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MECHANICAL PERFORMANCE OF CARBON - ARAMID FIBER-REINFORCED LAMINATED COMPOSITES UNDER IMPACT AND SHEAR LOADING

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ABSTRACT

In this study, the drop weight impact response and the interlaminar shear strength of hybrid carbon/aramid fiber-reinforced laminated composites with different stacking sequences were investigated. Seven different laminates including two types of sandwich-like interply hybrid, three types of interply hybrid, and two types of non-hybrid named carbon and aramid were produced using the vacuum-assisted resin transfer molding method. Drop weight impact and short-beam shear tests were applied to the laminates to calculate the low-velocity impact response and the interlaminar shear strength, respectively. It is observed that while the outer layer of the hybrid structure is carbon, the structure can carry less load but absorb more energy. Pure carbon and pure aramid composites cannot carry loads but can absorb energy as much as their hybrid versions can. Sandwich-like interply hybrid with central carbon showed the best results when load and energy values were compared. Also, sandwich-like interply hybrid with central carbon has higher ILSS among hybrid structures because its center region consists of carbon layers.

Keywords: Carbon fiber, Aramid fiber, Hybrid composites, Low-velocity impact response, Interlaminar shear strength (ILSS)

1. INTRODUCTION

Composite materials are widely used in many areas especially in aviation due to their mechanical and light-weight properties [1]. Increasing demand for composite materials led to the combination of different composite materials called hybrid structures [2]. These hybrid composites are used for increasing the effectiveness of non-hybrid structures. Carbon-aramid composites are one of the most known hybrid structures used in different areas [3].

The DWI test is generally applied to structures to determine the resistance of the material to a sudden impact force. A typical example of sudden impact is hail rain on aircraft wings. For each sequence, three samples were tested to include deviation of results from each other. The impact material effect on the peak load and energy absorption was discussed. Yang et al. [4] studied the low-velocity impact response of plain-woven glass and carbon fiber fabrics. Experimental results show that the energy absorption capacity of hybrid composites can be higher than non-hybrid composites in the impact event. In the study of Sun Ying et al. [5], it is observed that hybridization of carbon and aramid improves the impact properties of carbon/epoxy composites by softening the sharp drop after peak load.

The interlaminar shear strength (ILSS) parameter which can be determined by the short beam shear (SBS) test method, indicates the strength of composite material against delamination type damage. Previous studies on the carbon/glass fiber hybrid composites [6] and carbon/aramid fiber hybrid composites [7] showed the effects of the hybridization process, ply angle, and stacking sequence on the ILSS parameter.

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Since the hybrid composites consist of different plies, there might be different problematic cases. There might be problems such as stress concentrations due to transverse multifilament failure [8], compatibility of different polymer phases [9], delamination of different layers [10]. These problems might cause catastrophic failures at the earlier stage of the composite. Therefore, necessary precautions should be taken by using standard test methods.

This study aims to examine and compare the low-velocity impact response and the interlaminar shear strength (ILSS) of carbon/aramid hybrid composites by drop weight impact (DWI) and short beam shear (SBS) tests.

2. EXPERIMENTAL

2.1 Material

A 200 g/m^2 plain woven carbon fiber fabric (DOWAKSA, Turkey) and TWARON CT709 aramid fiber fabric (Teijin, Holland) were used as reinforcement materials for the composites. The DTE1200 series of Duratek epoxy resin was used with the DTS2110 hardener.

2.2 Method

Carbon-aramid reinforced epoxy composite structures were produced with vacuum-assisted resin transfer molding (VARTM) technique as shown in Figure 1. In this system, 12 layers of reinforcing fabrics were stacked over a flat surface. A release film was laid under fabrics to remove the sample after production. Then, a flow mesh is used to make the resin flow fast, and a peel ply is used to separate the composite sample from the flow mesh. Two spiral tubes were placed to opposing edges. Furthermore, a vacuum bag was used to create a vacuum ambient to the system. The resin was fed from one spiral tube towards the other with the help of a vacuum pump. Hence, resin impregnation was completed after nearly 10 minutes. After resin impregnation, the system kept 36 hours under vacuum ambient to complete the curing process of the resin.

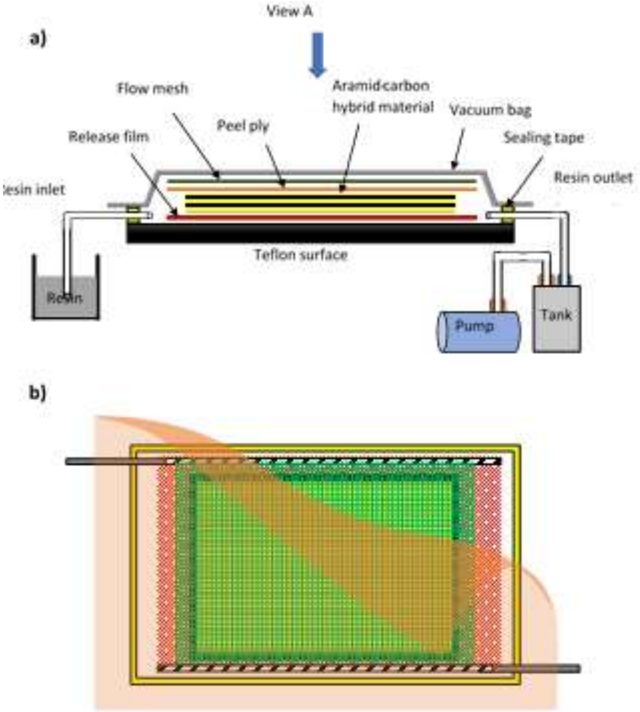

Figure 1. VARTM method demonstration **(a)** side view; **(b)** top view (view A)

Two types of sandwich-like interply hybrid ($[C_3A_3]_s$, ($[A_3C_3]_s$), three types of interply hybrid ($[C_3A_3]_2$, $[A_3C_3]_2$ and $[CA]_6$ and two types of non-hybrid carbon ($[A_{12}]$) and aramid laminates ($[C_{12}]$) were tested for the comparative study. The stacking sequences of the laminates are given in Table 1. It has been seen that different stacking sequence of hybrid structures has shown different results under DWI and SBS tests [4], [5].

Table 1. Different stacking sequences of carbon/aramid hybrid laminates

Stacking Sequence	Ply number											
	1	2	3	4	5	6	7	8	9	10	11	12
$[C_{12}]$	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
$[A_{12}]$	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
$[C_3A_3]_s$	⬛	⬛	⬛	🟨	🟨	🟨	🟨	🟨	🟨	⬛	⬛	⬛
$[A_3C_3]_s$	🟨	🟨	🟨	⬛	⬛	⬛	⬛	⬛	⬛	🟨	🟨	🟨
$[C_3A_3]_2$	⬛	⬛	⬛	🟨	🟨	🟨	⬛	⬛	⬛	🟨	🟨	🟨
$[A_3C_3]_2$	🟨	🟨	🟨	⬛	⬛	⬛	🟨	🟨	🟨	⬛	⬛	⬛
$[CA]_6$	⬛	🟨	⬛	🟨	⬛	🟨	⬛	🟨	⬛	🟨	⬛	🟨

Low-velocity impact tests were carried out using the BESMAK BMT-DW series drop weight impact material testing machine according to the ASTM D7136 [6]. The demonstration of the DWI test is shown in Figure 2. The dimension of the DWI sample was 80 mm x 50 mm. At least five samples were tested and the average value was calculated. As a result of the literature review, the impactor energy required for the test was selected as 30 J. If a larger amount of energy were used, it would pierce the samples. Therefore, the damages in all samples would be the same. In this study, how much energy it absorbs at a given joule value and how it causes damage was analyzed.

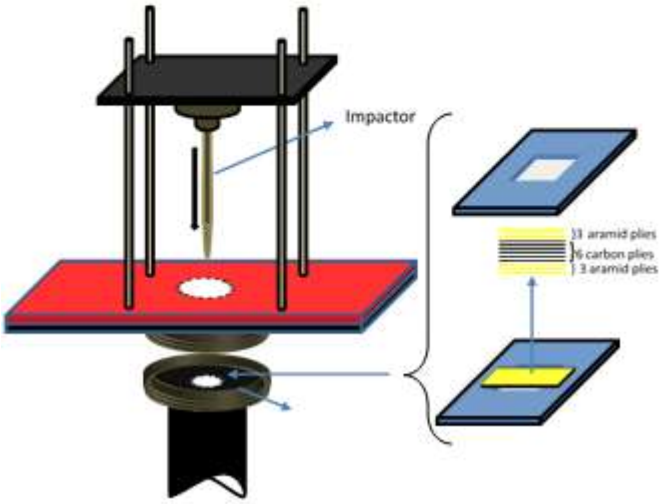

Figure 2. A closer demonstration of the DWI test setup.

ASTM D2344 [7] standard was used for the SBS test. The rectangular samples with dimensions of 24 mm x 8 mm were used. For each sequence, five samples were tested. The test was conducted using the AG-100kNXplus model of SHIMADZU. The demonstration of the SBS test is shown in Figure 3.

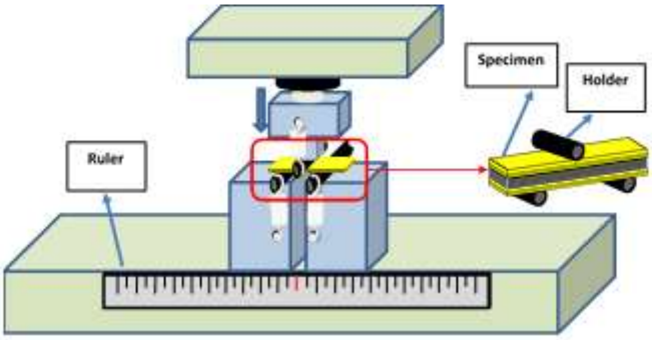

Figure 3. A closer demonstration of the SBS test setup

3. RESULTS AND DISCUSSIONS

After the laminates were produced, the thickness of each laminate was measured to use for the ILSS calculations. The thickness values are shown in Table 2.

Table 2. The thicknesses of the laminates

Sample	Thickness (mm)
$[A_{12}]$	3.15
$[C_{12}]$	3.20
$[C_3A_3]_s$	3.15
$[A_3C_3]_s$	2.95
$[C_3A_3]_2$	3.25
$[A_3C_3]_2$	3.05
$[CA]_6$	3.10

3.1. Low-Velocity Impact Test

Damage to the specimens reveals information about the characteristic behavior of materials. When Figure 4 is examined, different forms of damage are observed. Aramid fiber absorbs the load in a ductile manner. On the contrary, carbon shows brittle behavior under the test. Damage types in the hybrid samples were different from those in the non-hybrid samples. Since one side of the laminate $[CA]_6$ is carbon fiber and one side is aramid fiber, the force was applied to the carbon fiber side in half of the samples and to the aramid fiber side in the other half, and damage behaviors were observed.

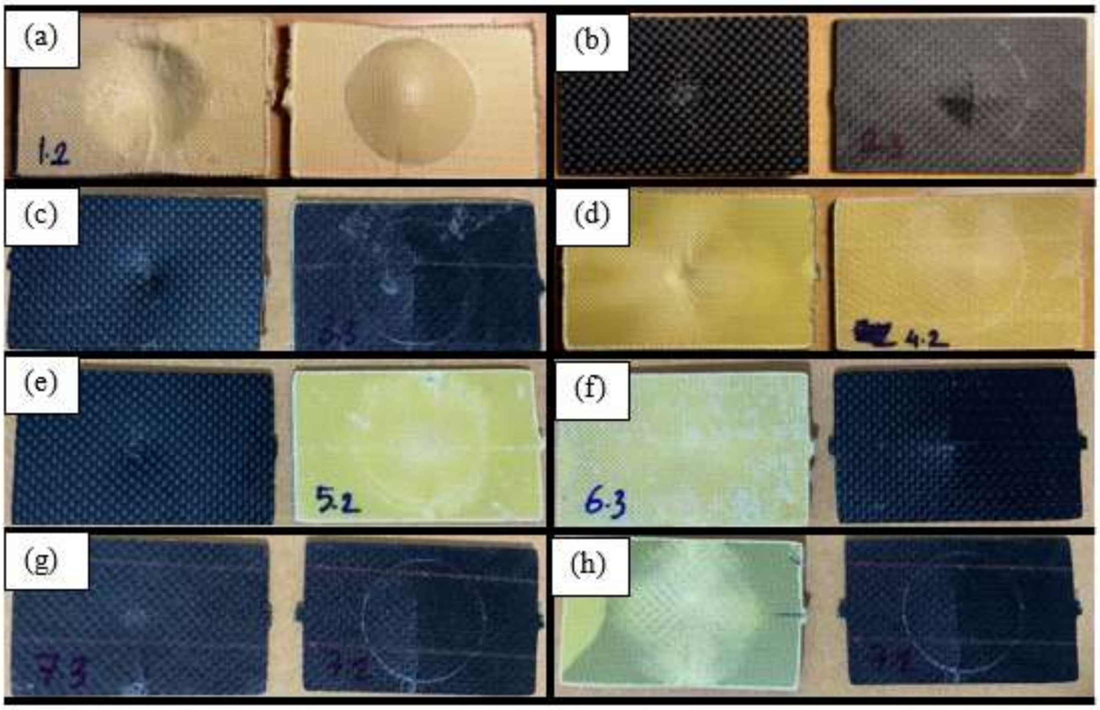

Figure 1. The damages in the specimens of the laminates (a)$[A_{12}]$, (b) $[C_{12}]$, (c) $[C_3A_3]_s$, (d) $[A_3C_3]_s$, (e) $[C_3A_3]_2$, (f) $[A_3C_3]_2$, (g) $[CA]_6$ from front and (h) $[CA]_6$ from back, respectively

When Figure 5 is investigated, it can be observed that the maximum load that the pure carbon and pure aramid composites can carry is less than hybrid composites.

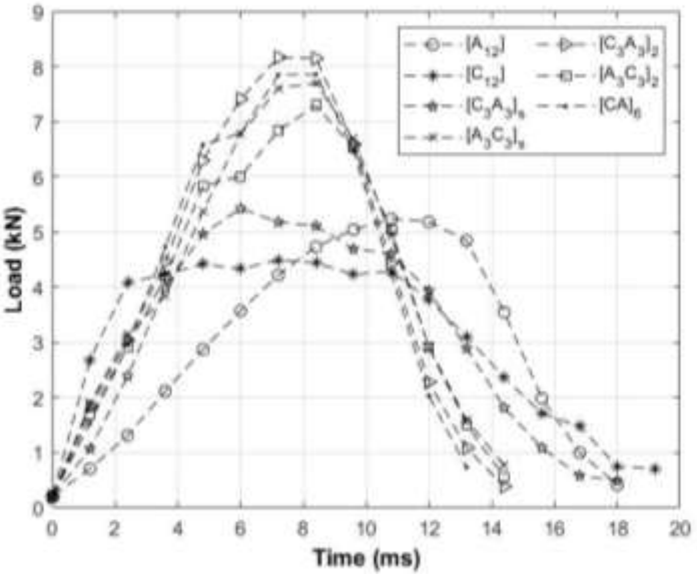

Figure 5. Load-time curves of hybrid composites

When Figure 6 is investigated, it is noticed that while non-hybrid carbon sample peak moment point energies shifts to the left, non-hybrid aramid sample peak moment point energy shifts to right, and remaining hybrid structures lie in between.

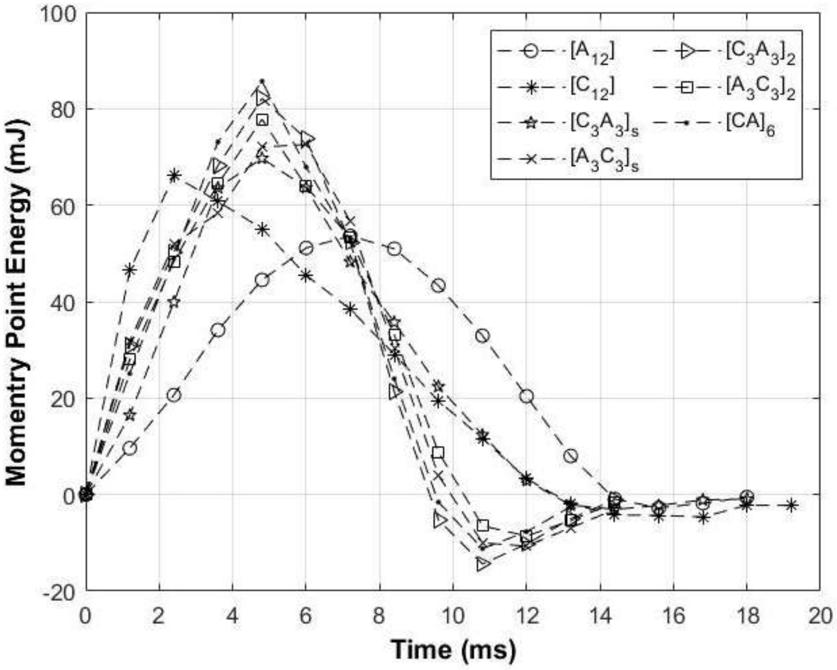

Figure 6. Momentary point energy-time curves of hybrid composites

The initial energy was set to 30 J for the DWI test. According to data in Table 3, as $[A_3C_3]_s$ carried the maximum load, in contrast, it showed the poorest energy absorption. When the data of the seven samples are compared, it is seen that $[A_3C_3]_s$ has the most proper maximum load, absorbed energy, and fiber weight fraction values.

Table 3. The average loads, absorbed energies, and fiber weight fraction values of the samples.

Sample	Max. Load (kN)	Absorbed Energy (J)	Fiber Weight Fraction (%)
$[A_{12}]$	5.139 ± 0.102	27.193 ± 0.035	54.962 ± 0.149
$[C_{12}]$	4.599 ± 0.126	26.700 ± 0.132	63.862 ± 0.528
$[C_3A_3]_s$	6.075 ± 0.557	27.091 ± 0.298	59.632 ± 0.527
$[A_3C_3]_s$	8.141 ± 0.314	25.463 ± 0.429	60.379 ± 0.310
$[C_3A_3]_2$	8.103 ± 0.320	26.023 ± 0.504	54.969 ±0.649
$[A_3C_3]_2$	7.777 ± 0.650	26.767 ± 0.204	58.068 ± 0.437
$[CA]_6$	7.743 ± 0.436	26.715 ± 0.330	57.143 ± 0.000

3.2 Short Beam Shear Test

As shown in Figure 7, the weakest configurations have higher displacement, and the strongest configuration has low displacement [11].

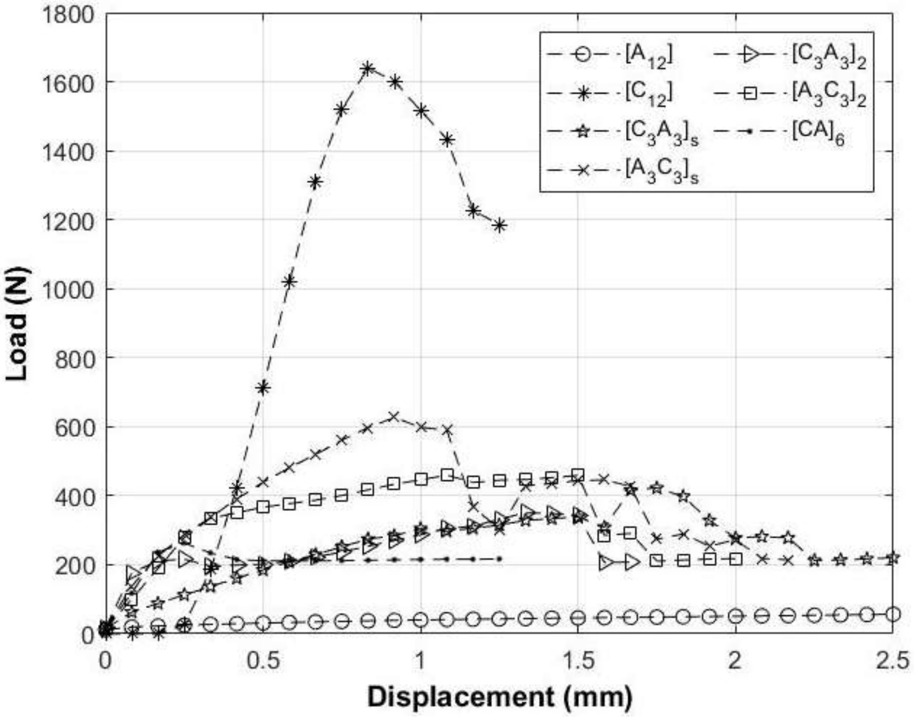

Figure 7. Load - displacement curves of hybrid composites

As seen in Table 4, $[A_{12}]$ full aramid composite configuration has the lowest ILSS due to its nature while the opposite situation is valid for $[C_{12}]$ full carbon composite configuration. The other five configurations contain the same amount of carbon and aramid. However, the ILSS of $[CA]_6$, is the weakest configuration because it has the greatest number of faces which is between different materials and this situation decreases its shear strength. In the SBS test, maximum normal stresses occur upper and lower surfaces of a specimen and maximum shear stress occurs at the middle plane of the specimen. $[A_3C_3]_s$ the configuration has higher ILSS among hybrid structures because its center region consists of carbon layers.

Table 4. Overall results for the SBS test

Sample	Max. Load (kN)	ILSS (MPa)
$[A_{12}]$	62.39 ± 9.03	1.86 ± 0.27
$[C_{12}]$	1604.98 ± 127.25	47.02 ± 3.73
$[C_3A_3]_s$	293.16 ± 41.28	8.72 ± 1.23
$[A_3C_3]_s$	590.82 ± 54.16	18.78 ± 1.72
$[C_3A_3]_2$	445.10 ± 39.41	13.68 ± 1.21
$[A_3C_3]_2$	352.53 ± 59.40	10.17 ± 1.71
$[CA]_6$	244.43 ± 28.90	7.39 ± 0.87

4. CONCLUSION

In this study, the effect of carbon aramid hybrid structures on the low-velocity impact response and ILSS was investigated experimentally. The following conclusions are obtained:

- It is observed that while the outer layer of the hybrid structure is carbon, such as $[C_{12}]$, $[C_3A_3]_s$, $[C_3A_3]_2$, $[CA]_6$, the structure can carry less load but absorb more energy.
- Pure carbon, and pure aramid, composites cannot carry loads but can absorb energy as much as their hybrid versions can.
- The sequence of $[A_3C_3]_s$ showed the best result when load and energy values were compared.
- It was observed that the DWI tests results were close and not affected by the stacking sequences of $[C_3A_3]_2$, $[A_3C_3]_2$, and $[CA]_6$.
- $[A_3C_3]_s$ the configuration has higher ILSS among hybrid structures because its center region consists of carbon layers.

5. FURTHER WORK

The further aim of the research will be conducting the other tests such as tensile, flexural, and dynamic mechanical analysis (DMA).

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CONFLICT OF INTEREST

The authors stated that there are no conflicts of interest regarding the publication of this article.

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