# INVESTIGATION OF MECHANICAL AND TRIBOLOGICAL BEHAVIORS OF CARBON/GLASS FIBER REINFORCED HYBRID EPOXY COMPOSITES

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# INVESTIGATION OF MECHANICAL AND TRIBOLOGICAL BEHAVIORS OF CARBON/GLASS FIBER REINFORCED HYBRID EPOXY COMPOSITES

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*"I declare that all the information within this thesis has been gathered and presented in accordance with academic regulations and ethical principles and I have according to the requirements of these regulations and principles cited all those which do not originate in this work as well."*

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## ABSTRACT

**M. Sc. Thesis**

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This study aims to comparatively examine the mechanical and tribological behavior of short carbon fiber (SCF) and short glass fiber (SGF) hybrid epoxy composites. Here, hybrid composites with two different amounts (5% by weight and 10% by weight) SGF and SCF reinforced, as a single layer, were produced by the hand lay-up production method. In addition, only glass or carbon fiber reinforced composites were produced in the same proportions to compare with the hybrid composites produced. 3-point bending tests were performed to investigate the flexural strength from the mechanical properties of composites (E5GF, E10GF, E5CF and E10CF) and hybrid composites (E5GCF and E10GCF). Izod impact measurements were made to determine the impact absorption behavior of the samples. The wear tests of the samples were evaluated under 10 and 20N loads. In addition, the examination of the broken and worn surfaces of the samples after the bending test was analyzed by scanning electron microscopy. According to test results, hybrid composites have approximately 26% and 23% better flexural strength and 23% better impact absorbability than glass fiber reinforced composites, respectively. However, only 10% by weight carbon reinforced composites showed the lowest removal rate and smooth worn surface among all samples. For this reason, hybrid epoxy composites may be preferred for structural applications, but for applications where wear is important, it is advantageous to reinforcing epoxy matrix composites only with carbon fiber.

**Keywords** **:** Short carbon fiber, short glass fiber, composite materials, mechanical properties, tribological properties

**Science Code** **:** 91417

# ÖZET

**Yüksek Lisans Tezi**

**KARBON/CAM ELYAF TAKVİYELİ HİBRİT EPOKSİ KOMPOZİTLERİN MEKANİK VE TRİBOLOJİK DAVRANIŞLARININ İNCELENMESİ**

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Yapılan bu çalışma, kısa karbon elyaf (SCF) ve kısa cam elyaf (SGF) takviyeli hibrit epoksi kompozitlerin mekanik ve tribolojik davranışlarını karşılaştırmalı olarak incelemeyi amaçlamaktadır. Burada, el yatırması yöntemi ile iki değişik miktarda (ağırlıkça %5 ve ağırlıkça %10) SGF ve SCF takviye edilmiş, tek katmanlı olarak hibrit kompozitler üretilmiştir. Ayrıca üretilen hibrit kompozitlerle karşılaştırmak için aynı oranlarda yalnızca cam veya karbon elyaf takviyeli kompozitler de üretilmiştir. Kompozitlerin (E5GF, E10GF, E5CF ve E10CF) ve hibrit kompozitlerin (E5GCF ve E10GCF) mekanik özelliklerinden eğilme mukavemetini araştırmak için 3 nokta eğme testleri yapılmıştır. Numunelerin darbe sönümleme davranışlarını tespit etmek için İzod darbe ölçümleri yapılmıştır. Numunelerin aşınma deneyleri, 10 ve 20N yük altında değerlendirilmiştir. Ayrıca numunelerin eğme testi sonrası kırık ve aşınmış yüzeylerinin incelenmesi taramalı elektron mikroskobu ile analiz edilmiştir. Test sonuçlarına baktığımızda, hibrit kompozitler, cam elyaf takviyeli kompozitlere oranla sırasıyla yaklaşık %26 ve %23 daha iyi eğilme mukavemeti ve %23 daha iyi darbe sönümleme kabiliyetine sahiptir. Bununla birlikte, sadece ağırlıkça %10 karbon takviyeli kompozitler, tüm numuneler içinde en düşük alınma oranı ve pürüzsüz aşınmış yüzeyi göstermiştir. Bu sebeple, yapısal uygulamalar için hibrit epoksi kompozitler tercih edilebilecektir, ancak aşınmanın önemli olduğu uygulamalar için epoksi matrisli kompozitlerin yalnızca karbon fiber ile güçlendirilmesi avantajlı olmaktadır.

**Anahtar Sözcükler** **:** Kısa karbon elyafı, kısa cam elyafı, kompozit malzemeler, mekanik özellikler, tribolojik özellikler

**Bilim Kodu** **:** 91417

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## SYMBOLS AND ABBREVITIONS INDEX

### SYMBOLS

a : wear width of sample

Al : aluminum

b : wear depth of sample

c : stroke

Cu : copper

Mg : magnesium

Mo : molybdenum

Si : silicon

wt : weight

### ABBREVITIONS

ASTM : American Society for Testing and Materials

PE : Polyethylene

PP : Polypropylene

PS : Polystyrene

PU : Polyurethane

RTM : Resin Transfer Method

SEM : Scanning Electron Microscobe

# PART 1

# INTRODUCTION

Composite materials: They are materials created by combining the best properties of the same or different groups of materials in a new and single material at a macro-level. Composite material is basically a material system consisting of a mixture or combination of two or more components that are insoluble in each other and have different shapes and/or material compositions. Composite materials are obtained by physically combining these materials under certain conditions and at a certain rate to obtain a certain feature from at least two separate materials that are not used directly for the desired purpose. A composite material generally consists of a resin or metallic matrix main phase with low modulus and strength and a reinforcement element with a less common secondary phase dispersed therein. However, materials that are combined at the molecular and atomic level are not classified as composite materials because alloys are microscopically homogeneous [1].

Polymer matrix composites have a wide application area in many industries such as aviation, especially in the automobile industry [2]. In recent years, great developments have been observed in the use of fiber-reinforced polymer matrix composites such as polyurethane, epoxy, vinyl ester and polyester [3]. Among them, epoxy resins are the most widely used polymer type due to their superior adhesion abilities, low viscosities, dimensional stability and corrosive abilities [4–6]. In addition, the mechanical properties of this polymer matrix, such as strength and toughness, are some disadvantages that limit its wide range of uses. For this reason, it is inevitable to add fibers to the epoxy matrix to improve its mechanical and tribological properties [6].

Fibrous composites are formed by placing thin fibers significantly longer than the cross-sectional diameter in a matrix structure. In these composites, the fibers can be placed in the structure continuously, discontinuously (short), randomly or in a certain order [7]. In conditions where maximum strength and rigidity are not the main parameters, short fiber composites, which are easier and more economical to produce, can be produced. In these composites, the short fibers are homogeneously distributed in the matrix material. In industrial use, the majority of composite materials are formed with glass, carbon, kevlar fibers and thermoset, thermoplastic polymeric matrices [7,8].

Glass fibers are the most widely used and least expensive reinforcement material in composites. Glass fibers generally have a high strength/weight ratio [9]. Thus, as the researchers have shown, glass-reinforced epoxy resins are widely used in construction and military fields. Ozsoy et al. [10] investigated the effects of different contents of chopped E-glass fibers (10%, 20%, and 30%) on the mechanical properties and tribological properties of epoxy composites. It was reported that additions of chopped glass fiber had not increased the bending strength. However, the impact energy starts to increase as the amount of glass fiber reaches 30%. In another study, Yadav et al. [11] investigated the consequences of different contents of short E-glass fiber (0%, 10%, 15%, and 20%) on the mechanical properties of the epoxy composites. It was observed that the flexural strength of composites increases with an increase in fiber loading up to 15 wt.% and then decreases with a further increase of the fiber loading. Furthermore, this study shows that increment in strength enhances the wear resistance behavior of materials, and it was found that epoxy composites with 15 wt.% E-glass fiber loading exhibit minimum specific wear rate among the samples for all the testing conditions. The effect of different volume fractions (40%, 50%, and 60%) addition of glass fibers onto the mechanical properties of the epoxy composite were examined by Swapnil et al. [12]. Test results indicated that better mechanical properties were observed with 50 wt.% glass fiber addition but the further increment in fiber content caused delamination [12].

Alongside glass fibers (GF), carbon fibers (CF) are another type of synthetic fiber used for reinforcing epoxy-polymer composites. Although glass fiber is the most widely used and valid reinforcement material today, pure carbon fiber is generally used in advanced composite materials [13]. Due to their high specific strength and stiffness, these fibers are extensively applied in various kinds of structural areas [2,14].

Therefore, various academic studies have been carried out to improve the tribological and mechanical properties of CF reinforced epoxy composites CF [15]. Solomon et al. [16] investigated the effect of carbon fiber contents (30% by weight, 35% by weight and 40% by weight) on epoxy matrix composites. The test results have been reported to achieve a maximum strength value with a carbon content of 35% by weight. The tribological properties of short carbon fiber (SCF) reinforced epoxy composites were investigated by Khun et al.[17]. The test results clearly demonstrated that the addition of SCFs was an effective way to improve the tribological properties of epoxy-based composites. In addition, CF reinforced composites have slightly lower impact resistance due to delamination [14]. For this reason, not compromising strength as well as increasing the toughness of epoxy-based composites is very important to expand the application areas. For this reason, researchers are examining the blended effect of glass and carbon fibers by turning to hybrid polymer composites. On the other hand, Soni et al. [18] investigated the mechanical properties of carbon-glass-epoxy hybrid multilayer (laminated) composites. Bending and impact test results of the sample showed maximum results at the addition of 2% by weight carbon fiber. Jesthi and Nayak [19] observed that the flexural strength and modulus of the laminated type hybrid composite increased by 46.1% and 49.5%, respectively, compared to plain glass fiber reinforced polymer composites. In addition to these results, the test results revealed that the laminated hybrid composite had the lowest wear rate of $18.8476 \times 10^{-3}$ $mm^3$ $Nm^{-1}$ among all fabricated specimens.

There are many production methods for composites due to the combination of more than one material. The selection of the material used to determine the production method, production speed, suitability, part costs are important factors [20]. The hand lay method is a simple method that does not require a lot of tools and equipment. In this method, the determining factor of the quality of the composite material is workmanship. Various mold release materials are placed on the mold surface to be used for easy separation of the composite material. Prepared fibers are placed in the mold. Various resins are applied on the placed fibers with the help of a roller. The important thing here is that the resin wets the fiber used well. With this method, which is very low in cost, various boat, cabin, and car parts are obtained [21,22].

To the best of our knowledge, there is not yet any study on the mechanical and tribological behavior of single layer chopped carbon and glass added epoxy composites on hybrid ones. This study examines the mechanical and tribological properties of hybrid epoxy composites reinforced with SGFs and SCFs, which will fill a major gap in the literature.

# PART 2

# COMPOSITE MATERIALS

## 2.1. GENERAL TERMS IN COMPOSITE MATERIALS

Composite materials have taken their samples from nature and have a very long history of use. Although nothing is known about their origin, they have been used since ancient times. The most suitable example for the composite structure found in nature is the pine tree. The trunk of the pine tree shows a composite structure. The wet rings that have occurred in the summer and winter seasons in the body have a concatenated appearance, and the winter rings are hard but brittle, while the summer rings are soft but flexible. Thus, a feature of the pine tree is that it is stronger than trees that do not have a similar structure, such as poplar and beech. The adobe, which is reinforced with straw as a building material in rural areas, is one of the most primitive examples of composite materials [1].

Recently, fiber-reinforced resin composites with high strength/weight and stiffness/weight ratios have found important areas of use in weight-sensitive applications such as aircraft and spacecraft. Until yesterday, boats, yachts and boats made of hair and wood are now being replaced by similar ones made of polyester-glass fiber. Composite materials, which are more advantageous in terms of maintenance and repair, are also preferred because they are light, long-lasting, and fast. Many parts in the manufacturing industry are now made of composite materials [1].

As an example of the features that can be corrected with the use of composite materials; strength, rigidity, corrosion resistance, wear resistance, beauty of appearance, weight, fatigue life, heat insulation, heat resistance, acoustic insulation and ease of manufacture can be counted. However, not all these benefits are available at the same time. In reality, there is no need for all these properties to be controlled and at certain values. Depending on the place of use and its properties, the required properties are increased and controlled, and thus suitable composite materials are obtained in a way that carries the combination of the properties of the matrix and secondary phase used (Figure 2.1) [1].

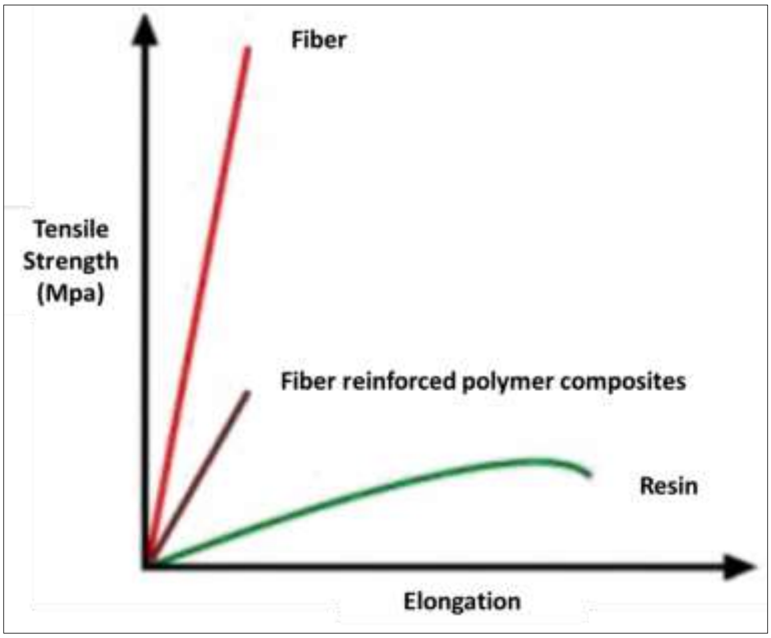


Figure 2.1. Tensile-extension feature developed with composite structure [1].

## 2.2. CLASSIFICATION OF COMPOSITE MATERIALS

A composite material consists of a reinforcing element known as the core and the surrounding matrix material. Composites can be grouped within themselves with different approaches, but the most used one is made according to the type of reinforcement material and matrix shown in Figure 2.2 [1].

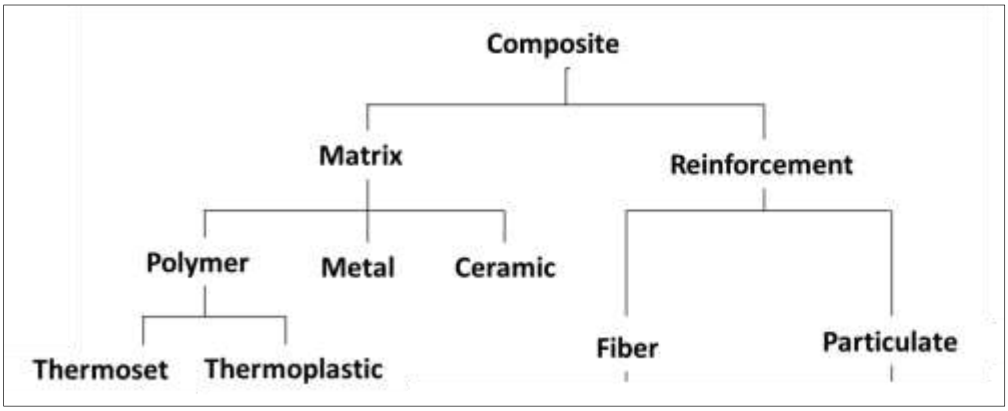


Figure 2.2. Classification of composites [1].

# PART 3

# CLASSIFICATION OF COMPOSITE MATERIALS ACCRODING TO MATRIX TYPE

In composite materials, the matrix is the component that holds the filler together and protects it from external influences. It also determines the shape of the composite material. All loads acting on a composite material are transferred to the filling elements through the matrix. For this reason, the main task of the matrix used in the composite material is to wrap the filling elements and hold them together, and to preserve the settlements arranged so that they can withstand the stress affecting the material at the highest level [23]. Since many filling elements are brittle and brittle, the matrix protects their surfaces from external and environmental influences. According to the matrix type, composite materials are divided into three as metal matrix, ceramic matrix, and polymer matrix [24].

## 3.1. METAL MATRIX COMPOSITES

The new material obtained by processing the filling element with a metallic phase is called metal matrix composite material [25]. Metal matrix composites have high modulus of elasticity, high tensile compressive strength, high wear resistance and resistance to high temperatures. However, besides these advantageous aspects, metallic composites; It has important disadvantages such as high densities, high processing temperature and tendency to corrosion at fiber-metal interfaces. Al and Al/Mg, Al/Si alloys, Cu/Mo, Cu/W alloys, Ti alloys and Zn alloys are used extensively in metal matrices [26]. The first uses of metal matrix composites were the aerospace industry. Metal matrix composite materials are used in the construction of some parts of electronic devices, automobiles, and aircraft due to their resistance to external environment and heat. Figure 3.1 shows an example of aluminum metal matrix composite material reinforced with boron fibers [24].

Figure 3.1. Boron fiber reinforced aluminum space shuttle body [24].

### 3.2. CERAMIC MATRIX COMPOSITES

Ceramic matrix composites are composite materials formed by combining a ceramic matrix with filler. Although ceramics are light and have high thermal properties, they are hard and brittle materials. Due to their high hardness, they are suitable for use as an abrasive. They have high melting temperatures and low thermal and electrical conductivity. Compounds such as $Li_2O_2$, $SiO_2$, $Al_2O_3$, SiC, $Si_3N_4$, $B_4C$ are commonly used in ceramic matrix composites. Ceramic matrix composites can be produced by using one or more of these compounds, which have different structures, according to the purpose. Armor, various military-purpose parts, and space vehicles are the main uses of these products. In Figure 3.2, as an example of ceramic matrix composites, bulletproof glass material with silicon oxide matrix and polycarbonate support is given [24].

Figure 3.2. Polycarbonate backed silicon oxide bulletproof glass [24].

### 3.3. POLYMER MATRIX COMPOSITES

Composite materials obtained by combining polymer matrix composites with polymer and filler as matrix is called polymer matrix composites. Such materials were developed to replace metal parts in spacecraft with other, more durable and lightweight materials. Commercially, the first polymeric composite material named fiberglass was produced in 1940. This polymeric composite is prepared from phenolic resins and melamine resins. This composite is prepared from unsaturated polyester and glass fibers and is a well-known and widely used material today. Polymeric composite materials are used for aviation and military purposes, in the automobile industry, in the construction of sports equipment, in marine vehicles and in space applications. Polymers to be used as a matrix may exhibit thermoplastic or thermoset properties [24].

#### 3.3.1. Thermoplastic Polymers

When heat energy is applied to a polymeric material, there is an increase in the mobility of the polymer chains. This mobility, which initially starts in small parts of the chains, covers large parts of the chains as the temperature increases and spreads to the entire material. In this position the chains will slide over each other and the solid polymer will melt and flow. While shaping polymers, the property of polymer material to become liquid at a certain temperature is utilized. Thus, because of the solidification of the mixture by reducing its temperature, the plastic part is taken out of the mold and offered for use. In some plastics, this solid plastic can be reheated and melted and cooled and solidified when desired. This event, which is completely physical and reversible, can be repeated. This type of plastic is called thermoplastic material, which means that it can be shaped with heat. Thermoplastics are the group that fully meets the word plastic, and the largest share among polymers used in daily life belongs to thermoplastic polymers. Chain structures can be linear or branched. Thermoplastics soften and melt with the effect of heat, they can be reshaped. They dissolve easily in suitable solvents. The most widely used polymers are thermoplastics such as polyethylene (PE), polystyrene (PS) and polyvinylchloride (PVC) [24].

### 3.3.2. Elastomer Polymers

They are polymers with a high degree of formability. Their molecular structure is different from thermoplastics because they form organic compounds such as Cl or C, H, S, F, O. The molecular chains of the elements are slightly cross-linked in certain areas with the unsaturated C [27].

These features give them the ability to shapeshift at high speed. When exposed to mechanical stress, the transverse links begin to open, so that the chains arranged in a completely chaotic manner can be stacked in the direction of elongation and thus have an elongation capacity of up to 1000%. When the applied mechanical force is removed, the material returns to its original state. The most common known example of elastomer is rubber [27].

### 3.3.3. Thermoset Polymers

Thermosets are polymers with dense cross-links between their chains (Figure 3.3). Polymers in this group do not melt when heated. It retains its initial solid state despite the rise in temperature. The bonds in the polymer chain can resist heating up to a certain limit value.

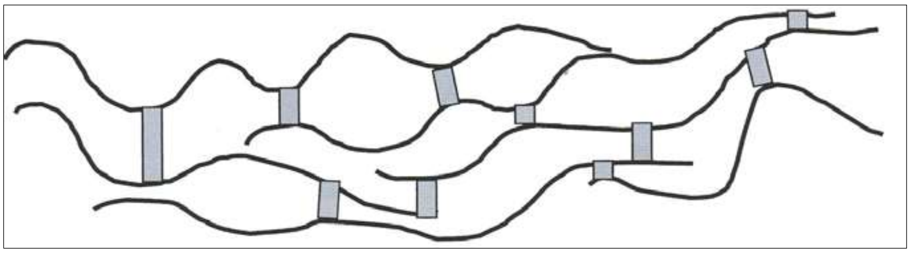

Figure 3.3. Crosslinking of thermoset polymer chains.

When it exceeds that value, the bonds break at high temperatures. Thermoset material decomposes and becomes irreversible. Thermosets cannot be formed by heating and cooling. While obtaining thermoset products, it is reacted in a special mold. In some special cases, such as electrical sockets, a thermoset product is needed. Examples of such polymers that cannot be melted by heating are phenol formaldehyde or urea formaldehyde polymers and cross-linked polyethylene. Phenolic polymers are generally obtained initially in a linear and fluid form. Then, cross-links are formed by the effects of radiation, temperature and sometimes pressure of chemical substances. Figure 3.4 shows the high-speed train, the outer surface of which is covered with epoxy sheet [24].

Figure 3.4. High-speed train, the outer surface of which is covered with epoxy sheet using the prepreg method [24].

#### 3.3.3.1. Polyurethanes

Polyurethanes are a group of polymers formed as a result of an exothermic reaction with many large molecules. The most important advantage of polyurethanes is that it creates an opportunity to control the properties of the product to be obtained, and it reveals its difference from other polymers groups. One of the most important polyurethane composite materials in the industry is fiber reinforced thermoset polyurethane produced by reaction injection method. The reason why this composite is accepted in the automotive industry is that it has high impact resistance in the high temperature range, high thermal expansion, good compatibility with metallic materials, can be colored with standard parts, and the smooth structure of the surface remains stable during the painting phases [27].

#### 3.3.3.2. Polyesters

It is a thermoset that is frequently used in matrix preference in composite production. Some types can be processed at room temperature and high temperature, like epoxy. There are special varieties according to the usage area. They can be modified depending on the properties to be obtained in polyester resins, the molding process used and their compatibility. They are widely used in all areas of the composites industry, as they are versatile and can be replaced when polymer chains are formed. They are less costly materials than epoxies. However, it has disadvantages compared to epoxy, such as poor adhesion and thermal shock resistance, being susceptible to cracking during processing, and varying electrical properties in humid conditions. It is possible to produce polyesters with different physical properties. Composite materials obtained from polyesters are mostly preferred in the production of products such as ship skeletons, pipes, automotive body panels, construction panels [27].

#### 3.3.3.3. Epoxy Resin

Polymers containing epoxide groups shown in Figure 3.5 are called epoxy resins. Epoxy resins form an important group of polyethers. This is due to their polyether structure. It is called epoxy resin because of the presence of epoxide groups in the monomer and prepolymer before curing [24].

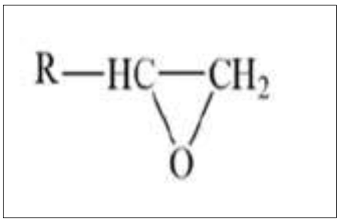


Figure 3.5. Epoxide group [24].

95% of the epoxy resins produced are obtained by the reaction between epichlorohydrin and bisphenol A in basic medium. In this production, epoxy resin is obtained in two stages. In the first step, a low molar mass prepolymer containing epoxide groups at the chain ends is prepared by using excess epichlorohydrin (Figure 3.6) [24].

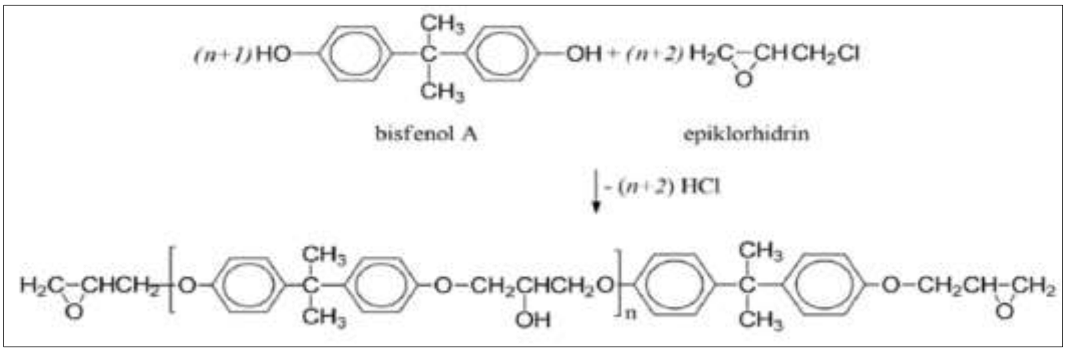


Figure 3.6. Epoxide prepolymer [24].

In the second step, the prepolymer is cured with a suitable crosslinker to obtain a cross-linked epoxy polymer (Figure 3.6). The curing reaction of epoxy resin and hardener containing amine group is given in Figure 3.7 [24].

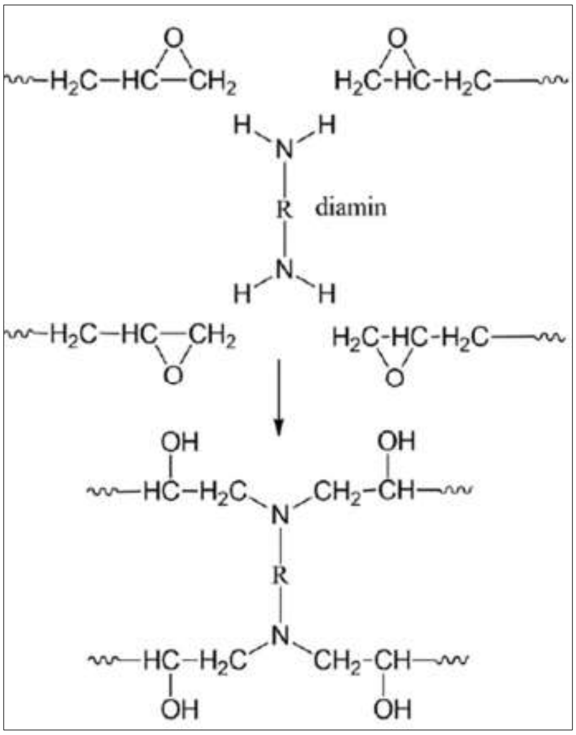


Figure 3.7. Cross-linked epoxy resin [24].

The size of the repeating unit (n) in the prepolymer determines the properties of the polymer to be obtained. If the size of the repeating unit (n) in the prepolymer is small, while the polymer is viscous, when the repeating unit reaches around 25, a solid and hard polymer is obtained at room temperature. Some properties of epoxy resins are as follows:

- They have good water resistance,
- They show very good adhesion to all kinds of surfaces,
- Its resistance to chemicals and solvents is quite high,
- Its hardness, unbreakability and flexibility properties are excellent,
- They provide ease of application of layer upon layer [24].

Epoxy resins with different structures and properties are as follows [28];

- Diglycidyl ether bisphenol A (DGEBA)
- Diglycidyl ether bisphenol F (DGEBF)
- Novalac epoxy (NE) [24].

# PART 4

# CLASSIFICATION OF COMPOSITE MATERIALS ACCRODING TO REINFIRCEMENT TYPE

## 4.1. FIBER REINFORCED COMPOSITES

Fibrous composites are formed by placing thin fibers significantly longer than the cross-sectional diameter in a matrix structure. In these composites, the fibers can be placed in the structure continuously, discontinuously (short), randomly or in a certain order. By placing the continuous fibers parallel to each other, high mechanical properties are obtained in the direction of the fibers, while low mechanical properties are obtained in the direction perpendicular to the fibers. The structure is anisotropic because the fibers are oriented in certain directions. Since the values such as strength and elastic modulus are high in the direction of the fibers, the fibers are placed at an angle to increase these properties in the necessary directions [7].

In conditions where maximum strength and rigidity are not the main parameters, short fiber composites, which are easier and more economical to produce, can be produced. In these composites, the short fibers are homogeneously distributed in the matrix material. In industrial use, the majority of composite materials are formed with glass, carbon, kevlar fibers and thermoset, thermoplastic polymeric matrices [7,8].

### 4.1.1. Glass Fibers

It is obtained by melting together some inorganic materials such as glass, clay, dolomite, kaolin, colemonite, limestone and cooling down without crystallization. Determining the proportions of the materials put into the melting furnace is important for obtaining a good glass composition. The first step in the manufacture of glass fiber is to obtain the continuous fiber. The fiber is obtained by drawing the glass under heat at a certain speed in very fine mesh (0.8–3.2 mm) platinum sieves. Continuous fiber, on the other hand, is composed of individual fibers of infinite length. The thickness of the fiber changes with the drawing speed. After the drawing process, the fiber is covered with a binder and wound on the bobbin. After the bobbins are dried in drying ovens, bundles of different diameters are formed by twisting the fiber bundles or wrapping them together without twisting. These fibers are used for roving without twisting and for yarn making by twisting [9].

Glass fibers are the most widely used and least expensive reinforcement material in composites. Glass fibers generally have a high strength/weight ratio. While the elastic modulus is higher than aluminum alloys, it is lower than graphite and aramid fibers. The internal structures of glass fibers are not amorphous. The stiffness/density ratios of glass fiber reinforced plastics are lower than those of metals. Glass fibers have very high chemical resistance. They do not absorb water. However, their tensile strength decreases in humid conditions. The creep resistance and stiffness of glass fibers decrease with increasing temperature. However, the useful use temperature range is quite large. Glass does not soften up to 500˚C [9].

### 4.1.2. Carbon Fibers

Although glass fiber is the most widely used and valid reinforcement material today, pure carbon fiber is generally used in advanced composite materials. Although carbon fiber is stronger and lighter than glass fiber, its production cost is higher. It is used instead of metals in the skeletons of aircraft and sports vehicles [13].

Carbon fiber was produced for the first time because carbon was known to be a very good conductor of electricity. Since the hardness of glass fiber is very low compared to metal, it was an obvious goal to increase the hardness by 3-5 times. When carbon fibers are subjected to very high heat treatment, the fibers literally become carbonized, and these fibers are called graphite fibers. Today, this difference disappears. Now, carbon fiber and graphite fiber describe the same material. When combined with carbon fiber epoxy matrices, it exhibits exceptional durability and rigidity properties. Since carbon fiber manufacturers work in a continuous development, the types of carbon fibers are constantly changing. Because carbon fiber is very expensive to produce, it is only used in aircraft industry, sports equipment, or high-value applications of medical materials [13]. Carbon fibers are available on the market in 2 forms:

- Continuous Fibers: It is used in weaving, knitting, wire coil applications, unidirectional tapes and pre-resin-impregnated fibers. They can be combined with all resins [13].

- Chopped Fibers: They are generally used in injection molding and pressure molding to make machine parts and chemical valves. The obtained products have excellent corrosion and fatigue resistance as well as high strength and hardness properties [13].

### 4.2. PARTICULATE REINFORCED COMPOSITES

In particulate composites, the reinforcement component, which has approximately the same size in all directions, is contained in a matrix material as particles (Figure 4.1). The shapes of the particles can be spherical, cubic or in different geometries [7].

In these materials, the charge is carried together by the reinforcement and the matrix, and the properties are usually isotropic. Aluminum alloys, hard inserts and concrete materials reinforced with silicon carbide particles are examples of particulate composites [7,29].

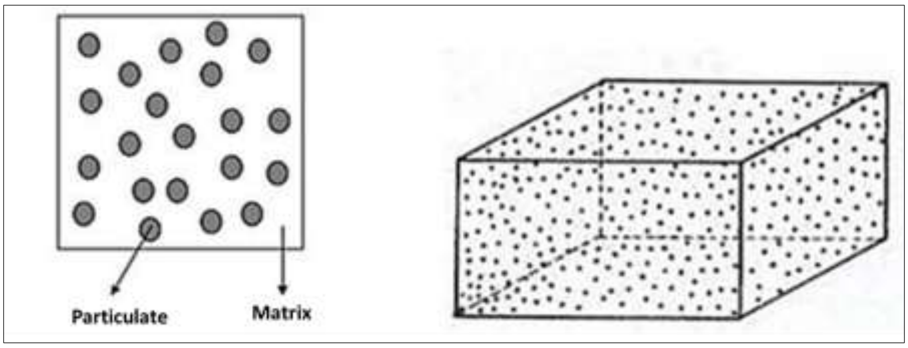


Figure 4.1. Particle reinforced composite [30].

## 4.3. LAYERED COMPOSITES

Layered composite materials are formed by combining layers with different properties by placing them on top of each other in a certain order. Layers can be formed by placing random fibers, unidirectional fibers, or different fibers (hybrid) such as glass and carbon into the matrix [7,29].

It is an example of layered composite in plates produced by combining aluminum alloy and fibrous polymeric composite layers. Fibrous polymeric materials have high fatigue strength, but these materials can easily be damaged by mechanical impacts. Aluminum alloys, on the other hand, have low fatigue resistance and are resistant to low-energy mechanical impacts. By combining 0.2-0.4 mm metal layers with fibrous composite layers, the negative properties of these two different materials are improved. It is also commonly used on aircraft control surfaces [7].

Sandwich structures with high resistance to buckling and bending loads are layered composites. These structures are obtained by bonding resistant plates to the lower and upper surfaces of a porous metallic or polymeric core material in the form of a honeycomb with low density [7,31,32].

## 4.4. HYBRID COMPOSITES

Composites with more than one reinforcing element in the matrix. This type of composite was obtained in order to add additional qualities to composites containing only one type of fiber. With this method, expensive materials such as boron, graphene, and kevlar can be diluted with cheaper fibers such as glass fiber [33]. Obtaining hybrid composites by classifying them in different ways can be in the following ways:

- They contain two or more layers in the matrix. Each layer contains reinforcements in a limited direction, and a designated fiber is embedded in each layer. It is created from layers that are placed according to the final product.

- There is more than one fiber in the layer and these layers are positioned according to the desired shape and size.
- Hybrid composites can be made with various composite structures such as resin matrix layers and metal matrix layers. In hybrid composites, the layers are joined by an adhesive material [27].

# PART 5

# PRODUCTION METHODS OF THERMOSET COMPOSITES

There are many production methods for composites due to the combination of more than one material. The selection of the material used to determine the production method, production speed, suitability, part costs are important factors. [20]. Factors such as temperature and pressure should be considered when producing composite materials. These parameters can be effective in the properties of the produced composites [21].

## 5.1. HAND LAY UP METHOD

The hand lay method is a simple method that does not require a lot of tools and equipment. In this method, the determining factor of the quality of the composite material is workmanship. Various mold release materials are placed on the mold surface to be used for easy separation of the composite material. Prepared fibers are placed in the mold. In general, the product to be produced by using polymeric gel is ensured to have a smooth surface. Various resins are applied on the placed fibers with the help of a roller. The important thing here is that the resin wets the fiber used well. With this method, which is very low in cost, various boat, cabin, and car parts are obtained. Figure 5.1 shows schematically the manual laying method [21,22].

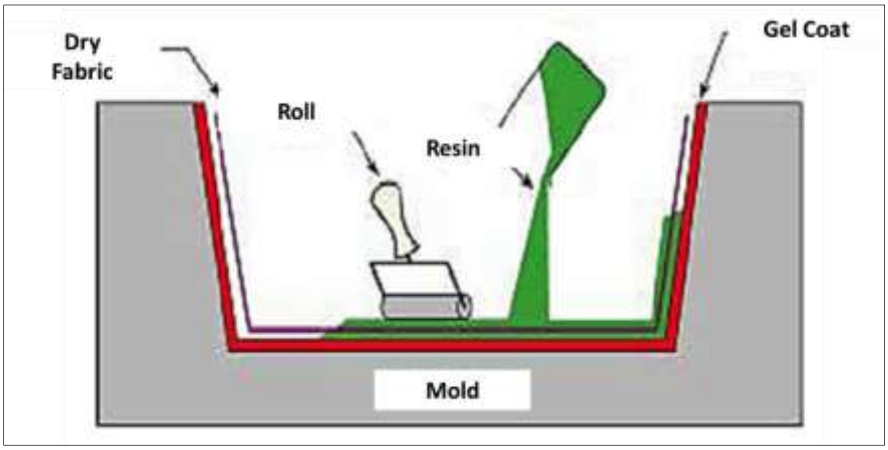


Figure 5.1. Hand layup method [22].

## 5.2. SPRAY UP METHOD

Production with the spray technique is like the production with the manual layering technique, and its application is a simple method. After the surface of the mold is coated with a release agent, a gel coat is applied to the surface and left to harden. The fibers are converted into short fibers with the help of a handgun. The production is carried out by spraying these short fibers mixed with the hardener absorbed from a tank into the mold of the part to be made. After reaching a certain wall thickness, it is left to cook under ambient conditions. While polyester is used as a resin, that is, as a hardener, fibers in the form of bundles are used as a reinforcement element. Advantageous features of this production technique such as low-cost production in a short time, use in complex parts, and ease of application make it preferred. On the other hand, the disadvantages of this production technique are that the composite becomes a heavy structure due to the high amount of resin in the manufactured product, the desired final properties are limited due to the use of short fibers, and the resulting chemical styrene component is harmful to health after a certain limit. This technique is used in simple wall-type structures, in places where no load-bearing operation is performed, in some bathtubs and in the production of caravan body parts [34].

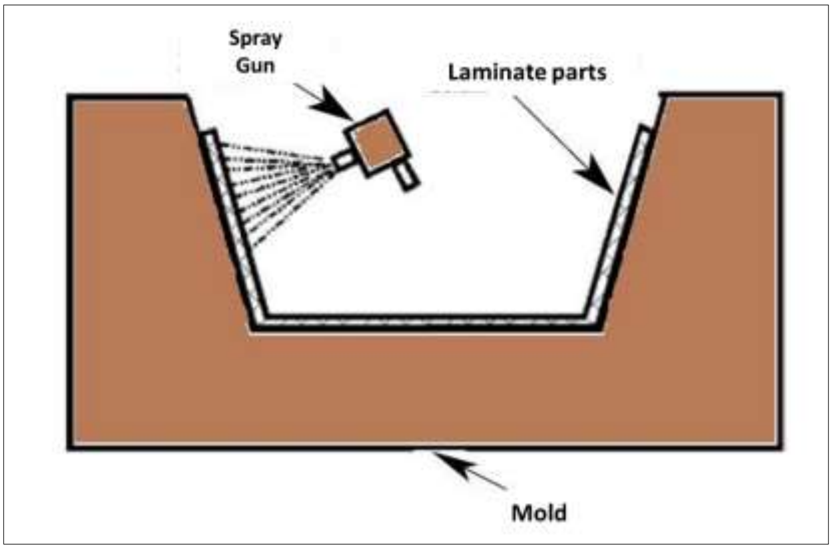


Figure 5.2. Spray molding - production scheme by spraying technique [34].

### 5.3. FILAMENT WINDING METHOD

In the fiber winding method, it is formed by immersing the continuous fiber fibers in a container containing resin and hardener and wrapping them on the mold with the help of a rotating mandrel after soaking. After the wetted resin hardens, the rotating tool is removed, and the composite takes the desired shape. It is important at what angles the continuous fiber fibers are wound in the winding of the fibers into the mold. Because this factor is effective on the mechanical properties of composites. The fiber winding method is shown in Figure 5.3 [21].

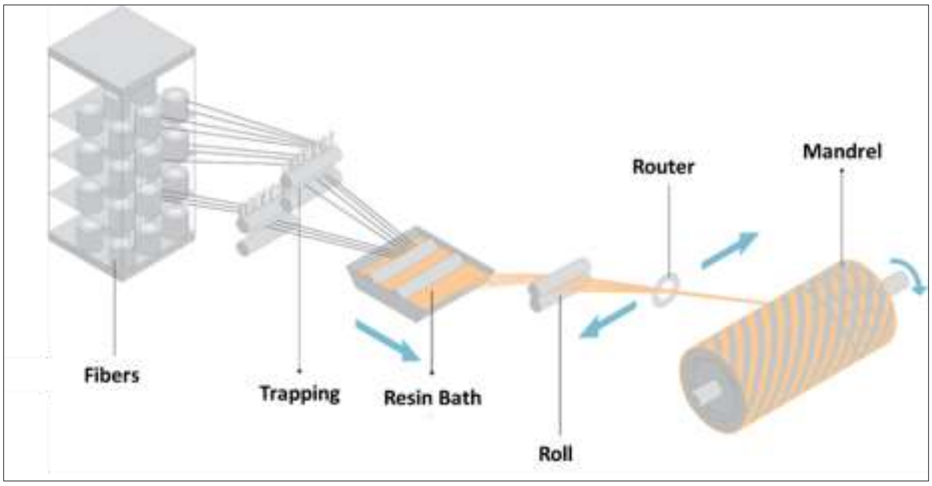


Figure 5.3. Fiber winding method [35].

It is used to mass produce cylindrical shaped materials such as fuel tanks and high-pressure vessels with the Filament Winding method [21].

## 5.4. RESIN TRANSFER METHOD

The resin transfer method is a method used to produce complex shaped composites. Thanks to this method, it is possible to provide a smooth surface on the parts produced. In the method, parts are manufactured by transporting the resin to the reinforcement elements (glass fiber, kevlar, etc.) with the help of vacuum into the closed mold. Figure 5.4 shows the resin transfer method [21].

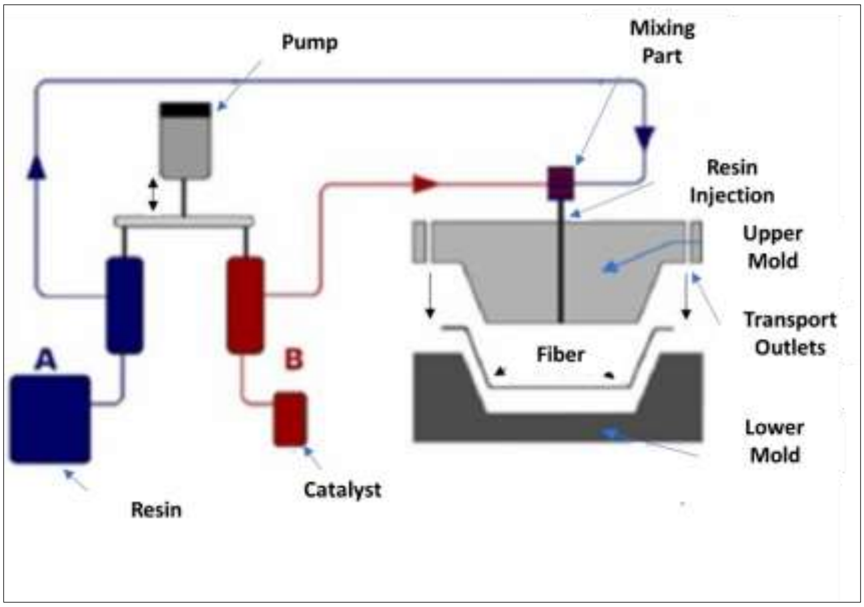


Figure 5.4. RTM method [36].

The excess resin is taken out with the help of a pipe in the system under vacuum. Thanks to the fact that the system is always controlled under vacuum, the rate of air voids in the composite is reduced [37]. After the resin transfer is finished, it is waited for curing. With this method, it is possible to produce complex structures such as aircraft parts [21].

## 5.5. VACUUM INFUSION METHOD

Vacuum infusion method is a production method used in the production of materials in different industrial branches all over the world for the last fifty years. It is a method that works with the principle of advancing the resin and wetting the fiber material in a vacuum environment. Its working principle is similar to the RTM method. Unlike other methods, composite materials with high fiber/matrix ratio are produced. It is ensured that the materials are lighter and longer lasting. The production method is shown in Figure 5.5 [21].

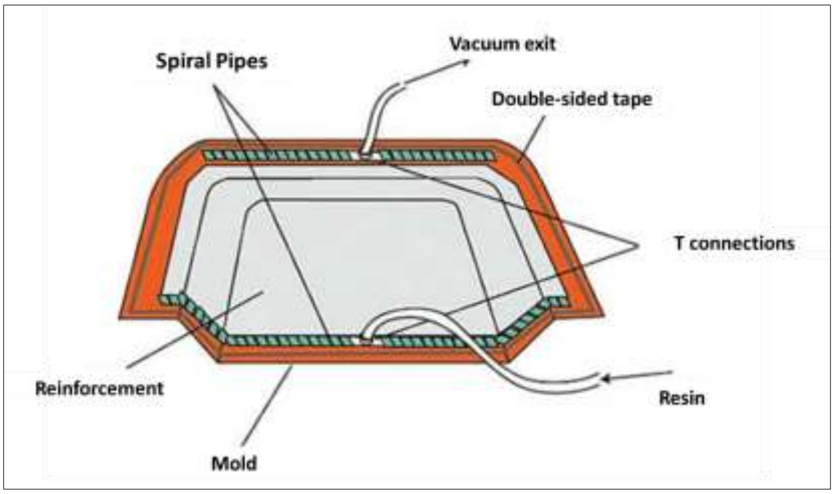


Figure 5.5. Vacuum infusion method [22,38].

The production steps in the vacuum infusion method are as follows:

- It should be noted that there are no scratches on the mold surface to be used and the mold must be kept clean.
- The mold surface is cleaned with various chemicals and the material is applied to separate the composite from the mold.
- Pre-prepared reinforcement element (glass fiber, carbon fiber, etc.) is placed.
- A peeling fabric that provides surface roughness is laid on the fibers. Flow nets are placed on the peeling fabric.
- The area to be produced on the mold is covered with putties.
- The vacuum bag is cut and put on the pastes so that too much pressure is not exerted on the fibers.

- To provide resin flow and vacuum in the system, the ports are opened, and pipes are connected to them.
- By connecting the vacuum pump and vacuum gauge to the system, it is understood whether there is a leak or not.
- The resin required for production is prepared. The amount of resin remaining in the pipes is also considered.
- After it is understood that the system is under vacuum, the resin is introduced into the system through the ports.
- After making sure that the fibers are completely wet, the resin inlet is closed.
- The resin in the composite is kept under vacuum until it hardens.
- After the resin has hardened, the vacuum bag is removed. The composite is carefully removed from the mold and the excess parts are cut off.

With this method, it is used in the production of complex materials, wind turbine blades and ship parts. As a disadvantage of this method, there is a possibility of formation of unwetted areas during production. The result of this may lead to negative developments in the mechanical properties of the composite. It can also be a costly method in terms of labor [21].

### 5.6. AUTOCLAVE MOLDING

Autoclave molding technique is a production method in which high heat and pressure are applied to the material to increase the amount of fiber/resin and to eliminate the air gap that may occur in the material in order to obtain a better working efficiency in the composite materials in the thermoset group. This method is one of the best methods applied to combine composite materials between layers and improve their quality. In the production with the autoclave cooking technique, after vacuum packaging and prepreg method are applied in accordance with the layering scheme for the piece to be obtained, this piece is put into the autoclave oven, exposed to temperature and pressure, and cooked and solidified. The best desired cooking and solidification; the type of resin hardener is determined by the thickness and geometry of the part to be manufactured. In the autoclave method, there are two types, both internal and external pressure, and these pressures can be adjusted. It can be adjusted to the desired level for temperature as well as for pressure. Thus, in the autoclave cooking method, both temperature and pressure values can be controlled by the auto-control system to be installed. This production technique has advantages such as high volumetric fiber density, ability to manufacture a large part as well as the ability to manufacture many small parts together, very good pressure-temperature control, and good quality product with low air bubbles by using pressure. In addition, this production method has disadvantages such as the high initial investment cost and the fact that the thermosets used in the prepreg system are treated with very high pressure and heat compared to the general thermosets. Autoclave molding technique is generally used in parts of aerospace vehicles, in the manufacture of parts that need very precise firing and solidification, and in industrial areas such as the electrical-electronics industry [34].

Figure 5.6. Autoclave oven image [34].

## 5.7. PREPREG METHOD

This is not a production technique but can be considered a production process. Prepreg is a fibrous polymer reinforcement that has been pre-impregnated with any of the carbon, glass, or aramid fibers. Curing takes place by exposing the prepregs to a certain pressure and temperature. At the end of curing, the resin hardens and a composite structure with high thermal and chemical resistance, not heavy and high strength is obtained. Prepreg sheets are cut from a roll with the help of a die. Appropriate fiber angles and orientations are placed on top of each other and left to cure so that the final processes of the resin can be completed. Then the process steps are completed by cutting, drilling, joining and assembling. Although there are two types of prepreg production, they are diversified as unidirectional and knitted. Unidirectional prepregs are preferred due to their advantages such as being applicable to all angle distributions and being suitable for producing composites with high strength. On the other hand, the biggest disadvantage is that the labor cost and time are higher than the knitted prepreg. In knitted prepregs, there are advantages such as the ability to place two layers at once, ease of operation, and short labor cost and time. On the other hand, the fact that knitted prepregs can only be used for 0/90 and 0/0 angles can be counted as disadvantages [34,39].

The prepreg technique is generally used in the aerospace industry. Compared to other methods, values such as surface quality, thickness, and weight, which are the final product features, is obtained and the waste rate is kept at a minimum level. The ability of the resin to be adjusted provides an increase in the process efficiency rate as it eliminates the problems such as the rich and dry region of the resin and the air gaps of the resin. In the early 90s, prepregs were becoming an important material. They are used in aircraft designs and side parts with a ratio of 5%. Today, they have become the main parts of the aerospace industry. They are used in almost 50% of aircraft equipment produced by Airbus and Boeing aircraft companies. In addition to these, it has started to be used in space technology, wind energy, some automobile parts, tools and equipment in sports halls. Finally, by making use of the prepreg technique, it is used in oil and gas pipelines and in the manufacture of high pressure tanks, and unique designs with high strength and strength can be obtained in the production of composite materials [34,40].

## 5.8. PULTRUSION

It is used in the production of composite material with fixed cross-section and desired length. It is a fast production method and high production numbers are achieved. It is like the drawing method used to shape metals. The fibers passing through the resin bath are drawn and passed through the heated mold, where they are cured in the desired shape and then cut into specified lengths. In Figure 5.7, the production form of

Pultrusion is seen. This method has low operating costs. Cost-increasing features are chrome-plated molds and feeding systems. The desired type of fibers can be used in production, but glass fiber is widely used. Resins such as polyester, vinyl ester, epoxy can be used [41].

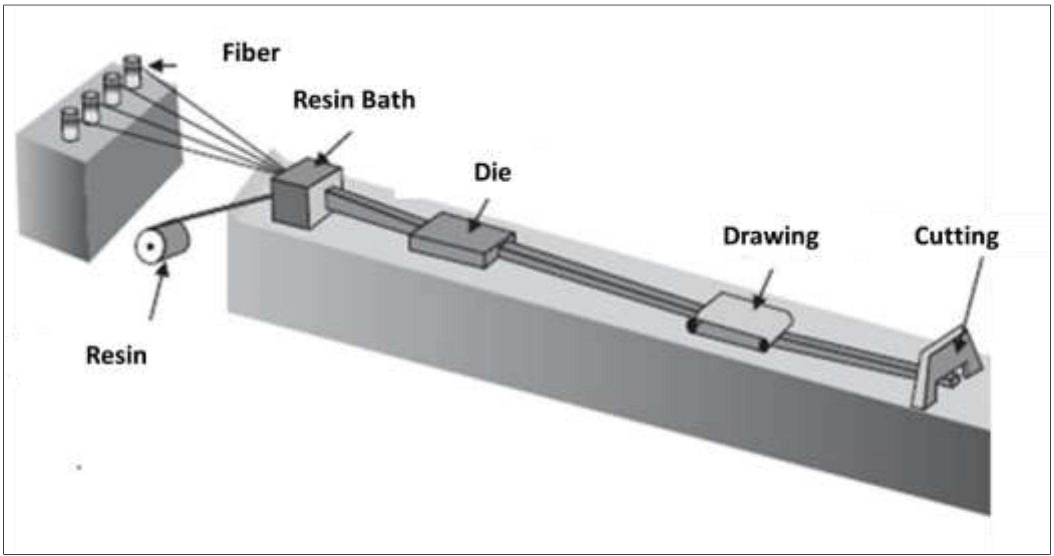


Figure 5.7. Pultrusion schematic view [41].

# PART 6

# EXPERIMENTAL STUDIES

## 6.1. MATERIALS

Composite materials consist of matrix and reinforcement elements. In the thesis study, epoxy resin was used as the matrix material. Glass fiber and carbon fiber were used as reinforcement. Shredded glass fiber (SGFs) with an average size of 3.2 mm and chopped carbon fiber (SCFs) with an average size of 3-6 mm were purchased from Turkey, respectively, from Omnis Kompozit and Dost Kimya. The epoxy resin (DTE 1000) and hardener (DTS 1100) used were purchased from San Duratek Protective Equipment and Trade Inc., Turkey.

## 6.2. FABRICATION OF COMPOSITES AND HYBRID SAMPLES

In the thesis study, composites of 6 different components were produced in three different reinforcement types, including only carbon fiber, only glass fiber and both glass fiber and carbon fiber. The mixing ratios of composite and epoxy hybrid polymer composites are given in Table 6.1.

Table 6.1. Compositions of produced composites.

| **Sample** | **Parameters** | | |
|---|---|---|---|
| | GF (wt.%) | CF (wt.%) | E (wt.%) |
| E5GF | 5 | - | 95 |
| E5CF | - | 5 | 95 |
| E5GCF | 2.5 | 2.5 | 95 |
| E10GF | 10 | - | 90 |
| E10CF | - | 10 | 90 |
| E10GCF | 5 | 5 | 90 |

GF-glass fiber, CF-carbon fiber, and E-Epoxy.

Pure epoxy was produced when DTE 1000 and DTS 1100 were mixed in the ratio of 2:1. Composites and hybrids were produced in two different weight fractions, 5 and 10 by weight. Productions were made using the hand layup method. The molds used during the production of test samples are shown in Figure 1. The manufacturing process takes place under pressure-free room conditions. If we want to express how the produced E5GCF hybrid is produced:

SGF/SCF reinforced epoxy-containing hybrid composite (E5GCF), 63.33 g of DTE 1000 epoxy resin was placed in a glass container. Pre-prepared SGF and SCF weighing 2.5 g each were added to the glass container. Then, the blended composition was thoroughly mixed by hand until a homogeneous mixture was obtained, and then 31.66 g of DTS 1100 hardener was added to the mixture when a homogeneous structure was obtained. A very rapid mixing takes place and then the casting process takes place. Curation takes about 24 hours to finish and it took 48 hours for the sample to be ready for testing. Before the tests, all surfaces of the samples were sanded with 240 mesh sandpaper.

These operations are performed for each composite and hybrid sample.

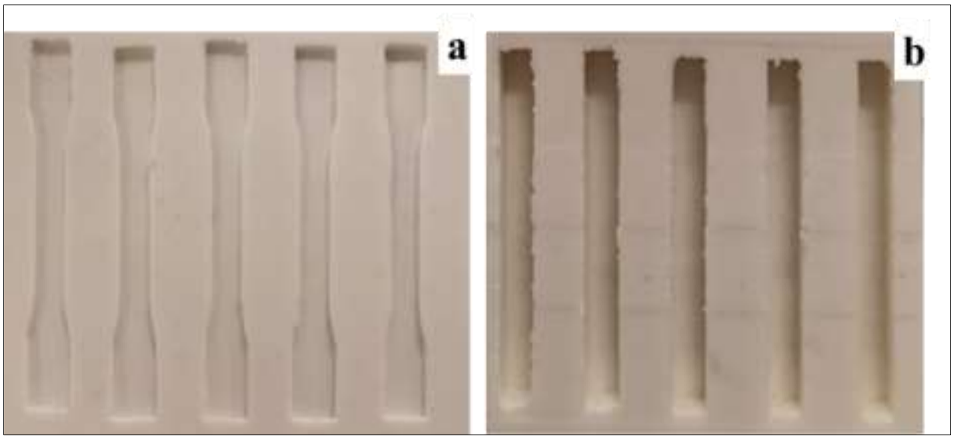


Figure 6.1. Molds for, (a) flexural composite samples and (b) Izod impact composite samples.

### 6.3. CHARACTERIZATION

Samples of (158 × 13 × 5) mm dimensions were produced for bending flexural tests. The tests were performed three times according to the ASTM D790 standard for each composite and hybrid sample and the average result was evaluated. 3-point bending tests were performed at the loading capacity of the 600KN Zwick Roell testing machine at a loading speed of 2 mm/min. The bending strength of the samples was measured with the “σ” Equation (6.1).

$$\sigma = \frac{3FL}{2wt^2} \tag{6.1}$$

Where:

F - applied load [N],

L - span length [mm],

w - Width of the sample [mm], and

t - thickness of specimens [mm] [42].

Izod impact tests were carried out on composites and hybrid composites produced with a cross section size of (80×10×10) mm. These tests were carried out on the loading capacity of the 450J Zwick Roell RKP 450 test apparatus. During the impact tests, 3-Izod impact tests were performed for each sample according to the ASTM D256 standard and the average values were calculated. In addition, wear resistance properties were investigated with the UTS Tribometer T10/20 device under dry sliding conditions. During the wear investigations, 6 mm stainless steel ball diameter, 150 m sliding distance, 40 mm/sec sliding speed and 10 mm stroke and applied loads of 10 and 20 N were applied. The volumetric wear rate is calculated by the “wr” Equation. (6.2).

$$Wr = \left(\frac{Wv}{dL}\right) = \left(\frac{2ab}{3}c \Big/ d\right) \tag{6.2}$$

Where:

$Wv$ - volumetric wear loss [$mm^3/s$],

a - wear width of sample [mm],

b - wear depth of sample [µm], and

c - stroke [mm] [43].

Finally, after the samples were coated with gold using a sputter coater (Quorum, Q150R ES Plus), the broken and worn surfaces of the samples were analyzed using scanning electron microscopy (SEM).

Figure 6.2 shows test machines applied to characterize mechanical and tribological behaviors. The flexural strength test of E5GF is given in Figure 6.2(a). Izod impact and abrasion resistance properties were investigated using Figure 6.2(b) and 2(c), respectively.

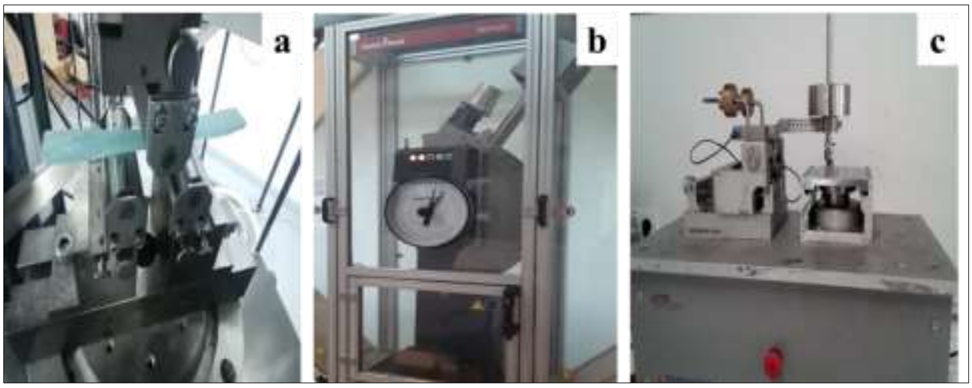


Figure 6.2. (a) Flexural bending test, (b) Izod impact test, and (c) Pin-on-disc wear test.

## PART 7

## RESULTS AND DISCUSSIONS

### 7.1. MECHANICAL PROPERTIES

The mechanical properties of the samples were investigated by applying the 3-point bending test and the Izod impact test. The flexural strength and fracture surface of the E10CF composite after impact tests are shown in Figure 7.1. Depending on the applied load, the deformation rises linearly upwards. During the bending test, pressure cracks appeared on the upper surfaces of the E10CF sample. The propagation of pressure cracks continued until the point where the stress was maximum. After the applied load reaches its maximum, the tension crack starts at the bottom surface of the sample and runs vertically upward along the midplane of the sample. The propagation of the shrinkage crack is accompanied by massive initiation and propagation of delamination. Eventually, as tensile and compression cracks continue to propagate, they finally converge, then E10CF fractures as shown in Figure 7.1(a) [44,45]. This fracture formation of sample E10CF was similarly seen in the remaining samples.

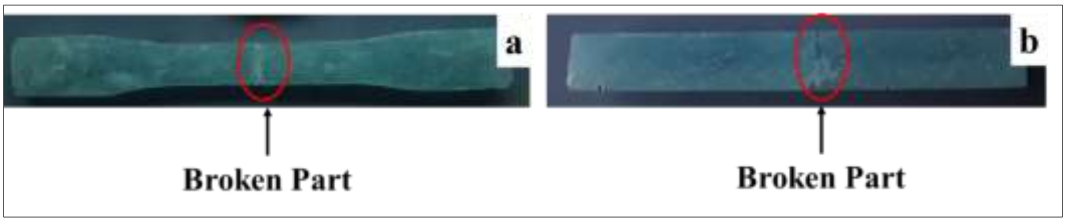


Figure 7.1. (a) Broken E10CF by flexural bending and (b) E10CF after impact tests.

Bending test behavior and impact resistance properties of composite and hybrid specimens are as shown in Figure 7.2. Bending bending tests were performed for the first three samples, E5GF, E5CF and E5GCF. Test results show 19.43% and 6.24% improvement in flexural flexural strength of hybrid composite E5GCF compared to E5GF and E5CF, respectively. This result may be due to the higher stiffness properties of chopped carbon and glass fiber [45,46]. Similarly, the Izod impact test results of E5GF, E5CF and E5GCF samples reveal that the E5GCF sample has an average max impact energy of 0.95J. The lowest impact resistance capacity of about 0.66J was observed in the E5GF sample. This is probably related to the morphological structure of the samples. The presence of river lines, cracks and pores on the epoxy matrices causes poor interfacial bonding between the SGFs and the epoxy of the E5GF composite, as can be seen in the SEM images in Figure 7.3(a). In addition, delamination, cracks, and separation effects on the matrices noticed under the SEM images for the example E5CF in Figure 7.3(b) reduce the amount of force transferred between the SCFs and the epoxy matrix. Like this, it is thought that these are the factors that decrease the impact strength of composites [6].

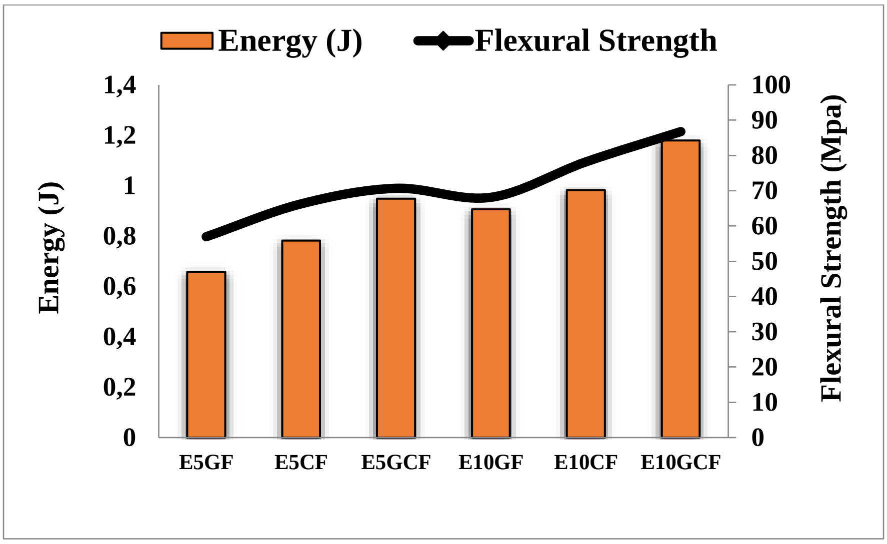


Figure 7.2. Flexural Strength and impact resistance of samples.

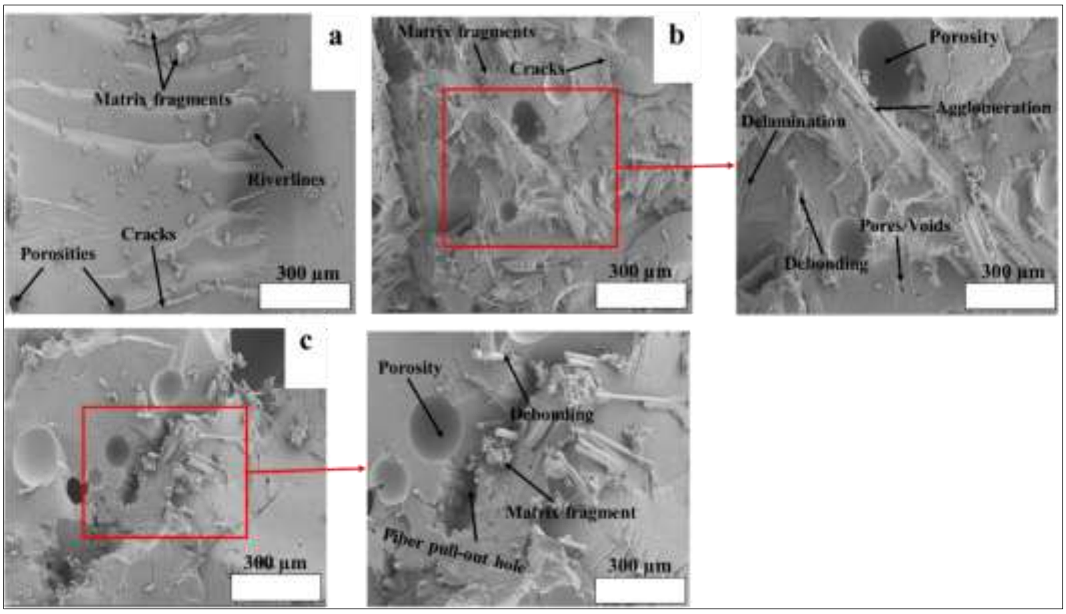


Figure 7.3. SEM images of broken surfaces of samples, (a) E5GF, (b) E5CF, and (c) E5GCF.

Researchers have shown in previous studies that the addition of a limited amount of carbon and glass fiber into the polymer matrix causes a significant increase in mechanical properties [6,47]. The reason for this can be shown as the high strength and hardness properties of SGF and SCF's. Therefore, as can be seen from the test data, E10GCF has better flexural and impact strength than E5GCF hybrid composite. These results are valid for both (E5GF and E10GF) and (E5CF and E10CF) composites. Therefore, this result shows parallelism with previous studies.

Subsequently, further bending tests were performed on the next three samples; E10GF, E10CF and E10GCF. According to Figure 7.2, maximum flexural strength was observed for hybrid composite E10GCF with 86.76Mpa, while E10GF exhibited the lowest flexural strength at 68.12Mpa. Also, considering the impact tests, the impact strength of E10GCF was approximately 22.88% and 16.95% better than E10GF and E10CF, respectively. This result is probably because of defects on the morphological structures of E10GF and E10CF composites.

Therefore, phenomena such as agglomeration, delamination and bond separation are considered in the SEM image of Figure 7.4(a) for the E10GF sample. Also, Figure 7.4(b) shows that agglomeration and debonding effects are observed in the E10CF composite. Therefore, these may be a trait for reduced impact strength [48]. Therefore, epoxy-based hybrid composites reinforced with mechanical testing, SGFs and SCFs show behavioral similarity. Thus, the linearity of the graph in Figure 7.4 proves the parallelism of the bending and impact properties of the samples as a function of fiber content.

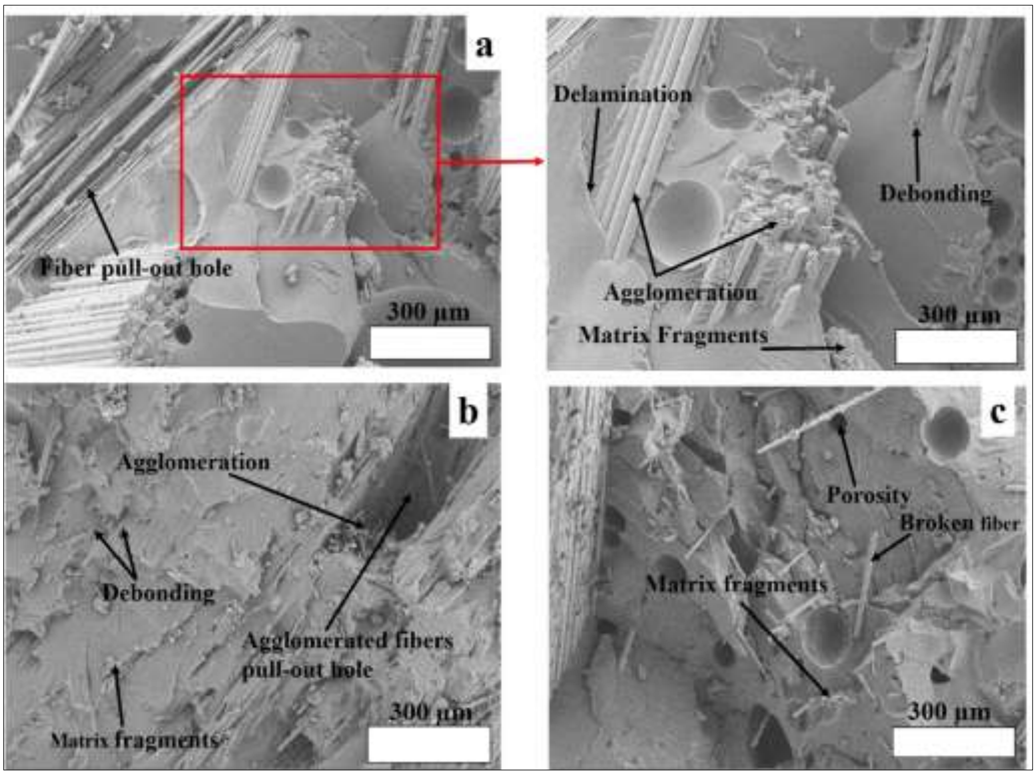


Figure 7.4. SEM images of broken surfaces of samples, (a) E10GF, (b) E10CF, and (c) E10GCF.

## 7.2. TRIBOLOGICAL PROPERTIES

Figure 7.5 reflected the wear resistance properties of composites and hybrids under applied 10 and 20N loads. However, the wear surface texture of the produced composites and hybrid composites was observed in Figure 8 using scanning electron microscopy (SEM).

Abrasion tests were carried out for the first three samples (E5GF, E5CF and E5GCF). When we look at the test results, it has been revealed that the highest wear resistance property is observed for $3.4\times10^{-4}$ and $1.58\times10^{-3}$ $mm^3/m$ E5CF composite under 10 and

20N applied loads. Although the mechanical properties of E5GCF were higher than E5CF, it exhibited lower abrasion resistance than E5CF. This was due to the self-lubricating property of short carbon fibers [17,47]. Therefore, the wear properties of composites can be improved depending on the carbon fiber content, and it should be noted that SCFs are even more effective than SGFs on the tribological behavior of composites. Additionally, the SEM images in Figures 7.6 (i) and 6(j) show that the worn surface of E5CF is less rough with little wear residue. So this proves that E5CF has better wear performance. In Figure 7.5, it was also observed that the lowest wear resistance property for E5GF composite was $7.5\times10^{-4}$ and $3.46\times10^{-3}$ $mm^3/m$ wear rate values under 10 and 20N loads, respectively. Here, under SEM images, large wear residue was seen in Figures 7.6(a) and 6(b).

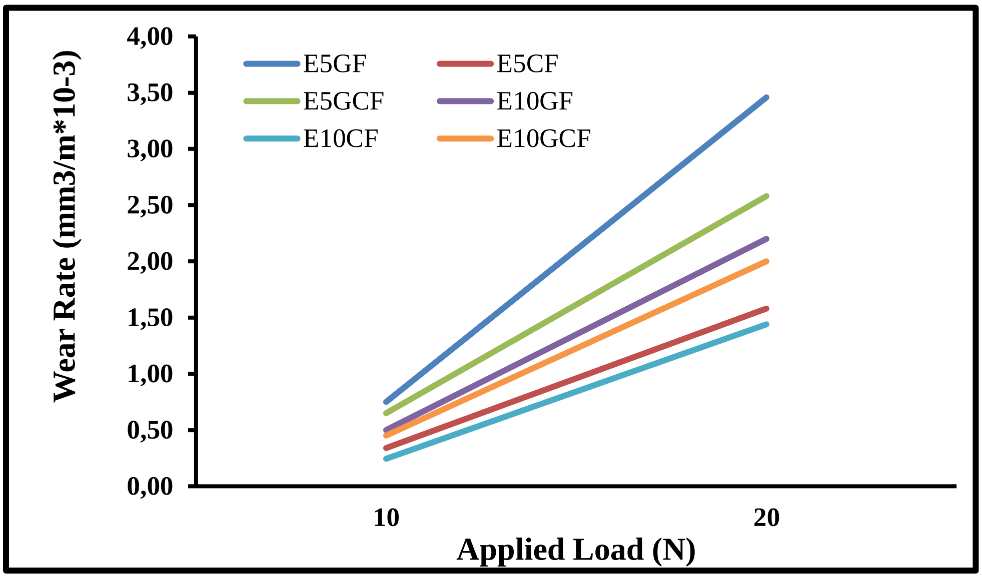


Figure 7.5. Wear rate under the applied loads.

Wear resistance tests were further studied on another set of samples; E10GF, E10CF and E10GCF. Similar results were noticed for 10% wt reinforced samples compared to 5% wt reinforced samples. According to Figure 7.5, the maximum wear resistance was monitored for E10CF composite with $2.4\times10^{-4}$ and $1.44\times10^{-3}$ $mm^3/m$ under 10 and 20N loads, respectively. Also, in Figures 7.6(k) and 6(l), smooth eroded surface profiles are seen. Therefore, the wear resistance capacity of E10CF under 20N abrasion load was found to be better than E10GF and E10GCF by about 34.55% and 28%, respectively. On the contrary, a higher wear rate was obtained for E10GF composite with 5×10-4 and 2.2×10-3 mm3/m under 10 and 20N wear loads, respectively. At higher fiber content of 10% by weight SGF, the agglomeration properties and thus the wear resistance behavior were significantly reduced for the weaker interfacial relationship [49]. Therefore, broken fibers and wear residue findings were seen in Figures 7.6(e) and 6(f) for the E10GF composite sample due to the higher wear rate.

On the other hand, it is stated that adding carbon and glass fibers with different contents to the fiber-matrix mixture indicates positive developments in mechanical properties. Therefore, the increase in strength causes a decrease in the wear rate of composites [11]. Therefore, it can be said that SCFs with 10% wt SGFs and E10GCF added have a lower wear rate than E5GCF hybrid composites with 5% wt SGFs and SCFs added. This can also be expressed by the morphology of the eroded surface tissues. In Figures 7.6(g) and 6(h), slightly rough surfaces were observed in the SEM images of the E10GCF. Figures 7.6(c) and 6(d) show higher wear signs on the worn surface of the E5GCF composite. These phenomena are confirmed in Figure 7.5 and the same should be stated for other composites (E5GF and E10GF) and (E5CF and E5CF).

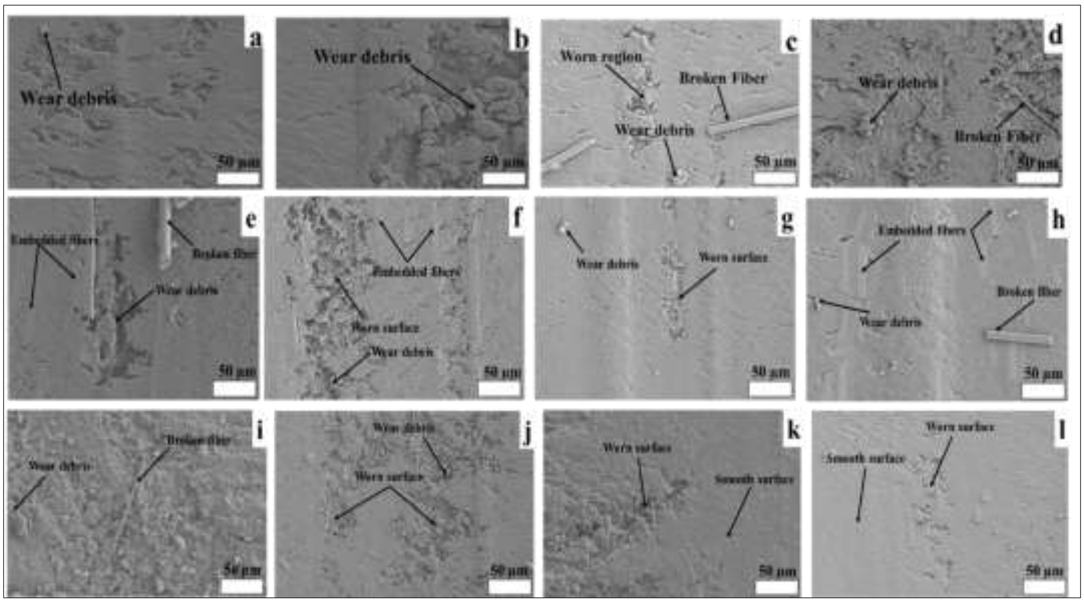


Figure 7.6. SEM images of worn surfaces of samples, (a,b) E5GF, (c,d) E5GCF, (e,f) E10GF, (g,h) E10GCF, (i,j) E5CF, and (k,l) E10CF.

# PART 8

## CONCLUSIONS

In this thesis, composites consisting of 6 different components, plain and hybrid, in three different reinforcement types, carbon and glass fibers in different proportions, single and double (hybrid) were produced by hand lay-up method. The results reveal that E5GCF has approximately 6.24% and 19.42% better flexural strength than E5CF and E5GF, while the E10GCF hybrid composite has 9.89% and 21.48% better flexural strength than E10CF and E10GF composites, respectively. development has occurred. In addition, the impact absorption capabilities of the samples were in the same direction as the bending strength of the samples. Thus, E10GCF hybrid composite achieved the highest energy absorption value of 1.18J compared to E10CF and E10GF. However, the E5GF composite showed the lowest energy absorption capacity of 0.66J compared to all fabricated samples. It was reported that the mechanical properties of the composites improved with the increase in the total reinforcement content. When the samples containing the same amount of reinforcement were compared, it was seen that the binary (hybrid) composites exhibited better mechanical properties.

Along with the mechanical properties, the results of the tribological properties of the samples are also included. The content of short carbon fibers has been found to have a significant influence on the tribological properties of short carbon fiber (SCFs) reinforced composites and hybrid composites. Therefore, it is stated that very low wear amount is seen for E10CF composite with 2.4×10-4 and 1.44×10-3 mm3/m wear rates under 10 and 20N loads, respectively. In addition, scanning electron microscopy observation reported that a slightly rough wear surface was obtained for the E10CF sample.

In summary, it has been stated that while E10GCF hybrid composite may be at the forefront in structural application areas, E10CF composite can be preferred in tribological applications.

## REFERENCES


1. Demircioğlu, G., "Kısa cam elyaf takviyeli epoksi kompozit malzemelerde elyaf boyutunun etkisi", ***Fen Bilimleri Enstitüsü, Gazi Üniversitesi Ankara***, (2006).

2. Jesthi, D. K., Nayak, A., Routara, B. C., and Nayak, R. K., "Evaluation of mechanical and tribological properties of glass/carbon fiber reinforced polymer hybrid composite", ***International Journal Of Engineering***, 31 (7): 1088–1094 (2018).

3. Karthik, K., Ahmed, I. I., and Renish, R. R., "Experimental Investigation of Polymer Matrix for Heat Distortion Temperature Test", .

4. Bello, S. A., Agunsoye, J. O., Hassan, S. B., Zebase Kana, M. G., and Raheem, I. A., "Epoxy Resin Based Composites, Mechanical and Tribological Properties: A Review.", ***Tribology In Industry***, 37 (4): (2015).

5. Mutalikdesai, S., Hadapad, A., Patole, S., and Hatti, G., "Fabrication and Mechanical Characterization of Glass fibre reinforced Epoxy Hybrid Composites using Fly ash/Nano clay/Zinc oxide as filler", (2018).

6. Muhammad, Y. H. and Ahmad, S., "Mechanical and thermal properties of glass fiber-reinforced epoxy composite with matrix modification using liquid epoxidized natural rubber", ***Journal Of Reinforced Plastics And Composites***, 32 (9): 612–618 (2013).

7. Karcı, A., "Uçak yapısal parçalarında kullanılan karbon/epoksi kompozit malzemelerin yorulma davranışı", PhD Thesis, ***Anadolu University (Turkey)***, (2010).

8. Clyne, T. W. and Hull, D., "An Introduction to Composite Materials", ***Cambridge University Press***, (2019).

9. Canan, F., "Açılı yüzey çatlaklı cam/epoksi kompozit malzemelerin kırılma davranışları", Master’s Thesis, ***Selçuk Üniversitesi Fen Bilimleri Enstitüsü***, (2007).

10. Ozsoy, N., Ozsoy, M., and Mimaroglu, A., "Mechanical and Tribological Behaviour of Chopped E-Glass Fiber-Reinforced Epoxy Composite Materials.", ***Acta Physica Polonica, A.***, 132 (3): (2017).

11. "Mechanical and Sliding Wear Behaviour of E GLASS Fiber Reinforced with EPOXY Composites", **https://1library.net/document/yjd8oemy-mechanical-sliding-behaviour-glass-fiber-reinforced-epoxy-composites.html** (2021).

12. Swapnil, A. S., SatheSandip, B., ChaudhariBapu, P., and Vishal, S. J., "Experimental investigation of mechanical properties of glass fibre/epoxy composites with variable volume fraction", ***Materials Today: Proceedings***, 4 (9): 9487–9490 (2017).

13. Demirel, A., "Karbon elyaf takviyeli epoksi kompozit malzemelerin karakterizasyonu", ***Master's Thesis, Gazi University Graduate School Of Natural And Applied Sciences, Ankara***, (2007).

14. Song, J. H., "Pairing effect and tensile properties of laminated high-performance hybrid composites prepared using carbon/glass and carbon/aramid fibers", ***Composites Part B: Engineering***, 79: 61–66 (2015).

15. Uthaman, A., Xian, G., Thomas, S., Wang, Y., Zheng, Q., and Liu, X., "Durability of an epoxy resin and its carbon fiber-reinforced polymer composite upon immersion in water, acidic, and alkaline solutions", ***Polymers***, 12 (3): 614 (2020).

16. Solomon, B., George, D., Shunmugesh, K., and Akhil, K. T., "The effect of fibers loading on the mechanical properties of carbon epoxy composite", ***Polymers And Polymer Composites***, 25 (3): 237–240 (2017).

17. Khun, N. W., Zhang, H., Lim, L. H., Yue, C. Y., Hu, X., and Yang, J., "Tribological properties of short carbon fibers reinforced epoxy composites", ***Friction***, 2 (3): 226–239 (2014).

18. Soni, S., Rana, R. S., Singh, B., and Rana, S., "Synthesis and characterization of epoxy based hybrid composite reinforced with glass fiber and milled carbon", ***Materials Today: Proceedings***, 5 (2): 4050–4058 (2018).

19. Jesthi, D. K. and Nayak, R. K., "Influence of glass/carbon fiber stacking sequence on mechanical and three-body abrasive wear resistance of hybrid composites", ***Materials Research Express***, 7 (1): 015106 (2020).

20. Solak, H. H., "Lif ve mineral takviyeli melamin matrisli kompozit malzemelerin ısıl ve mekanik özelliklerinin incelenmesi", Master's Thesis, ***Fen Bilimleri Enstitüsü***, (2012).

21. Yıldız, A., "BOR KATKILI EPOKSİ REÇİNELİ TERMOSET KOMPOZİT MALZEMELERİN GELİŞTİRİLMESİ", ***Ondokuz Mayıs Üniversitesi***, Ondokuz Mayıs Üniversitesi Fen Bilimleri Enstitüsü, (2020).

22. Durgun, İ., "Vakum İnfüzyon Yöntemi İle Kompozit Parça Üretimi", ***Otekon***, 14 (7): 26–27 (2014).

23. Harris, B., "Engineering composite materials", (1999).

24. PARLAK, M. F., "TÜF - EPOKSİ KOMPOZİT MALZEMELERİN HAZIRLANMASI VE ÖZELLİKLERİNİN İNCELENMESİ", Selçuk Üniversitesi Fen Bilimleri Enstitüsü, (2017).

25. Sahin, Y., "Kompozit malzemelere giris", ***Gazi Kitabevi, Ankara***, 67–69 (2000).

26. Miracle, D. B., "Metal matrix composites–from science to technological significance", ***Composites Science And Technology***, 65 (15–16): 2526–2540 (2005).

27. Avcı, S., "DOĞAL HAMMADDE TAKVİYELİ EPOKSİ KOMPOZİT SİSTEMLERİNİN ÜRETİMİ VE KARAKTERİZASYONU", MERSİN ÜNİVERSİTESİ FEN BİLİMLERİ ENSTİTÜSÜ, (2021).

28. Huang, X., Su, H., Wang, X., Zhang, B., and Li, J., "Effect of oligomeric-modified montmorillonite on morphology and properties of polycarbonate/montmorillonite nanocomposites", ***Polymer Composites***, 34 (5): 722–731 (2013).

29. Matthews, F. L. and Rawlings, R. D., "Composite Materials: Engineering and Science", ***Elsevier***, (1999).

30. Karadurmuş, M., "EPOKSİ REÇİNE İLE HAZIRLANAN KOMPOZİT MALZEMELERİN MEKANİK VE TRİBOLOJİK ÖZELLİKLERİNİN İNCELENMESİ", Ondokuz Mayıs Üniversitesi Fen Bilimleri Enstitüsü, (2017).

31. Baker, A. A., "Composite Materials for Aircraft Structures", ***AIAA***, (2004).

32. Schijve, J., "Fatigue of aircraft materials and structures", ***International Journal Of Fatigue***, 16 (1): 21–32 (1994).

33. Chou, T. and Kelly, A., "Mechanical properties of composites", ***Annual Review Of Materials Science***, 10 (1): 229–259 (1980).

34. Bardakçi, R., "Ortasında eliptik yarık bulunan cam-karbon/epoksi hibrit kompozit plakların burkulma davranışının incelenmesi", Master’s Thesis, ***Batman Üniversitesi Fen Bilimleri Enstitüsü***, (2020).

35. "Poliya | Fitil Sarma", **https://www.poliya.com/tr/fitil-sarma** (2021).

36. Ün, C. İ., "Epoksi matris E-camı dokuma fiber takviyeli termoset kompozitlerde üçüncü bileşen kalsit dolgunun özelliklere etkisi.", ***Yıldız Teknik Üniversitesi***, Yıldız Teknik Üniversitesi Fen Bilimleri Enstitüsü, (2015).

37. Brocks, T., Shiino, M. Y., Cioffi, M. O. H., Voorwald, H. J. C., and Caporalli Filho, A., "Experimental RTM manufacturing analysis of carbon/epoxy composites for aerospace application", ***Materials Research***, 16: 1175–1182 (2013).

38. GENÇ, Ç. and ARICI, A. A., "YAT İMALATINDA KULLANILAN CTP MALZEME VE İMALAT YÖNTEMLERİ BÖLÜM I: El Yatırma Yöntemi", .

39. Reyne, M., "Technologie Des Composites", ***Hermès***, (1998).

40. Kayrak, M. A., "Havacılık Kompozitleri ve Mukavemet-Maliyet Analizleri", ***TC Anadolu Üniversitesi Sosyal Bilimler Enstitüsü***, (1999).

41. Strong, A. B., "Fundamentals of Composites Manufacturing: Materials, Methods and Applications", ***Society Of Manufacturing Engineers***, (2008).

42. Voicu, R., "Structural Characterization and Mechanical Behaviour of Carbon Fiber/epoxy Composite for Aeronautical Field", ***Materiale Plastice***, 49 (1): 34–40 (2012).

43. Akgul, Y., Ahlatci, H., Turan, M. E., Simsir, H., Erden, M. A., Sun, Y., and Kilic, A., "Mechanical, tribological, and biological properties of carbon fiber/hydroxyapatite reinforced hybrid composites", ***Polymer Composites***, 41 (6): 2426–2432 (2020).

44. Lu, W. H., Kao, P. W., and Su, A. C., "Flexural failure of unidirectional carbon/epoxy composites: Effects of interleaving and flexural rate", ***Journal Of Polymer Research***, 5 (3): 133–142 (1998).

45. Jagannatha, T. D. and Harish, G., "Influence of Carbon & Glass Fiber Reinforcements on Flexural Strength of Epoxy Matrix Polymer Hybrid Composites", ***International Journal Of Engineering Research And Applications***, 5: 109–112 (2015).

46. Mohanty, S. S., Rout, A. K., Jesthi, D. K., Routara, B. C., and Nayak, R. K., "Evaluation of mechanical and wear performance of glass/carbon fiber reinforced polymer hybrid composite", ***Materials Today: Proceedings***, 5 (9): 19854–19861 (2018).

47. Olszewski, A., Nowak, P., Kosmela, P., and Piszczyk, \Lukasz, "Characterization of Highly Filled Glass Fiber/Carbon Fiber Polyurethane Composites with the Addition of Bio-Polyol Obtained through Biomass Liquefaction", ***Materials***, 14 (6): 1391 (2021).

48. Ambigai, R. and Prabhu, S., "Analysis on mechanical and thermal properties of glass-carbon/epoxy based hybrid composites", (2018).

49. Basumatary, K. K., Mohanta, N., and Acharya, S. K., "Effect of fiber loading on abrasive wear behaviour of Ipomoea carnea reinforced epoxy composite", ***International Journal Of Plastics Technology***, 18 (1): 64–74 (2014).

# RESUME

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