Journal of Physical Chemistry and Functional Materials

Home Page of Journal: https://dergipark.org.tr/jphcfum

Production of high performance eco-Composite materials for Aerospace Applications

Handan Aydin[1], *Cihat Aydin[2], Sinan Avci[3]

[1]Department of Medical Services and Techniques Optician Program, Munzur University, Tunceli,
[2]Department of Airframe and Powerplant Maintenance, School of Civil Aviation, Firat University, Elazig,
[3]Department of Metallurgy and Materials Engineering, Faculty of Engineering, Mersin University, Mersin
** Corresponding author: E-mail: caydin@firat.edu.tr*

ABSTRACT

In today's aviation industry, the use of composite materials has reached 30%. Studies on composite materials continue intensively and these materials are seen as the only solution to meet the material requirements of developing technology. The features expected from composite materials produced for use in the defense industry are high strength, formability, corrosion resistance and vibration damping. In the wing and tail elements of military aircraft such as airplanes and helicopters, in aircraft armors and unmanned aerial vehicles, economical, easily produced and superior composite materials are preferred.

ARTICLE INFO

Keywords:
Eco-Composite, Aerospace, Epoxy, Palm Fiber

Received: May 28, 2025
Accepted: June 2, 2025
ISSN: 2651-3080
DOI: 10.54565/jphcfum.1708165

1. INTRODUCTION

Aviation is one of the sectors most affected by developments in material science. Increasing fuel costs, operating and maintenance costs, and environmental regulations are fueling the search for “more lightness” in the aviation industry. Because reducing the fuselage weight of aircraft provides lower fuel consumption, reducing both carbon emissions and operating costs. At this point, composite materials are the solution to the sector’s need for more lightness without compromising safety. The superior features of aviation composites compared to traditional materials can be listed as lightness, high impact resistance, thermal stability, corrosion resistance, low material cost, radar stealth, creation of aerodynamic shapes that are not possible with wood or metal, and simplification of the assembly process by reducing the number of parts [1-4].

As a result of today's aviation technology, the limited use of pure materials has led to alternative searches. As a reflection of this, composite materials with improved properties have been developed and their areas of use have increased. Composite materials are a group of materials that largely constitute the needs of the aviation industry. For this reason, studies are constantly being carried out to increase the performance of composite materials with different reinforcement and filling material additions in order to increase their function or effectiveness [2-5].

As a result of developing technology and visionary perspective, factors such as improvement of conditions and high performance expectation from cheap material production, different searches have emerged in the preferences of reinforcement materials during composite production in the industry. Thus, natural raw materials and wastes have been preferred as reinforcement materials. Composite preferences produced with natural raw material reinforcement have emerged based on criteria such as environmental sensitivity, sustainability and reducing dependency on petroleum and derivative products. Composite production with waste reinforcement is a preferred way to raise awareness by evaluating materials that negatively affect the environment or are thought to have negative effects, to offer alternative solutions to waste storage problems and to provide cheaper reinforcement materials [4-7].

In composite materials, the matrix, or main material, holds the reinforcement together, while the reinforcement materials increase the strength by reducing the stress under the forces to which the composite material is exposed. Capillary crystals, short and long fibers with different arrangements, and particulate and chopped ceramics can be used as reinforcement materials in composite materials. The main purpose of these reinforcement materials is to carry the incoming load and to increase the hardness and durability of the matrix.

The reasons why epoxy resin is preferred as a matrix can be listed as having high mechanical properties, chemical and abrasion resistance, and electrical properties. In addition, other types of materials can be added to eliminate the problems that will arise due to the low resistance to crack propagation in epoxy resins, i.e. being a brittle material. These materials are polymers, inorganic fillers, reactive diluents, and similar materials. Another reason why epoxy resins are preferred is that they can be used with any type of filler or reinforcement [5-8].

Epoxy resin (ER) is one of the most important thermoset polymers widely used in high-performance composite materials due to its excellent mechanical and chemical properties such as high tensile and compressive strength, good chemical resistance and high heat distortion temperature. Epoxy resins are polyether resins and contain more than one epoxy group that can be converted into thermoset form. They are formed by epichlorohydrin and then dehydro halogenation reactions of compounds containing active hydrogen. Epoxy resin, which is the most widely used among thermosets, is preferred because it has excellent chemical and mechanical properties, low shrinkage and good adhesion to most fibers [6-9].

Epoxy resins are linear oligomer compounds. Therefore, their physical properties are weak. However, with the help of hardeners and catalysts added to their structures, they transform into a structure containing many cross-links. Cross-linked resins have now formed a thermoset polymeric material and have gained high mechanical properties, high chemical resistance and abrasion resistance. Epoxies are the most preferred polymer matrices despite being more expensive than many polymer matrices. The reasons for this are; Good tensile and impact strength, Resistant to abrasion, Hardenable at room temperature, High physical and mechanical efficiency in high temperature applications, Low viscosity and flow rates, Good electrical and chemical resistance [7-11]

Palm Trees are woody shrubs, called vines or trees. The trunk is cylindrical or vine-like, short or long, unbranched, sometimes dichotomous. The leaves are usually clustered at the top or vine-like and in some woody species alternate, petiolate, palmate or pinnate, very rarely simple [43]. In some species the leaf length can be up to 12 m. The flowers are small, radially symmetrical, hermaphroditic or rarely unisexual, showing rich branching. The fruit is a bacillus or drupe. It is rich in sugar, oil and fiber. Some species show a rich content of fiber. The length of the tree can reach from a few centimeters to 30 m. However, unlike other tree species, it does not have age rings on its trunk.

Palm trees are tree-like angiosperms that give the appearance of a crown with their leaves. Although they generally consist of a single trunk, it is sometimes possible to observe species without trunks. In some cases, the shoots on the sides of the trunk cause these species to have multiple trunks. The length of palm leaves can reach up to 18 m. Approximately 100 raffia fibers can be obtained from a palm branch. These fibers are obtained from mature palm leaves. The water-containing layer on the outer part of the leaf, that is, on the surface, is peeled off and dried, allowing access to the inner part containing the fiber. Dyeing can be done according to the area of use [12-16].

These palm fibers, whose mechanical properties are prominent, have been frequently used as reinforcement elements in composite material production in recent years; trunk, leaf, fruit and shell parts. The reason for this is that they are mechanically very elastic and durable. They are increasingly common as a composite reinforcement unit. These studies have been an approach that has increased the importance and cultivation of palm trees. It has also led to the conclusion that these palm fibers, which were previously studied, can be used as an alternative to cellulose-based fibers. Palm plant fibers have a very important place in the world in terms of economy and usage areas. Almost every part of the plant has found a use in human life in different ways. This plant, which is used in a wide range from the simplest to the most complex areas, is used in food, construction materials, daily life items such as bags, hats, walking sticks, baskets, furniture, and especially in the food sector in the production of oil and sugar. Yarn and fiber are obtained [17-20]]

In some palm species, the fibrous part of the trunk contains starch in the form of pure carbohydrates. This starch is preferred as food by some groups. Again, in some palm species, sugar is obtained from the glucose-rich liquid that is released by making a cut on the trunk, or beverages are obtained by using this liquid. The ivy trunks of different types of palms are called rats. Coffee tables, knitted chairs, cabinets and other household items obtained from bamboo trees are also obtained from these species. There are also some palm species whose growth tips or young shoots are edible. These foods are called palm heart or palm salad. The fruits of palms, especially dates and coconuts, are of great commercial importance. Palm oils, which are also used in chocolate production, have a very high percentage of use.

In this study, it is aimed to investigate the mechanical properties of palm fiber-added epoxy composites, which are defined as waste depending on the developing trend of the aviation industry. Natural raw materials and wastes (palm tree fiber) in different mass ratios were ground in different sizes and added to the matrix material epoxy. The physical and chemical characterization of easy-to-produce and low-cost eco-composites was performed and their usability in the aviation industry was investigated [8-22].

2. MATERIAL AND METHOD

The simplest method in the production of fiber-reinforced composites is the hand lay-up method. In this method, the fiber is placed on or in a prepared mold and the resin that forms the matrix is wetted with a brush. This process continues until the desired thickness is achieved and a multi-layered material is formed. The air remaining in the resin is removed with the help of a roller.

Production steps of the hand lay-up method;

- The most suitable ambient temperature for production should be a minimum of 10ºC. If the temperature is below these values, the amount of catalyst or hardener should be increased or the additive used should be added.
- If the temperature is 5^{o}C or lower, the manual laying process should be started when the ambient conditions are met.
- The ambient air should not be humid. Production should not be carried out in humid environments as much as possible.
- The surface of the mold into which the resin will be poured must be free of impurities that may affect the casting, such as traces, dust or oil, and if the mold has been previously cast, any mold release agent residue must also be cleaned.
- The first mold to be used should be polished three times at 6-8 hour intervals and once for subsequent applications. The mold is cleaned and then wax is applied as the first mold release agent. The mold release agent is left to dry so that the product does not stick to the mold.
- Then, polyvinyl alcohol (PVA) is applied as a second mold release agent.
- High fluidity gelcoat is applied to the mold with a brush in a thin layer in a single direction.
- Fiber material to be used as reinforcement element is prepared. Although glass fiber is the most preferred reinforcement material, aramid and carbon fibers can also be preferred as reinforcement material.
- In the hand lay-up method, polyester and vinylester resins that can harden at room temperature are used as resins, along with epoxies.
- If there is no accelerator additive in the resin, the accelerator is added at the specified rates until there are no air bubbles left in the resin and the air bubbles are removed.
- After applying resin on the mold release agent with a brush, fiber in the form of felt or fabric is placed and the resin is thoroughly absorbed with the help of a brush.

- Air bubbles are eliminated by passing over it with a roller.
- After the specified thickness is reached and the part hardens, it is removed from the mold. Since deformations will occur in the product removed from the mold without applying heat treatment, the product must be dried thoroughly and waited long enough before being removed from the mold.

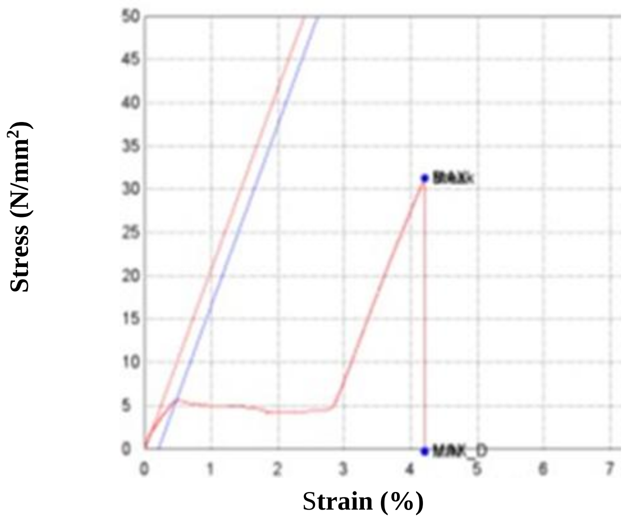
In this study, the grinding process was carried out in the ‘’IKA’’ M20 brand and model grinding device. The Ika M20 universal grinder allows grinding of hard and brittle samples up to a maximum volume of 250 mL at 20,000 rpm. In the experimental study, weighings were made with a ‘’G&G JJ224BC’’ brand and model 220 g capacity and 0.0001 g precision balance. Palm fiber to be used as reinforcement material in the production of composite materials was supplied from various places. The obtained products were first subjected to the cleaning process. The cleaned materials were then ground and passed through a 500 µm sieve to use under-sieve products and the over-sieve products were ground again and the same process was repeated. In the production of composite materials, ‘’Armor chemical AC520’’ brand and model epoxy with 16 °C curing temperature, 100 °C burning temperature, casting type ultra-transparent properties was used.

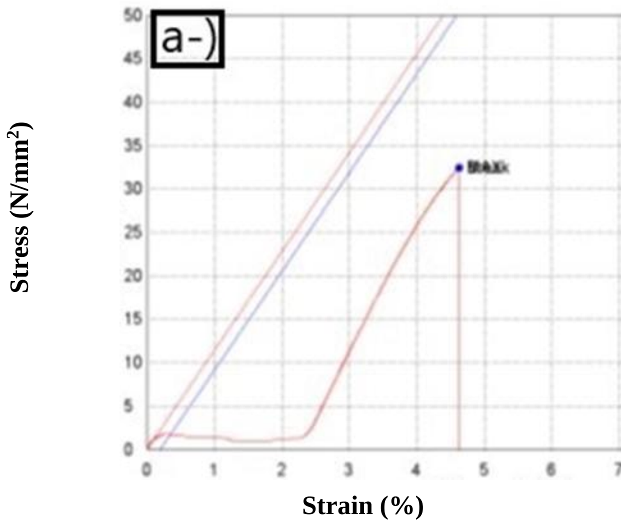
For the tensile sample, mold samples were provided according to the "TS EN ISO 527-2" standards with a distance of 75 mm between the jaws and 4 mm thickness. "Front RTV2" brand mold silicone was used to obtain the tensile molds. The tensile samples fixed on a flat mold were poured with mold silicone at room temperature and left to dry for 24 hours, then the mold and silicone were separated and the molds of the tensile samples were obtained.

In the study, the products to be used as reinforcement materials were first cleaned with pure water and left to dry. The dried materials were passed through a grinder with a speed of 20,000 rpm, then passed through a 500 µm sieve and the products under the sieve were separated for use. Epoxy was weighed on a precision scale as 2.5 gr and hardener as 1.25 gr. The product to be used as reinforcement material was added after the epoxy. After the reinforcement material, the hardener resin was added and mixed until a homogeneous mixture was obtained. After the mixing process, the product obtained was poured onto a preheated mold, heated to prevent the formation of air bubbles inside and waited for 24 hours for the curing to be completed. The tensile sample obtained was poured as 1%, 5% and 10% by weight for each reinforcement material.

3. RESULTS AND DISCUSSIONS

Tensile test, which is widely used in the investigation of mechanical behavior of the material, can be applied on many materials including metals, plastics, composites, films, elastomers, rubber and fabrics. The tensile sample fixed to the jaws of the machine is subjected to a certain load with the help of the integrated computer and graphic data is obtained as a result of the changes observed in the material. It provides important information such as the percentage elongation of the material, maximum tensile strength, elasticity modulus. The composite tensile samples produced were analyzed with the 'SHIMADZU AG-XD' brand and model tensile testing device.





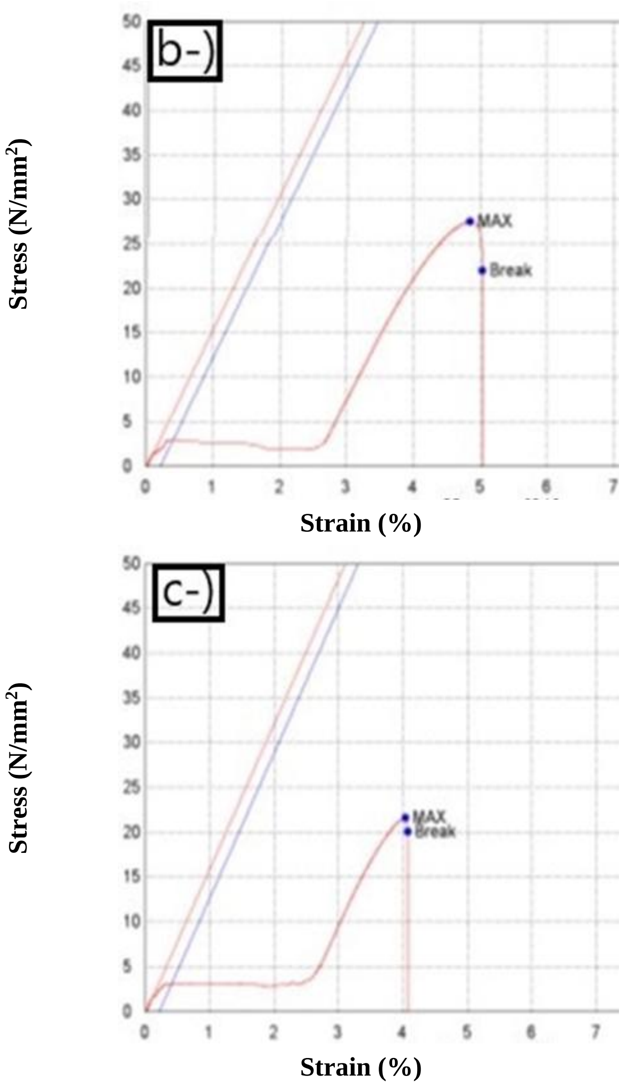


Figure 1 Stress-strain graphs of 1% b-) 5% c-) 10% palm fiber reinforced composites

The Stress-Elongation graph of eco composite samples prepared by adding pure epoxy resin and palm fiber is shown in Figure 1. While the tensile strength of the pure epoxy sample was determined as 31.2460 MPa, the percentage elongation amount was 4.2093% and the elasticity modulus was 2087.24 MPa, the tensile strength of the sample containing 1% palm fiber reinforcement by mass was determined as 32.4790 MPa and the percentage elongation amount was determined as 4.6247%. By reinforcing 1% palm fibers by mass to the samples, the tensile strength and elongation amount of the sample increased positively compared to pure epoxy. According to the graph, the tensile strength was 27.4849 MPa, the percentage elongation value was 4.8412%. When compared to the pure epoxy and 1% palm fiber reinforced composite samples, the tensile strength decreased with the increase in the amount of reinforcement, while a small increase in the percentage elongation amount was observed. According to the Stress-Elongation Graph of the composite sample reinforced with 10% palm fiber by mass, the tensile strength was 21.6202 MPa and the percent elongation value was 4.0355%. When compared with pure epoxy, 1% and 5% palm fiber reinforced composite samples, the tensile strength and percent elongation of the sample decreased with the increase in the amount of reinforcement.

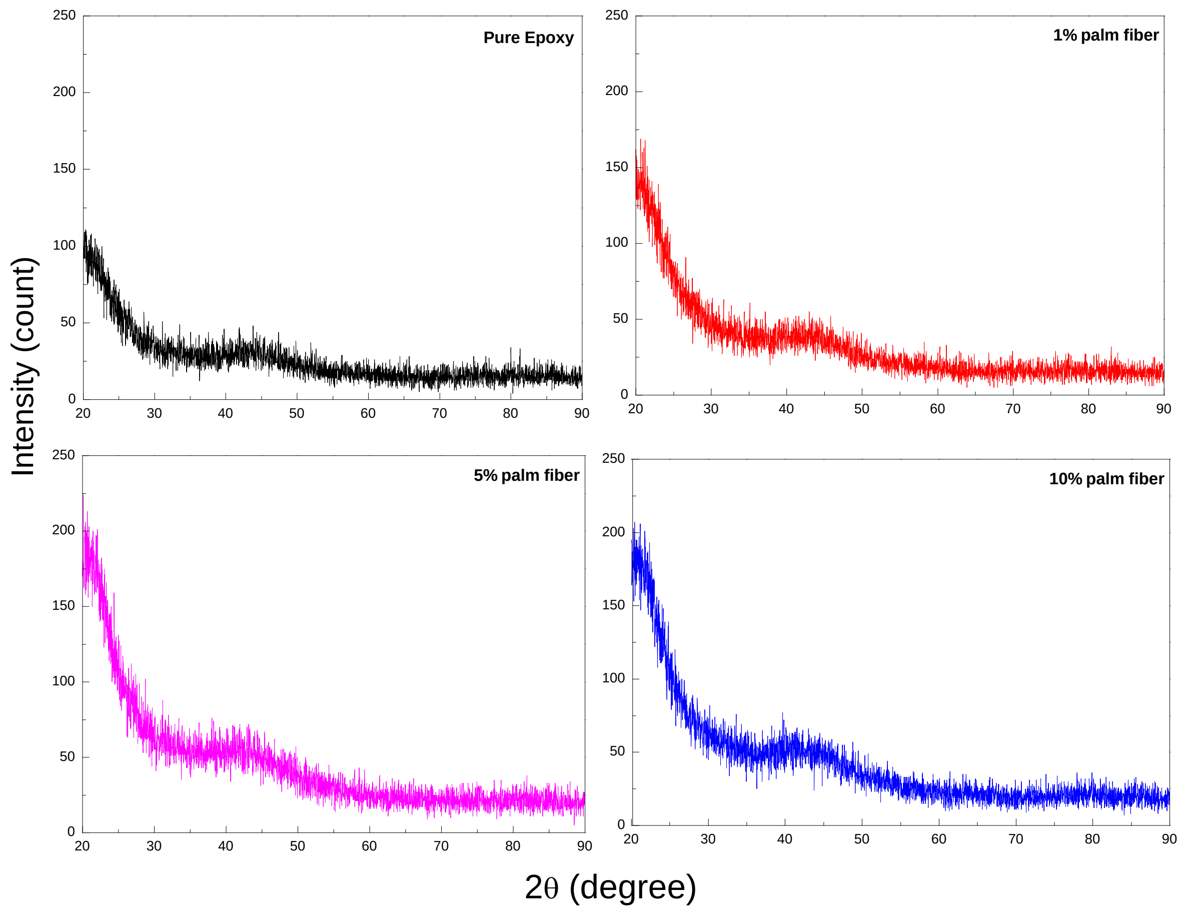


Figure 2 XRD spectra of palm fiber reinforced epoxy eco composites

The XRD results of pure epoxy resin and palm fiber reinforced eco composites are shown in Figure 2. The pure epoxy spectrum shows an amorphous peak around 20–2θ° in the diffractogram, which is quite similar to that reported by other researchers. Considering the XRD spectra; it is stated that the peak observed in palm fiber reinforced epoxy samples belongs to cellulose, which is one of the most important components of the cell wall structure of green plants. In order to examine the stages of the samples, powder XRD measurements were carried out and the XRD patterns of palm fiber/epoxy composite materials are shown in the figures. According to the literature, the peak of 22° around 2θ, which is clearly observed in the figure, is an evidence of cellulose, which is the main component of palm treefibers.

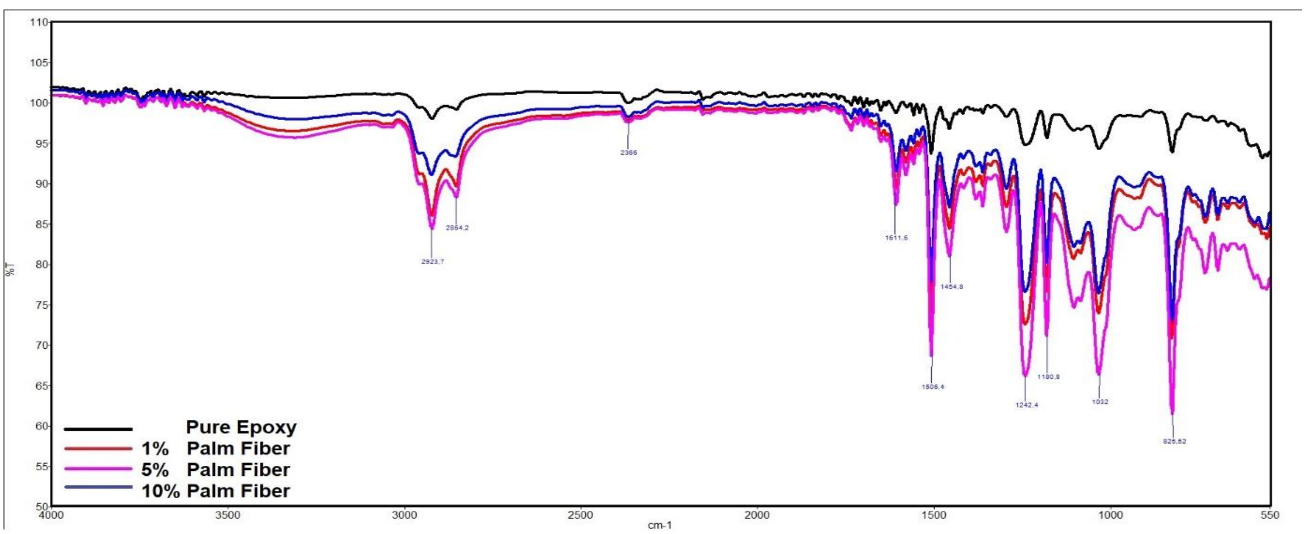
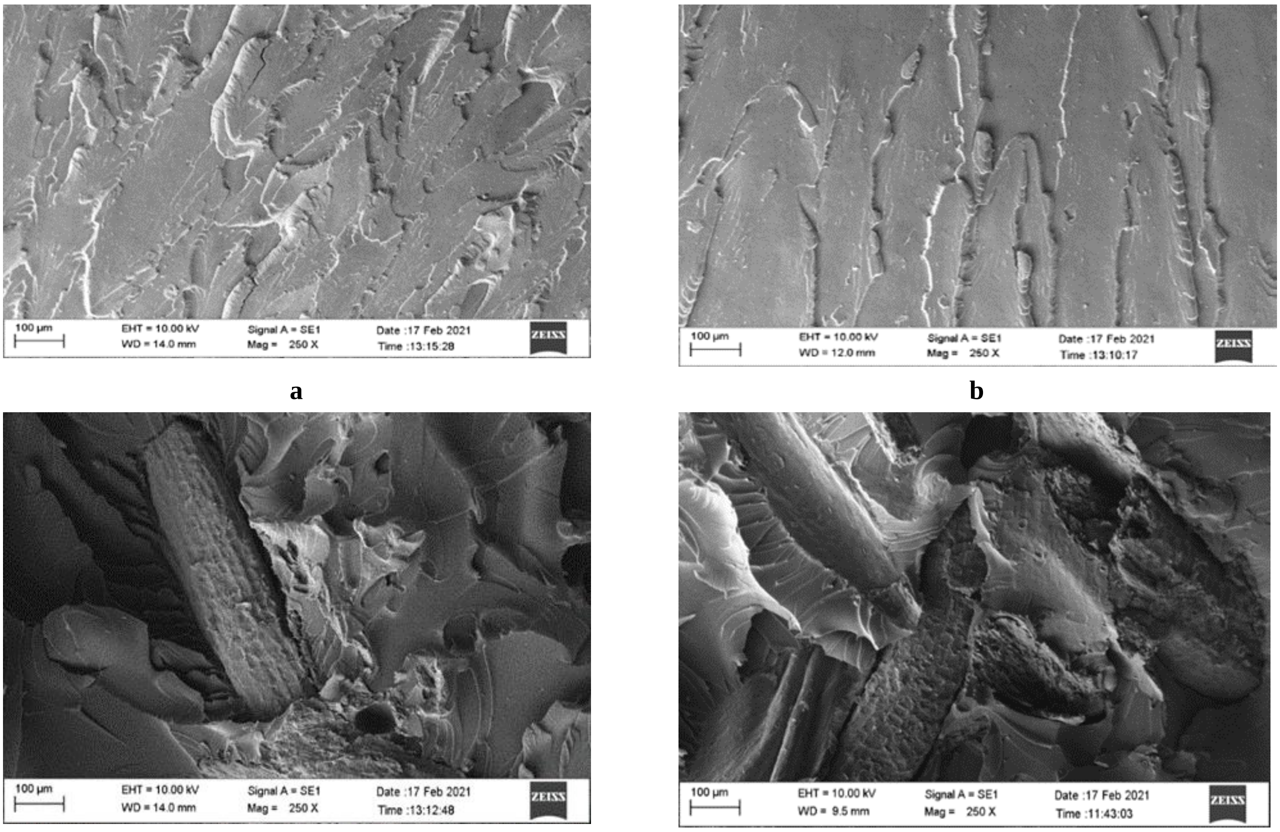


Figure 3 FTIR graphs of pure epoxy, 1%, 5%, 10% Palm fiber reinforced epoxy composites

FTIR spectrometry of palm fiber reinforced and pure epoxy composites with different mass ratios is shown in Figure 3. When the graph is examined, it is seen that there are C-OH stretching vibrations of cellulose originating from palm fibers. The O-H bond frequency value was observed as 2916.83 cm-1. The C=O bond frequency value was determined as 1717.81 cm-1. It is seen that permeability increases as the amount of palm fiber increases. Epoxy resin was used while creating composite structures. The characteristic peaks in the composite structures originate from the C-H bonds in the structure. The peaks at 1800-1650 cm-1 observed in the composite samples originate from the C=O groups.



a b c d

Figure 4 SEM micrographs of a-) Pure epoxy, b-)1%, c-)5%, d-)10% Palm fiber reinforced epoxy composites

SEM analysis is the analysis to determine the particle distribution and modifications in the morphology of the polymer matrix only with the addition of filler. The figure shows the SEM images of the tensile fracture samples of epoxy composites. The micrograph of the epoxy composites presented a smooth and glassy outer surface with numerous wavy or flow-like cracks, revealing its brittle plastic structure with poor resistance to fracture or tear and propagation. Therefore, relatively less energy is required during tensile fracture of epoxy composites. The SEM micrographs of 1%, 5% and 10% palm fiber/epoxy composites are shown in the images. It is clearly seen from the micrographs that the SEM morphology of epoxy composites containing 5% and 10% palm is similar to each other but relatively different from the pure epoxy composites. The inclusion of palm reinforcements makes the fractured surface more irregular and rough, indicating the relatively less brittle and ductile nature of the epoxy matrix. In this, the homogeneously distributed palm filler acts as a barrier to crack initiation and hence crack deflection mechanism and subsequently to the late rupture of the composite samples. Comparative SEM images showed that there is good interfacial adhesion between cellulosic palm and the polymer matrix. From the SEM image of the pure epoxy resin, the presence of regular crack-shaped stripes in its structure indicates that the structure is brittle. However, it was observed that these stripes completely disappeared with the addition of palm reinforcements into the epoxy. This situation can be explained by the fact that palm reinforcements are connected to the epoxy matrix with good adhesion forces. In all three types of composites, a more homogeneous distribution was observed in the structure up to the filler ratio. Accordingly, it was observed that the mechanical properties of the composites such as elongation at break and hardness were improved.

4. DISCUSSION

In this study, epoxy resin and palm fiber as additive were used to produce eco composites with natural raw materials and waste reinforcement. First, these natural materials were ground to different grain sizes. Then, they were turned into composites with epoxy and structural (physical and chemical) properties of these composites were determined by performing tensile, XRD, SEM, FT-IR analyses. The results related to all determined properties are listed below. For this purpose, it was aimed to compare the mechanical and physical properties of composite samples. The samples were subjected to tensile tests and their physical and chemical properties such as maximum stress and percentage elongation values, microstructures, bond structures were compared. It has been observed that the tensile strength of the samples reinforced with palm fiber increases as the additive ratio increases. Although these composite materials obtained have lower strength compared to other composites, when evaluated as waste and natural raw materials, a less costly and less harmful material will be produced in applications requiring lower tensile strength. It has been observed that the functionalization process increases the surface bonding property in natural fiber reinforced composite materials. For this reason, considering the costs of commonly used composite materials according to the desired feature in the place of use, it has been seen that natural fiber reinforced composites can be used instead. It has been predicted that different results can be obtained by using composite combinations with different ratios of reinforcement material and matrix material and by changing parameters such as mixing homogeneous structure. Test results also show that natural fiber reinforced composite materials can be preferred to classically used composite materials depending on the place of use. Especially considering the increasing waste and the high amount of natural raw materials, research and development studies should be carried out on low-cost, environmentally friendly and recyclable composite materials and they should be brought into industrial use.

REFERENCES

[1] Mustaţă, F., & Cascaval, C. N. (1997). Rheological and thermal behaviour of an epoxy resin modified with reactive diluents. Journal of polymer engineering, 17(6), 491-506.
[2] Mustata, F., Cascaval, CN. and Bicu, I. (1995). Viscosimetric investigation of plasticized epoxy resin. Polymer Plast Technol Eng, 34,461–73.
[3] Mustatâ, F., & Bicu, I. (1998). Plastified epoxy resins modified by hydrophilic and hydrophobic silica. Polymer–Plastics Technology and Engineering, 37(2), 127-140.
[4] Munz, M., Sturm, H., & Stark, W. (2005). Mechanical gradient interphase by interdiffusion and antiplasticisation effect—study of an epoxy/thermoplastic system. Polymer, 46(21), 9097-9112.
[5] Sánchez-Cabezudo, M., Prolongo, M., Salom, C., & Masegosa, R. (2006). Cure kinetics of epoxy resin and thermoplastic polymer. Journal of thermal analysis and calorimetry, 86(3), 699-705.
[6] Prolongo, MG., Arribas, C., Salom, C. and Masegosa, RM. (2007). Phase separation, cure kinetics, and morphology of epoxy/poly(vinyl acetate)blends. J Appl Polym Sci. 103, 1507–16.
[7] Nakamura, Y., Yamaguchi, M., Okubo, M.and Matsumoto, T. (1992). Effects of particle size on mechanical and impact properties of epoxy resin filled with spherical silica. J Appl Polym Sci. 45:1281–9.
[8] Francis, B., Thomas, S., Jose, J., Ramaswamy, R., Lakshmana Rao ,V. (2005). Hydroxyl terminated poly(ether ether ketone) with pendent methyl group toughened epoxy resin miscibility, morphology and mechanical properties. Polymer 46: s.12372–85.
[9] Iijima, T., Fujimoto, K-I. and Tomoi, M. (2002). Toughening of cycloaliphatic epoxy resins by poly(ethylene phthalate) and related copolyesters. J Appl Polym Sci 84: s.388–99.
[10] Sudhakara P, Kannan P. (2009). Diglycidylphenylphosphate based fire retard liquid crystalline thermosetts. Polym Degrad Stabil 94: s.1–7.
[11] Anwar, Z., Kausar, A., Rafique, I. ve Muhammad, B. (2015). Advances inepoxy/graphene nanoplatelet composite with enhanced physical properties: areview, Polymer-Plastics Technology and Engineering, 55, s.643-662.
[12] Kaw, A. K. ve Willenbring, G. (1997). A software tool for mechanics of composite materials,International Journal of Engineering Education, 13 (6), s. 433-441.
[13] Chou, T., and Kelly, A. (1980). "Mechanical properties of composites," Annu. Rev. Mater. Sci., 10 (1), s. 229-259.
[14] Boynard, C. A. ve Almeida, J. R. (2010). Morphological characterization and mechanical behavior of sponge gourd (luffa cylindrica) - polyester composite materials. Polymer-PlasticsTechnology and Engineering, 39 (3), s.489-499.
[15] Sinnott, E. W. ve Bloch, R. (1943). Development of the fibrous net in the fruit of various races of luffa cylindrica. Botanical Gazette, 105 (1), s.90-99.
[**16]** Oladoja, N. A., Aboluwoye, C. O., ve Akinkugbe, A. O. (2009). Evaluation of loofah as asorbent in the decolorization of basic dye contaminated aqueous system. Industrial &Engineering Chemistry Research, 48 (6), s.2786–2794.
[17] Bal, K.E., Bal, Y. and Lallam, A. (2004). Gross morphology and absorption capacity of cellfibers from the fibrous vascular system of Loofah (Luffa cylindrica). Textile Res J 74: s. 241-247.
[18] Ogbonna, J. C., Liu, Y. C., Liu, Y. K., and Tanaka, H., (1994). Loofa (Luffa cylindrica) Sponge as a Carrier for Microbial Cell Immobilization, J. Ferment. Bioeng. 78(6), s. 437-442.

[19] Slokoska, L. S., and Angelova, M. B., (1998). Immobilization of Polymethylgalacturonase Producing Aspergillus niger on Luffa Sponge Material. Z. Naturforsc. 53c, s. 968-972.

[20] Boyard, C. A., and D'almeida, J. R. M., (1999).Water Absorption by Sponge Gourd (Luffa cylindrica)/Polyester Composite Materials, J. Mat. Sci. Lett. 18, s. 1789-1791.

[21] Italo, O. Mazali and Oswaldo l. Alves. (2005).Morphosynthesis: high fidelity inorganic replica of the fibrous network of loofa sponge (Luffa cylindrica), Anais da Academia Brasileira de Ciências (2005) 77(1): s. 25-31.

[22] Potluri, P. and Thammandra, V.S. (2007). Influence of uniaxial and biaxial tension on mesoscale geometry and strain fields in a woven composite.Composite Structures, 77(3), s.405-418

.