ISTANBUL COMMERCE UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

PRODUCTION OF COMPOSITE WITH ADDITIVES BY HAND LAY-UP PROCESS

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ACCEPTANCE AND APPROVAL PAGE

On 15/09/2022, **Ertunga DİREK** successfully defended the thesis entitled "**Production of Composite with Additives by Hand Lay-Up Process**'' which he prepared after fulfilling the requirements specified in the associated legislations before the jury members whose signatures are listed below. This thesis is accepted as a **MASTER'S THESIS** by Istanbul Commerce University, Graduate School of Natural and Applied Sciences, **Department of Mechatronics Engineering**.

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Approval Date: 28. 09. 2022

Istanbul Commerce University, Graduate School of Natural and Applied Science, accordance with the 16th article of the Board of Directors Decision dated 28.09.2022 and numbered 2022/359, "Ertunga DIREK" who has determined to fulfill the course load and thesis obligation was unanimously decided to graduated.

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Head of Graduate School of Natural and Applied Sciences

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28/09/2022

Ertunga DİREK

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ABSTRACT

M.Sc. Thesis

PRODUCTION OF COMPOSITE WITH ADDITIVES BY HAND LAY-UP PROCESS

Ertunga DIREK

Istanbul Commerce University
Graduate School of Natural and Applied Sciences
Department of Mechatronics Engineering

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The development of composite materials and the usage of composite materials show progress in various stages. Composite materials provide lightweight materials with high strength to aircraft, automotive, and other industries. It has a high significance in improving the produced composite materials and their specifications. Due to the advantages of composite materials, it is seen that in the future, aircraft, automotive, and other industries will be increased the usage of composite materials. In this study, epoxy was incorporated with titanium dioxide and talc at different concentrations (0, 0.5, 1, 2, and 4 wt%), and then that mixture was combined with carbon fiber via a hand lay-up process. The mechanical properties of the resultant composites were determined using universal tensile testing. The tensile test results revealed that the mechanical properties of the polymer matrix composites were increased as a function of talc and titanium dioxide concentrations. The best tensile strength of the composite was obtained from the 0.5% talc and 1% titanium dioxide sides. The increasing weight ratio of talc 1%, 2%, and 4% and 0.5%, 2%, and 4% of titanium dioxide in composite production doesn't exhibit a significant difference. The tensile testing behavior of talc and titanium dioxide reinforced composite specimens shows better results compared to unreinforced carbon fiber composites. As a result, this study provides a detailed explanation of how to improve the strength of carbon fiber composites.

Key Words: Carbon fiber, composite, matrix, reinforcement elements, talc, tensile strength, tensile test, titanium dioxide.

ÖZET

Yüksek Lisans Tezi

ELLE YATIRMA YÖNTEMİ İLE KATKILI KOMPOZİT ÜRETİMİ

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Kompozit malzemenin gelişimi ve kompozit malzemelerin kullanımı çeşitli aşamalarda ilerleme göstermektedir. Kompozit malzemeler, uçak, otomotiv ve diğer endüstrilere yüksek mukavemetli hafif malzemeler sağlar. Üretilen kompozit malzemelerin ve özelliklerinin iyileştirilmesinde büyük öneme sahiptir. Kompozit malzemelerin avantajlarından dolayı gelecekte uçak, otomotiv ve diğer sektörlerde kompozit malzeme kullanımının artacağı görülmektedir. Bu çalışmada, epoksi, titanyum dioksit ve talk ile farklı konsantrasyonlarda (ağırlıkça %0, 0,5, 1, 2 ve 4 oranında) dahil edildi ve daha sonra bu karışım elle yatırma işlemi ile karbon fiber ile birleştirildi. Elde edilen kompozitlerin mekanik özellikleri, evrensel çekme testi kullanılarak belirlendi. Çekme test sonuçları, polimer matrisli kompozitlerin mekanik özelliklerinin talk ve titanyum dioksit konsantrasyonlarının bir fonksiyonu olarak arttığını ortaya koydu. Kompozitin en iyi çekme mukavemeti %0.5 talk ve %1 titanyum dioksitten elde edilmiştir. Kompozit üretiminde talkın %1, %2 ve %4 ve titanyum dioksitin %0.5, %2 ve %4 ağırlık oranlarının arttırılması önemli bir farklılık göstermemektedir. Talk ve titanyum dioksit takviyeli kompozit numunelerin çekme testi davranışı, takviye edilmemiş karbon fiber kompozitlere kıyasla daha iyi sonuçlar göstermektedir. Sonuç olarak, bu çalışma, karbon fiber kompozitlerin mukavemetinin nasıl iyileştirilebileceğine dair ayrıntılı bir açıklama sunmaktadır.

Anahtar Kelimeler: Çekme dayanımı, çekme testi, karbon fiber, kompozit, matris, takviye elemanları, talk, titanyum dioksit.

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First, I would like to thank my supervisor, Assist. Prof. Dr. Muhammet CEYLAN, for helping me to overcome the difficulties I faced during my thesis study and also for his guidance and advice throughout this research.

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Ertunga DIREK

ISTANBUL, 2022

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ABBREVIATION

ASTM	American society for testing materials
CFRP	Carbon fiber reinforced polymer
Mj	Megajoule
SiC	Silicon Carbide
TiO_2	Titanium Dioxide
wt	Weight
µm	micrometer

1. INTRODUCTION

The beginning usage of composite material is not known precisely. On the other hand, composite materials are used to overcome life's difficulties. For instance, the Egyptians used plywood when they realized that wood could be rearranged to succeed resistance and high strength for thermal expansion and swelling caused by moisture's absorption. Armors and swords in the Middle Ages were fabricated with different metal layers (Jones, 2014). The aircraft industry increased its usage of composites after World War II for military applications (Baker, 2004).

Andrei et al. (2006) said that carbon fibers/polymer matrix composites are used widely instead of aluminum structures in the aerospace industry. The requirement for strength, lightweight, and fuel-efficient materials in industries provides extensive research and development interest. The mechanical and corrosion resistance feature of Titanium (Ti) and alloys, which have strength and low specific gravity, makes them highly relevant to these industries (Topcu et al., 2019). Karataş and Gökkaya (2018) showed in their article that more than fifty thousand material types had been used in manufacturing and designing a wide range of engineering materials. Composite materials provide flexible designs because they can be molded into different shapes (Khan & Javed, 2020).

The composite material is manufactured by combining two or more insoluble materials to fabricate material with high properties and desired characteristics. The reinforcement is powerful material, and the matrix is weaker material. The fabrication of composite materials aims to improve one or more of the following characteristics (Jones, 2014).

- Strength
- Stiffness
- Corrosion resistance
- Wear resistance
- Fatigue
- Attractiveness
- Acoustical insulation
- Temperature-dependent behavior
- Weight
- Thermal insulation
- Thermal conductivity

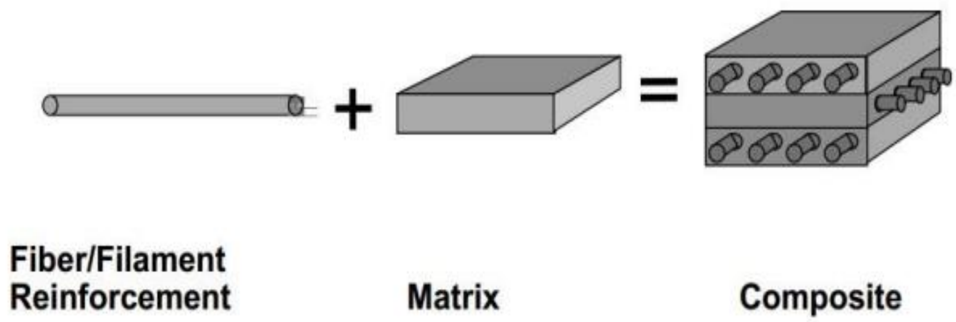

Figure-1.1. Fiber/Filament reinforcement, matrix, and composite (Mrazova, 2013).

Light structure and strength are difficult subjects for every industry. Composite Materials' have advantages such as smaller weight, good sealing, galvanic corrosion elimination, tightness, damping properties, good vibration, uniform stress distribution, low production cost, energy, and decreased stress concentrations (Ahmed, 2018).

The composite material ratio of usage has reached a balance in different industries. Wind energy 65 %, maritime 50 %, electric and electronic 35 %, and consumer goods 13 %. In different industries, the usage ratio of composite material;

- Aviation and space will increase from 9 % to 12 %
- The construction and building industry will increase from 6 % to 10 %
- Tank and pipe will increase from 1 % to 2 %

is expected (Konu, 2016).

Table-1.1 Value and volume representation of composite materials (Konu, 2016).

In Value	**Percentage**	**In Volume**	**Percentage**
Aviation and Space	23	Construction and Building	26
Automotive and Transportation	22	Automotive and Transportation	22
Construction and Building	14	Electric and Electronics	18
Wind Energy	12	Tank and Pipe	14
Electric and Electronics	12	Wind Energy	8
Consumer Goods	9	Consumer Goods	6
Maritime	5	Maritime	3
Tank and Pipe	2	Aviation and Space	0.5
Other	1	Other	2.5

Economy, efficiency, and comfort are significant in aircraft. Diminishing in commercial aircraft costs (DOC) for the companies. Research and Development programs at NASA (e.g., the Advanced Composites for Energy Efficiency program) have shown the DOC savings potential of carbon fiber polymer matrix composites. In addition, NASA has noticed the need to decrease manufacturing costs. NASA's Advanced Composite Technology program, which uses production concepts and design that would lower costs, improved prototypes such as wing structures and composite fuselage for aircraft. (Deo et al., 2001).

The first significant application of composites in aircraft was in Europe in 1983 when Airbus produced a composite rudder for the A300 and A310, followed by a vertical tail fin which is more complex. The vertical tail, made from metal, had almost 2,000 parts except for fasteners. However, the vertical tail, which was made from composite materials, had less than a hundred parts. As a result, the composite vertical tail was lower cost and lighter than the vertical metal tail because of the number of components and reduced assembly cost. This improvement reduced fuel consumption. To illustrate, the A300 and A600 airframe is 4.5 percent composite by weight (Deo et al., 2001).

Deo et al. (2001), Airbus fabricated the tail structure of the A320 from composite. Moreover, A320's fin/fuselage fairings, wing fixed leading/trailing edge bottom access panels, flap track fairings, deflectors, fuselage belly skins, trailing edge flaps, spoilers, main gear leg fairing doors, nose wheel/mainwheel doors, nacelles, ailerons, carbon brakes and interior manufactured from composite materials. In addition, glass fiber supported by polymer matrix composite has produced the floor panels. These structure parts correspond to twenty-eight percentage of the total A320 airframe's weight.

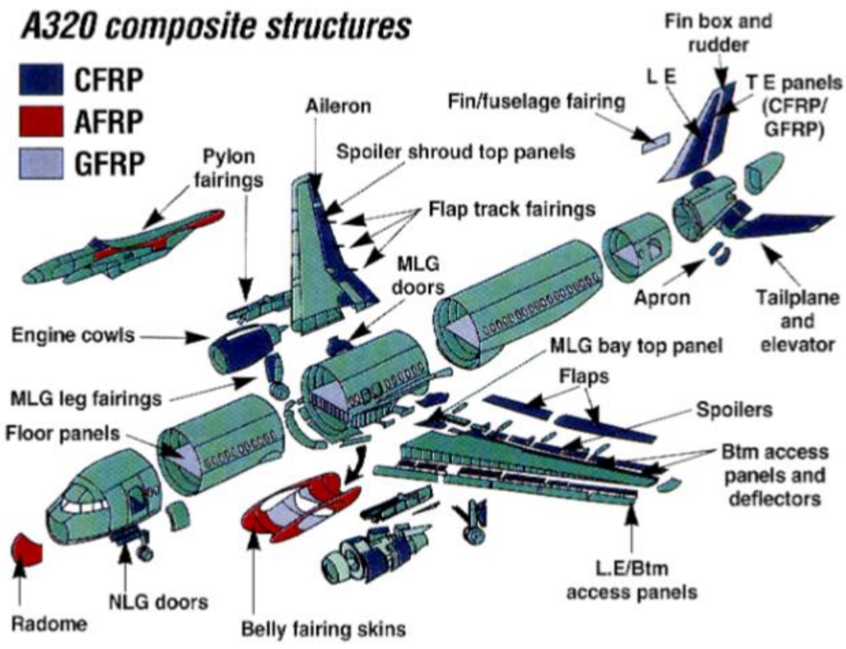

Figure-1.2. Composite materials on Airbus A320 (Deo et al., 2001).

The weight of the A380 is manufactured by composites which are nearly 22 percent. Airbus A380 makes usage of GLARE (Glass Fiber Reinforced Aluminum Alloy), which uses for the upper fuselage shell, crown, side panels, the front covering, aft upper fuselage, and the upper parts of the forward. Composite, made from four mm or more thick aluminum alloy sheets and glass fiber resin bond films, is called GLARE laminate. GLARE offers weight savings from fifteen percent to thirty percent over aluminum alloy with fatigue resistance. The top and bottom skin parts of the A380 and front, center, and rear spars include CFRP, which is utilized for the back pressure bulkhead, ailerons, spoilers, top deck floor beams, and outer flaps. Also, belly fairing is produced almost from one hundred composite honeycomb panels (Quilter, 2001).

The composite is almost twenty percent of Boeing-777 by weight. Composite is utilized for the wing's fixed leading edge, the trailing edge panels, the flaps and flaperons, the outboard aileron, and spoilers. Also, composite is used for the LG (landing gear) doors, floor beams, and wing-to-body covering. Using composite material in aircraft saves nearly 1,500 lb. in weight (Quilter, 2001).

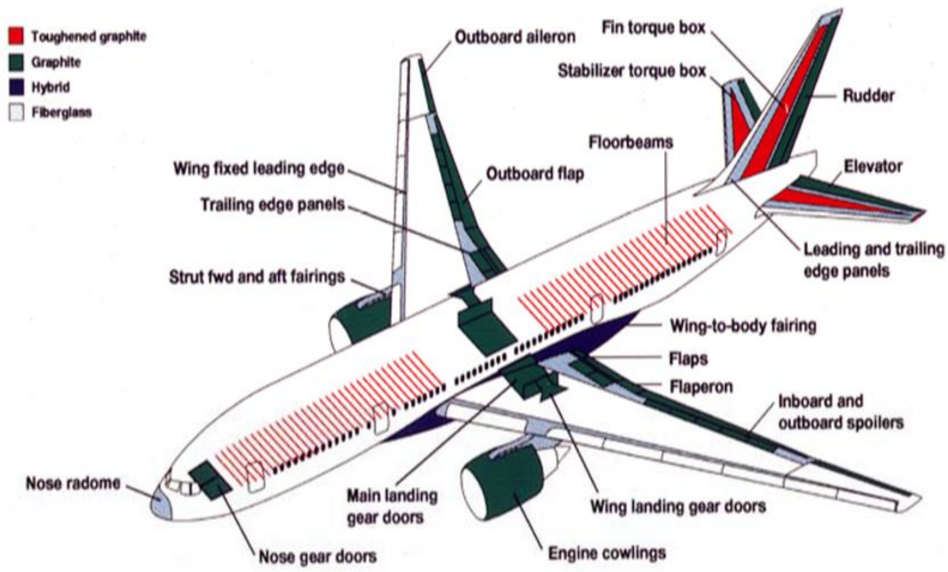

Figure-1.3. The usage areas of composite on Boeing 777 (Deo et al., 2001).

The findings obtained in the search can be listed as follows.

Padmavathi et al. (2008), in the study, Composite, which is reinforced with carbon fiber, is used as an aerospace material owing to material features such as high fracture toughness and strength. The problem is oxidation above six hundred centigrade in carbon composites. This issue solves by changing of carbon matrix with SiC. Also, this method is developed against oxidation resistance. A process is enhanced for fitting carbon fiber reinforced with SiC composite via solution application. This application allowed forming with high purity and fine-grained matrix in the fiber-reinforced composite materials. Moreover, composite materials' fracture energy and tensile strength were 0.74 Mj/m^3 at room temperature. Also, composite materials showed to be load carrying capacity after crack initiation.

Chia et al. (2018) showed in a conference article that the rapid conversion of the structural materials of airborne platforms from aluminum-based alloys to various composites has been a striking development in the aviation industry during the last few years.

Toensmeier (2005), in a study, indicated that the Boeing 787 would be fabricated the structure's 50 percent advanced composite such as carbon fiber and epoxy. This percentage is a greater ratio than in other commercial aircraft. In addition, Boeing and its manufacturers use fine-tuned assembly and manufacturing techniques to produce large composite parts cost-effective for the market. Also, it is combined with the performance and safety of the material. These features show to become the Boeing-787, an invention application that pushes requests for advanced composite into the mainstream of aircraft.

Kelkar & Williams (2002), in their research, fabric composites are replacing multi-directional laminates because of their properties in mutually orthogonal directions, better impact resistance, and more balanced properties. It is affordable, produced by SC-15 epoxy resin infusion or resin transfer molding, and utilizes graphite fibers. However, before these composites can be utilized in aircraft as load-carrying structures, these laminate's behavior is investigated and exposed to low-velocity impact loading. This research showed thin woven composites' damage and deformation mechanics exposed to low-velocity impact loading.

Industrial and academic researchers have recently focused on composites, improving the developing research field. For example, researchers are improving the properties of composite by adding filler materials to maximize their potential.

2. LITERATURE REVIEW

Fiber-reinforced composite can be obtained from different companies. Manufacturers are produced by methods such as hand lay-up and vacuum infusion depending on fiber direction, matrix type, orientation angle, and similar factors. Mechanical properties of the obtained composites and mechanical test equipment are detected. However, technological developments allow the improvement of the mechanical properties of existing composites. The development of nano and micro technology has allowed the addition of nano/micro-sized particles to the produced composites. Additional properties are added to the superior properties of the composites with the small-sized particles added. In the below paragraphs, the mechanical properties of fiber-reinforced composites improving the properties and bringing them into the final form are included (Bagatır, 2018).

Prasad et al. (2018) researched the effect of TiO_2 in improving the water absorption, mechanical and thermal properties of the flax fiber reinforced epoxy composites. TiO_2 improved the bending, tensile, impact, and interlayer shear strength values. The result showed significant development in the strength of the composite with the addition of TiO_2.

Naveen et al. (2019) aimed to investigate the tribological and mechanical features of nylon66 composites with TiO_2 at different volumes. Tensile, flexural, modulus, and compressive strength tests were used on specimens. The test results in the improvement of the composites' tribological, mechanical and thermal features with a decrease in coefficient of friction and wear rate up to 4 wt% of TiO_2 filled with the glass fiber. Furthermore, it was analyzed that at 2 wt% of TiO_2 filled with 2 wt% glass fiber, there is an effective improvement in tribological features with a reduction in coefficient of friction and wear rate.

Yetgin (2017), the mechanical properties such as impact and tensile of talc, polypropylene, and ethylene propylene diene monomer composite samples were researched in the study. For example, talc added to polypropylene polymer increased the tensile strength and modulus of elasticity while impact strength increased.

Topcu et al. (2020) showed the positive mechanical effect of using different concentration multi-wall carbon nanotubes in their article. Scanning electron microscopy (SEM) and X-ray diffraction (XRD) micrographs were utilized to determine the porosity, hardness, and density characteristics to observe if they are affected or not concerning the performance of composites in different reinforced % MWCNT rate conditions. Along with SEM and XRD studies, this was exhibited by a successive increase in hardness and abrasion resistance.

Mutlu, G. (2019) showed that to produce the graphene-based carbon fiber composites and characterize the advanced composites. Carbon fiber fabrics are manufactured by coating graphene film on carbon fiber fabric surfaces. The tensile tests showed that the tensile strength of the graphene film interleaved advanced composites compared to the control sample was increased.

Bagatır, T. (2018) showed that, Epoxy was mixed with 0%, 0.1%, 0.2%, 0.3%, 0.4%, 0.5% and 1% graphene. Composite specimens were tested by a universal tensile test. Tensile test results showed the maximum tensile strength in 0.2% graphene reinforced epoxy composite. Although 0.4% graphene reinforced fiber composites have the highest tensile strength, to compare 0.2% graphene reinforced fiber composite, it is understood to show no significant increase. The utilization of graphene positively affected the strength of the composite.

Karol, H. B. (2017), epoxy resin was used as the polymer in CFRP. Also, kaolin silicon carbide and magnesium silicate (talc) are preferred as additive materials. Although no action was taken to increase the wettability of the materials used as reinforcement, an enhancement was observed in the tensile and flexural strength values of magnesium silicate and kaolin-added carbon fiber composites.

Barut, E. (2016), zinc borate, antimony trioxide, and sodium borate were preferred as additive materials. The tensile test result showed that the ceramic additive that increased the tensile strength values more than the other additives was zinc borate. This was followed by sodium borate and antimony trioxide added samples, respectively.

Anaklı et al. (2018), in their study, that layered silicate clays such as the best-known montmorillonite among the inorganic powder materials, mica, hectorite, and talc, are preferred in composite preparation due to their large surface areas and layered structures suitable for nanocomposite preparation. Talc is an aqueous magnesium silicate. Talc has the chemical formula $Mg_3Si_4O_{10}(OH)_2$. Talc has a layered structure. Because the layers are held by weak Van der Waal's forces, it has weak shear stress. It can be easily dispersed in the polymer. Hence, talc is used as a filling material with various polymers. In addition, it has been observed that when used with polymers, it reduces the crystallization half-life, raises the crystallinity, and decreases the processing time. Due to talc's characteristics, researchers used talc to prepare nanocomposites with different insulating polymers. Talc/polypropylene nanocomposite show both mechanical and thermal properties development.

Wang et al. (2015), carbon nanotubes (CNTs) and graphene nanoplatelets (GNPs) have cost-effectiveness and high strength properties. An effect on the multi-walled- carbon nanotubes (CNTs) and graphene nanoplatelets (GNPs) were used to reinforce epoxy composite and epoxy/carbon fiber composite laminates to improve their mechanical properties. The mechanical properties of epoxy/carbon fiber composite laminates containing different proportions of CNTs/GNPs hybrids (0.5, 1.0, 1.5wt%) were increased over that of unreinforced laminates. Consequently, significant improvement in the mechanical properties was attained for these epoxy resin composites and carbon fiber-reinforced epoxy composite laminates.

2.1. The Classification of Composite Materials

Metals, plastics, and ceramics are utilized as a matrix in the composite. Due to the matrix material to be used, the composites are classified as follows.

2.1.1. Polymer matrix composites (PMCs)

Polymers are cured by cross-linking from a thermosetting three-dimensional network and long chain molecules. The fabrication of composites at pressures and low temperatures has great advantages (Baker, 2004).

Mallick (2008) showed that a polymeric material, which is called plastic, is a total of a large number of polymer molecules of similar chemical structure.

Thermosetting materials have low failure tension generally. Delamination, which is ply separation and weak resistance to mechanical impact damage, will take place and may cause thickness stresses. Thus, it absorbs moisture from the air. This reason will cause to reduce matrix-dominant features such as high-temperature cutting and compression strength. Current improvements are more resistant to moisture, modifications in resin chemistry, and harder polymeric systems, including thermoplastics. It has been produced in more rigid thermosetting systems through alloying (Baker, 2004).

Thermoplastic polymers, which are meltable linear (not cross-linked), and reformable, can be used as a matrix. Polyetheretherketone (PEEK) polymers are used in aircraft applications up to one hundred and twenty centigrade, and polyetherketone (PEK) is up to one hundred and forty-five centigrade thermoplastic polymers that can be applied for their high-performance properties. In addition, thermoplastic polymers, which are more resistant to malfunction and can face extensive deformations, can use (Baker, 2004).

2.1.2. Ceramic matrix composites (CMCs)

Mohammad et al. (2017) showed that ceramic matrix composites had improved thermal and mechanical features. It has lots of overcomes properties such as the monolithic ceramic (i.e., toughness) boundary and advantages. CMC is found in the aircraft’s turbine discs and the hot section of the aircraft’s aero engines. It contains flammable linear and turbine aerofoils.

2.1.3. Metal matrix composites (MMCs)

It consists of nitride, oxide, or carbide reinforced titanium or an aluminum matrix. They have lots of advantages over monolithic materials. The production of these materials is not expensive. It uses rotor blades of helicopters and turbine blades. It can expose to high weight, such as floor supports (Mohammad et al., 2017).

2.2. Reinforcement Elements

2.2.1. Fiber reinforced composites (Single layer composites)

Composite materials are made of high-strength fibers. The matrix structure consists of fine fibers. A significant feature is that the presence of fibers in the matrix affects the strength of the composite. Placing long fibers parallel to each other generally provide high fiber strength. Conversely, the perpendicular direction of the fiber provides low strength. Therefore, fiber reinforcements are positioned two-dimensional to ensure uniform strength in both directions. Short fibers, distributed in the matrix structure homogeneously, showed that it is possible to form an isotropic structure (Zor, 2018).

2.2.1.1 Carbon fiber

Walsh's (2001) comparison of composites made of carbon fibers with other structural materials that it is five times stronger than grade 1020 steel yet five times lighter. It is seven times harder and twice as rigid as 6061 aluminum alloy, yet 1.5 times lighter. In addition, carbon fiber composites become one of the most corrosion resistant materials when combined with suitable resins (Bagatır, 2018).

Figure 2.1. The carbon fiber fabric.

2.2.1.2 Aramid fiber

Chang (2001), aramid fiber, also known as kevlar, was first used to reinforce plastics and tires. If we refer to the material properties, lightweight and high strength are its distinctive features. Because of these properties, aramid fibers have been used in ropes, cables, and tires (Bagatır,2018).

Figure 2.2. The aramid fiber fabric (Bagatır,2018).

2.2.1.3 Glass fiber

Wallenberger et al. (2001), glass fibers have taken their place among industrial materials because they are economical. Glass fiber exhibits mechanical properties such as resistance to environmental influences and flexibility. Therefore, structural composites are used to manufacture special-purpose products (Bagatır,2018).

Figure 2.3. The glass fiber fabric (Yıldız, 2018).

2.2.2. Particle composites

The matrix is provided by the presence of other material in the form of particles. The structure is isotropic. Because of isotropic structure, they show the same material behavior in all directions. The hardness of the particle shows the strength of the structure. Particle and matrix are insoluble in each other (macro link), the most utilized type of plastic matrix with metal particles. Metal particles ensure thermal and electrical conductivity. Metal matrix structure includes ceramic particles. Ceramic particles have high- temperature resistance and high hardness. The production of aircraft engine parts use. Composite, which is the particle size at the nanometer level, are called nanocomposites (Zor, 2018).

2.2.3. Laminated composites

Matrix and the more durable fiber materials are manufactured in a composite layer (lamina). Then, more than one layer is produced by combining laminated composite materials. They are called to depend on the matrix type, the fiber mesh shape, or the fiber material. The direction of the fibers can show differences between layers. The application area in the industry has a wide range. It is a laminated composite material in sandwich structures which used in aircraft structures. Sandwich structures are obtained by bonding the low and high surfaces of a low-density core material with only isolation property (Zor, 2018).

2.2.4. Sandwich composites

Sandwich composites are produced by placing a different material in a different form between the two layers. Fiber reinforced or each isotropic material can be used as a layer (Zor, 2018).

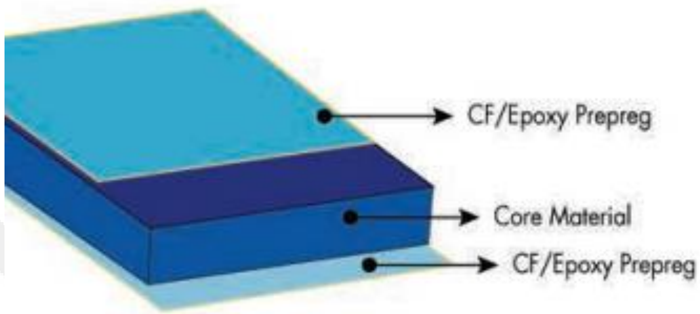

Figure 2.4. The sandwich composite (Kordsa, 2022).

2.3. The Advantages & Disadvantages of Composite in The Aviation Industry

Composite material is used in commercial, marine, aerospace, industrial and recreational. Advanced composite is stainless, but metals rust. Fatigue and corrosion are significant subjects for aluminum fuselage structures. Composites have advantages in the defense and aerospace industry. The advantage of fuel efficiency acquired by an aircraft is getting increasingly important with expensive fuel costs. The advantages are perfect fatigue, corrosion resistance, and impact resistance. The market composite has an annual growth rate of 7.3 percent, which will rise to $30 billion by 2026 (Mrazova, 2013).

2.3.1. Advantages of composite material

- Weight reduction - it saves in the range of 20 percent – 50 percent.
- The composite material's mechanical properties can be tailored.
- Improved impact resistance - kevlar armor (aramid) shields in aircraft. To illustrate, it decreases the damage of accidents the engine pylons which carry the lines of fuel and engine's control.

- The high damage tolerance increases the accident survivability.
- Galvanic – corrosion and electrical problems occur when the two different metals' contact is not avoided. Non-conductive fiber glasses play a role in this problem.

2.3.2. Disadvantages of composite material

- High material costs.
- The damage of non-visible impact.
- The repairment method is dissimilar to other structures.
- Isolation needs to get ahead of the used adjoining the galvanic corrosion aluminum part.

The composite, which is a lighter material, maximizes the reduction of weight. They are twenty percent lighter than aluminum. Composites are safer than conventional metallic materials. The aircraft maintenance expenses and the number of inspections decreased (Mrazova, 2013).

2.4. Production Methods of Carbon Fiber Composites

2.4.1. Hand lay-up method

The manual lay-up method produces fiber-reinforced thermoset composites on a mold with hand or hand-held tools. It can be used with any type of fiber reinforcement and all liquid thermosetting resins below room temperature. Molds can be plaster, wood, or metal (Bartın University, 2022). First, the fabrics are placed on the mold by hand. Then a resin-impregnated wetted to fabrics with a brush. In this way, it is aimed that the resin penetrates into the fibers. Contrary to the spray-up method, using the fibers without clipping provides better mechanical properties. The mixing ratio of the resin affects the quality of the produced composite (Ömerciklioğlu, 2009).

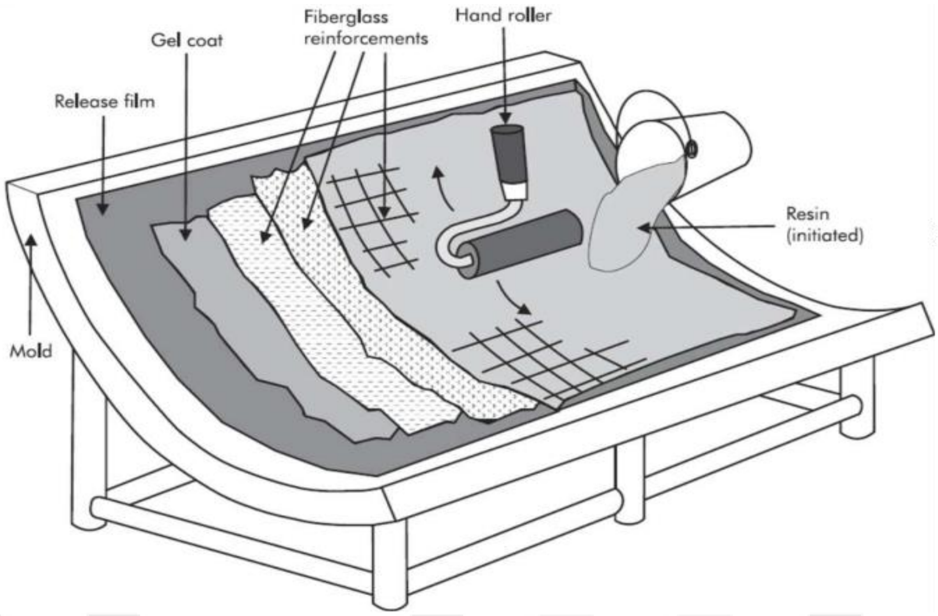

Figure 2.5. The hand lay-up methods (Bartın University, 2022).

2.4.2. Spray-up method

It is a production method by spraying a mixture of fiber parts and resin on the mold. In the production method, a spray gun is used. The fibers are used by cutting inside the spray gun. After spraying, the surface is smoothed with a roller and left to dry. Low-density resin is used for spraying the cut fibers. In addition, since the sprayed fibers are very dense in terms of resin, the produced part is heavier than other manufacturing methods (Ömercikli̇oğlu, 2009).

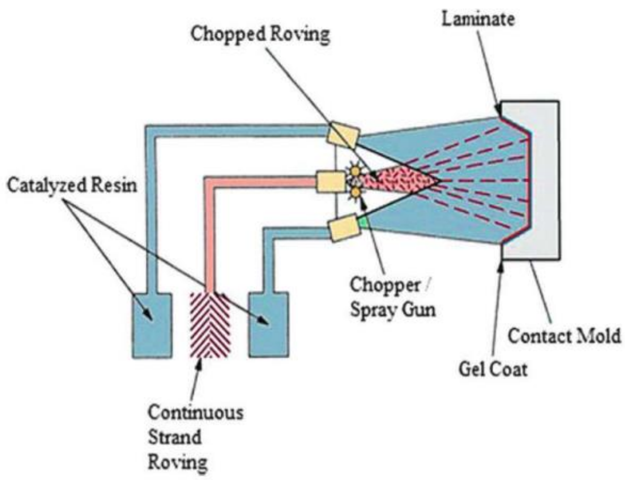

Figure 2.6. The spray-up methods (Bartın University, 2022).

2.4.3. Resin transfer molding

The fiber fabric is placed as in Figure 2.7. Resin is started to be given by pressure from the hole on the one side of the molds. In some applications, a vacuum is also applied through the hole on the other side of the molds so that the fabrics absorb the resin more smoothly. After all the fabrics are wetted, the resin-giving and vacuuming processes are stopped. Then, the resin is allowed to dry. This resin transfer molding method is preferred in parts where the lower and upper surfaces are desired to be smooth (Ömerciklioğlu, 2009).

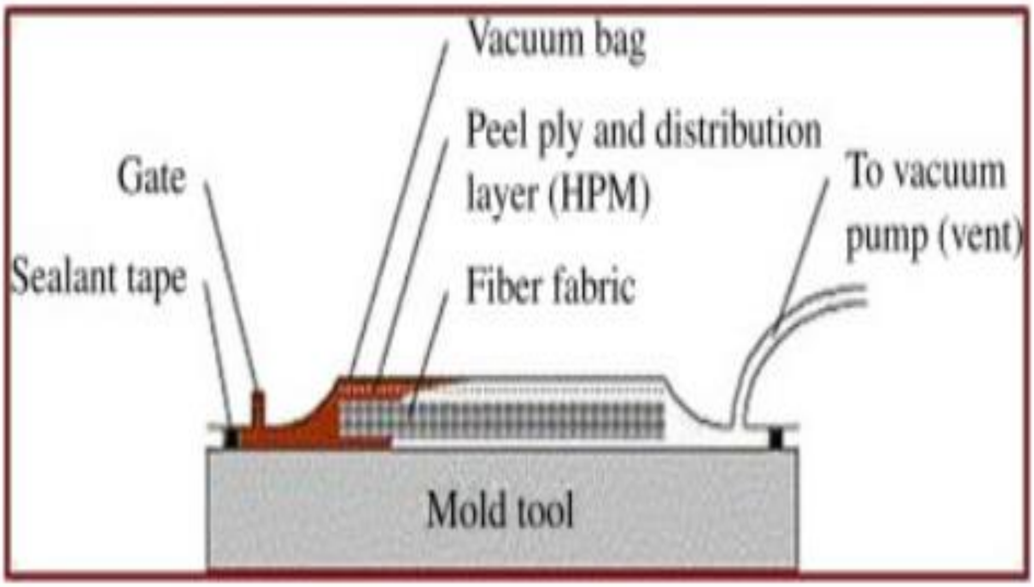

Figure 2.7. The resin transfer molding methods (Rout et al., 2021).

2.4.4. Prepreg

Prepregs are ready tapes that are made of fibers in a polymer matrix. Whether the polymer matrix is thermoset or thermoplastic, they are kept in the refrigerator or at room temperature. These tapes can be used in layers to obtain a composite structure. Vacuuming and curing can be done at high pressure and temperature. It is a resin fiber, fabric, or felt produced for use in prepreg hand lay-up and molding processes. The advantages of prepregs over metals materials are higher strength, rigidity, corrosion resistance, and rapid production. The disadvantage of the prepreg is the high cost (Baydar, 2011).

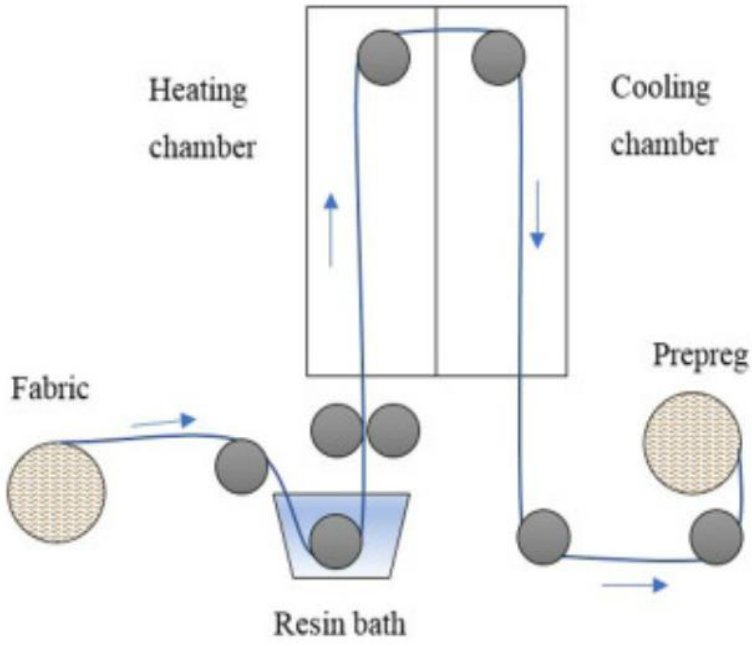

Figure 2.8. The production of prepreg (Jabber and Nasreen, 2021).

3. MATERIALS AND PROCESS

3.1. Preparation of Tensile Test Specimens by Hand Lay-up Method

Carbon fiber fabric and Fibermak F-3486 activator, and Fibermak F-1564 resin were used for the production of carbon fiber reinforced epoxy matrix composites. The provided carbon fibers have a density of 240 gr/m^2. The provided carbon fiber is shown in figure 3.1. and the epoxy and hardener figure 3.2.

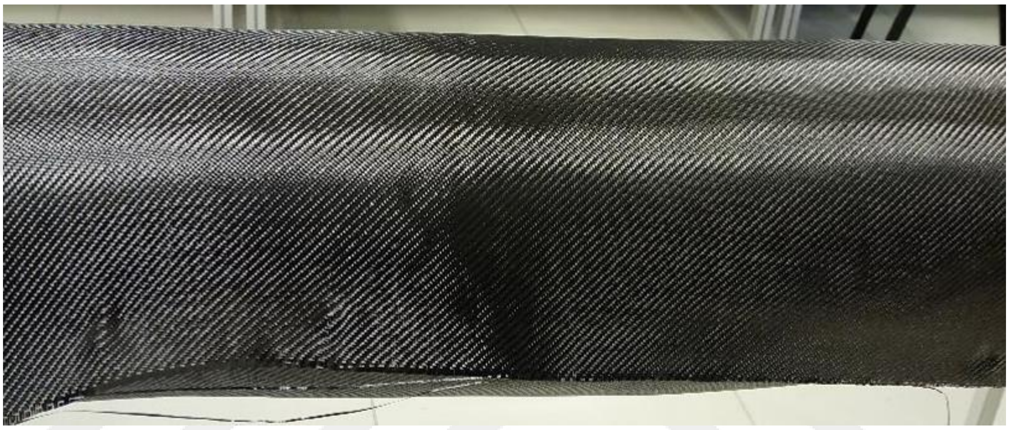

Figure 3.1. Carbon fiber fabric.

Figure 3.2. Fibermak F-1564 resin and Fibermak F-3486 activator (Fibermak, 2022).

The appearance of talc, which is one of the reinforcement materials used in this study at 0.5, 1, 2, and 4 wt%, is shown in figure 3.3.

Figure 3.3. Talc material as a reinforcement element.

Talc is a raw material used in many industrial products such as cosmetics, pharmaceuticals, pesticides, paper, paint, food, plastics, ceramics, and textiles (Ersoy et al., 2013).

Talc was provided by Omnis composite company. Chemical properties of talc materials is that MgO 32%, SIO_2 62%, CaO 1,8max%, Al_2O_3 0,3%, Fe_2O_3 0,6% max. Physical properties are density (ISO 787/10) and 2,73gr/ml hardness. There are some general properties of talc. For instance, Largest Grain ((average grain diameter) 99 %) is 23,7 μm. Also, average grain large ((average grain diameter) 50 %) is 4,52 μm and pH 8,2.

The appearance of TiO_2, which is one of the reinforcement materials used in this study at 0.5, 1, 2, and 4 wt%, is shown in figure 3.4.

Figure 3.4. TiO_2 material as a reinforcement element.

TiO_2, which is a known material, is widely used. Its electronic and structural properties make it extensively used. For instance, TiO_2 can be seen in the ingredients of paint. TiO_2 prevents ultraviolet. Because of this feature, it is used for sunscreen products. TiO_2 is also present in coatings and plastics, especially for external uses as an ultraviolet light barrier, where the aging effect of light must be minimized (Korotcenkov, 2020).

TiO_2 was provided by Omnis composite company - Dupont. The properties of TiO_2 are wt%, min. 93, specific gravity 4, bulking value, L/kg (gal/lb) is 0.25 (0.03), pH 7.9, resistance at 30°C (86°F) (1,000 ohm) 8.1 and carbon black undertone 11.7.

Carbon Fiber fabric was cut to 360 mm long and 330 mm wide, such as in figure 3.5.

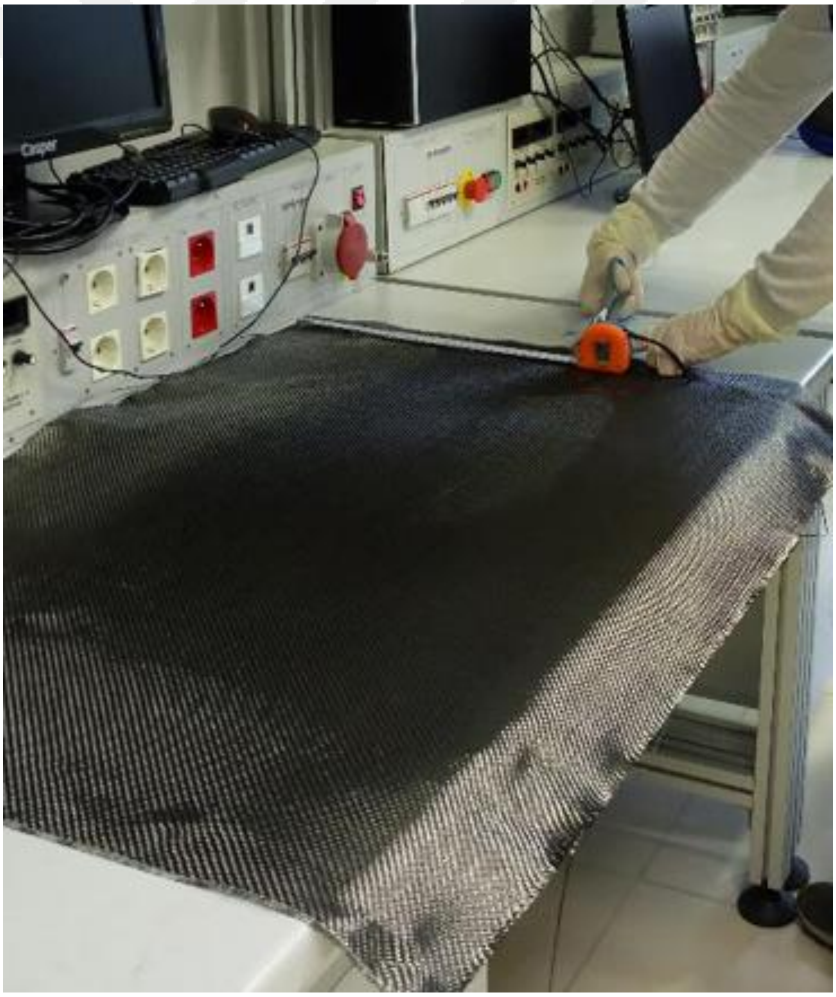

Figure 3.5. The carbon fiber fabrics were cut for composite.

Mold-release wax has been applied to the surface, as seen in figure 3.6.

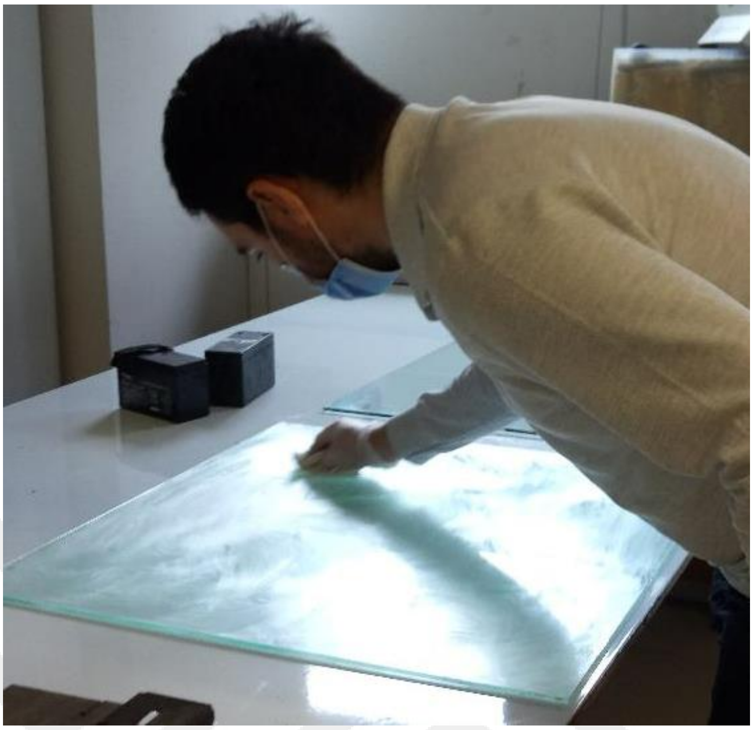

Figure 3.6. The application of mold release wax.

Epoxy and activator were weighed on a precision balance and used at a rate of 66% and 34%, respectively.
Then, the epoxy and activator were mixed for 20 min, as in figure 3.7.

Figure 3.7. The mixing process.

Figure 3.8. Hand lay-up application.

Composite was produced by hand lay-up production method of carbon fiber and epoxy and left to cure at room temperature.

3.1.1. Fabrication of the unreinforced/reinforced with talc and TiO_2 of carbon fiber composites

The Carbon Fibers were cut 330 mm wide by 360 mm long. Resin and activator reinforcement were weighed 34% to 66% on a precision balance. After mixing the epoxy, carbon fiber reinforced polymer composites consisting of 6 layers were produced by hand lay-up on carbon fiber fabrics cut in 330 mm x 360 mm dimensions. Then, the same process was repeated by adding 0.5, 1, 2, and 4 wt% Talc and TiO_2 to the epoxy material. As a result, talc-reinforced CFRP composites and TiO_2-reinforced CFRP composites were produced.

Figure 3.9. The carbon fiber composite.

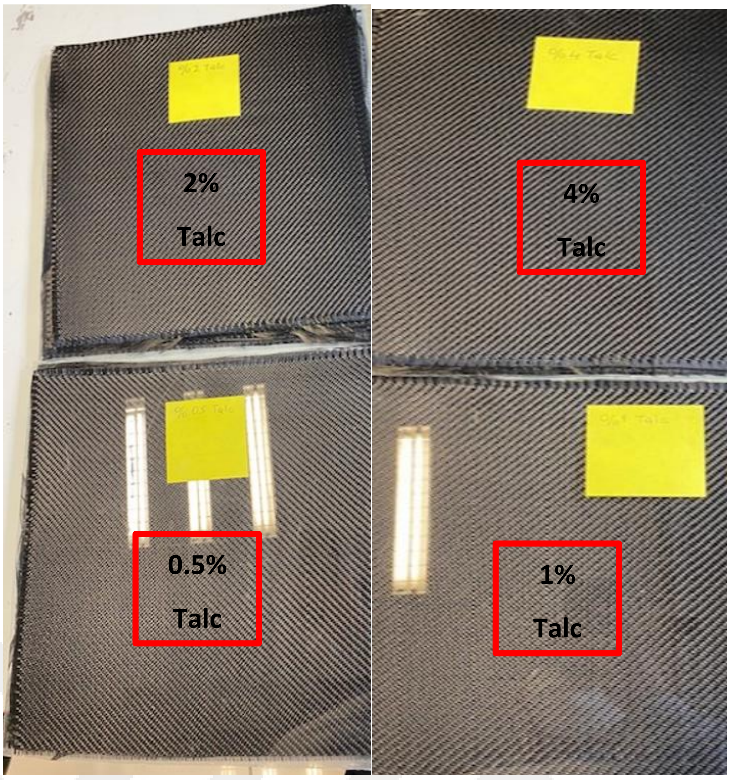

Figure 3.10. The talc reinforced carbon fiber composite.

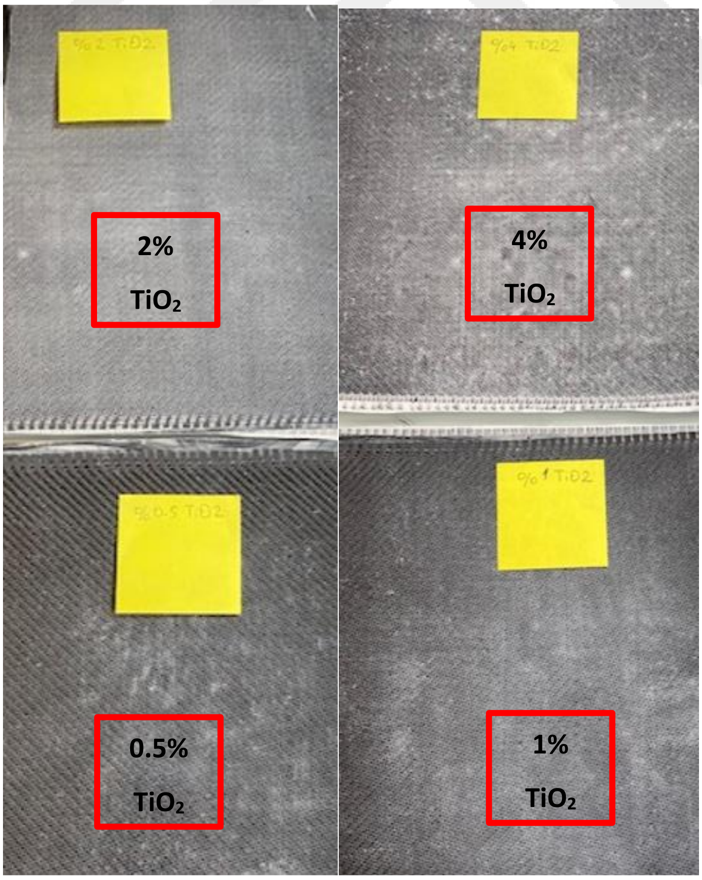

Figure 3.11. The TiO_2 reinforced carbon fiber composite.

3.1.2. The process of tensile test

The produced carbon fiber (unreinforced)/carbon fiber with talc reinforced (0.5, 1, 2 and 4 wt%)/ carbon fiber with TiO_2 reinforced (0.5, 1, 2 and 4 wt%) composite specimens were prepared in ASTM D3039 requirements. Test specimens were designed with AutoCAD. The dimensions of the specimen used for the tensile test specimen are shown in the technical drawing view Figure 3.12. Test specimens having dimensions of a length of 250 mm, and a width of 25 mm were prepared for tensile testing. Then, the test specimens, as per the required shape, were cut with the water jet. Figure 3.13. shows the water jet cutting machine. Figure 3.14. shows the water jet cutting process.

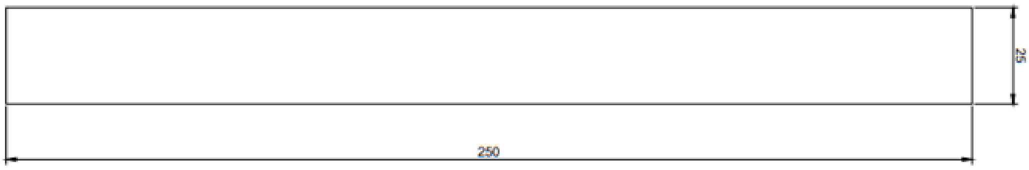

Figure 3.12. The technical drawing of test specimens (in mm).

Figure 3.13. The water jet cutting machine.

Figure 3.14. The water jet cutting of specimens.

A total of 18 test specimens were obtained, two of each extracted from unreinforced, talc reinforced (0.5, 1, 2, and 4 wt%) and TiO_2-reinforced (0.5, 1, 2, and 4 wt%) plates. It is essential that the material information of the test samples is determined precisely as a result of the tensile test. Therefore, to obtain more accurate results, the dimensional properties of each test sample were measured separately. For this task, each test sample is given a name.

Figure 3.15. The carbon fiber composite.

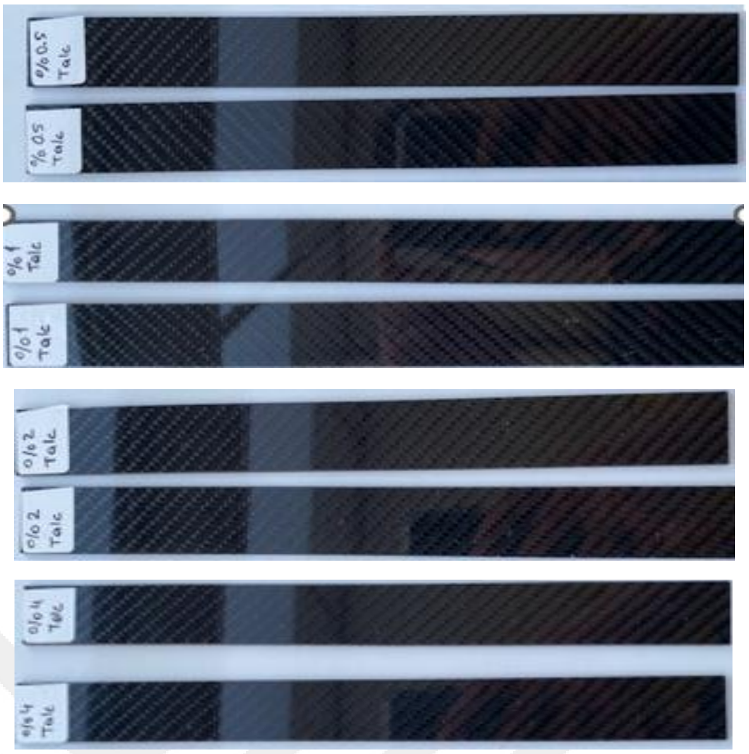

Figure 3.16. The carbon fiber composite with talc reinforced (0.5, 1, 2, 4 wt%).

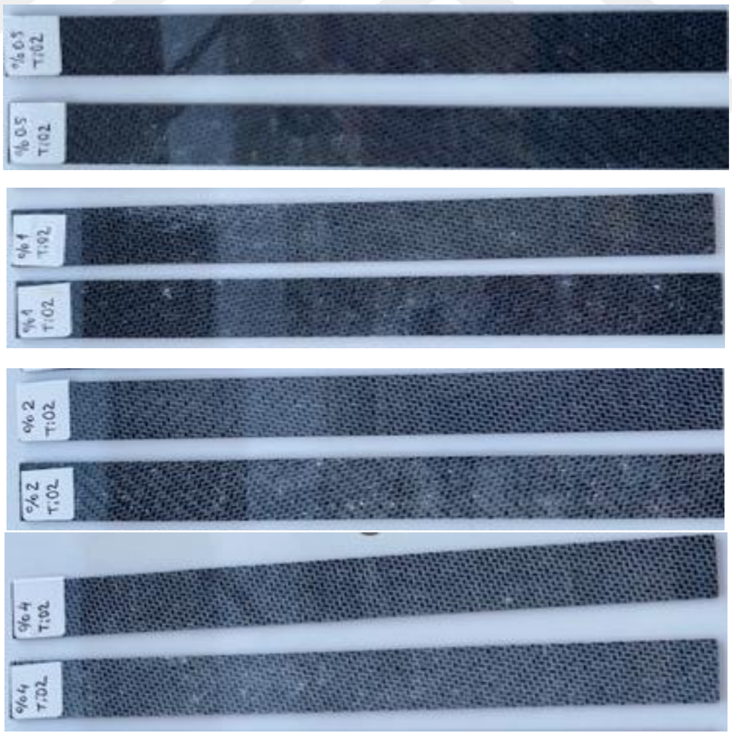

Figure 3.17. The carbon fiber composite with talc reinforced (0.5, 1, 2, 4 wt%).

The composite specimens were tested using a Teskon tensile test machine. Tensile tests were done at the speed of 2 mm/min. Each specimen was placed between the grips of the Teskon tensile machine. The tensile test machine has both a stationary gripper and a movable gripper. The material tensile test result was recorded instantly by the test machine. Then, the results were given as a stress-strain curve by the computer. Figure 3.18 shows the image of tensile testing of the samples.

Figure 3.18. The Teskon tensile test machine.

4. THE RESULT AND DISCUSSIONS OF THE TENSILE TEST

In the study, composite materials were produced by adding varying amounts of TiO_2 and talc to Fibermak brand F-1564 resin and F-3486 activator. The effect of TiO_2 and talc reinforcement ratio on the tensile strength of the produced composite materials was determined with a Teskon test device. The results obtained from the tensile tests performed were analyzed.

4.1. The Result of Tensile Test for Carbon Fiber Composites

The result of the tensile test applied to the CFRP composite without TiO_2 and talc reinforcement, the stress-strain graph, is given in figure 4.1. and figure 4.2. Tensile test results of CFRP composite without TiO_2 and talc reinforcements are 332 MPa and 327 MPa.

Firma	CARBON FİBER EPOKSİ	TestDate	5/12/2022
SARJ	-	MODEL	0
Type	Flat	Operator	-
Rm(MPa)	332		

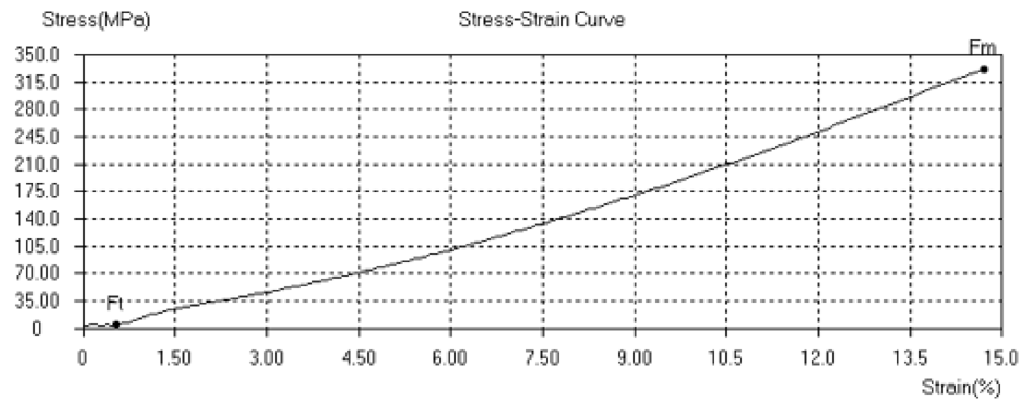

Figure 4.1. Specimen 1, the stress-strain graph of CFRP composite

Firma	CARBON FİBER EPOKSİ	TestDate	5/12/2022
SARJ	-	MODEL	0
Type	Flat	Operator	-
Rm(MPa)	327		

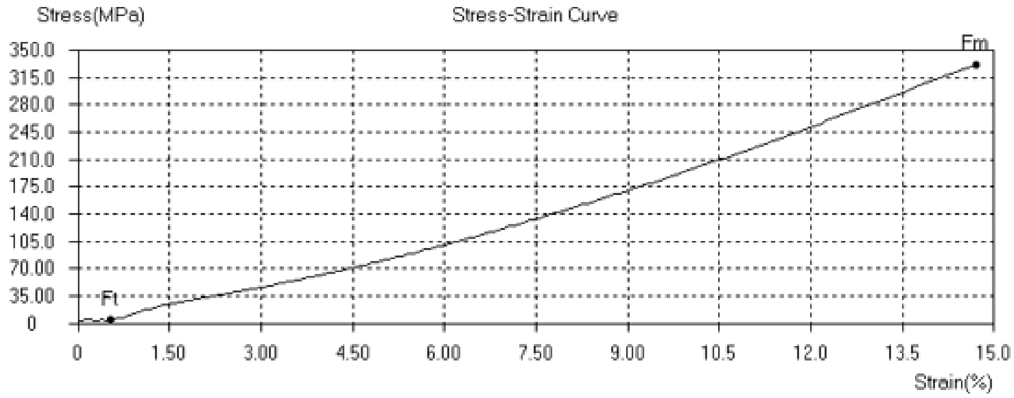

Figure 4.2. Specimen 2, the stress-strain graph of CFRP composite

4.2. The Result of Tensile Test for Carbon Fiber Composites Reinforced with TiO_2

The result of the tensile test applied to the 0.5 wt % TiO_2 reinforced CFRP composite, the stress-strain graph, is given in figure 4.3. and figure 4.4. Tensile test results of 0.5 wt % TiO_2 reinforced CFRP composites are 333 MPa and 342 MPa.

Firma	CARBON FİBER EPOKSİ-	TestDate	5/12/2022
SARJ	TİO2-0.5	MODEL	0
Type	Flat	Operator	-
Rm(MPa)	333		

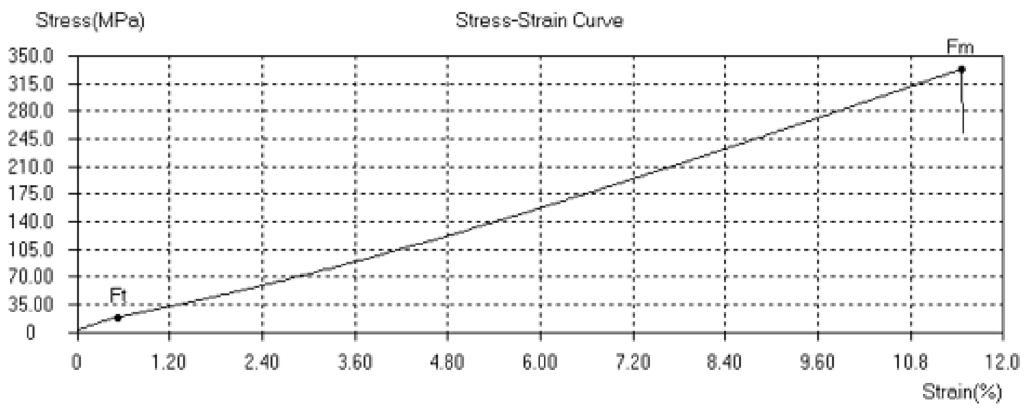

Figure 4.3. Specimen 1, the stress-strain graph of 0.5 wt % TiO_2 reinforced CFRP.

Firma	CARBON FİBER EPOKSİ-	TestDate	5/12/2022
SARJ	TİO2-0.5	MODEL	0
Type	Flat	Operator	-
Rm(MPa)	342		

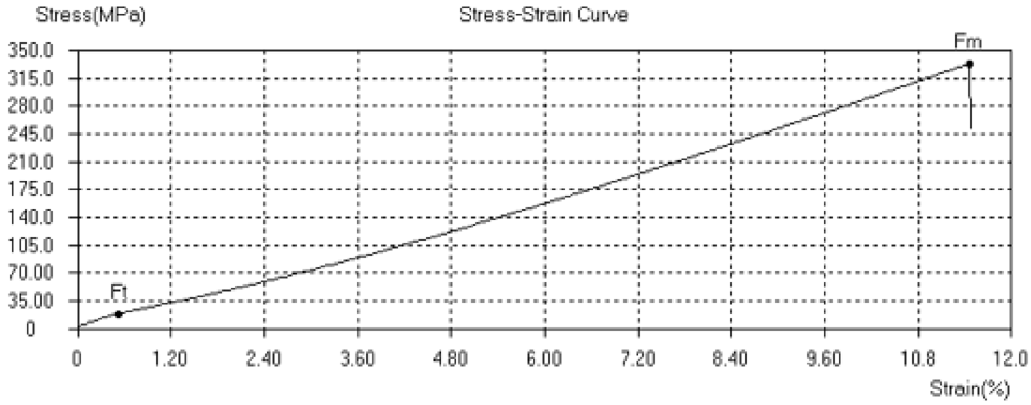

Figure 4.4. Specimen 2, the stress-strain graph of 0.5 wt % TiO_2 reinforced CFRP.

The result of the tensile test applied to the 1 wt % TiO_2 reinforced CFRP composite, the Stress-Strain graph, is given in figure 4.5. and figure 4.6. Tensile test results of 1 wt % TiO_2 reinforced CFRP composites are 394 MPa and 382 MPa.

Firma	CARBON FİBER EPOKSİ-	TestDate	5/12/2022
SARJ	TİO2-1	MODEL	0
Type	Flat	Operator	-
Rm(MPa)	394		

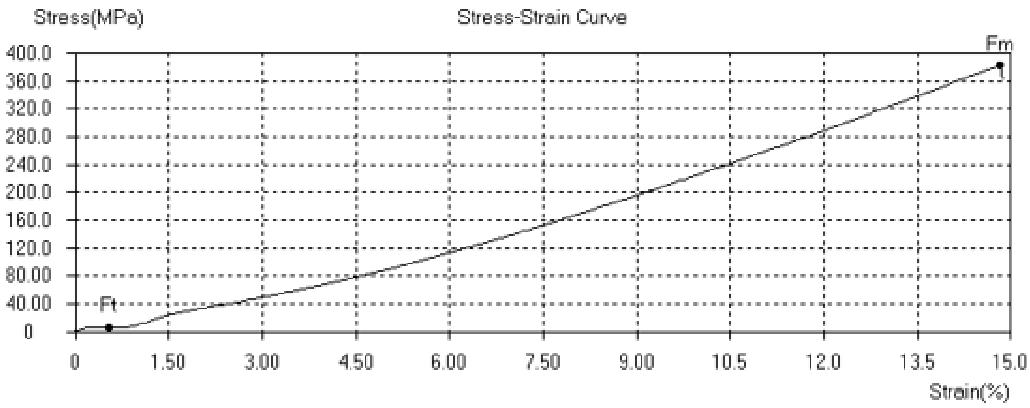

Figure 4.5. Specimen 1, the stress-strain graph of 1 wt % TiO_2 reinforced CFRP.

Firma	CARBON FİBER EPOKSİ-	TestDate	5/12/2022
SARJ	TİO2-1	MODEL	0
Type	Flat	Operator	-
Rm(MPa)	382		

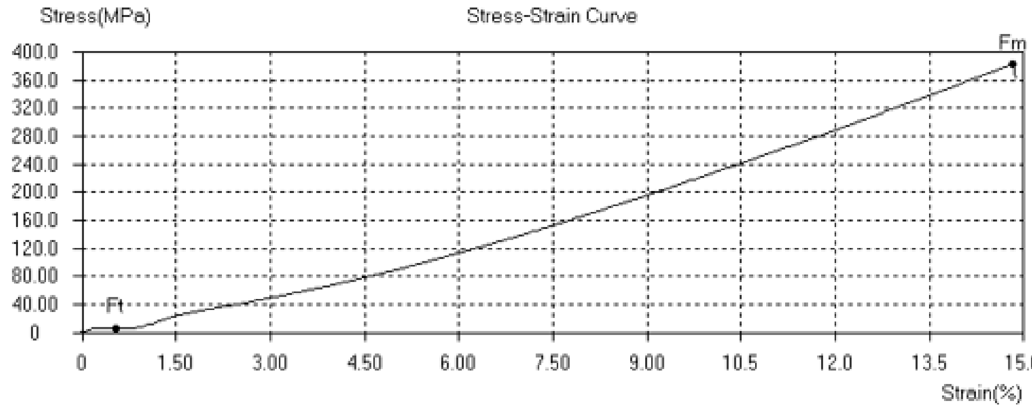

Figure 4.6. Specimen 2, the stress-strain graph of 1 wt % TiO_2 reinforced CFRP.

The result of the tensile test applied to the 2 wt % TiO_2 reinforced CFRP composite, the Stress-Strain graph, is given in figure 4.7. and figure 4.8. Tensile test results of 2 wt % TiO_2 reinforced CFRP composites are 333 MPa and 325 MPa.

Firma	CARBON FİBER EPOKSİ-	TestDate	5/12/2022
SARJ	TİO2-2	MODEL	0
Type	Flat	Operator	-
Rm(MPa)	333		

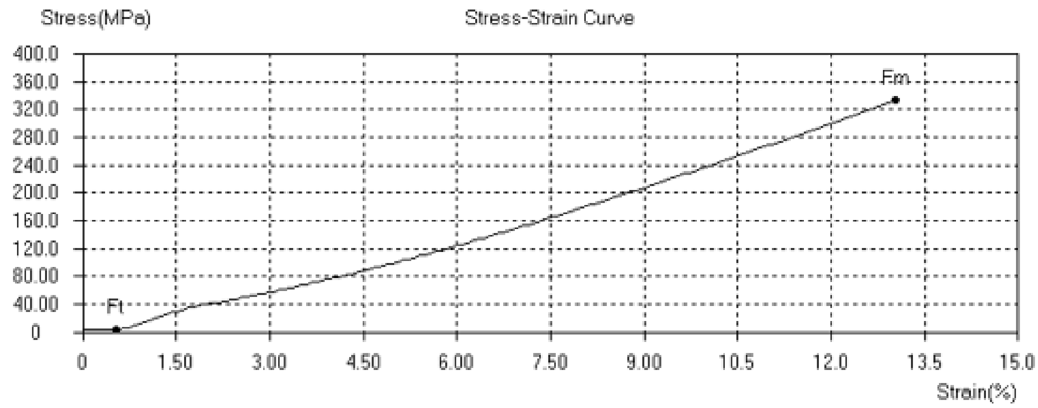

Figure 4.7. Specimen 1, the stress-strain graph of 2 wt % TiO_2 reinforced CFRP.

Firma	CARBON FİBER EPOKSİ-	TestDate	5/12/2022
SARJ	TİO2-2	MODEL	0
Type	Flat	Operator	-
Rm(MPa)	325		

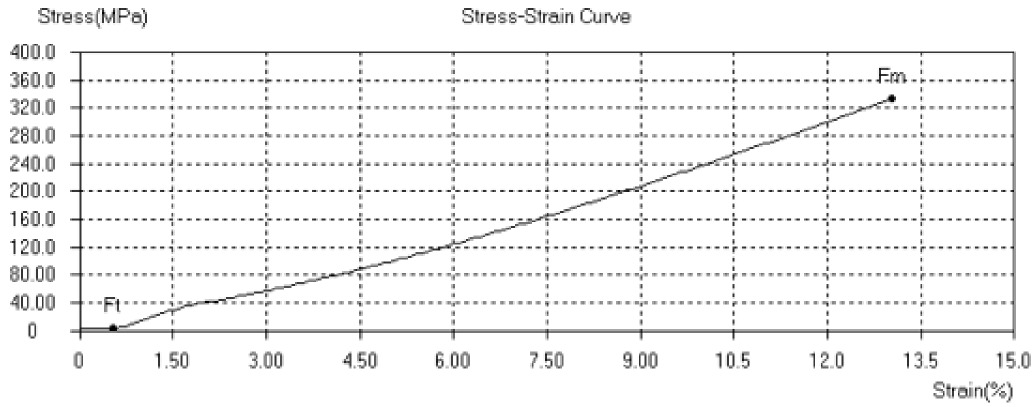

Figure 4.8. Specimen 2, the stress-strain graph of 2 wt % TiO_2 reinforced CFRP.

The result of the tensile test applied to the 4 wt % TiO_2 reinforced CFRP composite, the Stress-Strain graph, is given in figure 4.9. and figure 4.10. Tensile test results of 4 wt % TiO_2 reinforced CFRP composites are 346 MPa and 345 MPa.

Firma	CARBON FİBER EPOKSİ-	TestDate	5/12/2022
SARJ	TİO2-4	MODEL	0
Type	Flat	Operator	-
Rm(MPa)	346		

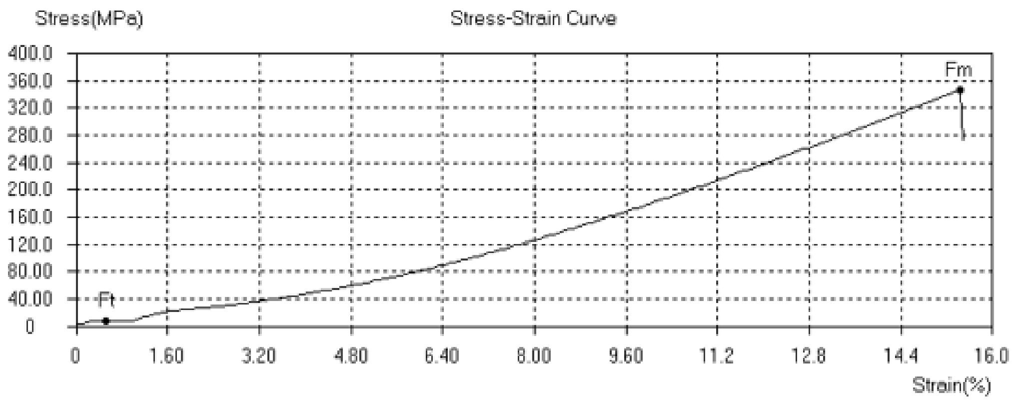

Figure 4.9. Specimen 1, the stress-strain graph of 4 wt % TiO_2 reinforced CFRP.

Firma	CARBON FİBER EPOKSİ-	TestDate	5/12/2022
SARJ	TiO2-4	MODEL	0
Type	Flat	Operator	-
Rm(MPa)	345		

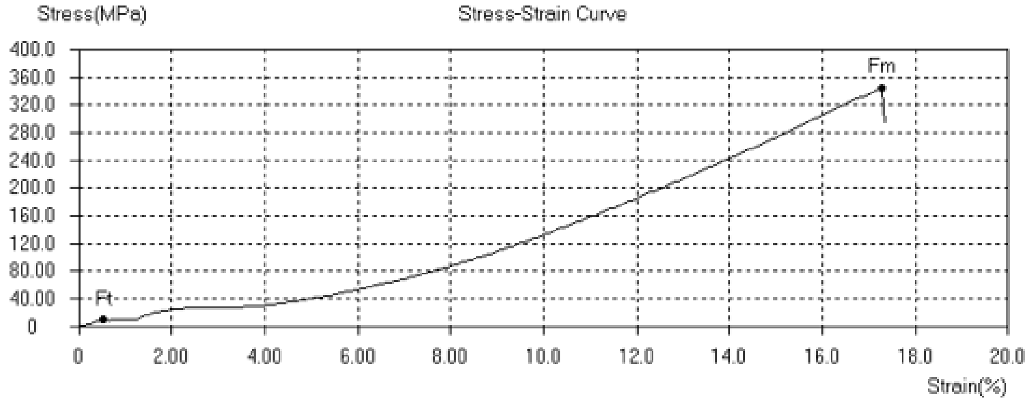

Figure 4.10. Specimen 2, the stress-strain graph of 4 wt % TiO_2 reinforced CFRP.

4.3. The Result of Tensile Test for Carbon Fiber Composites Reinforced with Talc

The result of the tensile test applied to the 0.5 wt % talc reinforced CFRP composite, the Stress-Strain graph, is given in figure 4.11. and figure 4.12. Tensile test results of 0.5 wt % talc reinforced CFRP composites are 373 MPa and 411 MPa. These values are the optimum values for the study.

Firma	CARBON FİBER EPOKSİ-	TestDate	5/12/2022
SARJ	TALC-0.5	MODEL	0
Type	Flat	Operator	-
Rm(MPa)	373		

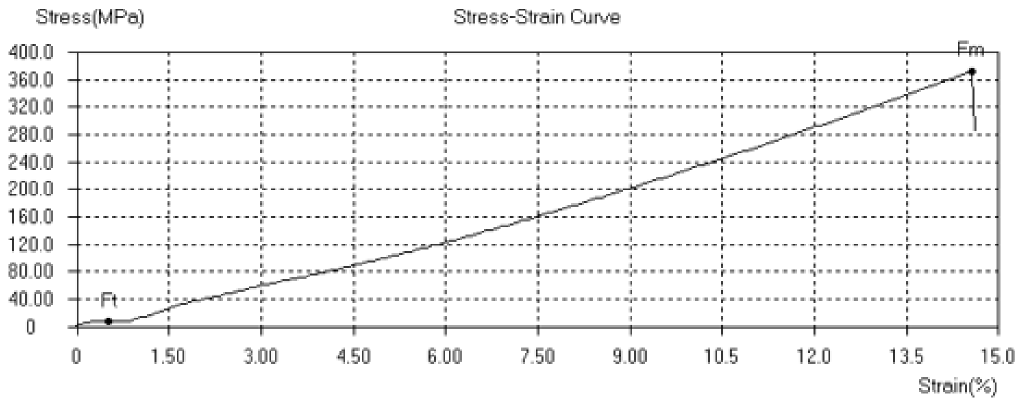

Figure 4.11. Specimen 1, the stress-strain graph of 0.5 wt % talc reinforced CFRP.

Firma	CARBON FİBER EPOKSİ-	TestDate	5/12/2022
SARJ	TALC-0.5	MODEL	0
Type	Flat	Operator	-
Rm(MPa)	411		

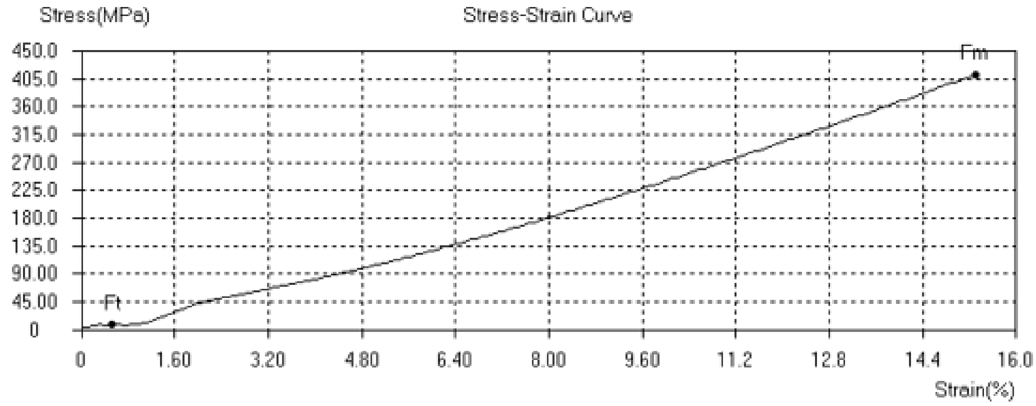

Figure 4.12. Specimen 2, the stress-strain graph of 0.5 wt % talc reinforced CFRP.

The result of the tensile test applied to the 1 wt % talc reinforced CFRP composite, the Stress-Strain graph, is given in figure 4.13. and figure 4.14. Tensile test results of 1 wt % talc reinforced CFRP composites are 393 MPa and 373 MPa.

Firma	CARBON FİBER EPOKSİ-	TestDate	5/12/2022
SARJ	TALC-1	MODEL	0
Type	Flat	Operator	-
Rm(MPa)	393		

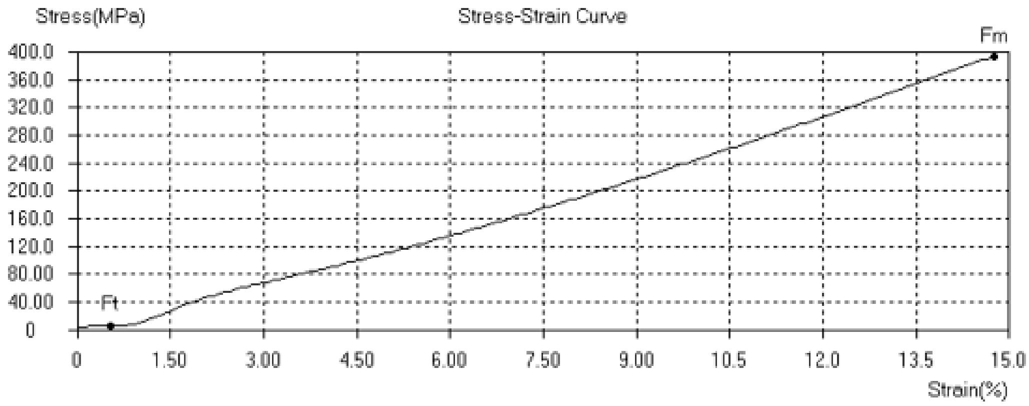

Figure 4.13. Specimen 1, the stress-strain graph of 1 wt % talc reinforced CFRP.

Firma	CARBON FİBER EPOKSİ-	TestDate	5/12/2022
SARJ	TALC-1	MODEL	0
Type	Flat	Operator	-
Rm(MPa)	373		

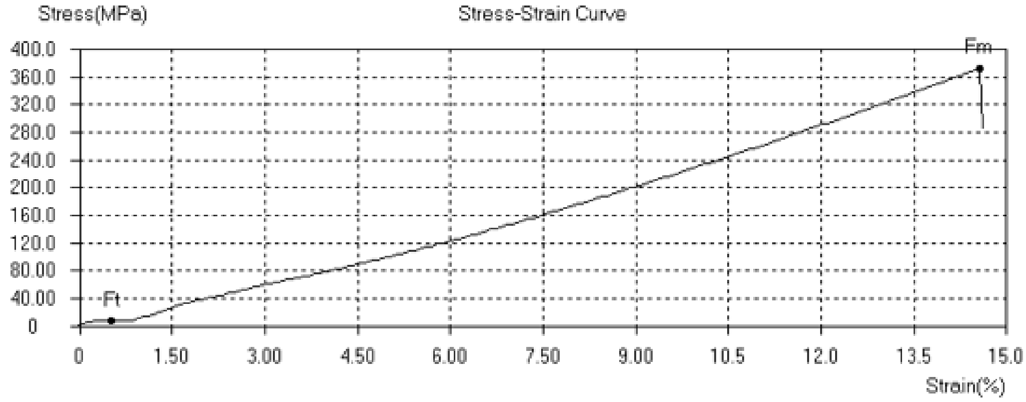

Figure 4.14. Specimen 2, the stress-strain graph of 1 wt % talc reinforced CFRP.

The result of the tensile test applied to the 2 wt % talc reinforced CFRP composite, the Stress-Strain graph, is given in figure 4.15 and figure 4.16. Tensile test results of 2 wt % talc reinforced CFRP composites are 365 MPa and 372 MPa.

Firma	CARBON FİBER EPOKSİ-	TestDate	5/12/2022
SARJ	TALC-2	MODEL	0
Type	Flat	Operator	-
Rm(MPa)	365		

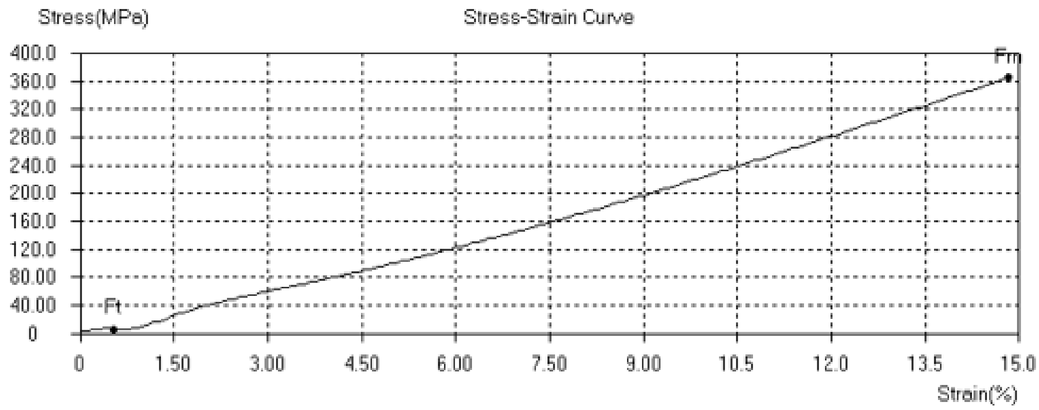

Figure 4.15. Specimen 1, the stress-strain graph of 2 wt % talc reinforced CFRP.

Firma	CARBON FİBER EPOKSİ-	TestDate	5/12/2022
SARJ	TALC-2	MODEL	0
Type	Flat	Operator	-
Rm(MPa)	372		

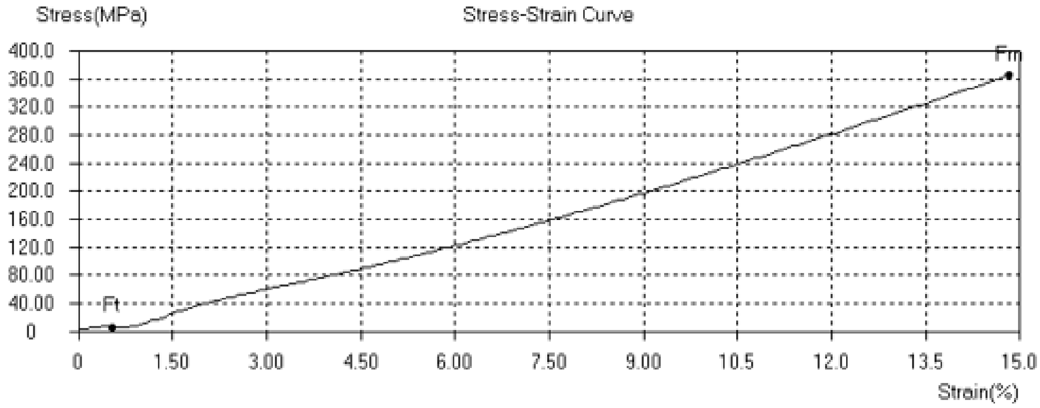

Figure 4.16. Specimen 2, the stress-strain graph of 2 wt % talc reinforced CFRP.

The result of the tensile test applied to the 4 wt. % talc reinforced CFRP composite, the Stress-Strain graph, is given in figure 4.17. and figure 4.18. Tensile test results of 4 wt. % talc reinforced CFRP composites are 338 MPa and 371 MPa.

Firma	CARBON FİBER EPOKSİ-	TestDate	5/12/2022
SARJ	TALC-4	MODEL	0
Type	Flat	Operator	-
Rm(MPa)	338		

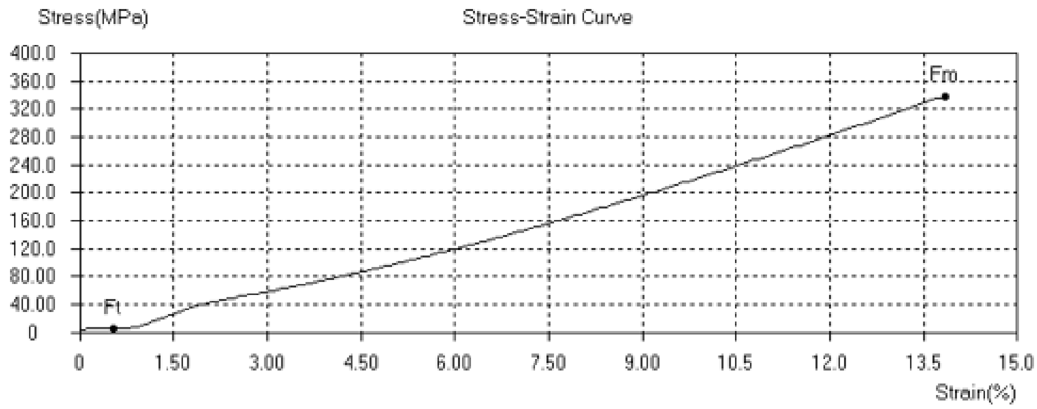

Figure 4.17. Specimen 1, the stress-strain graph of 4 wt % talc reinforced CFRP.

Firma	CARBON FİBER EPOKSİ-	TestDate	5/12/2022
SARJ	TALC-4	MODEL	0
Type	Flat	Operator	-
Rm(MPa)	371		

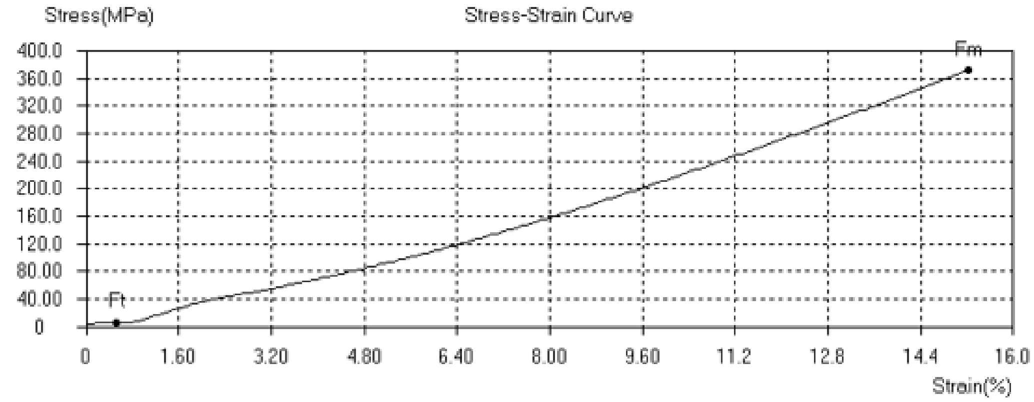

Figure 4.18. Specimen 2, the stress-strain graph of 4 wt % talc reinforced CFRP.

Produced carbon fiber composite unreinforced and reinforced with TiO_2 and talc carbon fiber composite's specimens tensile test average result is on the below figure 4.19. and figure 4.20.

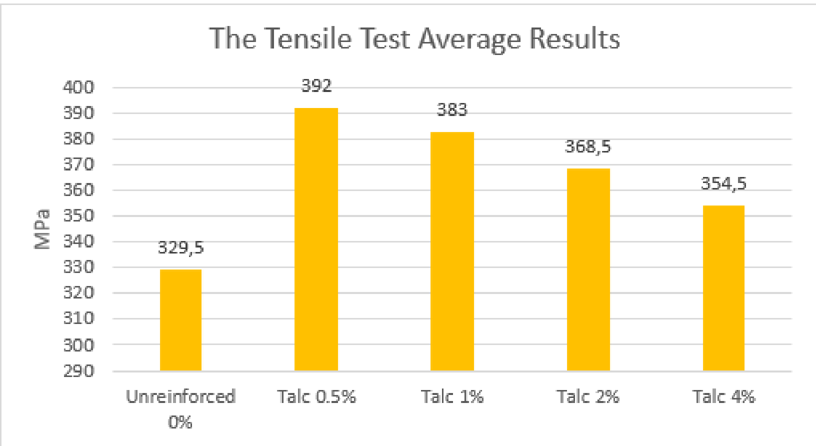

Figure 4.19. Carbon fiber epoxy composite unreinforced and talc tensile test result.

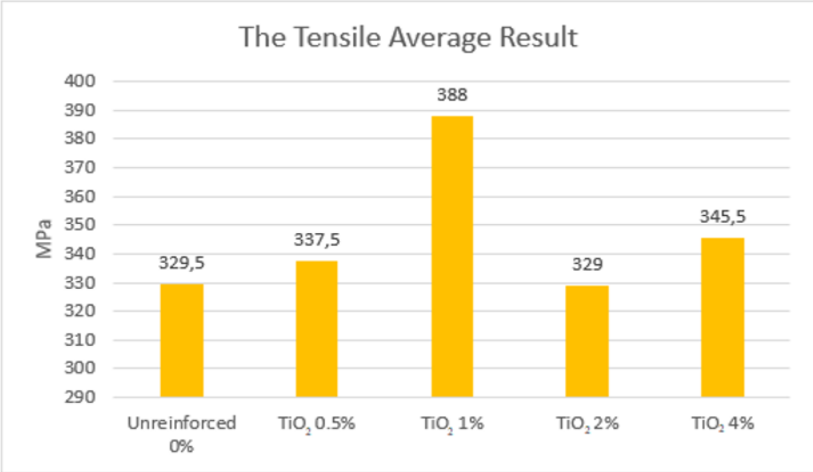

Figure 4.20. Carbon fiber epoxy composite unreinforced and TiO_2 tensile test results.

The bar graph showed the result of tensile test values of carbon fiber composites in the unreinforced and reinforced with TiO_2 and talc. Figures 4.19. and 4.20. seem that the result of the tensile test, the best tensile strength, was obtained from the 0.5 wt% talcs and 1wt% TiO_2. In comparing of 0 and 0.5 wt% of talc in the matrix, the tensile result of the samples increased from 329.5 MPa to 392 MPa, corresponding to a 19% improvement in the tensile strength. A significant increase was observed as a result of the tensile test in talc and TiO_2 -reinforced composite samples. On the other hand, because of the non-homogenous distribution of additives observed the decrease of talc after 0.5 wt% and increase and decrease of TiO_2 additives tensile strength. In the comparison of unreinforced carbon fiber composites and reinforced carbon fiber composites, it has been understood that the tensile behavior of talc and TiO_2 reinforced composite specimens have been significantly changed, added by reinforcement percentage.

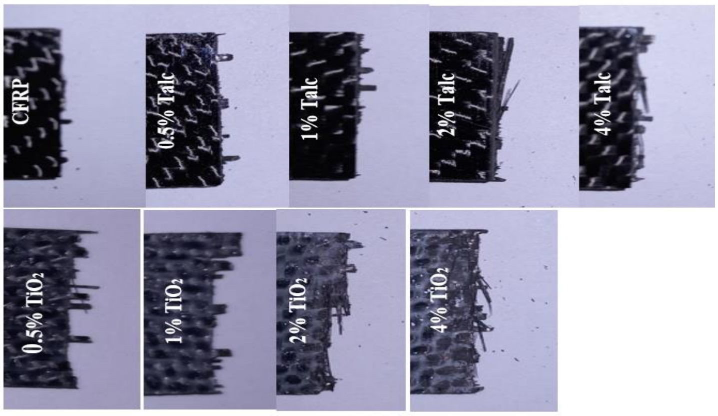

Figure 4.21. Fracture surfaces of specimens applied to tensile test.

The ASTM D3039/D3039M standard classifies different types of fractures as a result of the tensile test. As shown in Figure 4-21, the fracture type's damaged surfaces show the lateral gauge middle (LGM).

As seen in the separate literature studies, it is observed that positive results have emerged regarding the improvement of the mechanical properties of talc and TiO_2 in different materials. In this study, it was observed that talc and TiO_2 had a positive effect on the mechanical properties of the carbon fiber.

The hand lay-up method was used in the formation of the carbon fiber composite material, which is formed by the combination of talc and TiO_2 with resin mixtures. Homogenization problems may occur during the mixing and spreading of talc and TiO_2 particles in the manual laying method. Because of the mechanical mixing, regional differences may occur in the carbon plates formed.

5. CONCLUSION AND IMPLICATIONS

Talc and TiO_2 were incorporated with carbon fiber, and the fabricated composites with the hand lay-up method were analyzed with a universal tensile test. Tensile test results showed that adding TiO_2 and talc to carbon fiber composites increased tensile strength. carbon fiber epoxy composite reinforced with 1 wt% TiO_2 and 0.5 wt% talcs have the best tensile strength. However, comparing the weight ratio of 0.5 talc and 1, 2, 4 wt%, increasing the weight ratio at talc, the tensile strength decreased. Moreover, increasing the weight ratio of TiO_2 by 0.5%, 2%, and 4%, a significant difference in tensile strength test results was not found. Therefore, the result of the comparison of unreinforced carbon fiber composites with talc and TiO_2 reinforced composite specimens showed that the reinforcement percentage by weight changed the composite's strength.

Due to the inhomogeneous distribution of the reinforced (talc and titanium dioxide) carbon fiber composites, some differences in the tensile test result were observed. The strength of talc decrease after 0.5%. TiO_2 results show that the results fluctuate by weight percentage.

Water jet was used to produce test specimens of unreinforced composites and talc and TiO_2 reinforced composites. Methods such as scissors and saws can create invisible cracks and cause test specimens to show less strength than they actually are. Therefore, the waterjet cutting method can be used.

In fabricating carbon fiber composite plates, resin and its additives were made by mechanical mixing. Differences may occur between samples during mechanical mixing and manual application of the material. Mixers that can make more homogeneous mixing and PLC-controlled mixing method can be used.

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