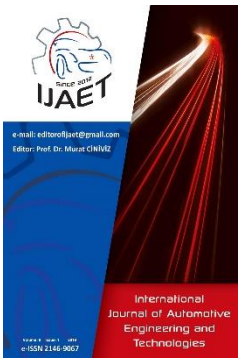
e-ISSN: 2146 - 9067

International Journal of Automotive Engineering and Technologies

journal homepage:
https://dergipark.org.tr/en/pub/ijaet



Original Research Article

Investigation of use of hybrid composite materials in automobile interior

Berkay Karaçor[1*], Mustafa Özcanlı[2]

[1, 2] Cukurova University, Engineering Faculty, Department of Automotive Engineering,01330, Adana, Turkey

ARTICLE INFO

1. 0000-0001-5208-366X

2. 0000-0001-6088-2912

Doi: 10.18245/ijaet.827239

* Corresponding author
berkaykaracor01@gmail.com

Received: Nov 18, 2020
Accepted: Dec 30, 2020

Published by Editorial Board Members of IJAET

ABSTRACT

Today, the issue of developing alternative new composite materials that can be obtained from environmentally friendly, renewable resources is an area that most researchers focus on. In many industrial sectors, the aim of transforming unsustainable products into sustainable products is common. Especially in the automotive sector, the rate of use in environmentally friendly materials with minimal damage to nature is increasing gradually instead of traditional materials. In this study, linen material, one of the natural fibers, and glass fibers with different weights per square meter were selected and the composite material was produced by vacuum-assisted resin transfer molding (VARTM) method using natural fiber reinforced epoxy matrix. Experimental studies have been conducted to examine the application of natural fiber reinforced composite materials as an alternative to traditional materials used in the vehicle interior. Thermogravimetric analysis, differential scanning calorimetric analysis, hardness, and impact tests were applied to the composites produced by the vacuum infusion method, and the basic mechanical properties and thermal stability of the materials were determined. The results show that adding different weights of glass fiber per square meter to natural fiber has been found to significantly increase the properties of composites in both thermal and mechanical aspects.

Keywords: Natural Fiber, Hybrid Composites, Mechanical Properties, Thermal Properties

1. Introduction

The increasing competition in rapidly developing technology and engineering applications and in daily life requires the design of high performance, low density, lightweight, corrosion resistant, and high strength products. Composites are one of these products that are researched as an alternative to existing materials in many fields such as the defense industry, aviation industry, space technologies, and automotive industry. In order to reduce vehicle fuel consumption and exhaust emissions, it is important to produce vehicles from lighter materials. However, traditionally many vehicle parts are made of metal materials. In recent years, these parts have started to be produced mainly from composite materials and it has been possible to produce much lighter parts with similar mechanical properties. Composite materials have great advantages over metal materials in terms of parameters such as strength/density. On the other hand, the costs of materials produced specially with carbon reinforcement materials are high. Moreover, the

production method of composite materials differs from traditional production methods and therefore causes large investment costs. However, the global composite industry- currently roughly 90% based on glass fiber - is now valued at 80 billion and has become the largest industry in automotive and transportation for the past five years. Although the composite industry has a 1.5% share in the global market, the ultimate goal is to replace this percentage with other materials [1]. There are different global applications to reduce vehicle weight, such as making materials from lighter materials, improving the functionality of existing parts, and applying these innovations in vehicle design. The most direct and effective method for weight reduction is the use of the latest lightweight materials such as composites, aluminum alloys, and high tensile steel. Automotive bodies are widely used in the production of Carbon Fiber Reinforced Plastics, especially in German cars. Carbon fiber reinforced plastics (CFRP), which are essential technical parts of modern industries, have recently been applied to a wide variety of engineering fields [2]. Especially in the last thirty years, the use of composite materials has become an integral part of society. The dramatic rise of this rapid development coincided with what is often called the green movement. As a result of this increasing environmental awareness, it has become clear that the industry must be more involved than ever in the development of waste disposal strategies. This is particularly important for the composite material industry, with the increasing number of composite parts coming to the end of their life [3]. In line with technological developments, high-safety, lightweight, low-emission, quality, and low-cost vehicle production is directly related to material technology research. Green composites are also good examples to illustrate these developments. Green composites that emerge from renewable resources provide great potential and future to end customers, the natural environment, and companies in terms of decreasing oil resources. In the automotive sector, the transition to such sustainable structures is necessary to provide a more viable environment and cost effectiveness and also to meet the requirements of a European regulation [4]. New materials development and optimization; seems to have solved the problems of the global competitive environment in cost reduction and meeting the legal requirements of motor vehicles. The desire to reduce total costs and provide ecological protection greatly encourages the use of new materials and plays a major role in reducing emission rates in future vehicles. Thus, a new environmental awareness about green compounds has arisen due to various reasons [5 - 7]. While sustainability is the most important problem in material technologies, developing renewable and sustainable material technologies is of great importance for industrial sectors. From this point of view, it is aimed at to minimize the environmental concerns of end users, various industrial applications, and innovative material studies have been carried out which cause minimal damage to the environment and reduce the dependence on fossil resources. At this point, recycling has an important place in sustainability. The resource and energy savings required to produce new and optimized materials will be achieved by recycling [8 - 10]. Significant changes have been observed in the types of materials used in modern automobile manufacturing from past to present. Increasing environmental awareness and public interest, unsustainable oil consumption and new environmental regulations lead to the use of natural fiber materials. It was stated that the demand for the use of biofiber composite materials has increased and the increasing area of use is mainly in interior applications in vehicles. These types of composites, which have the potential to reduce weight according to existing designs and materials, are used in automotive interior door panels, front fenders, tailgate, roofs. These products, which are used for various purposes in the automotive industry, are preferred due to their lightness, sound absorption capacity, flexibility, versatility, and easy adaptability. Today, there are many examples of the use of vegetable fibers such as reinforcements of thermoset and thermoplastic polymers such as epoxy, polyethylene, polypropylene, and polyester to produce environmentally friendly composites [11 - 16].

Composites are a heterogeneous compound of two or more supplements, matrix, and material, giving the material fully different superior chemical, physical, and mechanical features

[17]. Composite materials can be exposed to unusual loading states, which are sometimes compelled researchers to use different types of reinforcing materials in the composite structure. Such composites reinforced with two or more types of materials are known as hybrid composites [18]. Hybrid composite materials are designed for special task applications. The properties of the composites can be improved by careful design of the hybrid configuration. Two or more fibers and fillers are mixed to take advantage of the mechanical, thermal, and tribological properties of both of the fiber/fillers. A possible cause of the improved properties is that the fibers and fillers of certain properties are mixed in a particular pattern to provide the desired properties which cannot be achieved by mixing individual fibers in the matrix [19]. They are hybrid composites that combine two or more reinforcing materials in a matrix. Mechanical performance in composites is highly dependent on the reinforcement materials, matrix properties, and their interaction [20]. The task of the matrix is to combine the fibers regularly and protect them from the environs. In addition to transferring loads to the fibers, the matrix plays a critical role in intercepting premature defects caused by fiber micro bending in compression loading. Thermal and oxidative stability, maximum operating temperature, resistance to liquids, and moisture are determined from the properties of the matrix. Polymeric matrices for advanced composites are categorized as thermoplastics and thermosets [21]. Considering that thermoset resins are the most common matrix system for composite materials, they have low melt viscosity, good fiber impregnation, and very low processing temperatures [22]. The reinforcements are the ones that assume the essential role of providing strength and stiffness mainly in composite materials. Today, a wide variety of supplements, usually in fiber form, are available on the market. It is a high aspect ratio (length/diameter) of the fibers, which allows the load to be transferred to the fibers very efficiently through the matrix and makes the fibers a very effective and attractive reinforcing material [23]. Generally, fiber reinforced composites are preferred in automotive applications, aviation industry, etc. due to the need for high mechanical properties [20]. Among all-natural fibers, flax is one of the fibers with potentially best mechanical properties [24]. Flax fibers originating from renewable sources are an interesting alternative to mineral fibers. Low densities, high specific stiffness, and low cost together with recycling are the main incentives for their use in composites [25]. New technologies and separation techniques, such as the use of more homogeneous color, strength, length, and fineness to reduce fiber production costs, thus make linen more suitable for composites. Environmental legislation in Germany recyclable or biodegradable forced to use parts. At this point since 1995, Daimler-Benz has produced the flax fiber door panels in the Mercedes G class. Automobiles manufactured by BMW, Volkswagen, Rover, Opel, and Audi contain composite panels made of flax fiber. These fibers back up to decrease the weight of the vehicle [26]. Glass fibers used in this study are known as the world's most important permanent inorganic composite reinforcement fiber. These fibers are sold more than continuous ceramic fibers, boron fibers, and carbon fibers. General or commercial purpose E-glass fibers are reinforcing fibers covering the majority of today's market [27]. While the density of the e-glass is very low, its strength is rather high; nevertheless, Young's module is not very high. Therefore, although the strength-weight rate of glass fibers is fairly high, the module-weight rate is just moderate. The use of glass fibers continues to strengthen epoxy, phenolic, and polyester resins. It is fairly inexpensive and present in various forms [28]. E-glass fibers are the useful reinforcement material that not only reduces the number of critical defects but also increases the surface volume ratio and consequently increases strength [20].

While Long and Rudd [29] investigated models for indiscriminate and directed reinforcement deformation, Komus and Beley [30] examined how the properties of the material are affected when different types of reinforcements such as glass and carbon are used. Besides, Davoodi et al. [31] researched application of natural fiber composites and their hybridizations with other reinforcement or matrices, furthermore the importance of geometric optimization. Tian and Chen [32], and Rwawiiere [33] worked on

applying different materials to automotive dashboards, reducing the number of incompatible polymers in dashboards, and removing interior and exterior coverings. Petrone et al. [34] presented the results of the study on two ecologically compatible sandwich panels. The core materials of these panels are the same, and the front plate is made of different materials. To study the replacement of glass fiber with flax fiber experimental modal analysis was used. As a result of these analyzes, it shows that the high functional capacity of the panel made of natural fibers in terms of damping attracts attention in terms of natural frequencies, average values of mechanical properties, and low weight. Parikh et al. [35] explored how to avoid unwanted noise in the passenger compartment of motor vehicles using natural fibers that can be renewed and biodegradable. When the analysis results from two underpads are examined, the PU (polyurethane) underpad, which has a high density and thickness, was more influential in decreasing noise. As a result of this study, it has been shown that natural fiber-based non-woven composites (floor coverings) can be produced with sound absorbing properties suitable for use as automobile sound reduction parts. Tseng [36] studied the environmental impact of PLA (polylactic acid resin) + flax fiber composites and then PLA + flax fiber composites compared to PP (polypropylene)+ wood powder composites used in the internal components of the currently produced cars. Buchenauer [37] conducted the study to investigate the usage of natural wood fibers qua filler in polyamide composites. The result of the study was found on how to improve the sustainability and environmental friendliness of a polyamide composite for use in the automotive applications. Luz et al. [38] made an environmental impact comparison of talc-PP composites of sugarcane pulp-PP composites for automotive parts applications. A comprehensive Life Cycle Assessment (LCA) was used in this comparison. It was seen that sugarcane bagasse fiber production leads to a low environmental effect, composites reinforced with sugarcane bagasse were slighter and had equal performance when used in the aesthetic coating of the inside of the car. They researched and compared the application areas of natural fibers in terms of many different parameters in the automotive industry. The results also showed that the tested natural fibers can compete well with traditional materials It is believed that the application of natural fibers will enhance in many areas when surface modifications for natural fibers are developed, new joining techniques are used. In these studies, it has been seen that natural fiber reinforced composites are a very suitable choice for automotive applications [39 - 41].

In this study, the main goal is to investigate the usability of hybrid composite materials made with natural fibers and glass fiber fabrics of different weights as an alternative to vehicle interior plastics. In composite structures produced with this study, two different fabrics, reinforcement material linen, and glass fiber were preferred, epoxy resin was chosen as the matrix material, and the products were produced by vacuum supported resin transfer molding method. By analyzing the mechanical, thermal properties, microscopic-macroscopic structure of these structures, it was examined whether their use in the automotive industry is more suitable for our ecosystem.

2. Material and Methods

2.1. Material

In this study, flax (country of origin: Istanbul, Turkey) and three different types of weight glass fibers (country of origin: Istanbul, Turkey) were used as a reinforcement material. The properties of natural and synthetic fibers used in this study are given in Table 1.

Table 1. Fabric Properties

Fabric	Flax	Glass Fiber	Glass Fiber	Glass Fiber
Weave	Plain	Plain	Plain	Plain
Weight (gr/m²)	280	49	86	100
Thickness of Fabric (mm)	0.5	0.02	0.06	0.08
Warp	-	11x1	34x1	22x1
Weft	-	24x19	12x12.5	24x2.8

Table 2. Specimen Codes

Composite Codes	Fabric types
FL	Flax fabric
G49	Glass Fiber fabric (49 gr/m²)
G86	Glass Fiber fabric (86 gr/m²)
G100	Glass Fiber fabric (100 gr/m²)
FLG49	Flax/Glass Fiber composite (49 gr/m²)
FLG86	Flax/Glass Fiber composite (86 gr/m²)
FLG100	Flax/Glass Fiber composite (100 gr/m²)

In this study, the most widely used epoxy among thermosets was preferred. Moreover, epoxy resins have higher temperature resistance than polyester and vinyl ester resins. Matrix materials are in liquid form and can be cured at room temperature. For this study, in accelerator L160 (country of origin: Istanbul, Turkey) and as a hardener in LH260S (country of origin: Istanbul, Turkey) created the epoxy resin mixture for the matrix material system. One of the most important points to be considered in the manufacture of composites is to determine the mixing ratios of matrix materials. These rates were prepared as 100:36 ±2 by weight according to the manufacturer's specifications. If these chemicals are less necessary, they will defect the manufactured product, which will prevent the adherence of the fabric and resin and harden the sample. In other cases, using it more than necessary may cause the resin to solidify.

Four different types of composites were produced for this research. 25% of the produced parts are made of 100% linen fabric and the rest is made of glass and linen hybrid composite. Glass fibers were classified according to their weight and the sample codes produced were determined as in Table 2.

2.2. Method

2.2.1. Composite Manufacturing

Manufactured parts were produced with a vacuum supported resin transfer molding technique. Composite fabrication was carried out at room temperature (20°C ± 2°C). First, the surface was cleaned with substances such as acetone and thinner. A layer of mold separator material was applied to the surface one layer, if necessary, a second layer can be applied after fifteen minutes. The fabrics were laid on the surface in the specified order and then peel ply and infusion mesh was placed on the end respectively. Infusion and vacuum hoses were attached to the infusion mesh with a sealant strip to stabilize the position of the laid fabrics and to ensure a homogeneous resin flow. The frame was determined by vacuum sealing tape. Two hoses were affixed to the frame as input and output. The vacuum bag was carefully installed around the frame so that there was no air leak. The vacuum pump was run to test for air leaks. Simultaneously, epoxy resin was prepared in the calculated amount and the vacuum machine started. When the pressure gauge showed -760 mm-Hg, the infusion was continued until the entire surface got wet. The vacuum pump was operated until it absorbed the required amount of resin, the vacuum pump, and all holes must be closed when the process was finished. After waiting 24 hours in this position for the sample to cure, the vacuum bag opened and the infusion mesh, peel layer was separated from the composite product. The composite products produced were kept in the oven for 1 hour at 60°C. Two of the preparation steps of this technique are shown in Figures 1 and 2. The schematic view of this technique was shown in Figure 3.

Twelve different fabric-reinforced composite materials were produced using this method. Three of these were pure flax-reinforced composites, whereas the other nine were composite hybrid structures of glass fiber and flax.

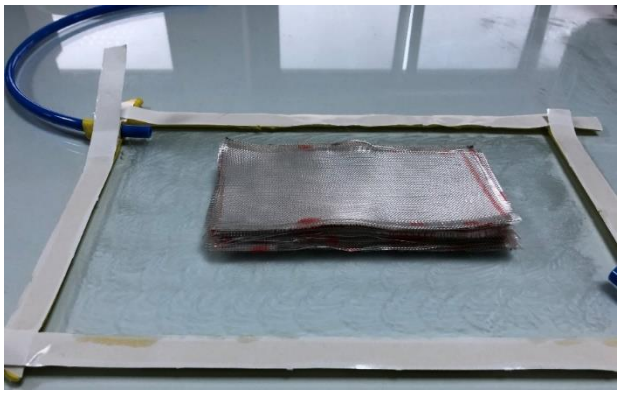


Figure 1. Layered fabrics were placed in the frame

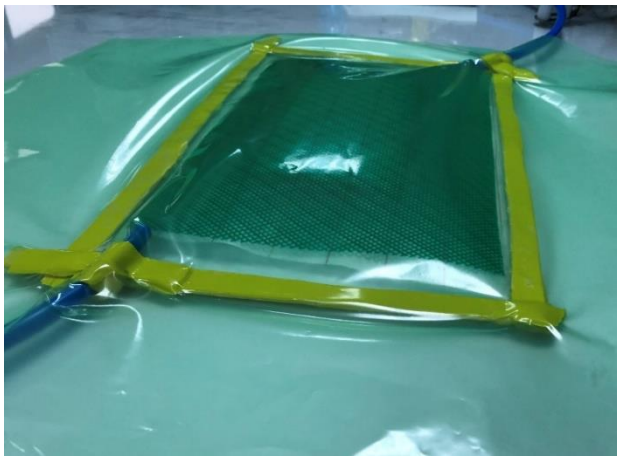


Figure 2. Vacuum bag attached to the system

2.2.2. Test and Analysis

2.2.2.1. Thermal Analysis

In this study, thermogravimetric analysis and differential scanning calorimetry were used to analyze the thermal properties of fabric

reinforcement, epoxy resin matrix, and composite structures.

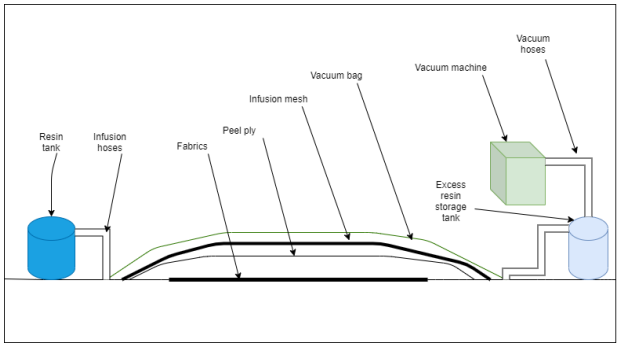


Figure 3. Typical Vacuum Assisted resin transfer molding (VARTM) process

2.2.2.1.1. Thermogravimetric Analysis

Thermal analysis, which is an ideal analytical method for the good shifting of industrial production technology of different polymeric materials, especially considering fiber reinforced composites, is a guide in understanding the structure-property relationship and understanding the molecular design. It also provides an important benefit in determining the thermal stability of materials [42]. In this study, Mettler Toledo TGA 3+ analyzer was used to perform thermogravimetric analysis (Figure 4).

Figure 4. Mettler Toledo TGA 3+ analyzer

While the weight of fabric samples varies between 4-9 mg, the weight of composite samples was prepared as 8-27 mg and was put into the aluminum oxide crucible. Then, closed crucibles were placed in the heating tunnel and the experiment was started. The samples were heated at 25°C to 600°C with a heating rate of 5°C/minute in a nitrogen atmosphere. Thermogravimetric analysis of epoxy and stiffener matrix, fabric, and composite samples were made to the same measurement standards.

2.2.2.1.2. Differential scanning calorimetry analysis

DSC is a thermal analysis technique used to record the temperature required to generate a zero-temperature difference between a substance subjected to the same temperature programs at controlled temperature or in a cooled environment and a reference material. It provides information about a measure of the amount of energy absorbed or developed in a given physical or chemical conversion, such as recorded heat flow, glass transition, melting or crystallization temperatures [43].

In DSC analysis, the analysis was started by first preparing the aluminum crucibles with lids. After that, the sample pieces weighing between 1-22 mg were cut from fabrics and composite products according to the crucible dimensions to be put into the device. The cut pieces were weighed with precise balance and put on the aluminum pot with tweezers and a lid was put on it. Using the ladle press, the sample pieces were sealed in these small cups. Samples were then placed on the DSC instrument (Figure 5).

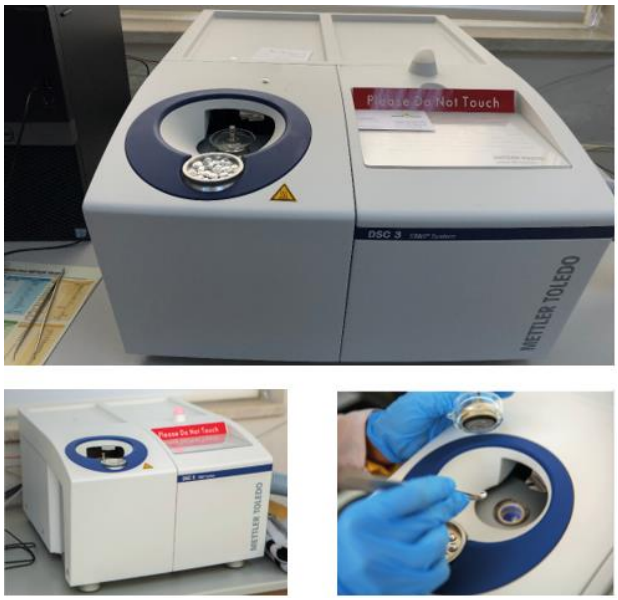


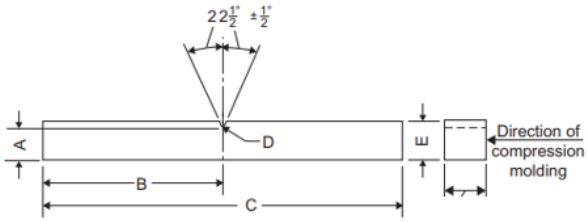
Figure 5. Mettler Toledo DSC 3+ analyzer

The Mettler Toledo DSC 3 device was used for analysis, which measures the amount of energy

absorbed or released by heating, cooling, or keeping the material at a constant isothermal temperature. The analyzes were performed in a dynamic state in the following standard procedures:
Raw fabrics in weights of about 1-4 mg, composite products in weights of 14-22 mg, were heated from 20°C to 500°C at a heating rate of 10°C/minute. The pieces were then cooled to 20°C at a rate of 10°C/minute.

2.2.2.2. Impact test analysis

For the Charpy Impact Test, a rectangular sample with a sample size of 125x12.5x10 mm was prepared according to the ASTM D 6110 standard, with a 2.0 mm 'V' notch per sample and an angle of 45° (Figure 6). 12 composite samples were taken from the products produced for the analysis of impact resistance. The notches were opened in the middle of each sample with a notch opening device (Figure 7).



A	10.16±0.05	0.400±0.002
B	63.5 max 61.0 min	2.50 max 2.40 min
C	127.0 max 124.5 min	5.00 min 4.90 min
D	0.25R±0.05	0.010R±0.002
E	12.70±0.15	0.500±0.006

Figure 6. Dimensions of Charpy type test specimen [44]

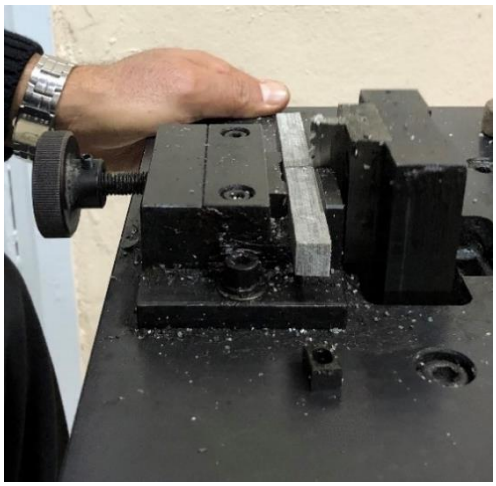


Figure 7. Notching device

TOTOMAK Charpy Impact Testing Machine was used to measure the impact resistance of the samples prepared according to the ASTM D 6110 standard (Figure 8).
In this test, the sample is held securely at both ends and the energy absorbed by the sample is given by hitting a hammer on a pendulum arm with the sample made according to the standards. The hammer hits against the notch in the sample being produced. The energy absorbed by the sample is decided by precisely measuring the decrease in the movement of the pendulum arm [45].

Figure 8. Impact tester

After analysis, impact strength can be calculated from the following equation:

$$Impact\ strength = \frac{E}{t}\ x1000 \quad (1)$$

'E'-Energy used to break (J)
't'-Thickness in mm [46]

2.2.2.3. Hardness test analysis

The hardness test was carried out by the AOB Lab product machine with test loads ranging from 10 grf to 1000 grf to estimate the degree of abrasion of the material to cut, scratch, or indentation according to the ASTM E92-17 standard (Figure 9).
The Vickers hardness test uses an indentation that generally has an effect called the indentation on the material test sample. Vickers hardness value directly depends on the applied load and the area formed by the indentation formed on the test surface of the material. The indentation used in the Vickers hardness test process has the geometric configuration of a square pyramid made of diamonds at an angle of 136° between opposite faces. After the indenter actuation, the material sample presents an indentation region with the approximate shape of a regular lozenge, Figure 10.
Using the equation below, the hardness value

(Vickers Hardness number) is calculated:

$$HV = 1.8544 \frac{F}{d^2} \quad (2)$$

where the F is the applied load in kgf, d is the mean diagonal length in millimeter[47].

Figure 9. Hardness test machine

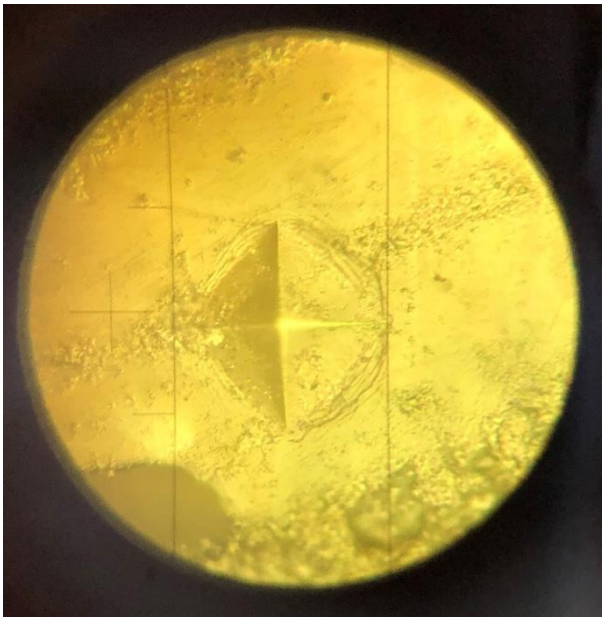


Figure 10. Regular lozenge shape

3. RESULTS AND DISCUSSIONS

3.1. Thermal Analysis Results

3.1.1. Thermogravimetric Analysis

An example of the TGA plot of a fabric linen sample obtained from the Mettler Toledo Software Program is shown in Figure 11. The change in the weight of a sample with increasing temperature can be seen in this graph. The regions indicated in the figure are the temperatures at which the decreases in sample weight begin.

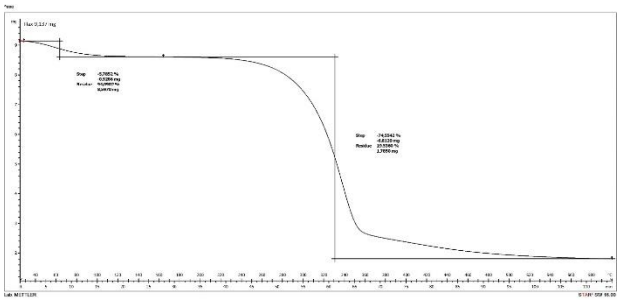


Figure 11. TGA graph of a flax fabric

The initial and final weights of the raw fabric samples and their onset temperatures are given in Table 3.

Table 3. Weight losses and onset temperatures of raw fabric sample

Fabric Sample	Initial Weight (mg)	Final Weight (mg)	Onset Temperature (°C)
Flax	9.137	1.785	68/332
G49	3.71	3.71	-
G86	7.19	7.19	-
G100	4.35	4.35	-

It was observed that the linen fabric had a weight loss of 74.5% and had two initial temperatures (68°C and 332°C), whereas the three glass fiber fabrics of different weights did not change for weights. Since the E-glass fiber did not have a decomposition temperature[48], no weight loss was observed in the E-glass fabric sample and did not have an initial temperature. On the other part, the linen fabric sample having two initial temperatures (68°C and 332°C) may be due to the molecular content of the flax fiber.

It contains 2.0% lignin, 1.8% pectin,1.5% wax,10% water,16.7% hemicellulose and 64.1% cellulose. The initial weight loss of flax fiber between 60° and 100°C corresponds to the evaporation temperature of the water in the sample. The second weight loss is caused by the thermal depolymerization of hemicelluloses and cellulose bonds[49]–[52]. Figure 12, Figure 13, Figure 14, and Figure 15 show respectively the TGA plots of the FL, FLG49, FLG86, FLG100 composite sample from the Mettler Toledo Software Program.

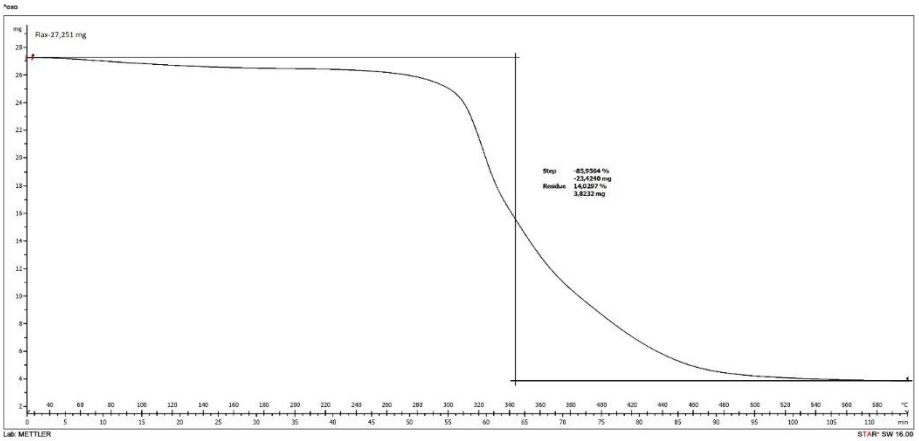


Figure 12. TGA graph of FL composite sample

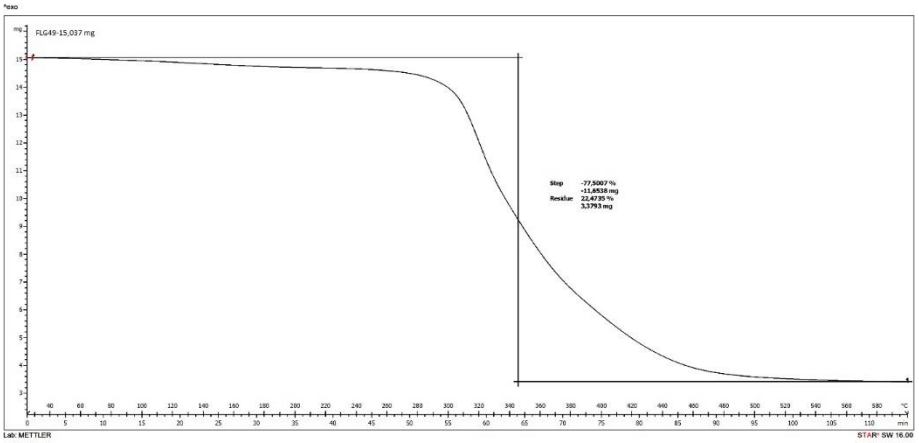


Figure 13. TGA graph of FLG49 composite sample

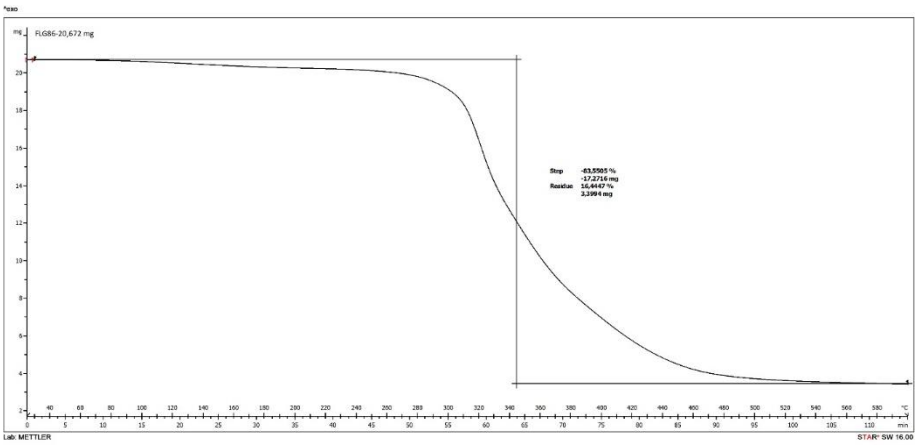


Figure 14. TGA graph of FLG86 composite sample

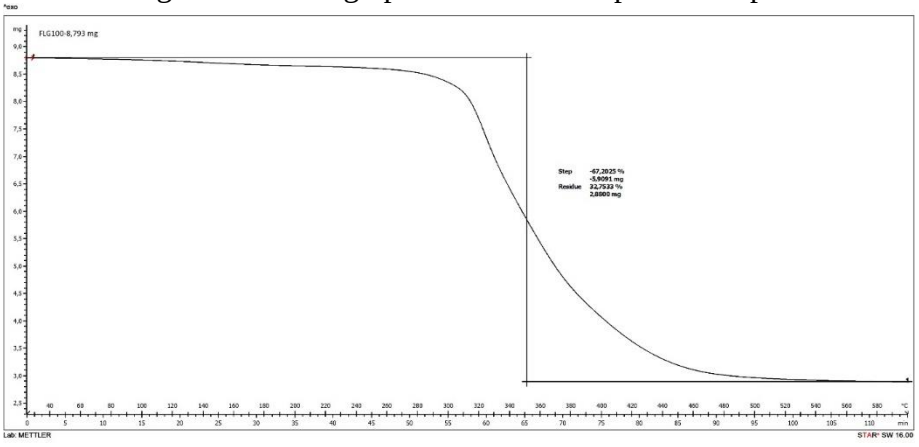


Figure 15. TGA graph of FLG100 composite sample

Weight changes and initial temperatures of epoxy resin, linen, and glass fiber fabric reinforced composites are shown in Table 4. The epoxy resin was heated from 25°C to 600°C, losing 60.08% of its weight and the temperature at which the decomposition started was 326°C. When the decomposition temperatures of pure linen-reinforced composite samples are compared to glass fiber-reinforced composites, the initial temperature of the pure linen-reinforced composite is 344°C, while the initial temperatures of FLG49, FLG86, and FLG100 glass fiber reinforced composite samples are 346°C, 345°C, and 352°C were obtained respectively. Making hybrid composites of linen fabric reinforced composites with glass fiber of different weight has been observed to increase their decomposition temperature by up to 8°C. When the decomposition temperatures of glass fiber fabric reinforced FLG49, FLG86, and FLG100 composites were examined, non-large temperature differences such as minimum 1°C and maximum 6°C were observed.

Table 4. Weight losses and onset temperatures of epoxy and composite samples

Composite Sample	Initial Weight (mg)	Final Weight (mg)	Onset Temperature (°C)
Epoxy resin	31.14	12.43	326
FL	27.251	3.8232	344
FLG49	15.037	3.3793	346
FLG86	20.672	3.3994	345
FLG100	8.793	2.88	352

Considering the weight loss percentages of the samples, the weight loss amount of the epoxy is 60.08%, although the loss of the linen fabric reinforced composite is 85.95% as shown in Figure 12. When the data in Figures 13,14 and 15 were examined, it was found that the weight loss percentages of glass fiber reinforced samples were 77.5%, 83.5%, and 67.2% for FLG49, FLG86, FLG100 composites, respectively. These percent losses were also found to be less than the weight loss amount of the linen fabric reinforced composite and more than the epoxy weight loss.

3.1.2. Differential Scanning Calorimetry Analysis

DSC graphics of flax and E-glass fabric samples are shown in Figures 16, 17, 18, and 19. As seen in Figure 16, exothermic reaction at 150°C and endothermic reaction took place at 350°C in flax fabric during the heating and cooling cycle. Amorphous cellulose is known to form hydrogen bonds at 60°C and recrystallize at 150°C as part of natural fibers. In previous studies, thermal analysis of cellulose fibers was performed and it was stated that crystalline orientation and crosslinking were effective on the pyrolytic behavior of cellulose. An exothermic reaction occurred in the graph because less crystalline material degrades faster with heat and lower thermal stability of flax fibers. In a typical DSC thermogram of cellulosic fibers, it is stated to be an endothermic peak between 370°C and 395°C, which is often shown to be caused by the production of laevoglucose. This situation explains the endothermic reaction in the graph. As can be seen from the Figure 17,18 and 19, E-glass fabrics did not have any endothermic or exothermic reactions during the heating and cooling cycle because they have high heat resistance, no glass transition, and melting temperatures, and also the decomposition temperatures were not between 20°C - 500°C.

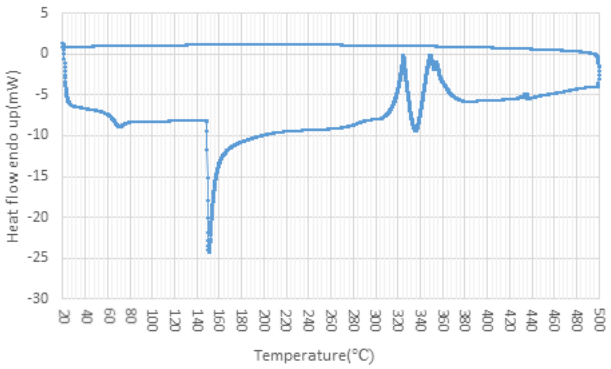


Figure 16. DSC graph of raw flax fabric sample

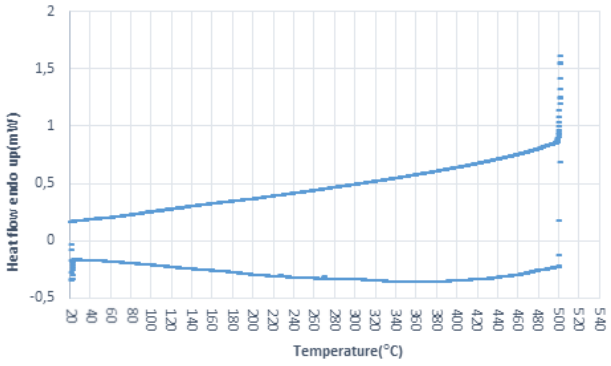


Figure 17. DSC graph of G49 fabric sample

The DSC curves of the epoxy resin are shown in Figure 20. It was observed from the DSC plot of the epoxy resin (Figure 20) that an endothermic reaction began at 130°C, which affected the

deterioration of the epoxy resin. In addition, an endothermic reaction occurred, indicating a change in the decay process at about 343°C.

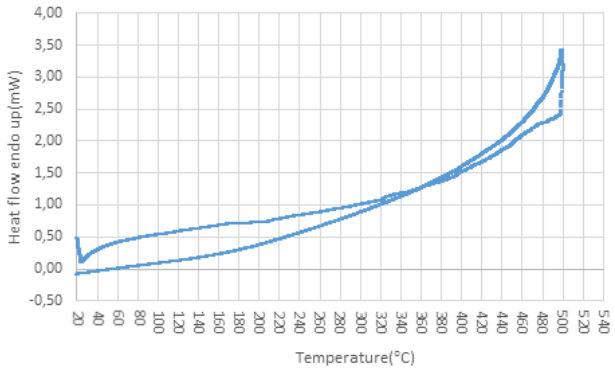


Figure 18. DSC graph of G86 fabric sample

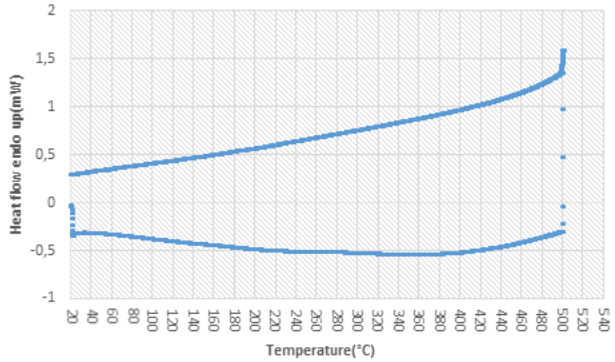


Figure 19. DSC graph of G100 fabric sample

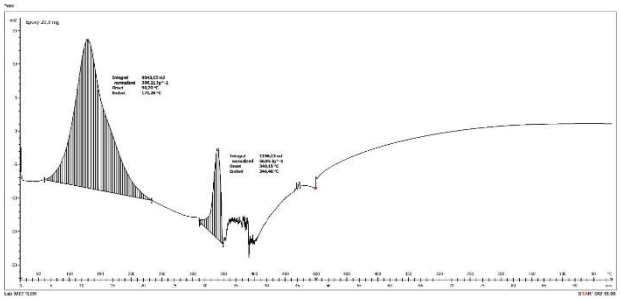


Figure 20. DSC graph of Epoxy

Figure 21, 22, 23, 24 shows DSC plots of hybrid composite samples reinforced with linen and E-glass fabric. It was observed that the deterioration in flax composite samples started at 148°C and peaked at 153°C, similar to the raw flax fabric samples. In all examples, an exothermic reaction appears to start at about 150°C, indicating degradation of the linen fabric. In addition, exothermic reactions peaked around 160°C. There is an onset of an endothermic reaction at approximately 310°C in the graphs; it was found that this was similar to the endothermic temperature occurring in raw flax. As mentioned earlier, E-glass is very heat resistant and it can be said that the exothermic reaction that starts at 150°C indicates the deterioration of the raw linen fabric. Although the epoxy resin had an endothermic reaction at 130°C, it was understood that this situation had no significant effect on the phase changes of flax and glass fiber composite materials. The heat flows of flax reinforced composites and flax/glass fiber reinforced composites did not show much difference either.

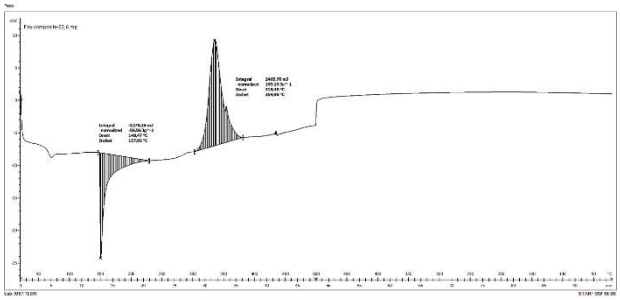


Figure 21. DSC graph of Flax composite sample

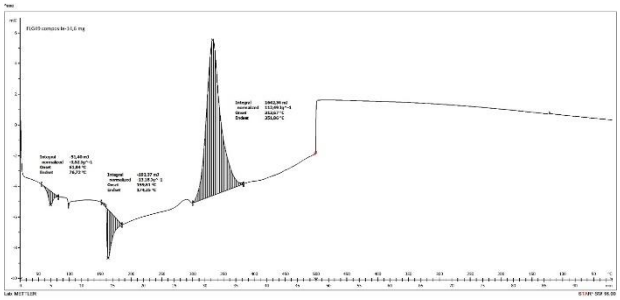


Figure 22. DSC graph of FLG49 composite sample

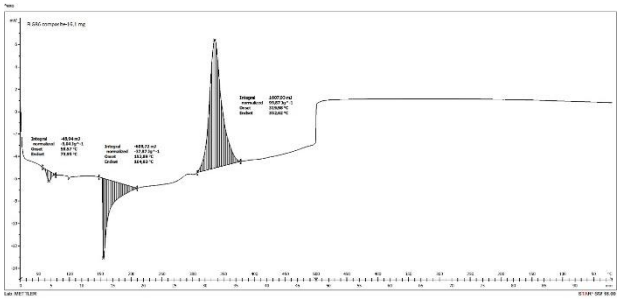


Figure 23. DSC graph of FLG86 composite sample

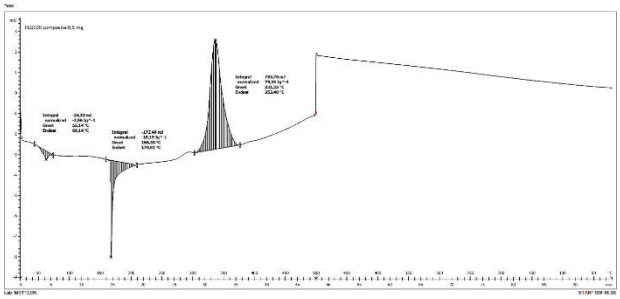


Figure 24. DSC graph of FLG100 composite sample

Besides, the temperature at which the exothermic reaction seen on the DSC graph of the raw linen fabric peaked (160°C); the composite samples of FL, FLG49, FLG86, FLG100 were also found to peak at about 160°C. The situation is the same at the

endothermic reaction start temperature (320°C). It was understood from the analyzed samples that changing the placement order of the fabrics or epoxy resin had almost no effect on the phase changes of the samples. Moreover, although E-glass fabrics have high thermal resistance, it has been found that the phase changes in the composite sample obtained from these materials depend on the properties of the linen fabric reinforcement.

3.2. Impact test analysis

The impact resistance of the composite samples produced was shown in Figure 25. The FLG100 glass fabric reinforced composite was found to have the highest impact energy (57.29-65.303 J) and pure linens had the lowest impact energy (41.88-46.39 J). Visible from this chart that FLG49 (flax/glass fiber reinforced composite) and FLG86 hybrid have similar impact energies. This can be explained by the chemical structure resulting from the production of fabric layers between linen and glass fibers and the adhesion between linen, epoxy, and glass fiber layers. By the time the influence of the stacking order was perused, it was found the GGGF sample (57.29 J-65.3 J) had the highest impact energy value among the flax/E-Glass reinforced composites, while the GFFF sample had the lowest impact energy (46.39 J) value. In addition, although there was no large difference between the impact energy values of pure flax and Flax/Glass fiber49 hybrid composites, the GFFF sample was found to have slightly higher impact energy than the FFFF. Those obtained from these tested composite parts explain for the mechanical performance of the gap fractions and the sliding behavior when the parts are subjected to sudden impacts.

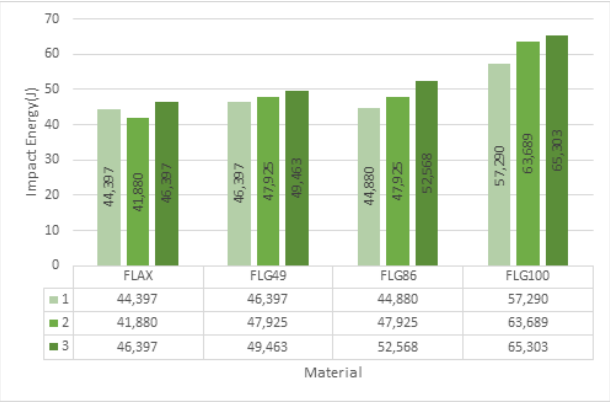


Figure 25. Impact energy values of produced composites sample

3.3. Hardness test analysis

The hardness value of the manufactured composites was shown in Figure 26. When Vickers hardness test results are examined, it is seen that FLG100 composite has the highest hardness value and flax composite has the lowest hardness value in the produced composites. As can be seen from the graphic, FLG49, FLG86, and FLG100 hybrid composites were found to have close hardness values. The difference between them was found to vary with the amount and order of linen and glass fabric fibers in their structure (e.g. GFGFG in FLG49, FGFGF in FLG86, GGFGG in FLG100). However, compared to the flax composite, it has been concluded that glass fabric reinforcement increases the hardness properties of the composites.

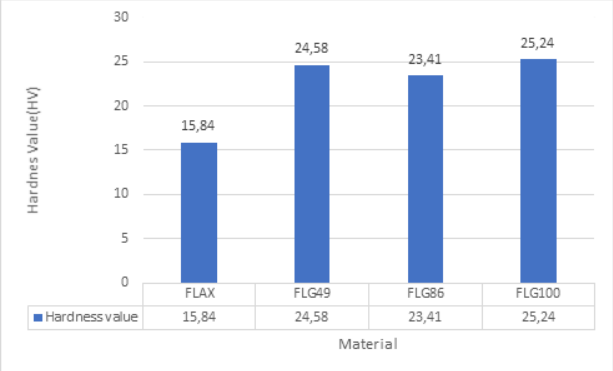


Figure 26. Hardness values of composites

4. Conclusions

In this study, natural fiber reinforced hybrid composites have been designed and manufactured. The thermal and mechanical properties of these products were researched and analyzed using three different weights (G49, G86, G100) glass fiber fabric (synthetic fiber) and flax fiber fabric (natural fiber). The results of TGA showed that the raw glass fiber fabrics did not lose any weight as the temperature increased, and the raw linen fabric lost 74.5% of its weight, which is related to the high thermal resistance of the glass fibers. In the TGA results of composite products and epoxy resin, a weight loss of 85.9% was observed in the composite product (FL) with a weight loss of 60% in the epoxy resin. This rate was found to be 77.5%, 83.5%, and 67.2% in glass fiber reinforced composites (FLG49, FLG86, FLG100), respectively. The raw linen fabric showed two decomposition temperatures, as glass fiber

fabrics had no decomposition temperature. While composite products show close decomposition temperatures, the final values obtained are approximately 20°C above the temperature value of the epoxy resin that begins to decompose. According to DSC analysis results, an exothermic reaction around 150°C and an endothermic reaction around 350°C were observed in linen fabric, where glass fiber fabrics did not show exothermic and endothermic reactions due to their thermal stability. In the DSC analysis results, an endothermic reaction was observed at epoxy at 130°C and 343°C. It was observed that exothermic reaction starts at approximately 150°C and an endothermic reaction occurred at around 310°C in composite products with flax and glass fiber. It was understood that these temperature values were similar to the graphic results of the raw linen fabric. In accordance with Charpy test results, it has been found that hybrid composites made by flax with glass fiber reinforced samples of different weights have higher impact values from 9.73% to 28.95% higher than those of pure linen composite reinforced samples. The hardness of the FLG100 composite is 25.24 HV, when the hardness of the FL composite is 15.84 HV. With glass fiber fabric reinforcement to linen fabric, an increase of 59.34% in the hardness value of the composite appears. While the lowest hardness value among glass fiber reinforced composites is seen in FLG86 composite, it is concluded that this difference is negligible with FLG49 as 4.99% and with FLG100 as 7.81%, and the difference is related to the amount and order of glass fiber reinforced composite. This indicates that E-glass fabric reinforced composite structures that are hybridized with linen fabric reinforcement are suitable materials for use in the automotive industry.

It is envisaged that the composite samples produced within the scope of this study may find a widespread area in the automotive industry in the future, and composite structures produced due to the low mechanical properties of linen-reinforced products can be used in the automobile interior.

Acknowledgement

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by the Cukurova University Scientific Research Project Coordination under grant no. FYL-2018-11207

Information

This study belongs to master graduation thesis.

5. References

1. Wilson, “Vehicle weight is the key driver for automotive composites,” Reinf. Plast., vol. 61, no. 2, pp. 100–102, doi: 10.1016/j.repl.2015.10.002, Mar. 2017.
2. T. Ishikawa et al., “Overview of automotive structural composites technology developments in Japan,” Composites Science and Technology, vol. 155. pp. 221–246, doi: 10.1016/j.compscitech.2017.09.015, Feb-2018.
3. R. Brooks, "Composites in Automotive Applications: Design", no. February 2016. Elsevier Ltd., 2004.
4. G. Koronis, A. Silva, and M. Fontul, “Green composites: A review of adequate materials for automotive applications,” Compos. Part B Eng., vol. 44, no. 1, pp. 120–127, doi: 10.1016/j.compositesb.2012.07.004, 2013.
5. H. Adam, “Carbon fibre in automotive applications,” Mater. Des., vol. 18, no. 4–6, pp. 349–355, doi: 10.1016/s0261-3069(97)00076-9, 1997.
6. H. S. Park, X. P. Dang, A. Roderburg, and B. Nau, “Development of plastic front side panels for green cars,” CIRP J. Manuf. Sci. Technol., vol. 6, no. 1, pp. 44–52, doi: 10.1016/j.cirpj.2012.08.002, 2013.
7. P. K. Bajpai, I. Singh, and J. Madaan, “Development and characterization of PLA-based green composites: A review,” J. Thermoplast. Compos. Mater., vol. 27, no. 1, pp. 52–81, doi: 10.1177/0892705712439571, 2014.
8. M. Misra, J. K. Pandey, and A. K. Mohanty, "Biocomposites: Design and Mechanical Performance." Elsevier Ltd, 2015.
9. Mayyas, A. Qattawi, M. Omar, and D. Shan, “Design for sustainability in automotive industry: A comprehensive review,” Renew. Sustain. Energy Rev., vol. 16, no. 4, pp. 1845–1862, doi: 10.1016/j.rser.2012.01.012, 2012.
10. Y. Yang, R. Boom, B. Irion, D. J. van Heerden, P. Kuiper, and H. de Wit, “Recycling of composite materials,” Chem. Eng. Process.

Process Intensif., vol. 51, pp. 53–68, doi: 10.1016/j.cep.2011.09.007, 2012.
11. L. Mohammed, M. N. M. Ansari, G. Pua, M. Jawaid, and M. S. Islam, “A Review on Natural Fiber Reinforced Polymer Composite and Its Applications,” Int. J. Polym. Sci., vol. 2015, pp. 1–15, doi: 10.1155/2015/243947, 2015.
12. S. A. Pradeep, R. K. Iyer, H. Kazan, and S. Pilla, "Automotive Applications of Plastics: Past, Present, and Future", Second Edi. Elsevier Inc., 2016.
13. K. Bledzki, O. Faruk, and V. E. Sperber, “Cars from Bio-Fibres,” Macromol. Mater. Eng., vol. 291, no. 5, pp. 449–457, doi: 10.1002/mame.200600113, 2006.
14. U. K. Vaidya, F. Samalot, S. Pillay, G. M. Janowski, G. Husman, and K. Gleich, “Design and manufacture of woven reinforced glass/polypropylene composites for mass transit floor structure,” J. Compos. Mater., vol. 38, no. 21, pp. 1949–1972, doi: 10.1177/0021998304048418, 2004.
15. G. Thilagavathi, E. Pradeep, T. Kannaian, and L. Sasikala, “Development of natural fiber nonwovens for application as car interiors for noise control,” J. Ind. Text., vol. 39, no. 3, pp. 267–278, doi: 10.1177/1528083709347124, 2010.
16. Alves et al., “Ecodesign of automotive components making use of natural jute fiber composites,” J. Clean. Prod., vol. 18, no. 4, pp. 313–327, doi: 10.1016/j.jclepro.2009.10.022, 2010.
17. G. Anuradha, “Composites from Natural Fibers: Hemp Fiber Reinforced Composites from 3D Orthogonal Woven Preforms and their Potential Applications in the US,” North Carolina State University, 2019.
18. H. Sezgin, “Investigation and Enhancement of The Mechanical Properties of the Fabric Reinforced Hybrid Composites,” Istanbul Techinical University, 2018.
19. G. Agarwal, A. Patnaik, R. kumar Sharma, and J. Agarwal, “Effect of stacking sequence on physical, mechanical and tribological properties of glass-carbon hybrid composites,” Friction, vol. 2, no. 4, pp. 354–364, doi: 10.1007/s40544-014-0068-9, 2014.
20. H. Sezgin and O. B. Berkalp, “The effect of hybridization on significant characteristics of jute/glass and jute/carbon-reinforced composites,” J. Ind. Text., vol. 47, no. 3, pp. 283–296, doi: 10.1177/1528083716644290, 2017.
21. F. C. Campbell, "Structural Composite Meterials." 2010.
22. G. Lee and N. P. Suh, "Axiomatic Design and Fabrication of Composite Structures: Applications in Robots, Machine Tools, and Automobiles". 2006.
23. Shahzad, “Impact and Fatigue Properties of Natural Fibre Composites,” University o f Wales, 2009.
24. H. L. Bos, M. J. A. Van Den Oever, and O. C. J. J. Peters, “Tensile and compressive properties of flax fibres,” J. Mater. Sci., vol. 7, pp. 1683–1692, 2002.
25. Baley, “Analysis of the flax fibres tensile behaviour and analysis of the tensile stiffness increase,” Compos. - Part A Appl. Sci. Manuf., vol. 33, no. 7, pp. 939–948, 2002, doi: 10.1016/S1359-835X(02)00040-4.
26. J. A. Foulk, D. E. Akin, and R. B. Dodd, “New low cost flax fibers for composites,” SAE Tech. Pap., doi: 10.4271/2000-01-1133, 2000.
27. T. Wallenberger, "Advanced Inorganic Fibers: Process - Structure - Properties - Applications", 1 st. Springer US, 1999.
28. K. K. Chawla, "Composite Materials:Science and Engineering," 3rd ed. 2012.
29. C. Long and C. D. Rudd, “A simulation of reinforcement deformation during the production of preforms for liquid moulding processes,” Proc. Inst. Mech. Eng. Part B J. Eng. Manuf., vol. 208, no. 4, pp. 269–278, doi: 10.1243/PIME_PROC_1994_208_088_02, 1994.
30. Komus and N. Beley, "Composite applications for ground transportation", vol. 3–8. Elsevier Ltd., 2018.
31. M. M. Davoodi, S. M. Sapuan, D. Ahmad, A. Aidy, A. Khalina, and M. Jonoobi, “Concept selection of car bumper beam with developed hybrid bio-composite material,” Mater. Des., vol. 32, no. 10, pp. 4857–4865, doi: 10.1016/j.matdes.2011.06.011, 2011.
32. J. Tian and M. Chen, “Sustainable design for automotive products: Dismantling and recycling of end-of-life vehicles,” Waste Manag., vol. 34, no. 2, pp. 458–467, doi: 10.1016/j.wasman.2013.11.005, 2014.
33. S. Rwawiire, B. Tomkova, J. Militky, A.

Jabbar, and B. M. Kale, “Development of a biocomposite based on green epoxy polymer and natural cellulose fabric (bark cloth) for automotive instrument panel applications,” Compos. Part B Eng., vol. 81, pp. 149–157, doi: 10.1016/j.compositesb.2015.06.021, 2015.
34. Petrone, V. D’Alessandro, F. Franco, B. Mace, and S. De Rosa, “Modal characterisation of recyclable foam sandwich panels,” Compos. Struct., vol. 113, no. 1, pp. 362–368, doi: 10.1016/j.compstruct.2014.03.026, 2014.
35. D. V. Parikh, Y. Chen, and L. Sun, “Reducing Automotive Interior Noise with Natural Fiber Nonwoven Floor Covering Systems,” Text. Res. J., vol. 76, no. 11, pp. 813–820, doi: 10.1177/0040517506063393, 2006.
36. S. C. W. Tseng, “Using bio-based materials in the automotive industry,” 2013.
37. Buchenauer, “Wood Fiber Polyamide Composites for Automotive Applications,” 2016.
38. S. M. Luz, A. Caldeira-Pires, and P. M. C. Ferrão, “Environmental benefits of substituting talc by sugarcane bagasse fibers as reinforcement in polypropylene composites: Ecodesign and LCA as strategy for automotive components,” Resour. Conserv. Recycl., vol. 54, no. 12, pp. 1135–1144, doi: 10.1016/j.resconrec.2010.03.009, 2010.
39. L. Leao, R. Rowell, and N. Tavares, “Applications of Natural Fibers in Automotive Industry in Brazil — Thermoforming Process,” Sci. Technol. Polym. Adv. Mater., pp. 755–761, doi: 10.1007/978-1-4899-0112-5_66, 1998.
40. Magurno, “Vegetable fibres in automotive interior components,” Angew. Makromol. Chemie, vol. 272, no. 4751, pp. 99–107, doi: 10.1002/(SICI)1522-9505(19991201)272:1<99::AID-APMC99>3.0.CO;2-C, 1999.
41. E. Ozen, A. Kiziltas, E. E. Kiziltas, and D. J. Gardner, “Natural fiber blend-nylon 6 composites,” Polym. Compos., vol. 34, no. 4, pp. 544–553, doi: 10.1002/pc.22463, Apr. 2013.
42. P. V. Joseph et al., “The thermal and crystallisation studies of short sisal fibre reinforced polypropylene composites,” Compos. Part A Appl. Sci. Manuf., vol. 34, no. 3, pp. 253–266, doi: 10.1016/S1359-835X(02)00185-9, 2003.
43. Z. Mei and D. D. L. Chung, “Glass transition and melting behavior of carbon fiber reinforced thermoplastic composite, studied by electrical resistance measurement,” Polym. Compos., vol. 21, no. 5, pp. 711–715, doi: 10.1002/pc.10224, 2000.
44. S. A. Ashter," Thermoforming of Single and Multilayer Laminates." 2014.
45. M. Jawaid, M. Thariq, and N. Saba, "Mechanical and Physical Testing of Biocomposites, Fibre-Reinforced Composites and Hybrid Composites″. Woodhead Publishing, 2019.
46. R. Sakthivel and D. Rajendran, “Experimental Investigation and Analysis a Mechanical Properties of Hybrid Polymer Composite Plates,” Int. J. Eng. Trends Technol., vol. 9, no. 8, pp. 407–414, doi: 10.14445/22315381/ijett-v9p278, 2014.
47. M. R. Mitchell, R. E. Link, P. P. R. Filho, T. da S. Cavalcante, V. H. C. de Albuquerque, and J. M. R. S. Tavares, “Brinell and Vickers Hardness Measurement Using Image Processing and Analysis Techniques,” J. Test. Eval., vol. 38, no. 1, p. 102220, doi: 10.1520/jte102220, 2010.
48. Zhou, “Structural responses of FRP elements under combined thermal and mechanical loadings: experiments and analyses,” no. July, pp. 15–16, 2005.
49. M. Lewin, "Handbook of Fiber Chemistry," 3 rd. CRC Press Taylor & Francis Group, 2007.
50. J. Lv, S. Bin Wu, and R. Lou, “Kinetic study of the thermal decomposition of hemicellulose isolated from corn stalk,” BioResources, vol. 5, no. 2, pp. 1281–1291, doi: 10.15376/biores.5.2.1281-1291, 2010.
51. K. C. Manikandan Nair, S. Thomas, and G. Groeninckx, “Thermal and dynamic mechanical analysis of polystyrene composites reinforced with short sisal fibres,” Compos. Sci. Technol., vol. 61, no. 16, pp. 2519–2529, doi: 10.1016/S0266-3538(01)00170-1, 2001.
52. Yang, R. Yan, H. Chen, D. H. Lee, and C. Zheng, “Characteristics of hemicellulose, cellulose and lignin pyrolysis,” Fuel, vol. 86, no. 12–13, pp. 1781–1788, doi: 10.1016/j.fuel.2006.12.013, 2007.