa clearly decreased compared to that value (148 MPa) for the stacking sequences [C/B/C/B/C]. In this regard, the carbon fibers were pulled-out and broken during the tensile loading of this hybrid configuration and as appeared in the microstructure, Figure 6, so the tensile strength was likely decreased. Figures 4 and 5 show the influence of the fiber configuration on the flexural strength and ILLS of composite laminates. It was noted that the higher flexural strength and ILLS as 448 MPa, 25 MPa obtained for the laminates S5 with stacking sequences [C/B/C/B/C] compared to the other laminates. This might be due to the strong interfacial bonding and best hybridizations between the basalt, carbon fabrics and the polyester matrix of this hybrid. When the basalt fabrics were placed at the intermediate between carbon layers leads to the increasing in the flexural strength and ILLS of the this combination.This is because of the high ductility of the basalt fabrics.For stacking sequence [C/G/C/G/C], the flexural strength and ILLS were slightly increased 11.54 and 20% over than that for the stacking sequence [C/C/G/C/C] while increased 19.58 and 33.14 %, when compared to the stacking sequence [G/C/G/C/G], respectively. The decrease in the flexural strength of the stacking sequences [G/C/G/C/G] is related to the carbon fibers were breakage between the glass fabric layers as shown in the microstructure, Figure 9b.

3. 2. Impact Strength Behavior The effect of the stacking sequences of composite laminates on the impact strength is represented in Figure 7. The impact strength reached the maximum value at 43.7 KJ/mm^2 for laminates S2 at stacking sequence [C/G/C/G/C] while the minimum value of impact strength was recorded at 13.8 KJ/mm^2 for laminates S8 at stacking sequences [G/B/G/B/G]. Addition of carbon fabrics as an external layer and in the core to the glass layers composite laminates enhanced the impact strength but reduced the flexural strength and flexural stiffness of this combination. Meanwhile, the basalt fabrics layers between the glass layers of composite laminates reduced the impact strength of the layup.

For hybrid composite laminates with laminates S5 stacking sequences [C/B/C/B/C], the impact strength increased by 4.60%, which is more than the laminates S6 with stacking sequences [B/C/B/C/B]. In addition, the impact strength of the combination [G/B/G/B/G] was 3.30 % lower than that the combination [B/G/B/G/B].

This is due to the position of the glass fabrics layers at the intermediate between the basalt layers for the combination [B/G/B/G/B] leads to the increasing in

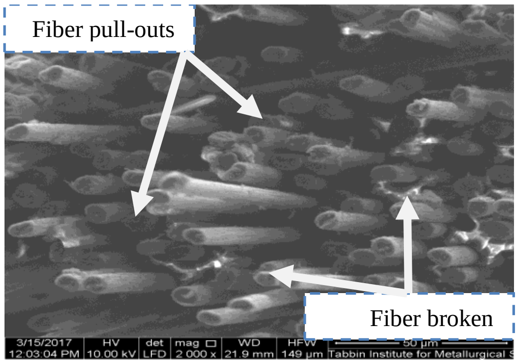

Figure 6. SEM micrographs of the composite laminates with stacking sequences [C/C/B/C/C]

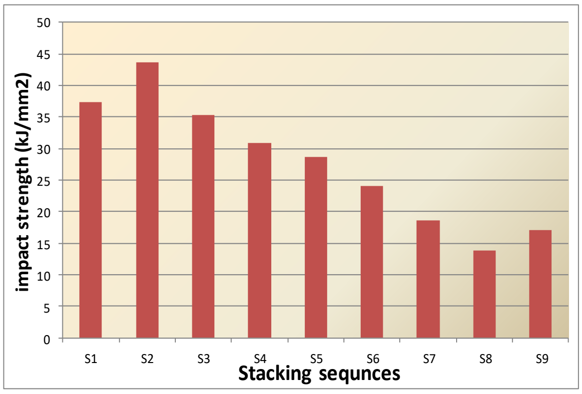

Figure 7. Effect of stacking sequences on the impact strength of composite laminates

impact energy compared to the combination [B/G/B/G/B]. On other side, the impact strength of the laminatesS2 with stacking sequences [C/G/C/G/C] was 6.40; 8.40 % greater than that the two laminatesS1 and S3 with stacking sequences [C/C/G/C/C], [G/C/G/C/G], respectively. There data reflect the positive role of carbon fiber in enhancing tougher of composite when they are located as a central layer between glass and carbon, respectively.

3. 3. Fracture Surface Figures 6, 8 and 9 show the SEM micrographs of the fracture surface for the composite laminates with stacking sequences [C/C/B/C/C], [G/G/B/G/G], [C/G/C/G/C] and [G/C/G/C/G] after proceeding the tensile and flexural strength test. As shown in Figure 6, the long carbon fibers was pulled-out and broken during the tensile loading of hybrid laminates with code S4 with stacking sequences [C/C/B/C/C]. For hybrid composites with stacking sequences [G/G/B/G/G], the presence of pores and voids were assisted clearly in the image of the Figure 8 after the flexural test. Also, it can be seen from this figure, the basalt fiber was broken initially, followed by polyester matrix.

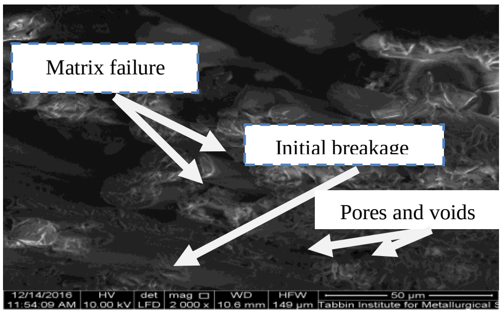

Figure 8. SEM micrographs of the composite laminates with stacking sequences [G/G/B/G/G]

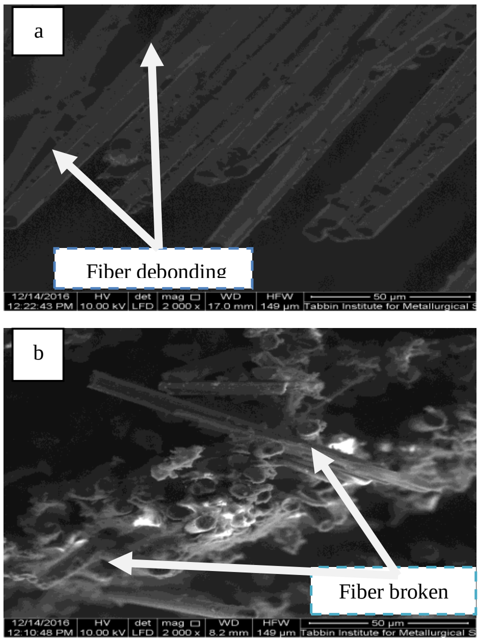

Figure 9. SEM micrographs of the composite laminates with stacking sequences a) for [C/G/C/G/C] and b) for [G/C/G/C/G]

As seen in Figure 9a, fiber debonding has been observed in the carbon fibers of the hybrid laminates S2 with stacking sequences [C/G/C/G/C]. This is attributed to the weak interfacial bonding between the matrix and the glass, carbon fibers. On other hand, for stacking sequences [G/C/G/C/G], the carbon fibers were broken between the glass layers and as seen in Figure 9b.

4. CONCLUSIONS

- Higher tensile and flexural properties exhibted for the hybrid composites for laminates S5 with stacking sequences [C/B/C/B/C] compared to other laminates.
- From the impact test results, the hybrid composites with laminates S2 at stacking sequences [C/G/C/G/C] exhibited high impact strength overthan the other laminates.

- The fiber configuration [C/B/C/B/C] gave positive effect on the mechanical properties of the composite laminates.
- Long fibers broken and pull-outs were suggested in the fracture surface of the hybrid laminates with stacking sequences [C/C/B/C/C], while initial breakage in basalt fiber followed by resin matrix failure for the fiber configuration [G/G/B/G/G] was observed.

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PAPER INFO

Paper history:
Received 21 December 2017
Received in revised form 26 February 2018
Accepted 9 March 2018

Keywords:
Stacking Sequences
Hand Lay-up Procedure
Fracture Surface
Mechanical Properties

چکیده

اثر انتزاعی توالی های انباشته از مواد مرکب هیبرید بر استحکام کششی مقاومت خمشی استحکام برشی بین آرام (ILSS) و تاثیر انرژی بررسی شد. ورقه کامپوزیت شیشه ای و کربن/استر هیبرید بروش دستیlay-up در دمای اتاق پردازش شد. شکستگی سطح ورقه کامپوزیت پس از تنش و خمشی تست توسط اسکن میکروسکپ الکترونیکی (SEM) مورد بررسی قرار گرفت. نتایج نشان می دهد که ویژگی های مکانیکی برای کامپوزیت به دست آمد لامینیت S5 در توالی های انباشته [C/B/C/B/C]، که در آن مقاومت کششی، مقاومت خمشی وILSS برابر با448 MPa, 148 MPa و 25 MPa میباشد. این کاهش در خواص مکانیکی منسوب به مطلوب بودن پیوند بین الیاف و ماتریس در این پیکربندی می باشد. از سوی دیگر بزرگترین تاثیر قدرت ($43.70\ kJ/mm^2$) به وضوح برای ورقه S2 در توالی انباشته [C/G/C/G/C] نسبت به دیگر ورقه به سادگی مشاهده گردید.

doi*: 10.5829/ije.2018.31.07a.19*