Bursa Uludağ University Journal of The Faculty of Engineering, Vol. 27, No. 2, 2022 RESEARCH

DOI: 10.17482/uumfd.978721

EVALUATION OF MECHANICAL PROPERTIES OF INTRAPLY HYBRID CARBON/ARAMID COMPOSITE MATERIALS

Berkay KARAÇOR *

Mustafa ÖZCANLI *

Received: 05.08.2021; revised: 09.04.2022; accepted: 20.04.2022

Abstract: Hybridization is an important application in obtaining the multi-functionality to combine the best properties of each reinforcing element makes up the composite. In this study, hybrid composites and uniform composites were fabricated using carbon, aramid, and intraply carbon/aramid hybrid weaves with two different production methods (vacuum-assisted resin transfer molding process and vacuum bagging process). The mechanical properties of the produced hybrid composites and uniform composites were analyzed with respect to two different methods. Epoxy resin from thermoset resins was used as a matrix element. The composite samples produced were analyzed mechanically (tensile test, hardness test) and morphologically, as well as in the production of intraply hybrid carbon/aramid composites and interply hybrid Carbon and Kevlar composites, how different production methods affect the results. Results show in the productions made with VABM (vacuum bagging method), the tensile strength value of Intraply carbon/aramid hybrid samples was 1.56 times better than the ones made with VARTM (vacuum assisted resin transfer molding). In the comparison of hardness values, 1.20 times higher results were obtained in the value of Intraply carbon/aramid hybrid samples produced with VARTM compared to those made with VABM. Using SEM analysis, the interfacial properties such as fiber breakage, fiber shrinkage, and fracture were determined in the specimens after the uniaxial tensile test, and it was found that the interactions of the fiber interfaces support the mechanical properties of the specimens.

Keywords: Intraply hybrid composites, Interply hybrid composites, carbon fiber, aramid fiber, mechanical properties

Intraply Hibrid Karbon/Aramid Kompozit Malzemelerin Mekanik Özelliklerinin Değerlendirilmesi

Öz: Hibridizasyon, kompoziti oluşturan her bir takviye elemanının en iyi özelliklerini birleştirmek için çok işlevliliğin elde edilmesinde önemli bir uygulamadır. Bu çalışmada, karbon, aramid ve intraply karbon/aramid hibrit kumaşlar kullanılarak iki farklı üretim yöntemiyle (vakum destekli reçine transfer kalıplama yöntemi ve vakum torbalama yöntemi) hibrit kompozitler ve tek tip kompozitlerin mekanik özellikleri analiz edilmiştir. Matris elemanı olarak termoset reçinelerden epoksi reçine kullanılmıştır. Üretilen kompozit numunelerin mekanik (çekme testi, sertlik testi) ve morfolojik olarak analiz edilmesinin yanı sıra, intraply hibrit karbon/aramid kompozitlerin ve interply hibrit karbon ve aramid kompozitlerin üretiminde farklı üretim yöntemlerinin sonuçları nasıl etkilediği incelenmiştir. Sonuçlar, VABM (vakum torbalama yöntemi) ile yapılan üretimlerde, Intraply karbon/aramid hibrit numunelerin çekme dayanımı değerinin VARTM (vakum destekli reçine transfer kalıplama) ile yapılanlara göre 1,56 kat daha iyi olduğunu göstermektedir. Sertlik değerlerinin karşılaştırılmasında VARTM ile üretilen Intraply karbon/aramid hibrit numunelerin değerinde VABM ile yapılanlara göre 1,20 kat daha yüksek sonuçlar elde edilmiştir. Tek eksenli çekme testi sonrasında numunelerde SEM analizi kullanılarak lif kırılması, lif çekmesi ve kırılması gibi ara yüzey özellikleri belirlenmiş ve lif ara yüzeylerinin etkileşimlerinin numunelerin mekanik özelliklerini desteklediği tespit edilmiştir.

* Department of Automotive Engineering, Engineering Faculty, Cukurova University, 01330 Adana, Turkey
Correspondence Author: Berkay KARAÇOR (bkaracor@cu.edu.tr)

Anahtar Kelimeler: Intraply hibrit kompozitler, Interply hibrit kompozitler, karbon elyaf, aramid elyaf, mekanik özellikler

1. INTRODUCTION

Composite materials, which come out a blend of two or more materials to achieve the desired properties or as an improved material combination, are an important type of structural component. There are two main components in composite structures as reinforcement material and matrix material. The reinforcing element is placed in a matrix called a continuous phase as a discontinuous phase. While polymers, metals, ceramic, and glass materials are used as matrix elements, fiber (long and short), whisker, particle, lamina materials, or ceramic, glass, textile, polymer materials are used as reinforcement elements (Kar, 2017). Composite materials are rapidly replacing traditional materials used in aviation, automotive, defense industry, and other industries due to their flexibility, lightweight, and also high corrosion capacitance, impact resistance, fatigue resistance (Balasubramanian, 2014; Kar, 2017). Depending on the dispersed phase, composites can be grouped into particulate composites and fiber reinforced composites. Fiber reinforced composites can be produced as a single layer and multilayer composites. In a multi-layer composite, it is called a laminate if the layers consist of the same type of fiber reinforcement, and if there are two or more fiber reinforcements in different layers, it is called a hybrid composite (Yalcın and Ergene, 2018; Atlıhan and Ergene, 2018). Hybridization allows designers to adapt the composite properties to the specified needs. The aim of hybridization is to obtain a new material by preserving the advantages of its components and overcoming some of its disadvantages. Generally, hybrid composites are designed using a low modulus and a high modulus reinforcement material. Carbon (high modulus), Glass fiber (low modulus), and Kevlar (low modulus) are the most preferred synthetic fibers in hybrid composites (Jesthi and Nayak, 2019; Sun et al., 2018). In these composite structures, high modulus reinforcement materials provide strength and high load carrying capacity, and ductile feature provides low modulus reinforcement material. Hybridization of a natural fiber with a high strength fiber is an important balance factor in a good performance, cost, and environmental aspects (Balasubramanian, 2014; Pegoretti et al., 2004; Sezgin, 2018). Hybrid composites are divided into several types based on the way their component materials are mixed. These are interply hybrid laminates, composites consisting of different types of fibers in different laminates, intraply hybrid laminates, composites consisting of two or more different types of fibers interspersed in the same layer, interply-intraply hybrid composites, composites consisting of interply and intraply laminates stacked in a specific order, resin hybrid composites are composites in which fiber types are not altered, which can be formed using two or more resins. Figure 1 shows a schematic drawing of interply and intraply hybrid composites (King, 1989).

.

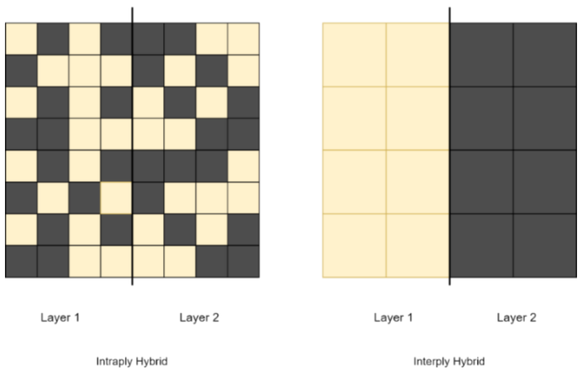

Figure 1:
Schematic drawing of a) Intraply hybrid b) Interply hybrid

Intraply and interply fiber hybridization techniques are being improved in order to provide more economical materials for structures with sufficient mechanical properties in polymer-based composites. It is stated there are experimental studies on the collision resistance behaviors of materials such as glass fiber reinforced polymer, aramid fiber reinforced polymer, carbon fiber reinforced polymer, and their interply hybridization from inside to outside (Özbek, Bozkurt, and Erkliğ, 2019). In the studies conducted, it was expressed that the effects of glass fiber and intraply hybrid carbon/ aramid fiber on the stress, bending, and Charpy impact behavior in hybridization hybrid composite laminates were examined, and some glass layers were replaced with carbon/ aramid layers and there was an increase in these properties (Alsaadi et al.,2020). In general researches, interply type hybridization of fibers has been investigated. In this type of hybrid composite, all features of composites such as mechanical features and impact behavior are affected by the stacking order of the composite layers. This brings a significant disadvantage to interply hybrid composites, which reduces flexibility in use under various loading conditions (Azimpour Shishevan and Akbulut, 2019). Attia et al. (2017) produced unidirectional glass fiber and polypropylene materials with non-hybrid, intraply hybrid, inter-intraply hybrid configuration and examined the effect of hybridization on mechanical properties. They concluded the layer stacking sequence and the hybrid configuration had a great impact on the mechanical properties of the manufactured composites. In the studies, vibration and damping properties and mechanical characterization of materials produced by hybridizing with glass fibers, intraply carbon/aramid fiber, and graphite fiber were investigated. It has been more suitable by hybridizing S-glass and intraply carbon/aramid fibers to meet the long part life and desired dynamic or mechanical property (Bulut et al., 2019; Chamis et al., 1979). In studies to increase low speed impact response of hybrid fiber composites, intraply fabric has been the main reinforcing element of the studies to produce both thermoplastic and thermoset matrix laminates and to see the effect of the added particle reinforcements. The results of the research show the use of intraply hybrid composites in low-speed impact tests gives much better results than composites containing mono fiber in absorbed energy, maximum fracture toughness, subsurface damage, preventing the growth of cracks and dynamic cushioning (Dehkordi et al. 2010; Gokuldass and Ramesh, 2019; Sarasini et al., 2019; Yan et al., 2015). Potluri et al. (2018) developed two different hybrid laminates using Kevlar/Glass fiber laminates and IM7-carbon/boron laminates in order to investigate the effectiveness of the hybrid stacking array, and performed the analysis in ANSYS and MATLAB programs. According to analytical results, it was found the stacking sequence has no significant effect on Poisson ratios, longitudinal and transverse Young's modulus values, and in-plane shear modulus, whereas it has a significant effect on bending modulus. In one of the studies, Bresciani et al. (2016) investigated the ballistic impact behavior of tungsten bullets on Kevlar plain woven fabrics with epoxy matrix at the composite component level. When they compared the developed numerical models with experimental results, they stated that a multi-layer plate with different materials and structures offers a possible solution to improve the resistance in the composite plate. In another research, Yahaya et al. (2016) observed the ballistic impact performance of non-hybrid Kevlar composites and kenaf-Kevlar hybrid composite products against fragment simulating projectiles. While the results show hybrid composites have lower specific energy absorption, it was found that increasing thickness and area density in hybrid composites increased ballistic performance. In a study of Kang et al.(2008), researchers aimed to create a new model of fatigue life prediction by forming carbon/epoxy laminates with different laying angles (0° and 90°). Models describing the change of fatigue life based on the probabilistic stress-strain and probabilistic damage accumulation behavior developed, also explain the fatigue life and its variation in carbon/epoxy laminates. Yhuzari et al. (Yuhazri et al., 2016) used various weave styles such as satin, plain, basket, twill, leno, and mock leno weave to analyze the effect of weave designs on the mechanical characteristics of laminated intraply hybrid composites. Samples produced using unsaturated polyester resin as matrix and kenaf fiber and glass fiber as reinforcement were subjected to tensile testing. In the results obtained, the Mock leno fabric showed better mechanical properties of about 54.74 MPa for kenaf fiber in warp direction interlace with glass fiber in the weft direction and about 99.46 MPa for glass fiber in warp direction interlace with kenaf fiber in the weft direction. In the literature, although the reinforcement elements used vary in low-speed impact test or high-speed impact test studies using intraply composites and hybridization, positive effects of the use of composites in both forms are seen. With these two hybridization techniques, materials with increased penetration resistance, higher buckling strength, more resistant to impact, and lower damage propagation emerged (Da Cunha et al., 2020; Muhi et al., 2009; Tehrani Dehkordi et al.,2013). Qing-dun et al. (2001) made a shear lag model analyze stress redistribution in intraply hybrid composites and this distribution was calculated by this method. Erkliğ et al. (2017) utilized intraply Carbon-Kevlar hybrid fiber and nano-silica of different weights to study the effects of fiber type on damping and vibration and to examine the effect of silica particles on the dynamic properties of the material. Bandaru et al.(2018) performed both numerical and experimental analysis by applying a low speed impact tests to hybrid composites they created using Kevlar and basalt fabrics. With the hybridization process of non-hybrid Kevlar composites, improvements in peak strength by 10.07-14.37% and energy absorption by 5.38-11.29% were achieved. In this investigation, composites formed with carbon, glass fabrics, woven Kevlar/Carbon, and Kevlar/Glass fabric reinforced epoxy resin were investigated. Kevlar/Carbon woven fabric laminates have been shown to show less extensive impact damage areas, while in terms of damage tolerance they are lower than Kevlar/Glass woven fabric composites (Imielińska et al., 2004). Considering the literature, even though there are researches investigating the mechanical characteristics of intraply hybrid reinforced composite models, it is seen that very little work has been done on the production of these reinforcement materials with different production methods. The aim of this study is to investigate the effects of the mechanical properties of the samples produced by both the vacuum assisted resin transfer molding method and the vacuum bagging method on the properties of carbon, aramid, and intraply hybrid carbon/aramid fabrics, which are potential reinforcement materials in the automotive, construction and marine industries.

2. MATERIAL AND METHODS

2.1. Material

Carbon, aramid, and intraply hybrid carbon/aramid fibers were selected as the reinforcing fibers for this survey. All reinforcement fabrics used in the study were supplied from Kompozitshop. Two different types of hybrid composites, including Interply and Intraply hybrid composites, have been produced. Along with these, homogeneous carbon fabric composite and homogeneous aramid fabric composite were also produced. The characteristics of the fabrics are indicated in Table 1.

Table 1. Fiber fabric properties

(https://www.kompozitshop.com/karbon-fiber-elyaf-takviyeler-carbon.)

Fabric	Weight(g/m²)	Thickness of fabric(mm)	Warp yarn count	Weft yarn count
Carbon	200	0.32	200	200
Aramid	200	0.4	10.5	10.5
Intraply Carbon/Aramid	165	0.2	200	200

The carbon, aramid, carbon/aramid hybrid, and intraply hybrid carbon/aramid fabric configurations are shown in Figure 2.

Figure 2*:*
Four different fabric configurations a) Carbon fabric b) Aramid fabric c) Interply hybrid carbon/aramid fabric d) Intraply carbon/aramid fabric

In the exploration, L160 Epoxy resin and H160 hardener were used as matrix elements. L160 Epoxy resin and H160 hardener were supplied by Kompozitshop (a company in Turkey). The reason for the use of epoxy resins is that they have a rather low molecular weight with low shrinkage during curing, as well as good thermal and mechanical properties of cured epoxy resins, high resistance to corrosion and chemicals (Kar, 2017). Table 2 indicates the properties of the resin system.

Table 2. Epoxy and hardener properties
(https://www.kompozitshop.com/epoksi-recine-ve-sertlestirici.)

	L160 Infusion Epoxy	H160 Hardener
Operating temperature (° C)	-60 / +50 without heat treatment -60 / +80 by applying heat	-
Process temperature (° C)	+10 / +50	-
Density (g/ cm³)	1.13-1.17	0.96-1.00
Viscosity (mPas)	700-900	10-50
Refractor index	1.5480-1.5530	1.5200-1.5210
Amine value (mg KOH / g)	-	550-650
Measurement conditions	25°C	25°C

In this work, sixteen composite samples were produced for tests in four different configurations. The reference codes for the fabric layers in the composite samples produced are given in Table 3.

Table 3. Codes of produced samples

Composite codes	Fabric types
C	Carbon fabric composite
A	Aramid fabric composite
C/A	Interply hybrid carbon/aramid laminate
INT C/A	Intraply hybrid carbon/aramid hybrid

The water jet process is a process generally used for cutting and shaping soft materials where water at high pressure water is sufficient (Ergene and Bolat, 2019). After curing, the composite samples were cut with a water jet machine in test dimensions of 250 mm length, 25 mm width, 2.5 mm thickness specified in the ASTM standards. Figure 3 indicates the samples after water jet application.

***Figure 3**:*
Samples after waterjet application

2.2. Method

Composite specimens are produced utilizing vacuum assisted resin transfer molding method (VARTM) and vacuum bagging method (VABM).

2.2.1. Vacuum Assisted Resin Transfer Molding (VARTM) Method

VARTM is a cost-effective process in the production of large structures where vacuum application helps to better impregnate fiber packaging. With the application of vacuum, it is easier to remove the trapped air and the resin flow through the fiber filler, as well as a high fiber volume fraction, and thus the structural performance of the produced part is also high (Balasubramanian, 2014). The eight composite samples in the study were produced using the vacuum assisted resin transfer molding method (VARTM). Composite fabrication was carried out at room temperature (20°C ± 2°C). First, the designated area for production was cleaned and a release agent was applied to the surface. Then, the fabrics were arranged in the determined order and placed on the peel layer and infusion mesh fabric. The designated area was surrounded by vacuum sealing tape. After the vacuum sealing tape was affixed around the designated area, the created system was closed with a vacuum bag. Small holes were opened in the vacuum bag so that the infusion hose and vacuum hose could enter and exit the system. During these processes, the resin and hardener were mixed and made ready by mixing according to the values given by the manufacturer. Mixing was initiated so that the ratio of this weight ratio epoxy to hardener was 100:25. Finally, the vacuum pump (approx. 1 bar) was turned on to allow resin flow through the sample, and the pump was turned off when the resin was completely infused through the reinforcement. Open fields were checked to prevent air entrainment and the sample was left in this position for 24 hours as shown in Figure 4 for curing. The test specimens were placed in an oven and kept at 60 ° C for 1 hour, post curing was applied. Figure 5 shows the samples after post curing operation.

Figure 4:
Vacuum assisted resin transfer molding process

Figure 5:
Samples after post curing

2.2.2. Vacuum Bagging Method (VABM)

This process is based on creating a vacuum under the vacuum bag and applying pressure up to one atmosphere to bond the laminate. Compared to hand lay-up, a high reinforcement, improved adhesion between layers, very good control of the fiber volume percentage are achieved by vacuum bagging (Kar, 2017). Composite manufacturing was made at room temperature (20°C± 2°C). First of all, the proportion of matrix materiel was specified according to the quantity of fibrous fabric, and the matrix material was prepared by mixing the hardener with the existing epoxy resin. Mixing was initiated so that the ratio of this weight ratio epoxy to hardener was 100:25. Before starting production, two layers of mold release agent were applied to the designated area, allowing the sample to be easily separated from the surface after production. Afterwards, a layer of fabric was laid on the surface, then a layer of epoxy resin mixture was applied and a layer of fabric is put down on it again. This procedure ended when the necessary counts of fabric layers were obtained. After the fabric layers were laid and the resin was applied, perforated release film and the breather cloth were put down on the fabric layers, respectively. Lastly, the vacuum sealing tape adhered around the specimen and a vacuum bag was affixed to the system. A hole was made in the vacuum bag for the infusion hose that allows the excess resin to pass. Thereafter, the excess resin in the sample was removed from the system through a vacuum pump. The vacuum pump was operated until approximately 1 bar of excess resin flow stopped. The infusion hoses were then sealed with sealing tape to avoid air entry. The specimen was left in this position for 24 hours to cure (Figure 6).

***Figure 6**:*
Vacuum bagging process

2.3. Tensile Testing

The tensile test was performed at KOLUMAN Otomotiv Sanayi A.Ş. with ALŞA Hydraulic Test Machine (Figure 8). With the tensile test; tensile strength, young modulus values, and stress-strain plots of hybrid composites were obtained.

The following equation is used to determine the tensile strength.

$$\sigma_u = \frac{P_{max}}{A_0} \quad (1)$$

σ_u=Tensile strength
P_{max}=Maximum load
A_0=Cross sectional area of the sample

σ_u is tensile strength is calculated by dividing the maximum load by the cross-sectional area of the sample.

Young Modulus calculation was made by the following equation.

$$E = \frac{\sigma_{axial}}{\varepsilon_{axial}} \quad (2)$$

E=Young's modulus
σ_{axial}=Engineering stress along loading the axis
ε_{axial}=Engineering stress

The composite specimen tensile strength was evaluated according to the ASTM D3039 standard. A load cell of 98000 kN at a cross-head speed of 2 mm/min was used(ASTM D3039/D3039-M, 2000). Five specimen tests were performed for each composite configuration and results are given as the mean value of five specimens.

2.4. Hardness Testing

In the Vickers hardness test, the material uses an indentation that has an effect called an indentation on the test specimen. The measured Vickers hardness value depends directly on the applied load as well as the area created by the indentation on the test surface of the material. The geometric configuration of a square pyramid made of the diamond at an angle of 136 ° between opposite faces is the indentation shape used in the Vickers hardness test. The sample of material presents an indentation region as in Figure 7 which has an approximately normal diamond shape. AOB Lab product machine is utilized to evaluate the hardness test of samples according to the ASTM E92-17 standard (ASTM E92-17, 2017). For each composite configuration, at least fifteen Vickers hardness test measurements were made on the sample and the results are given as the mean value of the fifteen measurements.

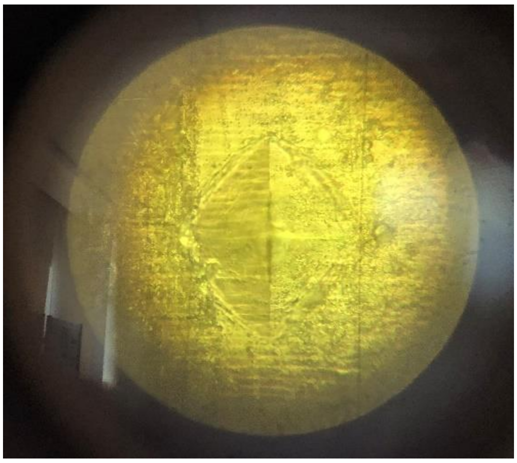

Figure 7:
Regular lozenge shape

2.5. Morphological Analysis

The interfacial surface morphologies of composite samples are observed by using a Scanning Electron Microscope (SEM) FEI Quanta 650 Field Emission at 100V-30kV acceleration voltage. The samples are sputter coated with gold to increase the surface conductivity. The device has the capacity to magnify 6-1.000.000 x times. This analysis would give the opportunity to examine the fracture surface of composite specimens and to see the fiber-matrix interactions.

3. RESULT AND DISCUSSIONS

3.1. Tensile Testing Results

In view of tensile test results as seen in Figure 8, carbon composite samples have the highest tensile strength value in both production methods. Moreover, Aramid composite samples have the lowest value. This may be due to the lack of a strong bond between Aramid and epoxy. C/A interply hybrid composites and intraply C/A hybrid composites performed better results than homogeneous aramid composites. Similar tensile strength values were found in the production of C/A hybrid composites under normal conditions in previous studies (Hashim et al.,2019). However, both hybrid composites could not reach the tensile value of carbon samples. In the samples produced with VARTM, the tensile strength of the C/A hybrid samples is 70.02% higher than the laminated aramid composite samples. While INT C/A hybrid specimens have 17.96% higher tensile strength than aramid composite specimens, they have 44.13% lower tensile strength than C/A hybrid composite specimens. In the samples produced with VABM, INT C/A hybrid composites have a higher tensile strength value in comparison with C/A hybrid samples. Intraply carbon/aramid composites demonstrated the superiority of both carbon and aramid composites over C/A hybrid composites. Intraply carbon/aramid composites, 20.42% higher tensile strength than homogeneous aramid composites, and 3.28% higher than carbon/aramid hybrid composites were obtained. In previous studies, the use of Intraply hybrid carbon and glass fiber reached 14.03% higher tensile strength than the interply hybrid carbon and glass fiber structure (Rajpurohit et al.,2020). When the tensile strength values of carbon composites are examined in terms of both production methods, the samples produced with the VARTM method have reached 20.88% better values than VABM. This ratio was higher for the samples produced with VABM as 53.03%, 4.94%, and 56.22% for aramid, carbon/aramid hybrid, and intraply carbon/aramid hybrid composites, respectively. It has been found that the vacuum bagging process provides a high bond, improved reinforcement between the layers produced according to the vacuum assisted resin transfer molding method.

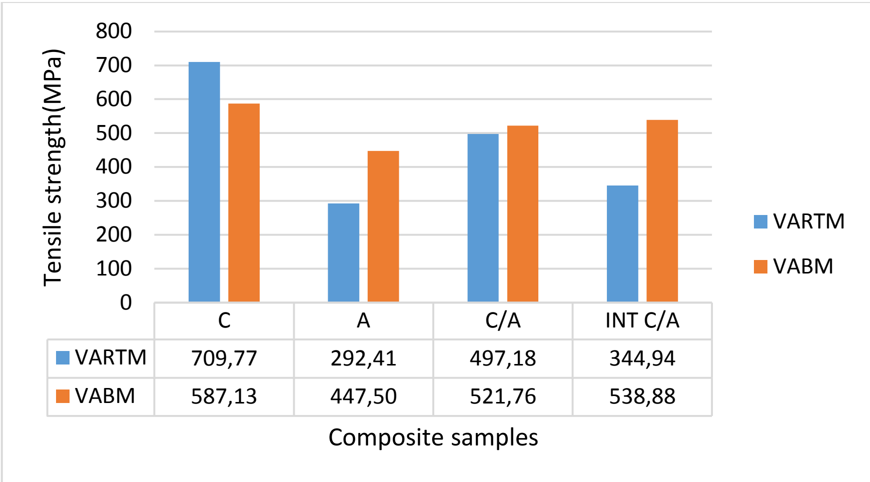

Figure 8:
Tensile strength of samples

According to elongation rate results in Figure 9, the highest elongation rate in the two methods is the homogeneous aramid composite samples. C/A hybrid samples have the lowest elongation rate in samples produced with the VARTM method, INT C/A samples have the lowest value in samples produced with VABM. In general, low tensile strengths were observed in samples with high elongation percentages, while low elongation rates were found to correspond to high tensile strength.

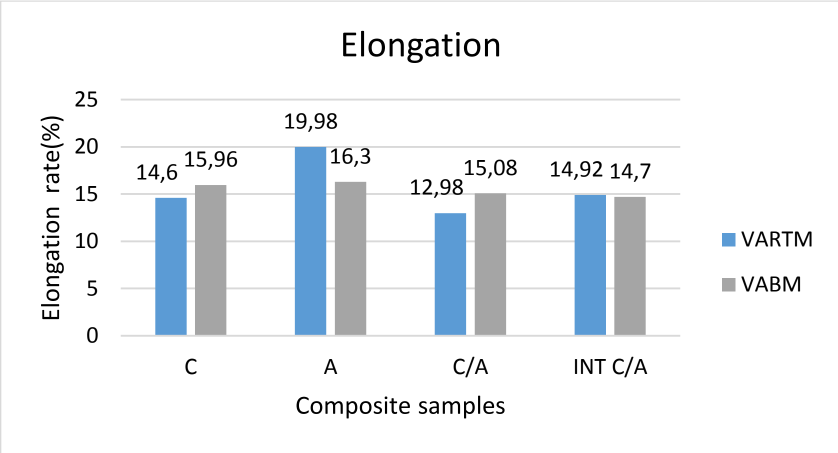

Figure 9:
Elongation rate of samples

Figure 10 indicates the elastic modulus of composite samples. Considering that the elastic modulus is the ratio of the stress applied to the sample to the difference between the two stress points, it is clear that high result values are obtained at high stress values in the transition region. While carbon composites reached the highest value with 7712.2 MPa in production with the VARTM method, C/A hybrid composite samples in production with VABM showed the best result with 6299.6 MPa. Aramid composite samples have the lowest elastic modulus values in both production methods. While the value of INT C/A hybrid composite is 4403 MPa in the samples produced with VARTM, the value is 6075.8 MPa in the samples produced with VABM.

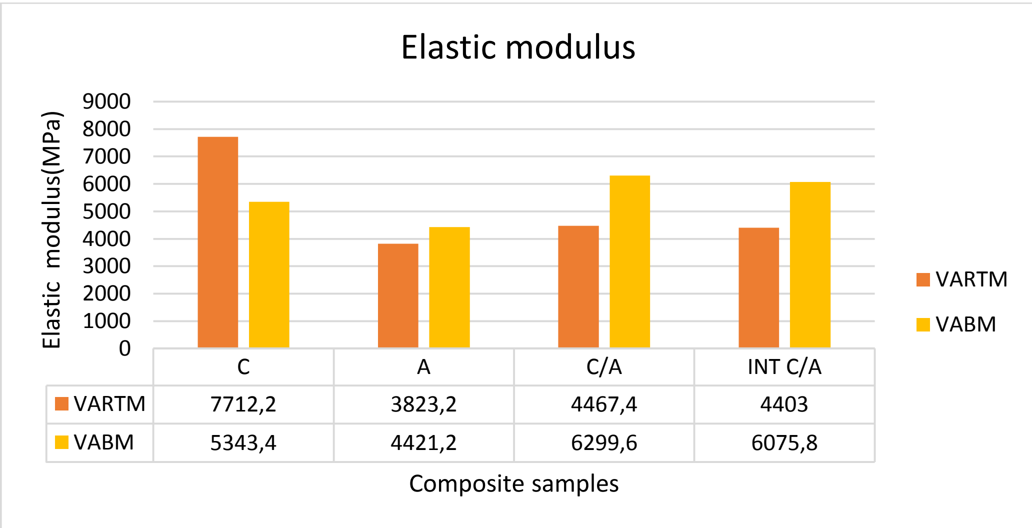

Figure 10:
Elastic modulus of samples

The maximum force applied to samples is shown in Figure 11. While the carbon composite specimens produced as a result of fabrication with VARTM are the specimens with the highest force, the force value applied to the INTC/A specimens during fabrication with VABM is the highest. The required fracture strength for INT C/A specimens prepared with VABM is 29.87% lower than the maximum strength required for carbon specimens prepared with VABM. Fabrication of INT C/A specimens using VABM increases the breaking strength by 45.81% compared to fabrication using VARTM, which supports the better results of specimens fabricated using VABM as well as the tensile strength results. Aramid composite samples were the samples requiring the lowest force as in the other results.

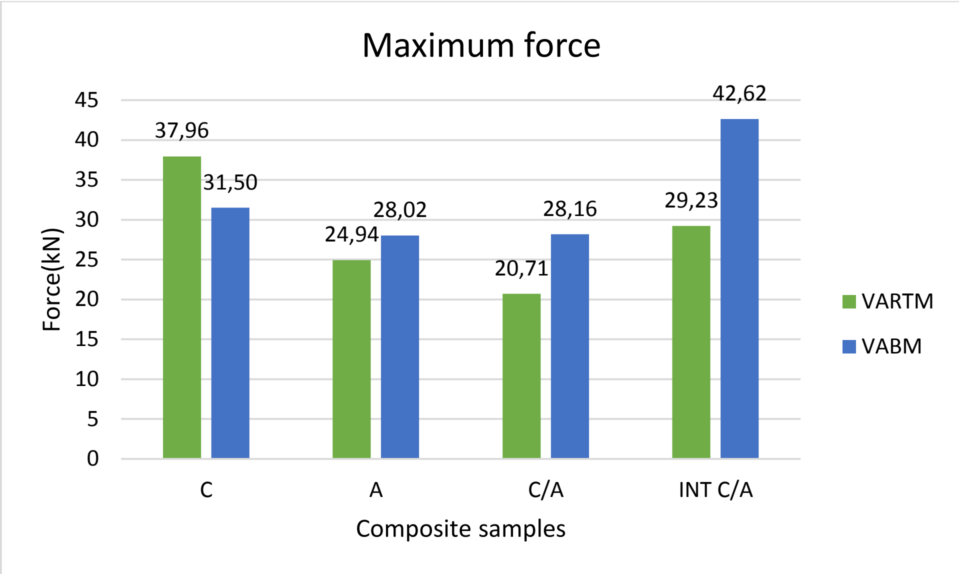

Figure 11:
Applied maximum force to samples before breaking

3.2. Hardness Testing Results

Results obtained from the Vickers hardness test as seen in Figure 12, Vickers hardness values of C, A, C/A, and INT C/A samples fabricated by the VARTM method are 171.61 HV, 231.71 HV, 349.72 HV, and 420.45 HV, respectively. Intraply Carbon/Aramid fiber reinforced composite samples have the highest Vickers hardness value among the samples fabricated with this method. The Vickers hardness value of carbon/aramid hybrid composite samples is the second highest value. The lowest Vickers hardness value belongs to carbon reinforced composite samples. Although carbon fabric has better mechanical properties than aramid fibers, the problems that may occur in the lamination of carbon fiber fabrics with the epoxy matrix can be shown as a reason for the high Vickers hardness value of aramid fiber. The hybridization of carbon and aramid increased the Vickers hardness value of the hybrid samples in comparison to carbon samples 2.03 times. The addition of aramid fiber fabrics inside the carbon fiber layers improved crosslinking and positively impacted the results. The Vickers hardness value of carbon/aramid samples is lower 1.2 times in compared with Intraply Carbon/Aramid samples. The Vickers hardness values of the samples produced with VABM were 268.29 HV, 208.82HV, 301.09 HV, and 348.05 HV for C, A, C/A, and INT C/A, respectively. As in the samples produced by the VARTM method, the highest Vickers hardness value was observed in the intraply carbon/aramid samples, while the lowest Vickers hardness value was observed in the aramid samples. During the polymerization of the epoxy matrix material, the lack of strong epoxy resin diffusion between aramid fibers and the cross-linking of aramid fibers may have weakened the interfacial bonds. The Vickers hardness value of the carbon/aramid hybrid composite samples is close to the Vickers hardness value of the intraply carbon/aramid samples. There is a difference of 1.15 times between the values. With the Carbon/Aramid hybridization process, the Vickers hardness value of the hybrid sample increased 1.12 times compared to the Vickers hardness value of the carbon samples.

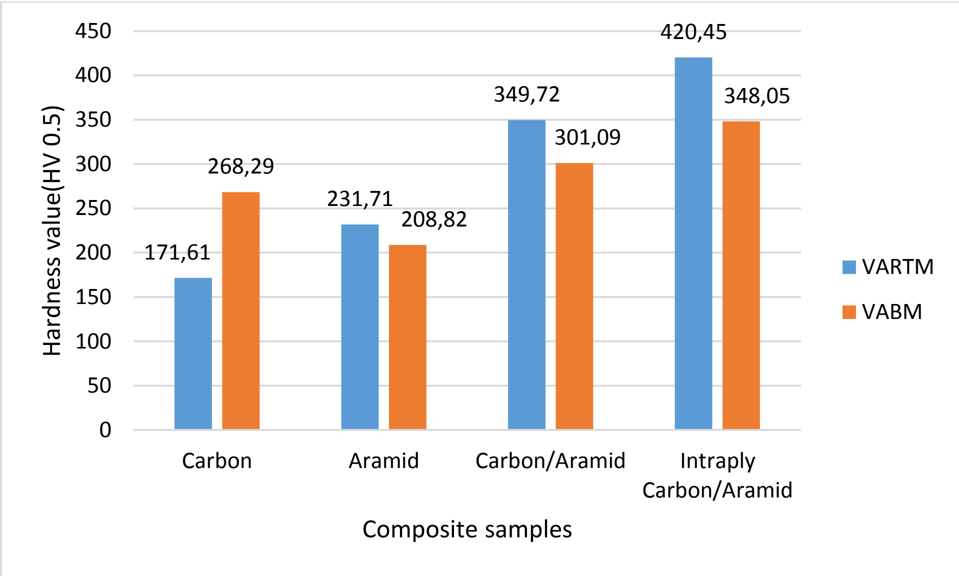

Figure 12:
Hardness test results

In both production methods, the highest Vickers hardness value is observed in the intraply carbon/aramid samples, while the carbon/aramid hybrid samples have the highest secondary Vickers hardness value. The Vickers hardness values of hybrid carbon/aramid samples are superior to lamina Carbon and lamina Aramid hybrid samples. Factors such as the different values that occurred between the two productions, the roughness of the surfaces, the formation of void structures in the material resulting from the production, and the importance of dexterity of the manufacturer in VABM were effective.

3.3. SEM Analysis Results

Figures 13-16 show the interfacial properties of samples with producing the VARTM method. The carbon sample showed strong fiber-epoxy bonding in the scanned images in Figure 13. However, Aramid samples in Figure 14 showed fiber pull out and fiber bundles. These are an indication of poor bonding of fiber and matrix (Ruban Rajesekar et al.,2018). The carbon/aramid hybrid structure in Figure 15 shows that aramid fibers are in bundles and show fiber pullout in some regions, while carbon fibers show good bonding with epoxy. In Figure 16, fiber breaks are seen as a result of good bonding of intraply Carbon/Aramid fibers with the matrix, explaining why intraply hybrid fabric reinforced composites give better results than hybrid fabric reinforced composites in tensile test results. It has also been noted in previous studies that most of the carbon/aramid fibers are pulled from the fractured surface compared to other fibers (Alsaadi,2019).

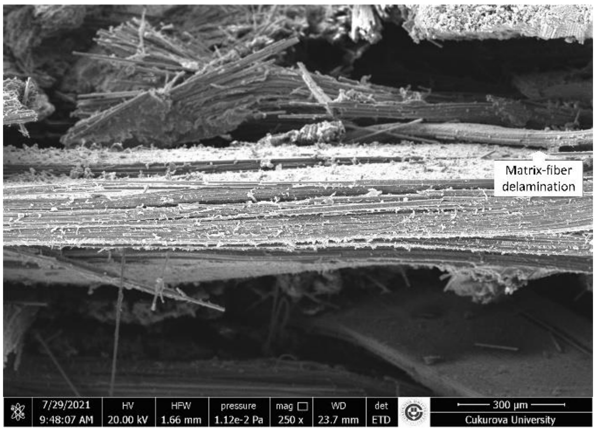

Figure 13:
After the tensile test SEM image of Carbon samples (VARTM)

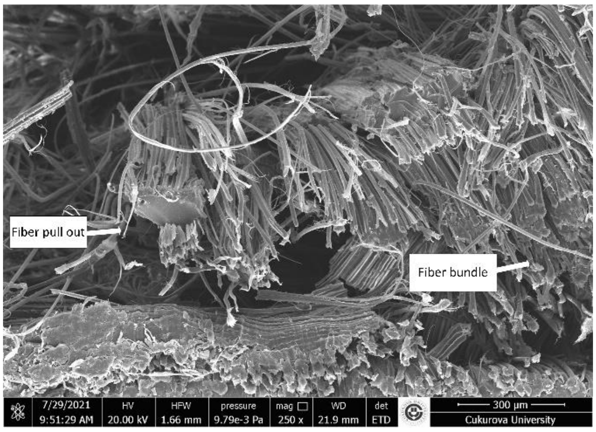

***Figure 14**:*
After the tensile test SEM image of Aramid samples (VARTM)

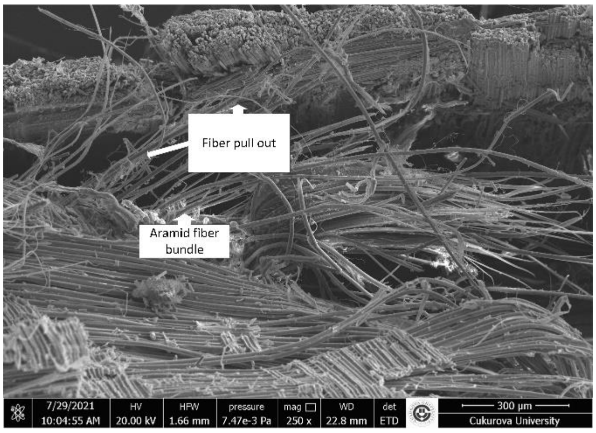

Figure 15:
After the tensile test SEM image of Carbon/Aramid samples (VARTM)

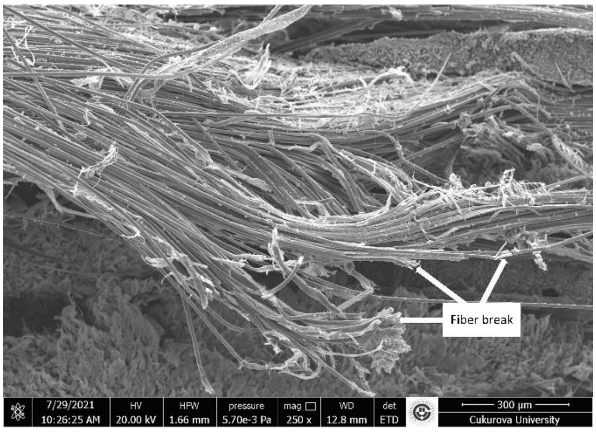

Figure 16:
After the tensile test SEM image of Intraply Carbon/Aramid samples (VARTM)

Figure 17-20 indicates the scanned images of samples producing VABM. The images taken from the carbon samples produced with VABM show the uniform distribution of the epoxy with the fibers in Figure 17. In the image of aramid fiber composite samples in Figure 18, it is seen that there are dense fiber bundles and fiber pullout. Carbon/aramid composite sample images, on the other hand, contain some void structures and fiber breaks as in Figure 19. Figure 20 shows an example of the stronger bonding of fibers with epoxy in intraply carbon aramid fabric-supported composites. The interface connections in these scanned images support the overall better results of the samples produced with VABM in the tensile test results than the sample results produced with the VARTM method.

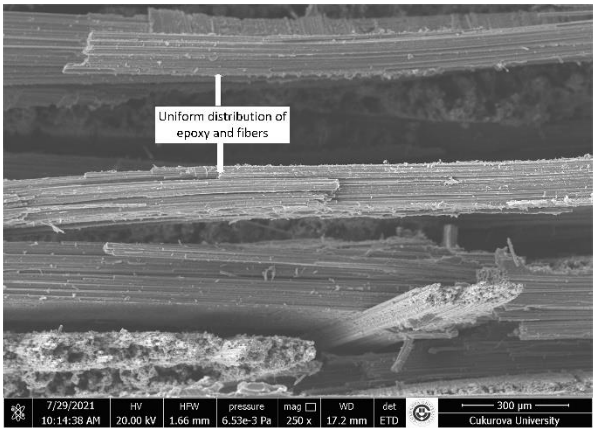

Figure 17:
After the tensile test SEM image of Carbon samples (VABM)

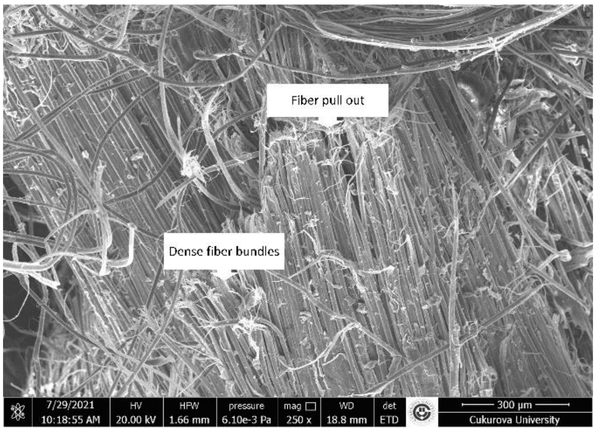

Figure 18:
After the tensile test SEM image of Aramid samples (VABM)

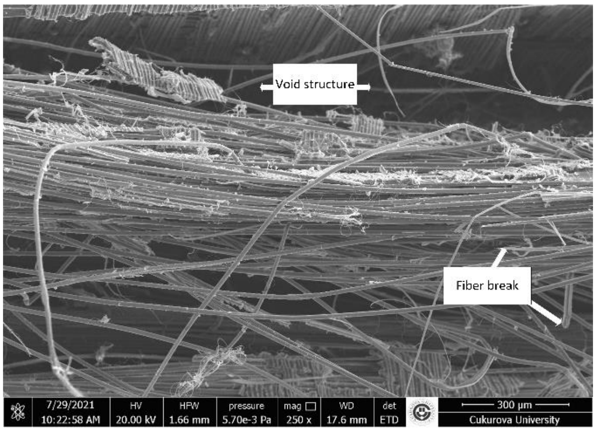

Figure 19:
After the tensile test SEM image of Carbon/Aramid samples (VABM)

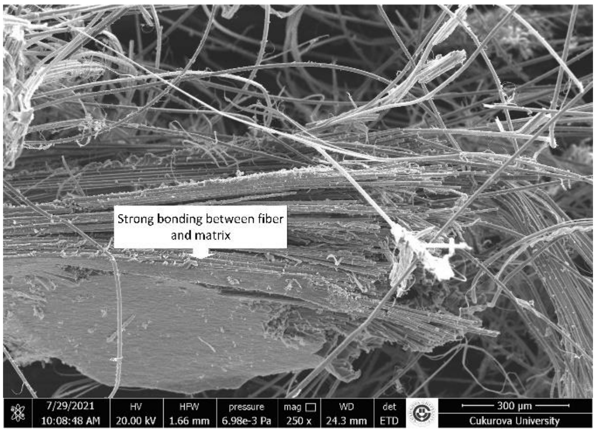

Figure 20:
After the tensile test SEM image of Intraply Carbon/Aramid samples (VABM)

4. CONCLUSIONS

The mechanical properties of intraply carbon/aramid, carbon fiber, aramid fiber, and carbon/aramid hybrid fiber reinforced epoxy-matrix composite laminates were investigated. In view of tensile test results, the tensile strength of carbon samples producing with VARTM is 1.2

times higher than samples producing with the VABM method. However, the tensile strengths of the composites made with the VABM method of aramid fiber, carbon/aramid hybrid fiber, and intraply carbon/aramid fibers gave better results than the samples produced with 1.53, 1.04 and 1.56 times VARTM, respectively. In production with VARTM, it was observed that interply carbon/aramid hybrid composites gave 1.44 times better tensile strength than composites made with intraply carbon/aramid fabric. It was understood that composites made with intraply carbon/aramid fabric in the production made by the VABM method gave 1.03 times better tensile strength results than interply carbon/aramid hybrid fabrics. When the Vickers hardness values are compared in terms of production methods, the values of carbon samples produced with VABM are 56.3% higher than those produced by the VARTM method. Nevertheless, the Vickers hardness value of aramid, carbon/aramid hybrid, and intraply carbon/aramid samples produced with the VARTM method are 10.96%,16.15%, and 20.8% higher, respectively, than those produced by VABM. The hybridization of carbon with aramid, the Vickers hardness value of hybrid carbon/aramid sample is 50.9% higher in the VARTM method and 12.22% higher in VABM compared to carbon samples. The difference in INT C/A hardness value produced using the VARTM method and VABM production methods are 20.8%. Vickers hardness values did not give excessively different results in both production methods. In general, the Vickers hardness value of produced samples with the VARTM method is higher than produced samples with VABM. In SEM analysis results, while the good bonding of carbon and epoxy is evident, it can be seen that aramid fibers are not as compatible with resin as carbon. In composites made with intraply carbon/aramid fabrics, the compatibility of carbon fibers with resin is successful in balancing the incompatibility of aramid fibers. This shows itself in composite samples made with intraply carbon/aramid fabric in the tensile test results. Different results between these two production methods can be attributed to the uniform distribution of resin flow and better affinity with fabric and epoxy in VARTM method products. In high-volume applications such as automotive components, the use of intraply carbon/aramid fibers instead of carbon/aramid hybrid fibers, the use of intraply hybrid composite materials is a viable economic option. Apart from the cost benefit, the mechanical properties of Intraply hybrid structures also show that they have the potential to be used in sports equipment and marine vehicles.

CONFLICT OF INTEREST

The authors acknowledge that there is no known conflict of interest or common interest with any institution / organization or person.

AUTHOR CONTRIBUTION

Berkay Karaçor organized the research topic, main conceptual ideas and subject outline. Prof. Dr. Mustafa Özcanlı analyzed the obtained data and interpreted the results. Berkay Karaçor carried out the preparation, production and testing of the samples. Prof. Dr. Mustafa Özcanlı supported Berkay Karaçor in researching and analyzing his findings in the study. All authors discussed the results and contributed to the final manuscript.

REFERENCES

1. Alsaadi, M., Erkliğ, A., and Abbas, M. (2020) Effect of Clay Nanoparticles on the Mechanical and Vibration Characteristics of Intraply Aramid/Carbon Fiber Reinforced Epoxy Composite, Polymer Composites, 41(7),2704–2712.

2. Alsaadi, M. (2019) Hybridization Effects of S-glass fiber on Charpy impact resistance of carbon/aramid fiber reinforced epoxy composite laminates, Materials Research Express, 6(12),125342.

3. ASTM D3039/D3039-M, (2000). Standard Test Method for Tensile Properties of Polymer Matrix Composite Material, ASTM, United States.

4. ASTM E92-17, (2017). Standard Test Methods for Vickers Hardness and Knoop Hardness of Metallic Materials, ASTM, United States.

5. Atlıhan, G., and Ergene, B. (2018) Vibration analysis of layered composite beam with variable section in terms of delamination and orientation angle in analytical and numerical methods, Acta Physica Polonica A, 134(1),13–17.

6. Attia, M. A., Abd El-Baky, M. A., and Alshorbagy, A. E. (2017) Mechanical Performance of Intraply and Inter-Intraply Hybrid Composites Based on e-Glass and Polypropylene Unidirectional Fibers, Journal of Composite Materials, 51(3),381–394.

7. Azimpour Shishevan, F. and Akbulut, H. (2019) Effects of Thermal Shock Cycling on Mechanical and Thermal Properties of Carbon/Basalt Fiber-Reinforced Intraply Hybrid Composites, Iranian Journal of Science and Technology, Transactions of Mechanical Engineering, 43(S1),441–449.

8. Balasubramanian, M. (2014) Composite Materials and Processing, CRC Press, Boca Raton.

9. Bandaru, A. K., Patel, S., Ahmad, S., and Bhatnagar, N. (2018) An Experimental and Numerical Investigation on the Low Velocity Impact Response of Thermoplastic Hybrid Composites, Journal of Composite Materials, 52(7),877–889.

10. Bresciani, L. M., Manes, A., Ruggiero, A., Iannitti, G., and Giglio, M. (2016) Experimental Tests and Numerical Modelling of Ballistic Impacts against Kevlar 29 Plain-Woven Fabrics with an Epoxy Matrix: Macro-Homogeneous and Meso-Heterogeneous Approaches, Composites Part B: Engineering, 88,114–130.

11. Bulut, M., Alsaadi, M., Erkliğ, A., and Alrawi, H. (2019) The Effects of S-Glass Fiber Hybridization on Vibration-Damping Behavior of Intraply Woven Carbon/Aramid Hybrid Composites for Different Lay-up Configurations, Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 233(9),3220–3231.

12. Chamis, C., Lark, R., and Sinclair, J. (1979) Mechanical Property Characterization of Intraply Hybrid Composites, ASTM International, West Conshohocken.

13. Da Cunha, R. D., da Cunha, R. A. D., de Amorim Junior, W. F., and Freire Júnior, R. C. S. (2020) Study of the Resistance Variation in Intraply/Yarn Kevlar/Glass Composite after Low-Velocity Impact, Journal of Materials Engineering and Performance, 29(8),5001–5007.

14. Dehkordi, M. T., Nosraty, H., Shokrieh, M. M., Minak, G., and Ghelli, D. (2010) Low Velocity Impact Properties of Intra-Ply Hybrid Composites Based on Basalt and Nylon Woven Fabrics, Materials and Design, 31(8),3835–3844.

15. Ergene, B. and Bolat, C. (2019) A Review on the Recent investigation trends in abrasive waterjet cutting and turning of hybrid composites, Sigma Journal of Engineering and Natural Sciences, 37(3),989–1016.

16. Erklig, A., Dogan, N. F., and Bulut, M. (2017) On the Vibration Behavior of Intraply Woven Carbon / Kevlar Reinforced Composites with Nano Silica Particle, III. International Conference on Engineering and Natural Science, Budapest,1258–1262.

17. Gokuldass, R., and Ramesh, R. (2019) Mechanical and Low Velocity Impact Behaviour of Intra-Ply Glass/Kevlar Fibre Reinforced Nano-Silica and Micro-Rubber Modified Epoxy Resin Hybrid Composite, Materials Research Express, 6(5),055302.

18. Hashim, N., Majid, D., Baitab, D., Yidris, N., and Zahari, R. (2019) Tensile Properties of Woven Intra-Ply Carbon/Kevlar Reinforced Epoxy Hybrid Composite at Sub-Ambient Temperature, Encyclopedia of Materials: Composites, 766-773.

19. Imielińska, K., Castaings, M., Wojtyra, R., Haras, J., Clezio, E. Le, and Hosten, B. (2004) Air-Coupled Ultrasonic C-Scan Technique in Impact Response Testing of Carbon Fibre and Hybrid: Glass, Carbon and Kevlar/Epoxy Composites, Journal of Materials Processing Technology, 157–158(SPEC. ISS.),513–522.

20. Jesthi, D.K. and Nayak, R.K. (2019) Improvement of mechanical properties of hybrid composites through interply rearrangement of glass and carbon woven fabrics for marine application, Composites Part B: Engineering, 168, 467–475.

21. Kang, K.W., Lim, D.M., and Kim, J.K. (2008) Probabilistic Analysis for the Fatigue Life of Carbon/Epoxy Laminates, Composite Structures, 85(3),258–264.

22. Kar, K. K. (2017) Composite Materials, Springer, Berlin.

23. https://www.kompozitshop.com/epoksi-recine-ve-sertlestirici, Access date:26.02.2021, Subject: Epoxy and Hardener.

24. https://www.kompozitshop.com/karbon-fiber-elyaf-takviyeler-carbon, Access date: 26.02.2021, Subject: Carbon, Aramid and Intra-ply Carbon/Aramid.

25. Mallick, P. K. (2007) Fiber-Reinforced Composites Materials, Manufacturing and Design, CRC Press, Boca Raton.

26. Muhi, R. J., Najim, F., and de Moura, M. F. S. F. (2009) The Effect of Hybridization on the GFRP Behavior under High Velocity Impact, Composites Part B: Engineering, 40(8),798–803.

27. Özbek, Ö., Bozkurt, Ö. Y., and Erkliğ, A. (2019) An Experimental Study on Intraply Fiber Hybridization of Filament Wound Composite Pipes Subjected to Quasi-Static Compression Loading, Polymer Testing, 79(May),106082.

28. Pegoretti, A., Fabbri, E., Migliaresi, C., and Pilati, F. (2004) Intraply and Interply Hybrid Composites Based on E-Glass and Poly (Vinyl Alcohol) Woven Fabrics: Tensile and Impact Properties, Polymer International, 53(9),1290–1297.

29. Potluri, R., Syam Dheeraj, R., and Vital, G. V. V. N. G. (2018) Effect of Stacking Sequence on the Mechanical and Thermal Properties of Hybrid Laminates, Materials Today: Proceedings, 5(2),5876–5885.

30. Qing-dun, Z., Xiao-qing, H., and Xue-hui, L. (2001) Study on Stress Concentrations in an Intraply Hybrid Composite Sheet, Applied Mathematics and Mechanics, 22(2),154–159.

31. Rajpurohit, A., Joannès, S., Singery, V., Sanial, P. and Laiarinandrasana, L. (2020) Hybrid effect in in-plane loading of carbon/glass fibre based inter-and intraply hybrid composites, Journal of Composites Science,4(1),6.

32. Ruban Rajesekar, B., Asokan, R., Senbagan, B., Karthika, R., Sivajyothi, K. and Sharma, N. (2018) Evaluation on mechanical properties of intra-ply hybrid carbon-aramid/epoxy composite laminates, Materials Today: Proceedings, 5(11), 25323-25330.

33. Sarasini, F., Tirillò, J., Ferrante, L., Sergi, C., Russo, P., Simeoli, G. Cimino, F., Ricciardi, M. and Antonucci, V. (2019) Quasi-Static and Low-Velocity Impact Behavior of Intraply Hybrid Flax/Basalt Composites, Fibers, 7(3),26.

34. Sezgin, H. (2018) Investigation and Enhancement of The Mechanical Properties of the Fabric Reinforced Hybrid Composites, PhD Thesis, Istanbul Technical University, Istanbul.

35. Sun, G., Tong, S., Chen, D., Gong, Z., and Li, Q. (2018) Mechanical properties of hybrid composites reinforced by carbon and basalt fibers, International Journal of Mechanical Sciences,148,636-651.

36. Tehrani Dehkordi, M., Nosraty, H., Shokrieh, M. M., Minak, G., and Ghelli, D. (2013) The Influence of Hybridization on Impact Damage Behavior and Residual Compression Strength of Intraply Basalt/Nylon Hybrid Composites, Materials & Design, 43,283–290.

37. Yahaya, R., Sapuan, S. M., Jawaid, M., Leman, Z., and Zainudin, E. S. (2016) Investigating Ballistic Impact Properties of Woven Kenaf-Aramid Hybrid Composites, Fibers and Polymers, 17(2),275–281.

38. Yalcın, B. and Ergene B. (2018) Analyzing the Effect of Crack in Different Hybrid Composite Materials on Mechanical Behaviors, Pamukkale University Journal of Engineering Sciences,24(4),616-625.

39. Yan, R., Wang, R., Lou, C.W., and Lin, J.-H. (2015) Low-Velocity Impact and Static Behaviors of High-Resilience Thermal-Bonding Inter/Intra-Ply Hybrid Composites, Composites Part B: Engineering, 6958–68.

40. Yuhazri, M. Y., Amirhafizan, M. H., Abdullah, A., Sihombing, H., Nirmal, U., Saarah, A. B., and Fadzol, O. M. (2016) The Effect of Lamina Intraply Hybrid Composites on the Tensile Properties of Various Weave Designs, IOP Conference Series: Materials Science and Engineering, 160(1),012022.