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ANALYSIS OF MECHANICAL PROPERTIES OF FLAX/CARBON FIBER REINFORCED HYBRID COMPOSITES PRODUCED USING TWO DIFFERENT PRODUCTION METHODS

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Keywords
Flax Fiber,
Carbon Fiber,
Hand Lay-up,
Vacuum Bagging,
Mechanical Characteristics.

Abstract
In this study, the hybridization process of carbon fabrics, which used in many areas today, and flax fabrics were carried out using two production methods, hand lay-up and vacuum bagging. The effects of both the production method and the hybridization process on the mechanical performance of the formed flax/carbon epoxy hybrid composites were investigated. Epoxy was used as a matrix element in production. Tensile and hardness tests were performed to evaluate the mechanical properties of the analyzed composite products. Moreover, the surface morphology of the samples broken after mechanical testing was analyzed using scanning electron microscopy. The experimental results reveal that the tensile strength of flax/carbon fiber hybrid composites increased from 226.36 MPa to 344.14 MPa when vacuum bagging method was used, resulting in an increase of 52.03% compared to hand lay-up method. An increment of 1.09% was achieved in comparison to hand lay-up when the hardness value reached 201.59 HV from 199.42 HV in linen/carbon fiber hybrid composites produced by vacuum bagging method. The results of the study reveal that both production methods are suitable for manufacturing of automotive parts using linen and carbon fiber fabrics, depending on the area to be used and the part to be produced.

İKİ FARKLI ÜRETİM YÖNTEMİ İLE ÜRETİLEN KETEN/KARBON LİF TAKVİYELİ HİBRİT KOMPOZİTLERİN MEKANİK ANALİZİ

Anahtar Kelimeler
Keten Fiber,
Karbon Fiber,
El Yatırması,
Vakum Torbalama,
Mekanik Karakteristikler.

Öz
Bu çalışmada, günümüzde birçok alanda kullanılan karbon kumaşlar ile keten kumaşların hibridizasyon işlemi, elle yatırma ve vakum torbalama olmak üzere iki üretim yöntemi kullanılarak gerçekleştirilmiştir. Hem üretim yönteminin hem de hibridizasyon işleminin, oluşturulan keten/karbon epoksi hibrit kompozitlerin mekanik performansı üzerindeki etkileri araştırılmıştır. Üretimde matris elemanı olarak epoksi kullanılmıştır. Analizi yapılan kompozit ürünlerin mekanik özelliklerini değerlendirmek için çekme ve sertlik testleri yapılmıştır. Ayrıca mekanik testlerden sonra kırılan numunelerin yüzey morfolojisi taramalı elektron mikroskobu kullanılarak analiz edilmiştir. Deneysel sonuçlar, keten/karbon fiber hibrit kompozitlerin çekme mukavemetinin vakum torbalama yöntemi kullanıldığında 226.36 MPa' dan 344.14 MPa' ya yükseldiğini ve elle yatırma yöntemine göre %52.03'lük bir artışa neden olduğunu ortaya koymaktadır. Vakum torbalama yöntemi ile üretilen keten/karbon fiber hibrit kompozitlerde sertlik değeri 199,42 HV' den 201,59 HV' ye ulaştığında elle yatırmaya göre %1,09 artış sağlanmıştır. Çalışmanın sonuçları, kullanılacak alana ve üretilecek parçaya bağlı olarak, her iki üretim yönteminin de keten ve karbon elyaf kumaşlar kullanılarak otomotiv parçalarının imalatına uygun olduğunu ortaya koymaktadır.

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Highlights

- The focus of this article is the hybridization of natural fibers with synthetic fibers.
- The effect of the production method on the hybridization of flax fibers with carbon fibers was observed.
- The change in sample production method had significant consequences on mechanical properties.

Purpose and Scope

The aim of this study is to create hybrid composite materials with synthetic and natural fibers produced by two different production methods, which are not often compared in the literature. Thus, it will be possible to examine how the two different production methods used affect the mechanical properties.

Design/methodology/approach

In the present study, two different production methods, hand lay-up method and vacuum bagging method, were used. Since the hand lay-up method and the vacuum bagging method were not encountered together in the studies, it was desired to examine the mechanical characteristics of produced composites with two production methods. The lower cost compared to other methods is among the reasons for the preference of these two production methods. The tensile strength, tensile modulus and microhardness properties of pure and hybrid composites formed with carbon and flax fibers were investigated. In addition, the post-fracture behavior of the samples was observed with the scanning electron microscopy method.

Findings

In the tensile test results, it was observed that the tensile strength of the hybrid composites increased 2.05 times when the hand lay-up method was used, and 5.34 times when the vacuum bagging method was used compared to the pure linen composite. In the comparison of production methods, 1.52 times higher tensile strength value was determined in the samples produced by vacuum bagging method in hybrid composites compared to the samples produced according to the hand lay-up method. In the hardness test results, hybrid composites reach 74.67% higher hardness than pure linen composites in hand lay-up method, while hybrid composites reach 71.86% higher hardness in vacuum bagging method. In the comparison of production methods, 1.09%, 1.32% and 2.74% higher hardness values were obtained in hybrid composites, pure carbon composites and pure linen composites, respectively, compared to the hand lay-up method in the samples produced by vacuum bagging method.

Originality

The effort to reveal a low-cost material that can be used in the automotive industry with minimal harm to the environment, without sacrificing its mechanical properties, when preferred over the traditionally used material in the research, reflects the original course.

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1. Introduction

In the last twenty years, interest in natural plant fibers has been increasing in the world. Renewability, biodegradability, and cost-effectiveness, which are not found in synthetic fibers, make natural fibers one step forward. Their lightweight, environmental cycles from the production stage to the end of life indicate that these fibers will have low pollution rates in polluting emissions and greenhouse gas emissions. It plays an important environmental role by almost neutralizing carbon dioxide (CO_2) with the amount of CO_2 that natural fibers capture in the atmosphere while growing. Moreover, in parallel with the developments in fiber harvesting and processing technology, it is expected that natural fibers will be used instead of synthetic fibers in structures that are not critical for load bearing (Chapman and Dhakal, 2019; Cheng et al., 2020; Wang et al., 2021). There are many types of natural fibers that can be used in composite materials. Flax, jute, hemp, ramie, and sisal fibers are among the most commonly used. It is linen fibers that come to the forefront in use as a reinforcing element in composites, especially due to the properties they have among other natural fibers. Flax fibers have the greatest potential to be used instead of synthetic fibers with their mechanical properties such as 12-85 GPa tensile modulus, 400-2000 MPa tensile strength, and 1-4% final strain, which can compete with glass fibers. Flax fibers have a lower cost and density than glass fibers, as well as increased stiffness and damping properties, which can be superior to glass fibers. It can be used as an important candidate material in infrastructures, the automotive industry, and consumer products instead of synthetic fibers, where cost-effective, lightness, and high stiffness properties are all gathered together. Furthermore, linen fibers are used in the production of composite materials by means of production methods such as hand lay-up, vacuum bagging process, and vacuum assisted resin transfer molding in the form of woven fabric, monofilaments, short fibers, and unidirectional linen tape forms (Ben Ameur et al., 2019; Rahman, 2021; Sarasini et al., 2016; Wang et al., 2021). However, natural fibers, including flax fibers, have high moisture absorption tendency, lower strength, and disadvantageous properties that vary according to the geographical location of the region where they are grown. Limiting their application areas, such as their use in structural components exposed to small mechanical loads, is one of the negative aspects that should be taken into account (Prakash and Maharana, 2017). Such disadvantages are also annihilated by the hybridization process. Hybrid composites are the scheme of components in which a suitable balance is achieved between the advantages and disadvantages, and the advantages of one of the components that make it up can compensate for the deficiency in the other. Thus, appropriate stability of cost and performance in material design is attained (Muralidhar, 2013; Shamsuyeva et al., 2019). Researchers have succeeded in hybridizing natural fibers with synthetic fibers such as glass and carbon, in hybrid products they created due to the high tensile stiffness and strength of carbon fibers. In addition to the high mechanical performance of carbon fiber, the different dynamic properties of flax fiber have directed the attention of researchers to this fiber combination. Linen/carbon hybrid composite products have been evaluated as environmentally friendly, although they have good mechanical performance (Assarar et al., 2015; Lee et al., 2020). In order to strengthen the positive properties found in flax fibers, synthetic materials such as carbon fibers are preferred, potentially by the hybridization process. Carbon fibers are known for their ability to absorb high energy in collision conditions, for excellent strength, and stiffness. Due to the properties, they have, carbon fiber reinforced polymer composites are preferred in sectors such as aerospace, aviation, maritime and automotive industries. However, the low viscoelastic properties, fragility, and high cost of carbon fibers may not allow the fibers to be used in all industrial composite applications (Al-Hajaj et al., 2019; Assarar et al., 2018). There are hybrid composites formed using carbon fiber and flax fibers in the literature, but there is no study in terms of the effect of hand layup and vacuum bagging method on mechanical properties in terms of production method comparison. Bahrami et al. (Bahrami et al., 2021) designed an environmentally friendly hybrid material using Poly-Butyl-Succinate materials along with carbon and flax fiber. They observed that mechanical properties were not lost in hybrid composites by replacing some carbon fiber layers with flax fibers while forming the composite material. In addition, they found that the thermal properties of the new hybrid composite structure they created by using flax fibers instead of carbon fibers did not deteriorate. In the study of Amiri et al. (Amiri et al., 2018), they produced a composite bike frame using carbon fiber and flax fiber. They discovered that the hybrid bike frame they produced offered better damping, ride quality, and was lightweight, environmentally friendly, and cost-effective compared to carbon skeleton structures. Hoekstra et al. (Hoekstra et al., 2022) examined how three different fabric orientations and two different perforation methods affect the mechanical properties of hybrid composites made of carbon and flax fibers. As a result of the cutting processes made with an abrasive water jet machine, higher damages occurred in the samples compared to the traditional drilling method. In another study using carbon and linen fibers, bending, tensile, vibration, and impact tests were applied to the hybrid composites produced. It has been observed by the mechanical and vibration test results of hybrid composites that the use of natural fibers by hybridizing with synthetic fibers in structural applications will not give rise to a problem (Flynn et al., 2016). The usage of hybrid composites produced with two different bidirectional fabrics and carbon fiber materials using the vacuum bagging method in structural applications has been investigated. It was observed that the flexural modulus of hybrid composite structures raised by 2.69-3.22 times compared to homogeneous structures, and the flexural strengths augmented by 1.39-2.1 times. In addition, it was determined that there was an increment of 1.91-3.66 times in tensile strength in favor of hybrid composite structures (Fiore et al., 2012). Yuan et al. (Yuan et al., 2021) compared a hybrid composite structure containing three-way flax-carbon-aramid fiber and laminated carbon fiber composite structures in terms of mechanical properties. They observed that the three-way hybrid structures improved the tensile strength by 1.33 times and the tensile modulus by 1.05 times. Although they have lower results in flexural and compression strength than laminated carbon composites in three-way hybrid structures, they revealed that the use of flax fiber can reveal a low-cost and environmentally friendly potential product. It was found that the flexural mechanical properties of the hybrid composites were increased by the hybridization process of flax fibers and recycled carbon fibers compared to pure flax composites. However, it has been observed that the damping properties of hybrid composites have improved compared to homogeneous natural fiber structures, and it has been stated that these hybrid structures have the potential to be used in structures where vibration damping is important (Bachmann et al., 2018; Le Guen et al., 2016). While discussing the effect of ply blocking of carbon fibers on tensile properties in carbon/linen fiber hybrid composites, both experimentally and theoretically, they stated that in their results, not only the nonlinear response of the linen fabric but also the surface roughness of both fabrics should be taken into account (Kureemun et al., 2018).In a study of Islam et al. (Islam et al., 2021), the tensile and fatigue characteristics of intra-ply hybrid carbon/linen fabric and inter-ply hybrid carbon and flax fibers were investigated. It has been observed that the tensile characteristics of intra-ply hybrid carbon/linen fabric structures are 1.05 times better and 21 times better in fatigue life than inter-ply hybrid carbon and linen fibers. The aim of this study is to create hybrid composite materials with synthetic and natural fibers produced by two different production methods, which are not found in the literature, and to investigate how two different production methods affect the mechanical properties. In our current study, two different production methods, the hand lay-up method and the vacuum bagging method, were used and the tensile strength, tensile modulus, and microhardness properties of pure and hybrid composites formed with carbon and linen fibers were investigated. In addition, the behavior of the materials after fracture was investigated by scanning electron microscopy analysis. The outcomes of the research will lead to the emergence of a low-cost, environmentally friendly material that can be used in the automotive industry in terms of production methods and the use of natural fibers, without compromising the mechanical properties of the material it replaces.

2. Material and Method

2.1. Material

Linen fiber fabric and carbon fiber fabrics were preferred in this study. Flax plain woven texture and Carbon twill woven texture were supplied by companies in Istanbul. These weavings were used as reinforcement material. These texture features used in this work are listed in Table 1. The fabric specimens are demonstrated in Figure 1. Figure 2 indicates the stacking sequences of fabric in this work.

Table 1. Fabric Characteristics (Kompozitshop, 2022; Kumascı.Com, 2022)

Fabric	Weight(g/m^2)	Thickness of fabric (mm)	Warp(tex)	Weft(tex)
Flax fabric	280	0.5	-	-
Carbon fabric	245	0.25	300	300

Figure 1. Fabric Specimens A) Flax Fabric B) Carbon Fabric

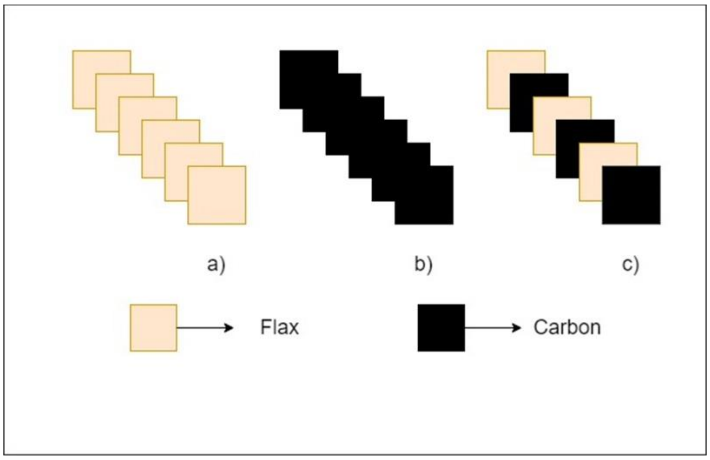

Figure 2. Stacking Sequences Of A) Pure Flax Fabric Composite B) Pure Carbon Fabric Composite C) Hybrid Flax/Carbon Fabric Composite

In this search, the related hardener LH160 and the epoxy resin L160 were utilized as matrix material. The related hardener and epoxy resin used in this work were supplied by Kompozitshop. The specific characteristics of the matrix group are given in Table 2. 4-part epoxy 1 part hardener as a weight ratio was determined for the mixture of epoxy resin and hardener, taking into account the values given by the manufacturer and data from previous studies.

Table 2. Hardener And Epoxy Features (Kompozitshop, 2022)

	LH160 Hardener	**L160 Epoxy**
Viscosity (mPas)	10-50	700-900
Density (g / cm^3)	0.96-1.0	1.13-1.17
Actuation temperature (°C)	-	60 / +50 except heat treatment -60 / +80 by performing heat treatment
Refractor index	1.520-1.521	1.548-1.553
Mensuration circumstances	25°C	25°C

In this search, twelve composite specimens were made up of homogeneous and hybrid composite structures with two different production procedures. The pattern code names given to the specimens for the composite laminates fabricated are listed in Table 3.

Table 3. Naming Codes Of Produced Samples

Pattern Name	**Textile variants**
F	Flax fabric
C	Carbon fabric
FHL	Flax fiber fabric reinforced homogeneous composite produced with hand lay-up method
CHL	Carbon fiber fabric reinforced homogeneous composite produced with hand lay-up method
FCHL	Flax/ Carbon fiber fabric reinforced hybrid composite produced with hand lay-up method
FVABM	Flax fiber fabric reinforced homogeneous composite produced with vacuum bagging method
CVABM	Carbon fiber fabric reinforced homogeneous composite produced with vacuum bagging method
FCVABM	Flax/ Carbon fiber fabric reinforced hybrid composite produced with vacuum bagging method

After the samples were post-cured at 60°C for 1 hour in the oven, the cutting process was carried out with a cutting device in the test dimensions specified in the norms.

2.2. Method

2.2.1. Hand Lay-up Method

One of the methods used when producing the composite samples for this research is the hand layup method. The hand lay-up process is a production method that is specified to be suitable for the production of medium-sized and large pieces with low volume, where the quality of the product is highly dependent on the skills of the person making it. While this method provides minimal tooling and part costs, manual impregnation can also present problems such as resin-rich and deficient areas or voids (Campbell, 2010). For this work, firstly, the surface to be treated was cleaned with cleaners, then mold release wax was applied to the surface. Whilst the fabric layers were laid sequentially until the required thickness was obtained, the prepared resin mixture was absorbed onto the fabric surface with the help of a roller brush. When the sample thickness reached the desired level, the resin impregnation was stopped and the part was left to cure for 24 hours. After 24 hours, the sample was removed from the surface and kept in the oven at 60°C for 1 hour for post-curing.

2.2.2. Vacuum Bagging Method

The vacuum bagging method, also called bag molding, is a process in which the deaeration cloth and perforated release film are placed on the mold, and a vacuum is applied between the mold and the coating materials. While the sample is curing at pressure, temperature, and time, problems such as gaps that may occur in hand laying, poor resin distribution, etc. can be eliminated with this method (Lee and Suh, 2006).In this work, first, after the area to be sampled was determined with vacuum sealing tapes, mold release wax was applied to the surface. While the fabrics were laid on the surface in sequence, resin impregnation processes were carried out with a roller brush. When the desired fabric thickness level was reached, the perforated film and air-blowing cloth were laid on the fabrics in sequence. The system was closed with vacuum nylon and the excess resin was discharged from the system with a single outlet hose. The vacuum pump connected to the system was operated at a pressure of 1 bar for approximately 2 hours and then turned off. After the sample was left to cure for 24 hours in this state, it was removed from the surface and placed in the drying oven. It was kept in the oven for post curing at 60°C for 1 hour.

2.3. Tensile Testing

Tensile test was performed to determine the mechanical characteristics of the composite products produced within the scope of the study. Samples cut 250 mm in length,25 mm in width, and 2.5 mm in thickness according to the ASTM D3039 norms were made ready for the tensile test (ASTM D3039/D3039-M, 2000). The tests were realized using the ALSA Hydraulic test device in KOLUMAN Automotive Industry Laboratory. The 98000 kN load cell at cross-head speed of 2 mm/min was utilized to perform tensile tests as it is indicated in Figure 3. Before starting the test, the width and depth of all test samples were measured and data were entered into the program connected to the device. As a result of the test, the tensile strength, modulus of elasticity, and strain rate values of the samples were presented by the program. In homogeneous and hybrid composite structures, 5 samples were tested in each of the FHL, CHL, FCHL, FVABM, CVABM, and FCVABM configurations, and the values related to the tensile strength of the samples were obtained by averaging the results of the 5 samples.

Figure 3. Tensile Testing Machine

2.4. Hardness Testing

Generally, the hardness of materials is defined as the resistance to plastic deformation. In order to determine the hardness values of the samples produced within the scope of this study, Vickers hardness tests, also known as 136-degree diamond pyramid hardness test measurement, were applied. The prepared hardness samples were 70mm in length,70 mm in width, and 1.5 mm in thickness. The Vickers hardness value was determined by making 15 hardness measurements from different areas on each sample surface and the Vickers hardness value of the samples was recorded by taking the average of these values. While measuring the hardness of the samples, the ASTM E92-17 standard was taken as reference and the tests were carried out by applying a force value of 0.2 kgf to the material for 10 seconds using an AOB Lab product machine (ASTM E92-17, 2017).

2.5. Morphological Analysis

Scanning Electron Microscope (SEM) analysis was preferred as the most suitable method for examining and analyzing the surface morphology of the produced composite products. This analysis was performed using the FEI Quanta 650 Field Emission device. While the SEM device is operating at 100V-30kV acceleration voltage, it has a magnification capacity of 6-1.000.000 x. The surface conductivity of the samples was increased by the gold spraying method and the surface coating process was carried out. Additionally, for the analysis of quantitative data to see the hybridization effects, morphological analysis such as observing the fracture surface of the samples, matrix cracks in the material, fiber-matrix interactions, fiber-matrix bond separation, and fiber breakage can be carried out by SEM.

3. Experimental Results

3.1. Tensile Test Results

As given in Figure 4, the tensile strength values of the samples produced by the VABM method were found to be higher than the samples produced by the hand layup method. While FCVABM hybrid sample had a tensile strength value of 52.03% higher than FCHL hybrid sample, in homogeneous composites CVABM sample reached 23.88% higher tensile strength than CHL sample and 43.07% higher tensile strength value of FVABM sample than FHL sample. While the standard deviation ratios were %4.69, %6.58, and %16.78 for the FHL, CHL, and FCHL samples, respectively, they were calculated as %2.85, %10.28, and %15.44 for the FVABM, CVABM, and FCVABM samples. However, the hybridization of linen fabric with carbon fabric in both the vacuum bagging method and hand lay-up method significantly increased the tensile strength values of linen fabrics. In the samples created with VABM, hybrid flax/carbon samples achieved tensile strength values 5.34 times better than homogeneous flax samples, while 5.02 times better tensile strength results were obtained in hybrid flax/carbon samples created with HL method than homogeneous flax samples. Fairlie and Njuguna(Fairlie and Njuguna, 2020) investigated the effect of fabric orientation angle and fabric sequencing on the mechanical properties of carbon fiber and flax fiber. The tensile strength results (224.4 MPa) for flax/carbon hybrid samples match the present study. Hybridization of linen fabrics to carbon fabrics provided an improvement of 1.70 to 3.52 times in hybrid composites in their study. It was stated that hybridization with carbon fabrics and linen fabrics reduced the general nonlinearity of hybrid composites and showed pseudo-ductility behavior. With the hybridization process, an increase in tensile stress of more than 5 times was found in the hybrid flax/carbon composite samples compared to the pure flax composite samples(Wang et al., 2020).

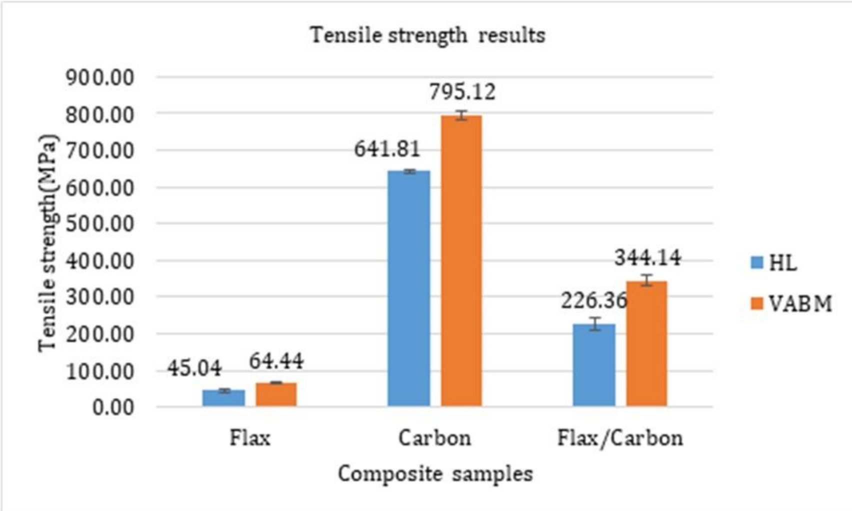

Figure 4. Tensile Strength Results Of Samples

The elastic modulus results of samples are illustrated in Figure 5. The elastic modulus value was 1.47 times higher in the hybrid samples produced with VABM compared to the hybrid samples produced by the HL method. Whilst this ratio is 1.09 times in favor of CVABM sample between CVABM and CHL samples, it is 1.94 times in favor of FVABM between FVABM and FCL samples. According to values about elastic modulus, the standard deviation ratios were %28.18, %20.20, and %18.40 for the FHL, CHL, and FCHL samples, respectively, they were calculated as %23.40, %11.04, and %28.60 for the FVABM, CVABM, and FCVABM samples. In hybrid linen/carbon composites, it was found that the production with VABM increased the elastic modulus by 3.36 times compared to pure linen composites, and the use of the HL method increased the elastic modulus by 4.44 times in the samples. In the study of Fehri et al., Young's modulus of hybrid samples increased between 5.92 and 7.27 times compared to pure linen samples. They stated that the way to improve the elastic modulus can be by changing the order of carbon and linen fabrics, but the real improvement is with the surface layers(Fehri et al., 2017). Fairlie and Njuguna(Fairlie and Njuguna, 2020) stated that the increase in carbon fiber content in hybrid composites has an improving effect on the elastic modulus since flax fibers have the lowest Young's modulus. It has been shown in the results of the study that the composite becomes stronger in the ratio of the closeness of the carbon fiber layers to each other.

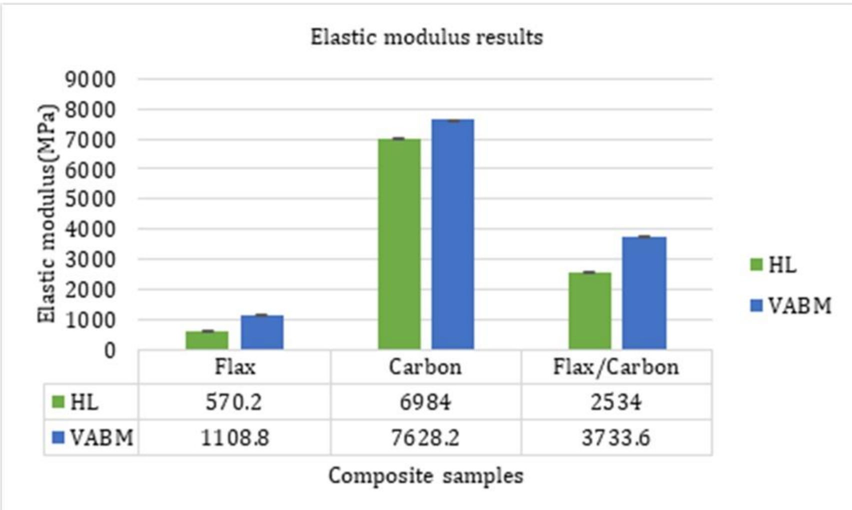

Figure 5. Elastic Modulus Results Of Samples

According to the elongation rate results of the samples given in Figure 6, the highest elongation rate was observed in the pure linen sample produced by the vacuum bagging method. Pure linen composites showed the most ductile behavior in both production methods. This was also the case in the study in which the composite samples formed by changing the order of the carbon and flax fibers were examined. While the difference between hybrid composite samples in different sequences was about 10% in their(Fehri et al., 2017) study, the difference between FCVABM and FCHL was 11.66% in the current study. The difference between FCL and FVABM samples is 2.5 times in favor of the FVABM sample, while the difference between CVABM and CHL samples is 1.13 times in favor of the CVABM sample. In percent elongation ratios, the standard deviation rates for the FHL, CHL, and FCHL samples were 0.33%, 0.66%, and 0.63%, respectively, while 1.12%, 2.01%, and 0.52% for FVABM, CVABM, and FCVABM.

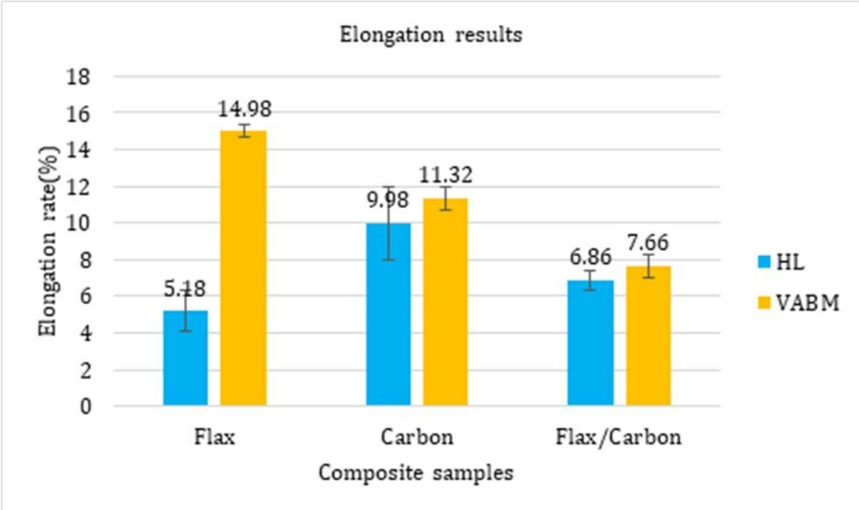

Figure 6. Elongation Rate Results Of Samples

3.2. Hardness Test Results

Figure 7 demonstrates the Vickers hardness test results of this work. In the evaluation of microhardness test results, the Vickers hardness values of the samples produced by the hand lay-up method and the vacuum bagging method were close to each other. Vickers hardness value of FCVABM sample was 1.09% higher than the hardness value of FCHL sample in hybrid composite samples. While this ratio was in favor of 1.32% CVABM sample in homogeneous carbon composites, it was also in favor of FVABM at a rate of 2.74% in homogeneous linen composites. In the vacuum bagging method, problems such as the resin not being well distributed in all regions and the formation of voids, which occur in the hand lay-up method, have been eliminated, and this has affected the hardness values that occur against deformation on the material surface. The hybridization process of linen fiber fabrics with carbon fiber fabrics increased the Vickers hardness value by 1.75 times in samples produced by hand lay-up. In hybrid linen/carbon samples produced by vacuum bagging method, the Vickers hardness value increased by 1.72 times compared to homogeneous linen fabric composites. The fact that these increase rates are close in the comparison of hybrid and homogeneous composites reveals that both production methods have the potential to be used for these materials. In studies with carbon/flax composite samples, the angled arrangement of the flax fibers ensured that the force applied by the penetrating tip was distributed equally in all directions. It is stated that this situation is caused by the network structure formed by flax fibers and this network structure increases the hardness value (Al-Hajaj et al., 2018).

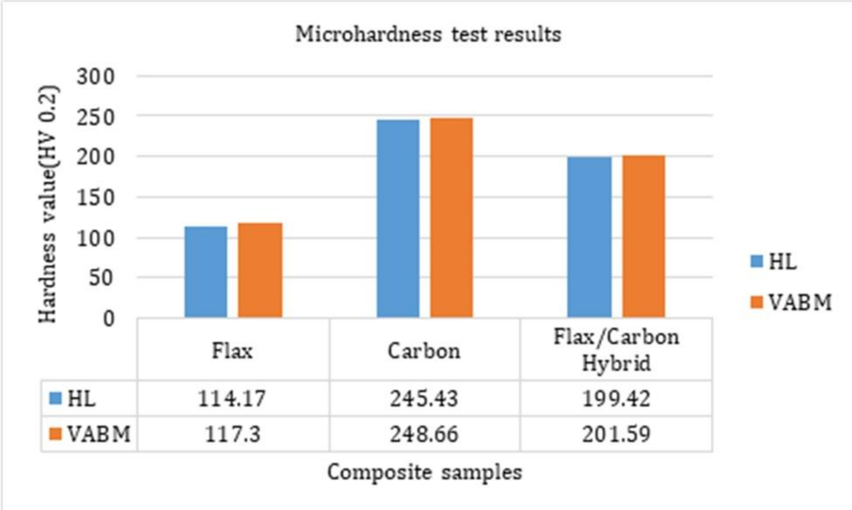

Figure 7. Vickers Hardness Test Results

3.3. SEM Analysis Results

According to SEM analysis results, there were more bubbles and hollow structures in samples produced with the hand lay-up process than samples produced with the VARTM process as seen in Figures 8 to 13. When the FHL sample in Figure 8 is examined, breaks and sudden breaks of the flax fibers were observed, while homogeneous breaks were detected in the fibers in the CHL sample in Figure 9. It was observed in the study of Dhakal et al.(Dhakal et al., 2013) that these fiber breakages and ruptures were observed even though the woven structure of flax fibers was different. In their study, they found that when cross ply flax and unidirectional flax were hybridized with carbon fiber, brittle fiber breakage occurred. They found that fiber shrinkage was seen in both structures hybridized with carbon fiber, even though two different flax structures were used. On the other hand, in the FCHL sample in Figure 10, no bubbles were found with less void structure compared to homogeneous linen and homogeneous carbon composite structures. It has been stated in the study that the resin does not have sufficient settling time during infusion between the fibers in natural fibers and a rapid curing process will create a void in the composite structure. This situation is of critical importance, especially since it is a situation arising from the natural structure of natural fibers(Kureemun et al., 2018).

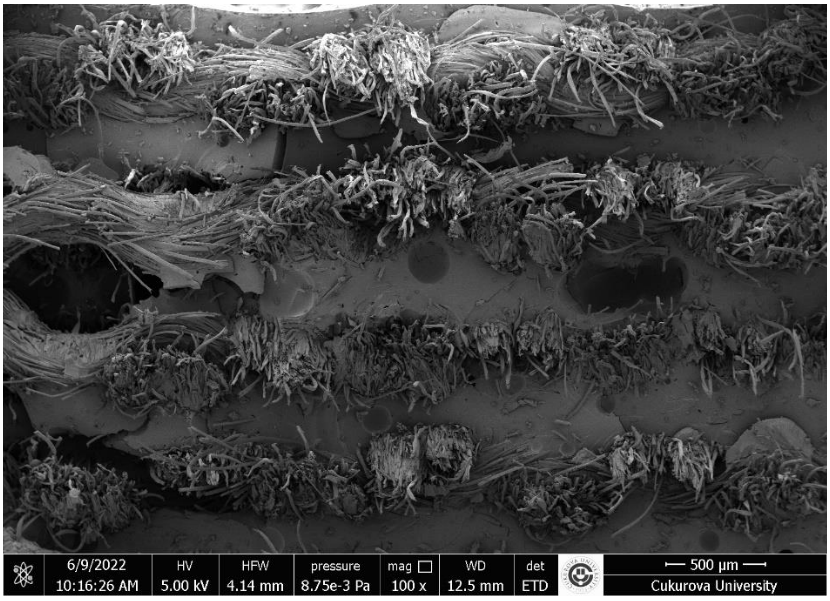

Figure 8. After The Tensile Test SEM Image Of FHL Sample

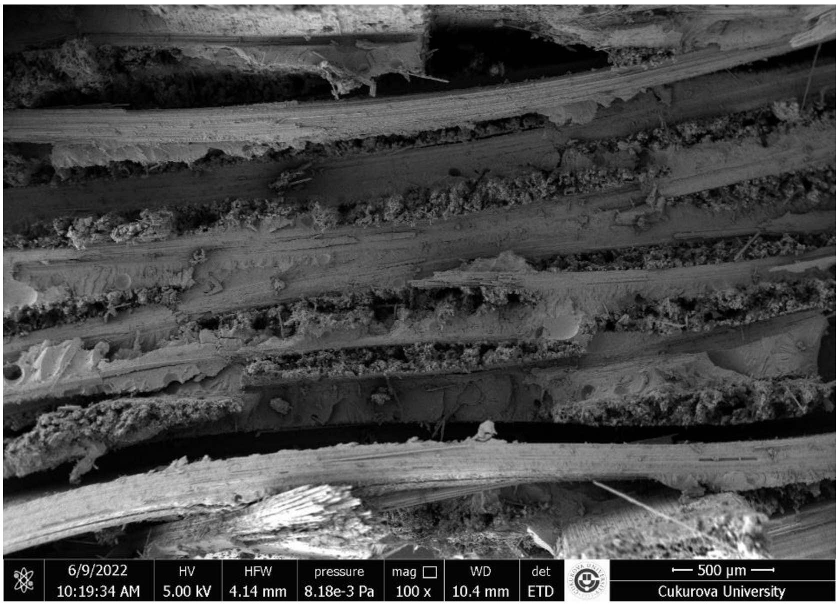

Figure 9. After The Tensile Test SEM Image Of CHL Sample

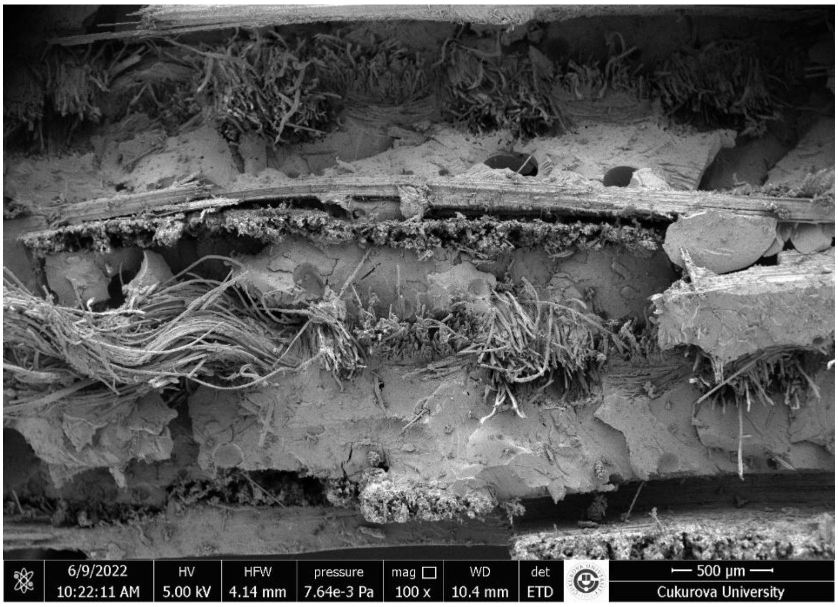

Figure 10. After The Tensile Test SEM Image Of FCHL Sample

In comparison to Figure 8, the morphological structure of FVABM sample in Figure 11 has fewer hollow structures. Moreover, while it has been determined that the epoxy resin has a more intense structure in the products made with the hand layup method, the vacuum removal of the excess resin in the production with the VARTM method is another difference in the morphological structures of the FVABM and FHL samples. In the CVABM sample in Figure 12, carbon fibers were found to break into bundles, while the epoxy fiber adhesion was better compared to the sample in Figure 11. In the FCVABM structure in Figure 13, fiber shrinkage and elongation are observed in flax fibers, while homogeneous ruptures are observed in carbon fibers. Whilst separations between fiber and matrix are observed in the FCHL sample in Figure 10, these damages are less common in the FVABM sample in Figure 13. In the study conducted by Dhakal and Sain(Hom Nath Dhakal and Sain, 2020), it was stated that in this case, fiber entanglement was observed in the morphological examination of flax fibers, as in the current study, causing fiber buckling and the damages started from this point. It was stated that carbon fibers also fracture perpendicular to the applied load, and carbon fiber failure and rupture is the main factor causing damage to carbon fiber composites. It has been determined that this situation is seen in CHL, CVABM, FCHL, and FCVABM samples using carbon fiber.

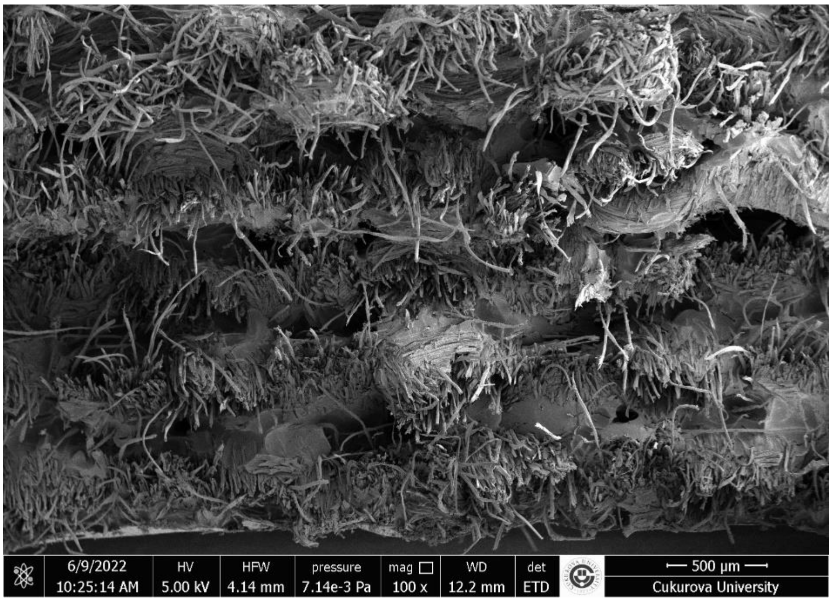

Figure 11. After The Tensile Test SEM Image Of FVABM Sample

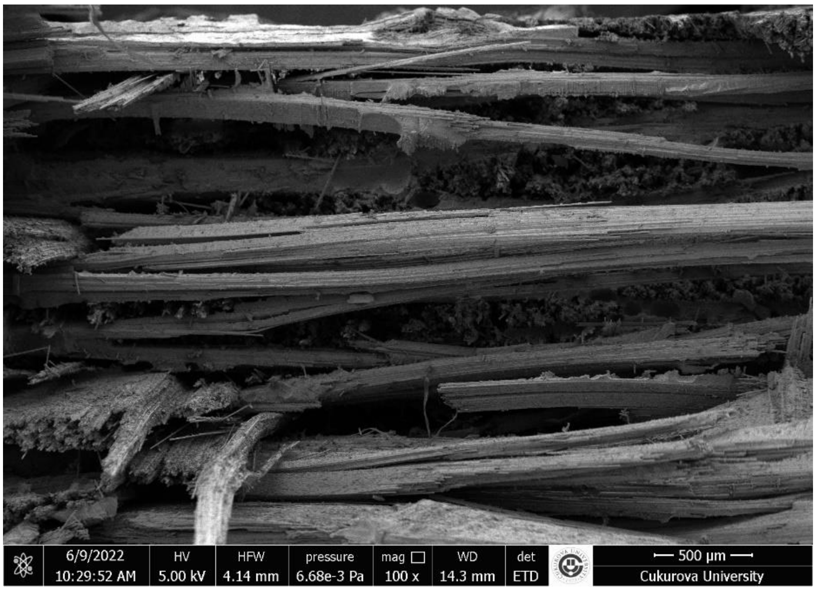

Figure 12. After The Tensile Test SEM Image Of CVABM Sample

Figure 13. After The Tensile Test SEM Image Of FCVABM Sample

4. Result and Discussion

In this study, linen and carbon fabrics were preferred as reinforcement elements, while the vacuum bagging and hand lay-up methods were used as production methods. The effect of these two different production methods on the mechanical properties of the homogeneous and hybrid composites produced is the highlight of the study. While the high cost of carbon fibers is eliminated by the hybridization process with flax fibers, an attempt was made to achieve a balance between cost, performance, and sustainability with an appropriate composite design by using two production methods. The microhardness value (201.59Hv) of the samples produced by the vacuum bagging method is close to the hardness value (199.42 Hv) of the samples produced by the hand lay-up method. However, in the tensile test results, it is observed that the production of the samples by vacuum bagging method provides a tensile strength value 1.52 times better than the production made by hand lay-up, and this is also observed with the morphological structures after the tensile test. Considering the number and design of the parts to be produced, it is thought that both production methods can be used in the automotive field and the most effective material can be found by choosing among different natural fiber/synthetic fiber combinations in further studies according to the cost-performance balance.

Conflict of Interest

No conflict of interest was declared by the authors.

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