T.C.
ONDOKUZ MAYIS UNIVERSITY
GRADUATE SCHOOL OF EDUCATION

INVESTIGATION OF MECHANICAL PROPERTIES OF CARBON NANOTUBES INTEGRATED THERMOPLASTIC COMPOSITES

Ahmed Mohamed Basem AHMED

MASTER THESIS

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INVESTIGATION OF MECHANICAL PROPERTIES OF CARBON NANOTUBES INTEGRATED THERMOPLASTIC COMPOSITES

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DEPARTMENT OF NANOSCIENCE AND NANOTECHNOLOGY

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THESIS APPROVAL

This master thesis study under the name of “Investigation of Mechanical Properties of Carbon Nanotubes Integrated Thermoplastic Composites” which is prepared and presented by Ahmed Mohamed Basem AHMED is approved as Master Thesis in Nanoscience and Nanotechnology Department at Ondokuz Mayıs University by committee members listed below on 00 / 00 / 2020

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ETHICAL STATEMENT

I declare that all the information given in this dissertation is true and absolute which is prepared in conformity with the regulations for Ondokuz Mayıs University Graduate School of Education and thesis writing rules, all the information were referred and kept on the right side of the laws according to scientific ethic during in the stage of production of information.

June 2020

Ahmed Mohamed Basem AHMED

ABSTRACT

Master's Thesis

INVESTIGATION OF MECHANICAL PROPERTIES OF CARBON NANOTUBES INTEGRATED THERMOPLASTIC COMPOSITES

Ahmed Mohamed Basem AHMED

Ondokuz Mayis University
Graduate School of Education
Department of Nanoscience and Nanotechnology

Supervisor: Assoc. Prof. Dr. Özgür DEMİRCAN

Within this study, multi-walled carbon nanotubes (MWCNTs) (0 and 0.9wt%) and modified multi-walled carbon nanotubes (MWCNTs-COOH) (0 and 0.9wt%) were combined with the thermoplastic polymer of polyethylene terephthalate and reinforcement fibers of the glass fiber to fabricate hybrid composites with non-crimp fabrics (NCFs). The fabricated samples were subjected to three-point bending tests. Samples with modified multi-walled carbon nanotubes (MWCNTs-COOH) in 0° direction exhibited highest value of flexural properties with an improvement of 58% flexural modulus and 14% flexural strength compared to that samples without MWCNTs-COOH in 0° direction. According to the obtained results most likely that the mechanical tests of the flexural properties of the integrated thermoplastic composite will increase with the addition of carbon nanotubes.

June 2020, 67 pages

Key Words: Carbon Nanotubes (CNTs), Flexural Properties, Non-Crimp Fabric (NCF), Polyethylene Terephthalate (PET), Optical Microscope and Scanning Electron Microscope.

ÖZET

Yüksek Lisans Tezi

CNT ENTEGRE TERMOPLASTİK KOMPOZİTLERİN MEKANİK ÖZELLİKLERİNİN İNCELENMESİ

Ahmed Mohamed Basem AHMED

Ondokuz Mayıs Üniversitesi
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Nanobilim ve Nanoteknoloji Anabilim Dalı

Danışman: Doç. Dr. Özgür DEMİRCAN

Bu çalışmada, çok duvarlı karbon nanotüpler (MWCNT'ler) (ağırlıkça %0 ve %0.9) ve modifiye çok duvarlı karbon nanotüpler (MWCNTs-COOH) (ağırlıkça %0 ve %0.9), polietilen tereftalat ve takviye liflerinin termoplastik polimeri ile birleştirildi ve kompozitler üretildi. Üretilen numuneler üç noktalı bükülme testlerine tabi tutuldu. 0° yönde modifiye edilmiş çok duvarlı karbon nanotüplere (MWCNTs-COOH) sahip numuneler 0° yönde MWCNTs-COOH içermeyen örnekler ile karşılaştırıldığında %58 oranında daha fazla eğilme modülü ve %14 oranında daha fazla eğilme mukavemeti değeri sergiledi. Elde edilen sonuçlara göre, entegre termoplastik kompozitin eğilme özelliklerinin mekanik testlerinin, karbon nanotüplerin eklenmesiyle artacağı görülmüştür.

Haziran 2020, 67 sayfa

Anahtar kelimeler: Karbon Nanotüpler (CNT'ler), Eğilme Özellikleri, Kıvrımsız Kumaş (NCF), Polietilen Tereftalat (PET), Optik Mikroskop ve Taramalı Elektron Mikroskobu.

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All thanks and gratitude to my dear friend Mohammed Sufyan for his help and efforts.

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Ahmed Mohamed Basem AHMED

TABLE OF CONTENTS

ABBREVIATIONS

1-D	One Dimesion
2-D	Two Dimensions
3-D	Three Dimensions
AFM	Atomic Force Microscope
ASTM	American Society For Testing And Materials
CNTS	Carbon Nanotubes
CVD	Chemical Vapor Deposition
FTIR	Fourier Transform Infrared
GF	Glass Fibers
MF	Mass Of Reinforcement Fibers
MI	Mass Of The Samples
MWCNTS	Multi-Walled Carbon Nanotubes
NCF	Non-Crimp Fabric
OM	Optical Microscopy
PA6	Polyamide-6
PC	Density Of The Specimens
PET	Polyethylene Terephthalate
PMC	Polymeric Matrix Composites
PP	Polypropylene
PR	Density Of Glass Fiber
SEM	Scanning Electron Microscopy
STM	Scanning Tunneling Microscope
SWCNTS	Single-Walled Carbon Nanotubes
TPNR	Thermoplastic Natural Rubber
VR	Volume Fraction
WR	Weight Fraction

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Nanotechnology indicates to the creation and utilization of the materials that constituents occur at the nanoscale and by convention up to 100 nm in size Hasan (2015). In mechanical terms, nanocomposites are different from classical composite materials according to the especially high surface to the volume ratio of the reinforcing phase and/or its uncommonly high aspect ratio. The reinforce material can be made up of particles, sheets or fibres like carbon nanotubes (CNTs). The area of interface between the matrix and the reinforcement phases is usually an order of magnitude greater than that of classical composites materials Gojny et al. (2005). Most of our newest technologies demands obtaining materials with exceptional combinations of the properties which cannot be appear by the classical ceramics, metal alloys and polymeric materials Grujić et al. (2010) Esawi and Farag (2007). CNTs attracted the attention of many researchers according to their unusual properties in terms of their special lightness, strength that is approximately 100 times stronger than the steel, high thermal conductivity and supplemental multi-functional characteristics. A CNT oftentimes refers to the single-walled carbon nanotubes (SWCNTs) with the diameters in the range of the nanometers. They were discovered separately by Iijima and Ichihashi Dresselhaus et al. (2004). Also sometimes refers to MWCNTs consisting of overlapping of SWCNTs Iijima (1991). MWCNTs consist of multiple of rolled layers of the graphene. Previous studies have been proved that the MWCNTs have higher resistance to the chemicals than SWCNTs Shen et al. (2007). The tensile strength of the CNTs is almost 100 times greater than the other strong materials such as steel when they are in the same diameter. Two main things represent this strength. The first one is the strength provided by the interlocking covalent bonds between carbon and carbon. And the second reason is the fact that each of the CNT is about one large molecule Shokrieh and Rafiee (2010). Because of these special properties, CNTs have been used in the different researches. In addition, the process of modification of the CNTs enhanced dispersion and interaction between the matrix and CNTs Kim et al. (2006), so MWCNT-COOH has been used to get better mechanical properties of flexural test. Thermoplastics are materials which melt when it is heated and that can be formed when they are in a melted or viscous stage. A thermoplastic has extensive properties, depending on their chemistry that they can be such as the rubber or very sturdy and strong like aluminum. Largely the integration of very light weight, superb very strength and relatively low manufacturing costs make the thermoplastics fully suitable for a lot of applications like automotive, aerospace and sporting goods Yousefpour et al. (2004) Amin and Amin (2011). The thermoplastics were commingled with reinforcement fibers and knitted to shape a fabric structure Wiegand and Mader (2017), one of the advantages of these materials is that can be manufactured in huge quantities with good accuracy and low costs compared to other materials. Also it can replace metals and other materials with a large weight savings, appropriate care is provided in the design. Most of the thermoplastics own better stress-strain properties than metals also they will tolerate a larger deflection than those metals without any deforming Njuguna (2013).

Polyethylene Terephthalate (PET) is one of the most usually used thermoplastic polymers in our world, and it is also the most widely recycled plastic Gómez-del Río et al. (2010). It is semi-crystalline plastic that used in many areas, used as an engineering plastic when combining it with the other materials like CNTs or glass fiber (GF) to significantly increase the strength of the materials. It has very good mechanical properties, thermal stability, melts viscosity and chemical resistance May-Pat et al. (2012) Vasile and Pascu (2005). Also it belongs to polymers of polyester family. Polyester resins are familiar on the thumbs up collection of properties like chemical resistance, dimensional stability and also mechanical properties. Recycled PET can be made to fibers, sheets and fabrics for packaging and fabrications automotive parts. In fact, PET is one of the most widely recycled plastic in the world. PET is so elastic, colorless and in its natural state considered as a semi-crystalline substance. Depending on how it is treated, it can be semi-rigid to rigid. It exhibits very good resistance to the impact, alcohols dimensional stability and solvents Vasile and Pascu (2005).

1.1. Literature Review

There are several research and studies on the amelioration of mechanical properties of the thermoplastic composites by combining CNTs into composites through fiber coating. And from here it is aimed to increase the bending and tensile properties of the new created nanocomposite which we will fabricating it by improving the bonding between the fiber and the resin interface, so reaching a new approved range of uses. Many of researchers have studied different parameters of commingled fibers which can effect on the properties and perfomance of the generated composite materials.

Demircan et al. (2019) investigated on the mechanical properties of the thermoplastic composites with the commingled yarn of the GFs/ LPET. In this research, there are four kinds of (MWCNTs; 0.0, 0.7, 0.9, and 1.1 wt %) have been used. Samples with 0.9-wt% MWCNTs in the direction of 90° presented the better values of the bending properties with an enhancement of approximately 33% in flexural modulus and about 65% in flexural strength if we compared to that samples without adding MWCNTs in also 90° direction. The enhancement can be referred to increasing in the interfacial adhesion because of the existence of the CNTs.

Svensson et al. (1998) Friedrich (1999) investigated about commingled fibers for a purpose to get rid of the problems of a high melt viscosity through consolidation and impregnation as the wanted procedure for fabricating of the components. In the last period, a material with PET fibers was advanced for many applications that need higher strength and better thermal resistance. Combination of the MWCNTs into the thermoplastic composites is predictable to appear the affirmative enhancements especially in the mechanical properties of thermoplastic composites mostly in case of the stiffness and strength, as mentioned previously Fakirov (2013).

Long et al. (2002) searched and studied the mechanical properties of thermoplastic composites with commingled yarns of GF/ polypropylene (PP) yarns. They mentioned that good ratio blend of the GF/PP filaments and the suitable bigness from the GFs roving it can have the effect of increasing the bending modulus and bending strength of the thermoplastic composites.

Shen et al. (2009) studied a preparatory investigation on the effect of blending CNTs into polyamide-6 (PA6) on mechanical and thermal properties of glass reinforced CNT-PA6 nanocomposite plates. The specimens were described by the flexural and tensile tests. The combination of 0.5 wt% CNTs in CNTs/PA6/GF plates enhanced the flexural stress of those plates up to approximately 36%.

Demircan et al. (2015) studied and investigated the influence of the different knitting techniques on mechanical properties of biaxial weft knitted of thermoplastic composites. They showed that bending impact, three-point bending and the tensile properties of the thermoplastic composites with commingled fibers could be improved by making changes in the knitting techniques. Also they showed that with this technique, the minimization of the manufacture time in the process of layering, the decrease of cut loss and the total production cost. So the connection between the melting temperature and molding temperature of thermoplastic composites are investigated.

Zulfli et al. (2013) investigated epoxy laminates by using GFs and MWCNT. GF and hybridization of MWCNT present best mechanical properties for this type of composites (epoxy). By adding 1 percentage of MWCNTs they improved strength and flexural modulus, also the impact strength. With the existence of MWCNTs the contents of the diffusion coefficient of the composites clearly increased.

Mader et al. (2008) studied and reported commingled fibers–processing aspects of PP/glass fiber composites, they exhibited that nanostructure interfaces presents by small amount of CNTs in sizings enabled to obtain several influences like improved modified morphology of interphases, tensile strength of GFs and modern fracture mechanisms.

Tarawneh et al. (2011) researched and investigated the mechanical properties of the thermoplastic natural rubber (TPNR) nanocomposite that reinforced by MWCNTs. They investigated with 1 to 7 percenage of MWCNTs, young’s modulus and the tensile strength improved about 30% for the young's modulus and 39% for tensile strength, at 3 percentages of MWCNTs. There are several studies on the improving interface and mechanical properties of the thermoplastic composites by integrating CNTs into the composites by coating the fiber. According to the studies and research and to the best of the authors’ knowledge, integrating CNTs into thermoplastic composites by the coating of CNTs at the fabric ten layers to get better the mechanical properties and the interfacial of thermoplastic composites with the commingled fibers of PET fibers and GFs it has not been studied nor published until now.

The aim and purpose of our study is to describe mechanical properties of MWCNTs thermoplastic composites with the PET/GF commingled fibers. This research also includes the investigation of the bending properties of the thermoplastic composites with the PET/GF commingled fibers with 0.9wt% of the MWCNTs. We as well studied the mechanical properties in two directions (0° and -45°). Fourier-transform infrared spectroscopy (FTIR), optical microscopy (OM) and scanning electron microscopy (SEM) were used to describe the samples.

2. COMPOSITE MATERIAL

2.1. Definition

Composite materials are combined from two or more constituent materials that have significantly different chemical or physical properties. There are two main stages can be featured in a composite materials; dispersed phase and the matrix. Callister (2000) pointed that the reinforcement stage geometry indicates to concentration, size, shape distribution and orientation of the reinforcement. As shown in Figure 2.1 for extra specifics.

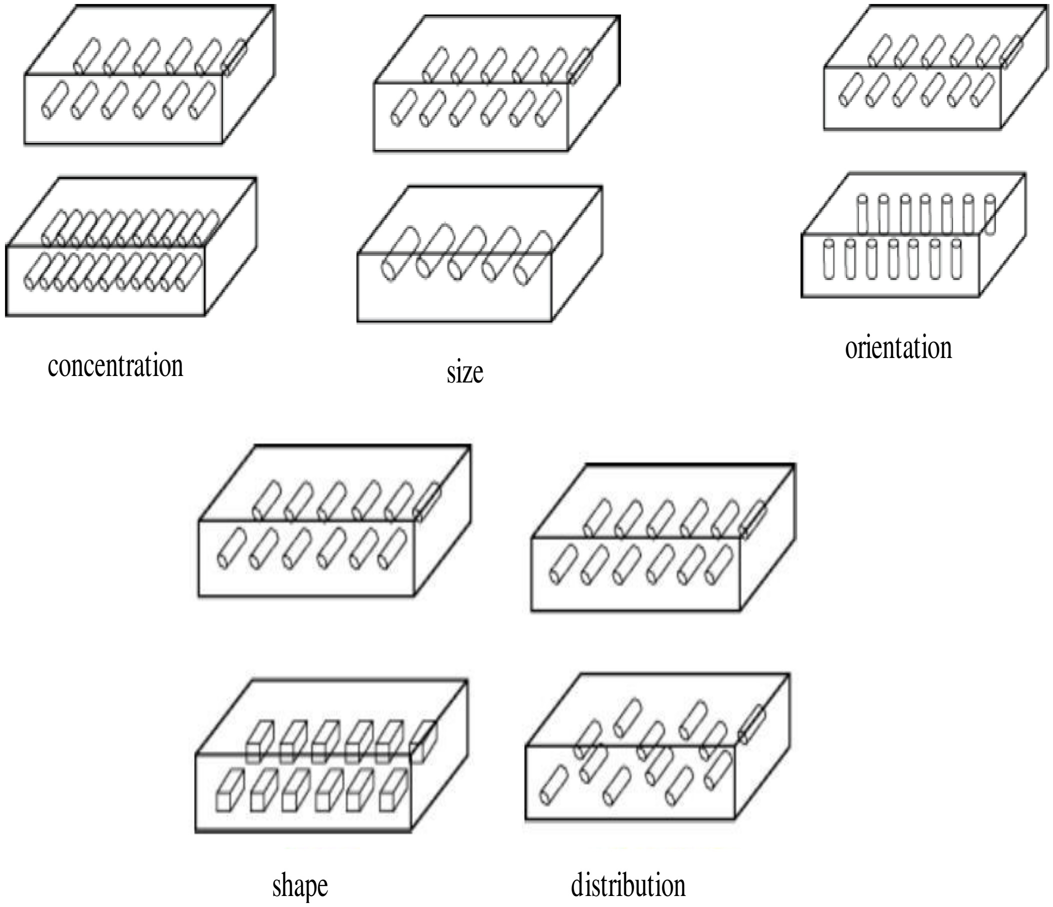


Figure 2.1. Reinforcement stage geometry Callister (2000)

2.2. Classification of Composite Materials

Composite material is a material that composed of at least two or more different phases (matrix phase and the other one is dispersed (reinforcing) phase) as shown in Figure 2.2 and they have a very big properties significantly various from those of any of the constituents.

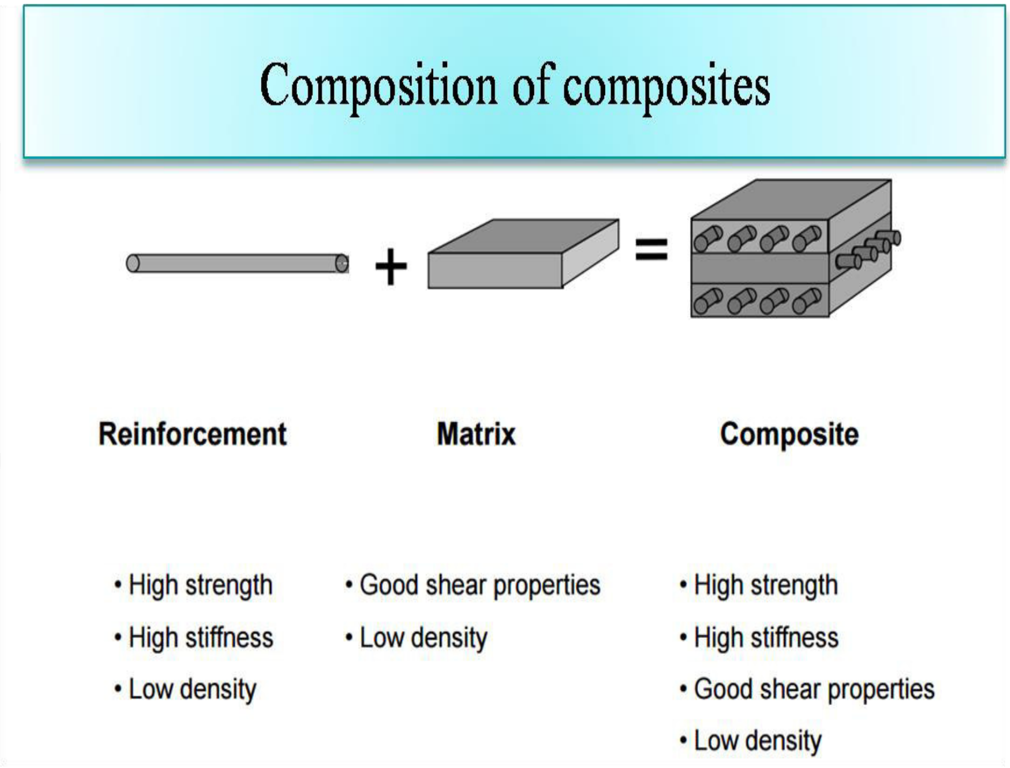


Figure 2.2. Classification of composites Kumar and Lohchab (2016)

2.3. Classification of Reinforcement

The form or shape of the reinforcement stage considered as the first classification. It can be sectioned to three main class: fiber reinforced, particle reinforced and structural. These three main classes can be divided into subdivisions as well. GFs is considered one of the common reinforcement.

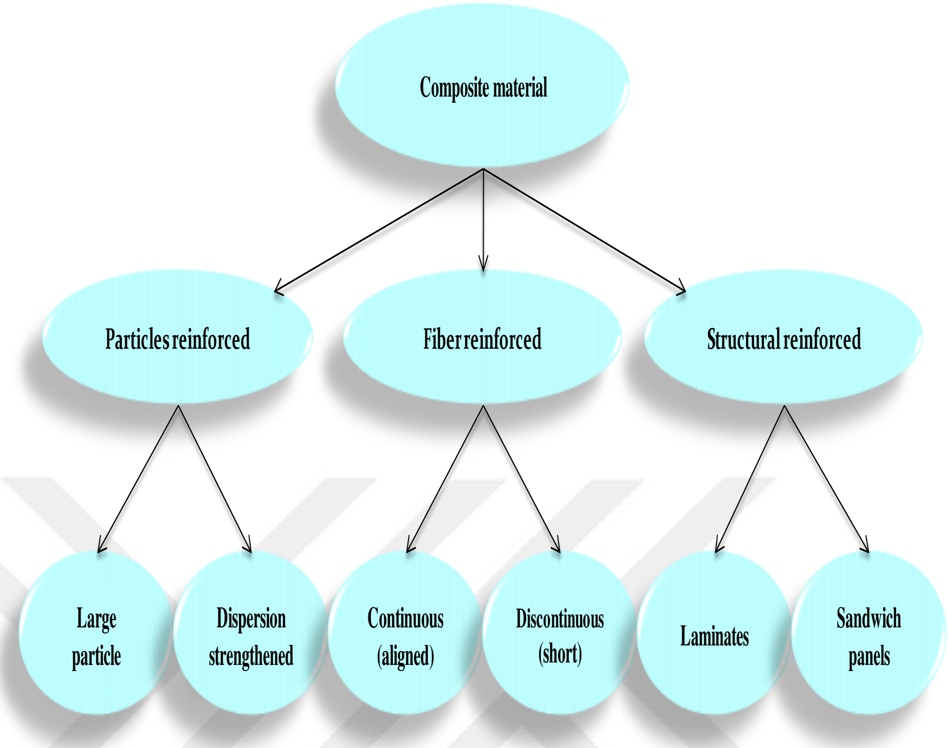


Figure 2.3. Composite classifications according to the reinforcement format Paul and Dai (2018)

2.4. Matrix Classification

There are three essential types of matrices: ceramic, metal and polymer as distinguished by Mallick Mallick (2007) in his studies as shown in Figure 2.4, we can also summarize the main functions of the matrix as follows: it protects the fiber, to transport the stresses between the reinforcement, also to provide a hurdle against an opposite environment like moisture and the last role is to protect surface of a reinforcement from the mechanical degeneration (for example by the abrasion). Metal matrix composites are composed of a metallic matrix (magnesium, aluminum, copper, iron) and a dispersed ceramic (carbides, oxides) or metallic (molybdenum, lead, tungsten) phase. Matrix composites are composed of the matrix from thermoset (epoxy for example) or thermoplastic (polystyrene, polyethylene terephthalate, nylon and polyvinylchloride) and carbon, embedded glass or kevlar fibers (dispersed phase). Ceramic matrix composites are composed of a ceramic matrix and embedded fibers of the other ceramic material (dispersed phase).

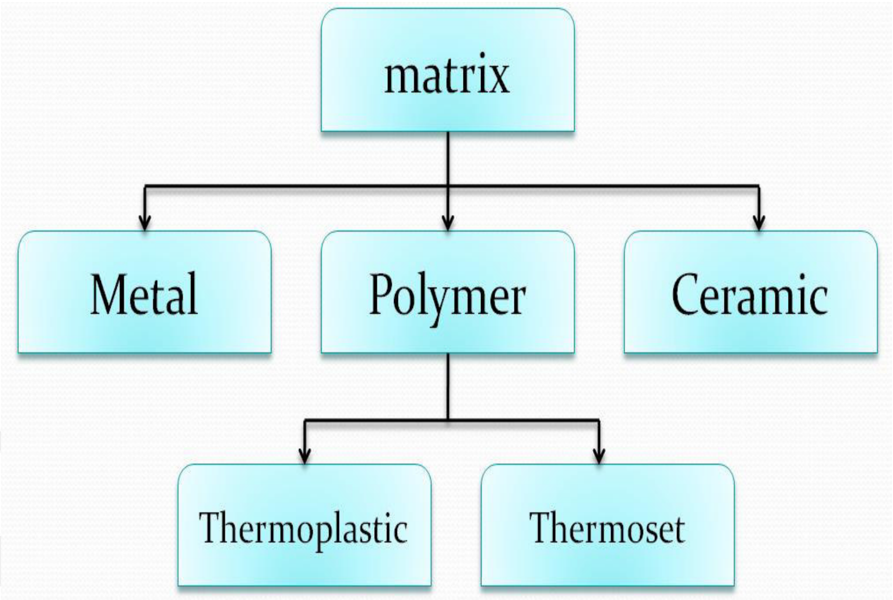


Figure 2.4. Composite classifications according to the matrix type Mallick (2007)

2.5. Thermoplastic and Thermoset Polymers

Polymer matrices consist of two essential types the first one is thermoplastic polymers and the other one is thermoset polymers. Nijssen (2015) studied and researched the effects of the matrix type on the thermal and mechanical properties of the composites. He also touched and added the differences between the thermosets and thermoplastics. Table 2.1 clarifies some of the most important differences between thermoplastics and thermosets.

Thermosets resins do not melt on heating, but they are disintegrating endly. From molecular point of view, most of thermosets are consisting of short chains sort of to ensure the non-cured polymers to have low viscosity. Processing is carried out by a starting a chemical reaction, which the short chains form bonds and after that create a three dimensional network. The temperature is generally regulated during curing. This can also be applying for the pressure (it is depending on the fabrication method). Polyesters that are classified as a thermosets can also be thermoplastic Gattineni and Nathi (2019). Phenolic resins behave like the thermoplastics up to a certain temperature.

Thermoplastic is one of common type of the plastic that synthetic from polymer resins it becomes very soft material after heating and it will becomes so hard after cooling. These materials are considered one of the most materials in the world which have the ability to be recycled with no change in chemical properties, even if we heated and cooled many times, but when thermoplastics are heated their physical property not like their chemical properties they are changes and become a liquid and can be resized and reshaped. Thermoplastics have a very good range of properties and are energy active both in their processing and manufacture. Thermoplastic can be made in high precision and very high volume with low cost. Metals can be replaced by thermoplastics with a large weight savings. Most of the thermoplastic have superb stress-strain properties that are better than metal materials also it will tolerate greater deflections than those metals without any deforming.

Thermoplastics are polymers that melt or soften when heated, becoming formable and recover their solid shape after cooling and are proper for the liquid flow forming like Chawla mentioned Chawla (2012). Thermoplastics are one of the most commonly used unreinforced polymers. In a molecular term, thermoplastics are consisting from a long entangled chain. Upon heating, several freedom of the movement is obtained through molecular movements. There are some exceptions regardless of them; thermoplastics are not mostly suitable for the impregnation of the fiber reinforcement because of their viscosity (very high viscosity in the liquid stage, linked to molecular stage). So, this prevents thermoplastics from wetting fibres appropriately (impregnating), thus it is not possible to produce a good quality composite. To manufacture composite materials using the thermoplastics, high temperatures and pressures are very necessary. There is a commonly used method that is to alternate dry plies with the thermoplastic films and manufacture a composite by means of a heated mould (for example compression moulding). Instead of that, thermoplastic fibers or fiber bundles are co-spun with fiber reinforcement. After that, a lower external pressure needed to reach at a perfect impregnation. The development of the last process is the infusion of thermoplastics. The infusion procedure uses monomers that polymerise during treating. Monomers have a short chain so they do not get entangled; leading to the low viscosity in the liquid stage and infusion will be suitable.

Table 2.1. Comparison between thermoplastics and thermosets

Thermoplastics	**Thermosets**
The chains have a low amount of the cross-linking	The chains are cross-linked with each other
Soft and less brittle	Strong and hard
Soften when it is heated	Do not soften when it is heated
Low chemical resistance	Better chemical resistance
Very Recyclable	Unrecyclable
Very high manufacturing temperature	Low manufacturing temperature
Short cure period	Long cure period
For example: Polypropylene	For example: Epoxy

2.6. Polyethylene Terephthalate

PET a stiff, very strong synthetic resin and fiber; it is considered one of the polymers of the polyester family. PET is manufactured by the polymerization of the terephthalic acid and ethylene glycol. Ethylene glycol is a liquid without color that is obtained from the ethylene, and the other one (terephthalic acid) is a crystalline solid that obtained from the xylene. They are heated together and then under the effect of the chemical catalysts, terephthalic acid and ethylene glycol produce the PET in the form of molten, viscous mass which can be spun immediately to fibers or solidified for the later processing like a plastic. In the chemical terms, ethylene glycol consider as a diol, alcohol with the molecular build which include from two of the hydroxyl (OH) groups, and the terephthalic acid is concidered as a dicarboxylic aromatic acid, an acid with the molecular build which includes from six-sided of carbon element ring and two carboxyl (CO2H) groups. Under the effect of heat and catalysts, the carboxyl and hydroxyl groups react to shape ester (CO-O) groups. In addition, water is also produced but not as a main product. The interactions can be seen in Figure 2.5.

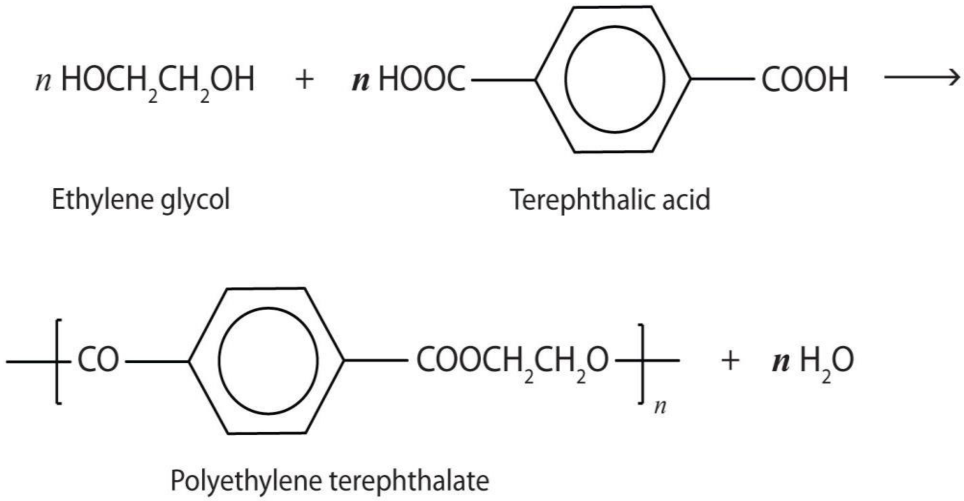


Figure 2.5. Production of PET by the reaction between ethylene glycol and terephthalic acid Kosmidis et al. (2001)

PET considered as one of the multi-industries, it is made into fiber filling for pillows and furniture. When made in a very fine yarn, it can be used in artificial silk, and when it is in large-diameter yarns it can be used in carpets. There are some industrial applications such as automobile tire filament, drive belts and conveyorbelts, reinforcement for garden, fire hoses and nonwovens using like diaper top sheets and disposable medical clothings. The PET is considered one of the most important man-made yarns in terms of its industrial value and in terms of its light weight compared to the rest of the yarns. The superb strength of the PET if we make comparison to its very light weight is a main special key to its energy efficiency. Outstanding improvements in light-weighting technologies continue to enhance its energy efficiency significantly. Life cycle researches of the PET have confirmed the environmental advantages of the PET like a packaging material Kamber et al. (2010).

2.7. Glass Fiber

GF made from very fine fiber of the glass that is a non-crystalline material. GF is one of the most widespread of all reinforcing fibers for the polymeric matrix composites (PMC). Some of the advantages of GFs are good chemical resistance, low cost, superb insulating properties and high tensile strength. In addition, they have a good electrical properties, outdoor weathering resistance to humidity and resistance to chemicals and heat. Also these properties are connected with the ease of fabrication. GF are formed and shaped from the melts and produced in different compositions by changing the ratio and amount of raw materials like clay for the alumina, sand for the silica, calcite for the calcium oxide and colemanite for the boron oxide. Thus, various type of GF presentation various performances such as alkali resistance or very high mechanical properties by using different amounts of the silica or the other sources.

GF can be classified according to the form of composite at which they are used. Furthermore, assembled rovings, direct draw rovings, chopped strands and mats are the most significant products that are used in filament winding, injection and sheet molding and hand layup processes for forming the GF-reinforced composites. Protections of GF yarns from fraction or disintegration is very important matter either through manufacturing of GF or through composite production GF are used like a reinforcement of polymers in different fields like marine, automobile, leisure goods, sporting, aerospace and civil engineering. One of the most main advantages of using GF for reinforcement of the polymers is their very high performance with low cost ratio. Basically and in a simplified way the essential steps for fabricating GF: - Mixing limestone, boric acid, silica sand with the rest of the ingredients.

- The first step the mixture should melt by heating at around 1250 °C/2300 °F.
- Allowing the molten glass stream during the fine holes. (In the plate)
- The strands of the glass are cooled and gathered.
- After that fibers are drawn in order to increase and improve the strength of the direction.
- The fibers are woven into different shapes into use in the composites as shown in Figure 2.6.

In this state mixing and fusion of the raw materials is carried out in batch furnace at a temperature approximately 1750 °C to form homogeneous glass. The glass fabricating can be end either with a liquid glass influx directly to the fiber forming furnaces that called "bushings" or glass can be formed into rods or marbles, cooled at a room temperature for the further use.

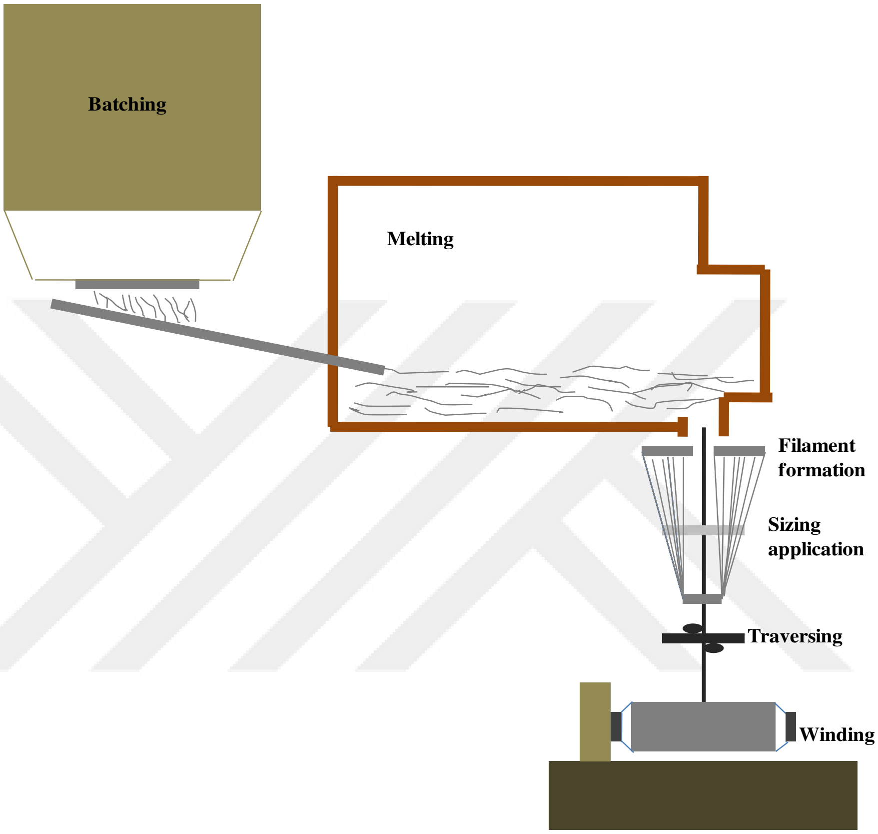


Figure 2.6. Production process of GF Mahltig and Kyosev (2018)

2.8. Commingled Fibers

The simple definition of the commingled fibers is a mix of matrix filaments and reinforcement within tow as shown in Figure 2.7, that supply a good material order to conquer the viscosity that is very high when matrices are melted by heat. There is one of a possible implement that applied for aligned fiber reinforced of the thermoplastic composites for a purpose to get rid of a problem of the highly soluble viscosity through consolidation and the impregnation as the desired procedure for fabricating of the technical components. This performance can be rated as a pre-prepared dry material, that the hard resin is physically divided after that distributed approximately equally between the reinforcement fibers. Polymer division can be made using powder or fiber form Friedrich (1999).

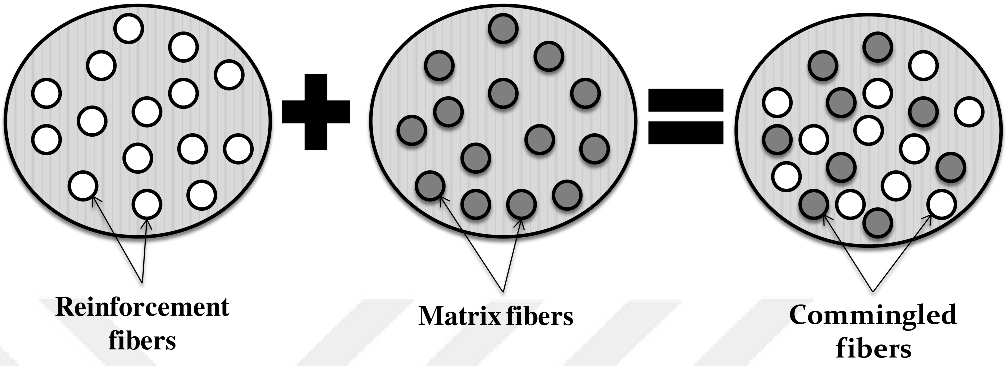
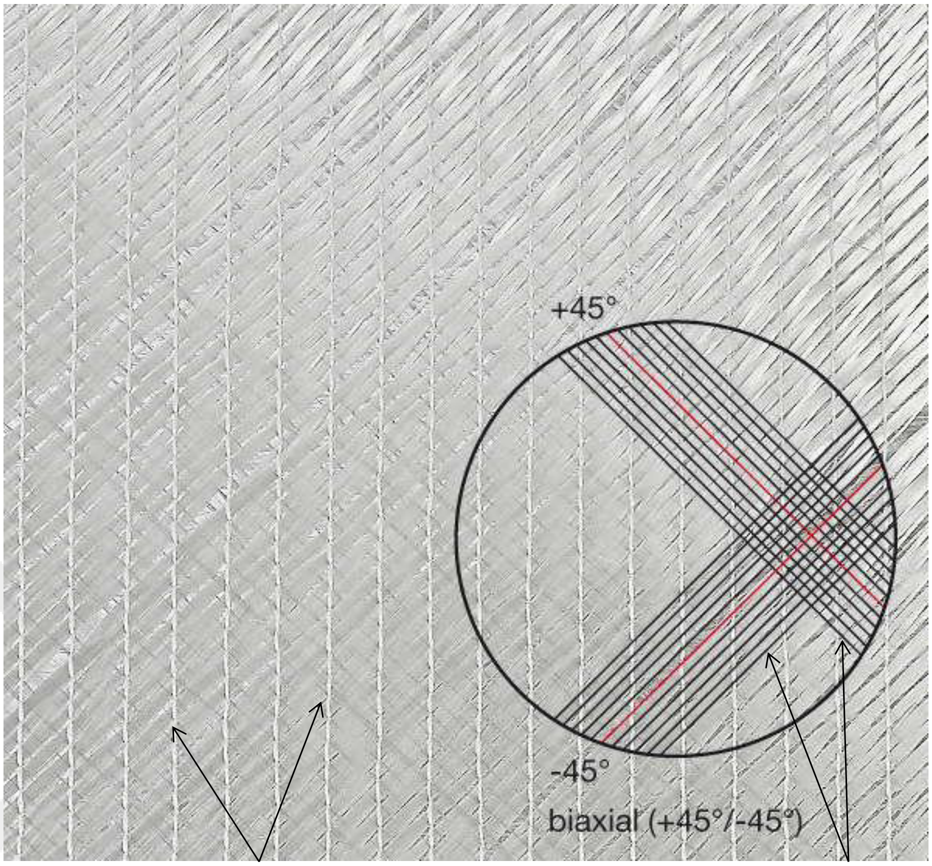


Figure 2.7. Structure of the commingled fibers Lionetto (2015)

2.9. Non-Crimp Fabric

Non-crimp fabrics (NCFs) simply defined as a fabric consisting of two layers or more than two layers of fibers that are unidirectional. NCF composites are reinforced with the mats of straight fibres (non-crimped), awarding them many features like ease of handling, more strength and low fabricating costs. NCF composites provide a comprehensive review of using of NCF composites, their applications and manufacture in engineering Lomov (2011). Basically the classification of NCFs is dependent on the orientation of the fibers in the layers. It can be divided accordingly:

- The orientations are (+45°/-45 or 0°/90°) and they are called biaxial fabric as shown in Figure 2.8.
- The orientations are (+45° / 0°/ -45°) they are called triaxle fabric.
- The orientations are (0°/ +45°/ -45°/ 90°) and they are called quadraxial fabric.



Stitch fibers **Fiber orientation**

Figure 2.8. Biaxial fabric of NCF with the (+45°, -45°) orientation

3. NANOSCIENCE AND NANOTECHNOLOGY

3.1. Introduction

Nanoscience and nanotechnology are the studies and applications of very small things which will be used in the rest of the fields and in the level of other sciences, like biology, chemistry, medicine field, materials science, engineering and physics. The concepts and ideas behind nanotechnology and nanoscience begins with a speak under the title of “There's a lot of space at bottom” by the German physicist Feynman during meeting in United States of America and specifically (California) Institute of Technology on 1959, before using the term of nanotechnology. In his speech, Richard describes the process by which scientists can rule and control on the individual molecules and atoms Bhushan (2010). After more than a decade, the Professor Norio Taniguchi formulating the term nanotechnology while researching and exploring ultra-precision machines that was not until 1981, with the evolution of a scanning tunneling microscope (STM) which can "see" the individual atoms that started with modern nanotechnology. Nanoscience and nanotechnology include the ability to see and the ability to rule and control individual molecules and atoms. Everything on earth consists of atoms: the food that we eat, clothes we wear, the buildings and homes that we live in even our bodies. Although there are atoms as we mentioned earlier everywhere, we cannot see them with our naked eye because of their very small size. Actually, it is also impossible to see this atom with these regular microscopes that were used in schools. It was necessary for these microscopes to see the very small things on the nanoscale that was nearly 30 years ago invented. We can say that the era of nanotechnology was born and appeared after scientists and researchers invented and obtained the required equipment and tools like atomic force microscope (AFM) and STM. Although modern nanoscience and nanotechnology are completely new, nanomaterials have been used for hundred years. Silver and gold particles formed colors in the glass windows of middle ages churches hundreds years ago. Today's engineers and scientists are finding an extensive different methods and ways for deliberately making materials on the nanoscale to benefit of their developed properties like superb strength, light weight and greater chemical reactivity than their counterparts.

3.2. Definition

Term “Nano” is taken from the word “Nanos” that is a Greek word, that means dwarf. Simply, nanotechnology is defined as the engineering and science of manufacturing and investigating the materials and devices that is within the nanoscale, and the nanometer scale contains that scales (1-100) nm Booker and Boysen (2005). Significant materials properties, like the optical, mechanical, electrical and thermal properties are specified by the way atoms and molecules gather on nanoscale to the bigger structures.

Nanotechnology is an application of nanoscience, which in turn will lead to the use of nanomaterials and nanoscale components for use in new products and industries. Nanotechnology will finally assort us with the ability and control to manufacture customized products and materials with the new developed properties, modern nanoelectronics components, modern kinds of the “smart” sensors and medicines. These newly born scientific are located in the interaction of chemistry, physics, biochemistry, biotechnology and materials science. Thus controlling these majors requires academic and interdisciplinary scientific education.

3.3. Nanomaterial

Nanomaterials are defined as substances possessing, that at least one external dimension scale at 1 nm to 100 nm. These nanomaterials can occur and form naturally without interfering, it can also be manufactured and produced through combustion reactions, also it can be produced and configured on purpose by engineering to benefit from it in the performance of specialized functions and applications.

These nanomaterials can possess chemical and physical properties and features that differ from other counterparts from larger materials. The use of these nanomaterials is predominant in the range of consumer and industries products. The sports industry also have been manufacturing baseball bats that made with addition of CNTs, making these bats lighter thus its performance become better. The superb properties and features of these materials, especially their ultra-small size, provide advantages and possibilities that you cannot notice in their larger counterparts. There is an further advantage the high porosity that increases of these materials for their use in the great number of industries.

Nanomaterial generally classified into three main classes according to there dimensions in nanoscale as shown in Figure 3.1.

1- Nanomaterials, in one dimesion (1-D) are layers such as surface coating.
2- Nanomaterials, in two dimensions (2-D) are tubes such as nanotubes.
3- Nanomaterials, in three dimensions (3-D) are particles like quantum dots.

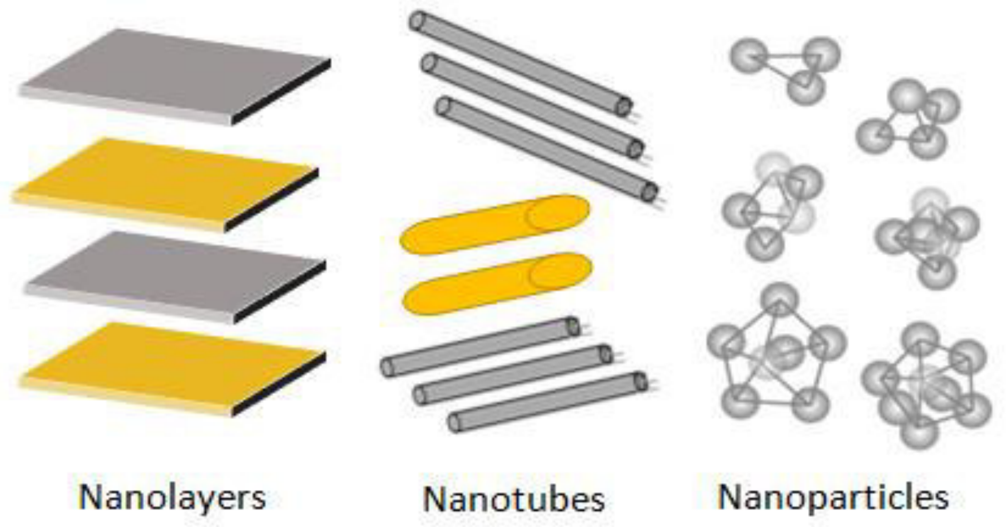


Figure 3.1. Types of nanomaterials due to their dimensions Moustafa et al. (2015)

3.4. Carbon Nanotubes

Carbon is the most diverse component of the periodic table, owing to the strength, type and number of the bonds it can be composed if we compare it with the other elements, the assortment of the bonds and their corresponding geometries enable existence of the structural isomers and enantiomers. The properties of the carbon are a direct result of the configuration of electrons around tnucleus of atoms. In the carbon atom, six electrons are shared equally between the 1s orbital, 2s orbital and 2p orbital.

CNTs are tube formed materials, made out of rolled up graphene layers and they have a small diameter that in nanometer scale. Due to the nature of the bonding between the atoms and the good aspect ratios, CNTs has unique properties. CNTs fundamentally classified into two types, SWCNT it consists of a single layer of graphene and MWCNT it consists of assembling multiple layers of graphene as shown in Figure 3.2.

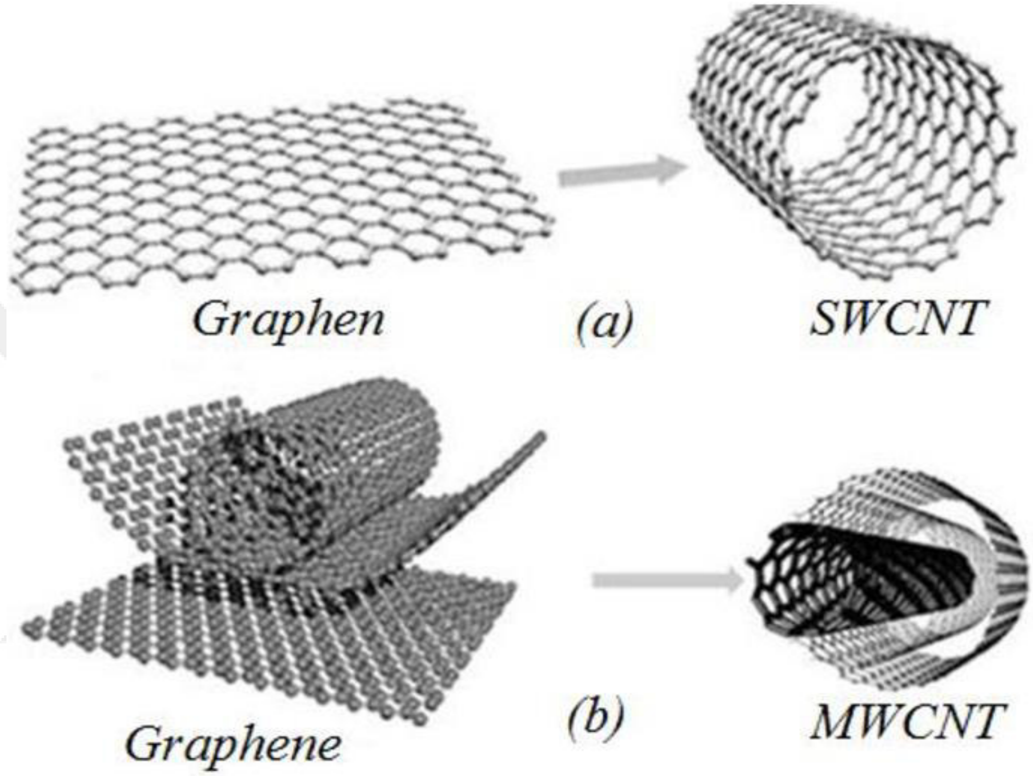


Figure 3.2. SWCNT and MWCNT structure Vidu (2014)

3.4.1. History of CNTs

The most diverse element found on earth is carbon. Also, there are different and unique properties and features in carbon that allow them to be used in various ways, given the dependence on the way carbon atoms are arranged. The carbon element was used by humans more than 6000 years ago to reduce the level of oxide removal. In 1779, the carbon element was discovered in the form of graphite, and in 1789 it was discovered, but this time in the form of diamonds. After that, the scientists decided that carbon in the form of the two discoveries is attached to the chemical elements. There was no progress, discovery or development of carbon until almost 200 years later. Curl, Kroto and Smalley discovered fullerenes in 1985; these scientists won the Nobel Prize in chemistry in 1996 for discovering fullerene Aqel et al. (2012). CNTs were discovered after a few years. The big interest now in the CNTs is a direct result of synthesis of the buckminster fullerene C60, and the other fullerenes. The detection of that carbon can form stable other than diamond and graphite induced the researchers in every part of the world to study and research for another shapes of carbon. After making sure of that the C60 can be produced in a simple arc evaporator, easily available in the most of laboratories the research was given a new boost when it was introduced in 1990. The carbon tubes include two layers at least MWCNTs, oftentimes more than that, the outer diameter ranged between (3-30) nm. In the wake of several surveys for MWCNT and studies by many scientists in 1993, a new type of carbon has been discovered as it consists of only one layer. These SWCNTs are generally narrower than MWCNTs, with the diameters in the range between 1 nm to 2 nm, and more curved rather than to be straight. After a continuous study on this type of CNT, it was found that it has many distinct characteristics and this led to an increase in studies and research related to CNT. It is worth noting that these nanotubes were discovered and known from many years and even before the discovery of the lijima and that the main reason for the lack of widespread interest in these materials was that they were structurally incomplete so their unique properties were not discovered. CNTs have been observed and produced under a diversity of conditions before in 1991. However, many researchers believe that the Iijima's research in 1991 is of special importance because it has made CNTs the focus of attention for the scientists and researchers in all parts of the world.

3.4.2. Properties of CNTs

The CNT structure consists of a layer of carbon atoms which are bound together in a hexagonal grid like. Every one-atom layer of carbon is called a graphene, then wrapped in form of a cylinder and connected together for forming a CNT. CNTs own a set of thermal, structural and electrical properties that can be changed based on physical design of the CNTs.

Mechanical properties: The carbon atoms in the CNT are the main cause of their unique properties. In theory, the mechanical properties especially strength and rigidity of CNTs are better than any another material. Yakobson (1998) Falvo et al. (1997) studies presented that a wonderful “curvature, don’t break” individual SWCNT response to large transverse deformations.

Strength: CNTs own a higher and better tensile strength than the steel. Their strength certainly comes from the sp^2 bonds between individual atoms of carbon Scoville et al. (1991). This bond in the carbon is stronger than sp^3 bond which is found in the diamond. When there is a very high pressure, individual CNTs can be bond together. This enables long nanotube wires to be produced. CNTs are not only strong element, but they are also flexible. You can press on any side of the carbon and you will notice that it bends but without any damage and soon it will return to its normal shape. The strength of the CNTs can be weakened by the defects in nanotube's structure Kotakoski et al. (2006).

Electrical properties: The CNTs structure determines the conductivity of the nanotubes. When the atoms structure in the CNT reduces to the minimum collisions between the conduction electrons and the atoms, the CNT become very conductive. The very strong bonds between the atoms of the carbon let CNTs to withstand higher electrical currents than the copper. SWCNT can direct electrical signals at the speeds of up to 10 GHz when it is used as interfaces on semiconductor devices, and nanotubes have resistance to stability Jat et al. (2015).

Thermal Properties: The strength of the atomic bonds in the CNTs allows them to withstand a very high temperature. For that, CNTs have confirmed to be one of the good thermal conductors. If we compare CNTs wires with copper wires, which are usually used as thermal conductors, the CNTs can transmit about 15 times the amount of the watts per kelvin per meter. The thermal conductivity of the CNTs depending on the temperature of the tubes and the outside environment.

3.4.3. Synthesis of CNTs

Until now, arc discharge, laser ablation and chemical vapor deposition (CVD) are the essential methods for the manufacturing of CNTs. Here is a summary of each of these three methods:

In the arc discharge technique, a vapor is created by an arc discharge between two of the carbon electrodes without or with the catalyst. Collect CNTs from carbon vapor that resulting as shown in Figure 3.3.

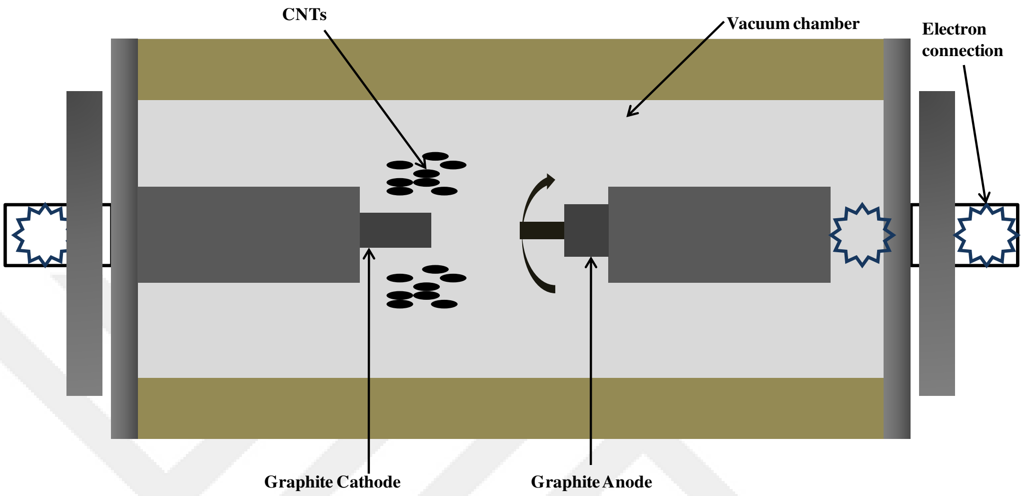


Figure 3.3. Arc discharge apparatus used in synthesis of CNTs Shi and Webster (2017)

Either in the second technique (laser ablation), a high power laser beam hits on the size of the carbon that containing feedstock gas (like carbon monoxide or methane) as shown in Figure 3.4. Quickly, in this technique produces a little quantity of CNTs and be in clean condition, while in the previous methods (arc discharge) mostly produce a large amount of the impure material.

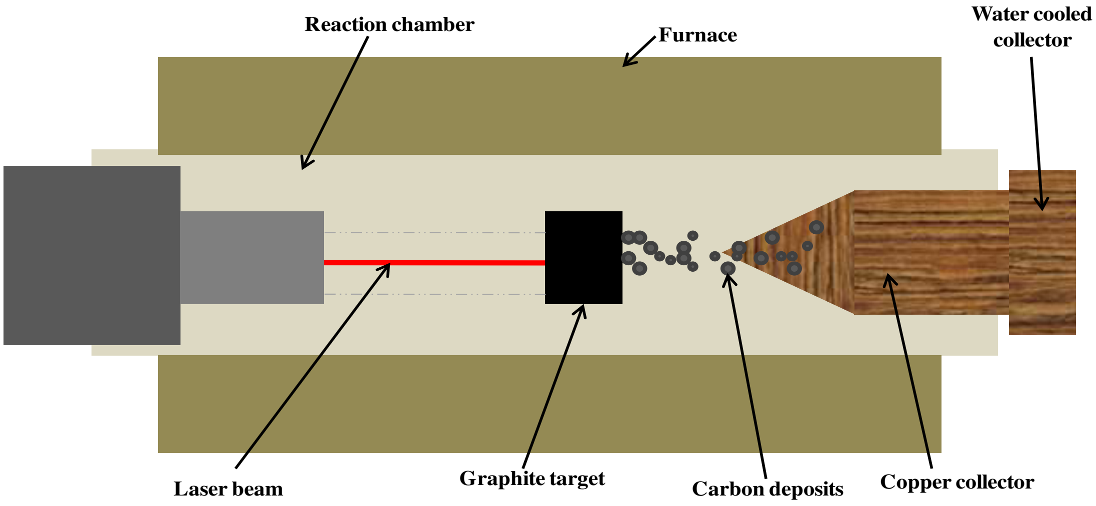


Figure 3.4. Laser ablation process for synthesizing CNTs Shi and Webster (2017)

In common, CVD results in MWCNTs or not good quality of SWCNTs. The SWCNTs produced with the CVD have a big diameter range that can be controlled not well. But it is worth noting, CVD is easy to scale up, that favors in the commercial production.

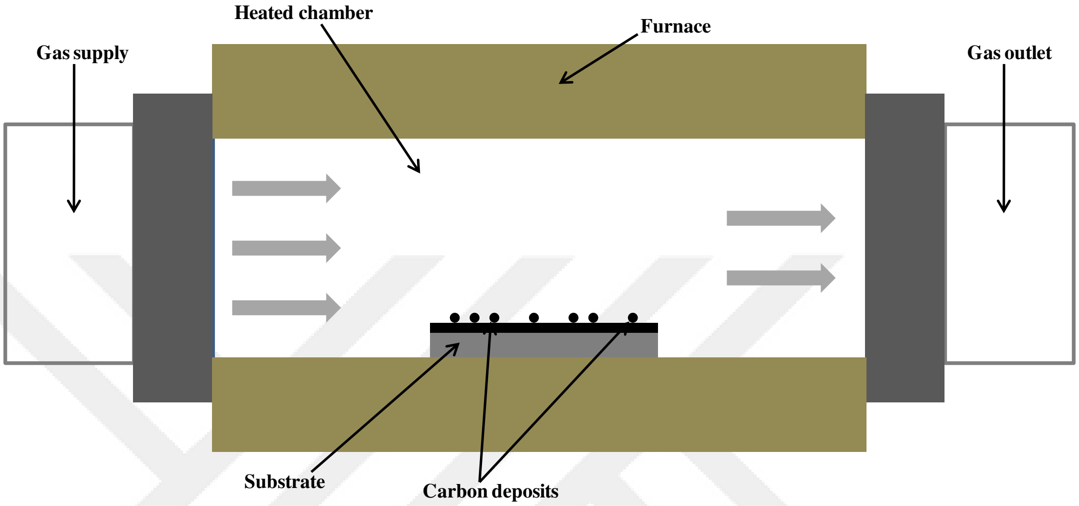


Figure 3.5. CVD used in synthesis of CNTs Shi and Webster (2017)

In laser ablation process, a part of graphite is vaporised by the laser irradiation under an inert atmosphere. The CVD and the most current fluidised bed CVD method has shown the most promise in terms of its price because of its superb heat and mass transfer ensuing a very homogeneous product and ralatively low cost. CVD in general includes reacting a carbon-containing gas (like ethanol and ethylene) with particle of the metal catalyst (generally what is nickel, cobalt or a blend of these like cobalt/molybdenum) at temperatures over than 600 °C as shown in Figure 3.5. Unluckily, though this method can manufacture big amounts of CNTs, but their price is still somewhat high for making any great scale enforcement Aqel et al. (2012).

3.4.4. Applications of CNTs

The unique nature of the carbon unite with molecular completeness of the CNTs to give them the superb properties of extraordinary materials, like impact resistance, electrical conductivity, high thermal, hardness, toughness and strength. Besides that carbon is the only component in the periodic table which bonds to itself in an expanded network with the toughness of carbon-carbon bond. In spite of they are very small that about one nanometer in diameter, but they are molecules that can be treated chemically and physically in very beneficial ways. Researchers have found an unbelievable range of the applications in chemical processing, electronics, materials science and energy management. There are a wealth of the other possible applications for the CNTs, like field emission, energy storage, thermal conductivity, conductive, molecular electronics that based on the CNTs, biomedical applications, structural applications, fabrics and fibers, water and air filtration and the other application of CNTs. Certainly, there will be many expected and unexpected applications that will appear in the coming years, which can prove to be the most important and useful at all.

4. MATERIALS AND METHOD

4.1. Materials

PET composite laminas are manufactured from biaxial NCFs of commingled yarns with GF as reinforcement. The PET NCFs consist of two various fiber orientation layers also the total weight of 765 g/m^2. The structure of the commingled yarns of PET with GF shown in Figure 4.1 the fibers orientations of all layers in PET NCFs are -45° and +45°. Figure 4.2 illustrated the commingled yarns and the stitch fibers orientations in a NCFs. PET NCFs were acquired from the Metyx Composites Company, Istanbul-Turkey. The properties and specifications of PET NCFs showed in Table 4.1. The commingled yarns in the NCFs were incorporated with the MWCNTs and MWCNTs-COOH like a next stage reinforcement. The properties and specifications of the MWCNTs and MWCNTs-COOH used in our study illustrated in Table 4.2 and Table 4.3 respectively. The provider of MWCNTs and MWCNTs-COOH is Ege Nanotek Kimya Sanayi, in Izmir/Turkey.

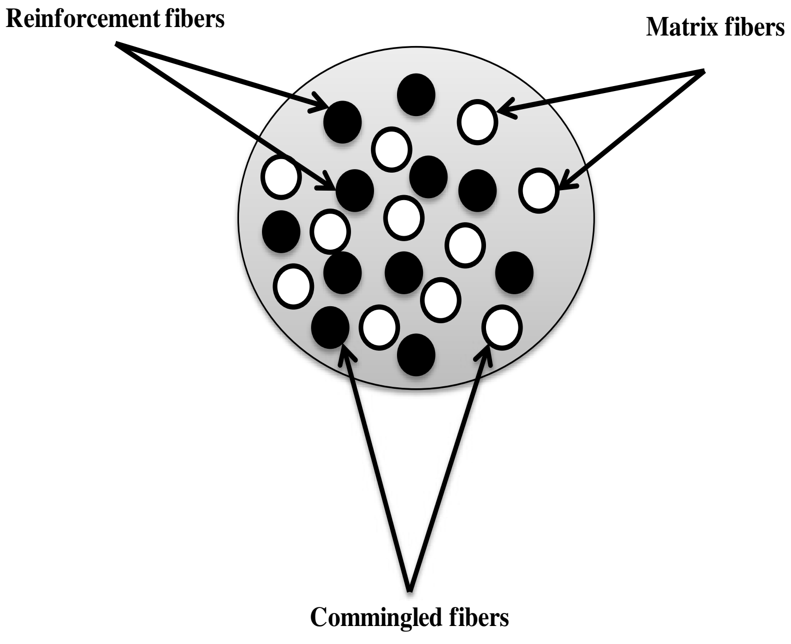


Figure 4.1. The structure of the single strand of the commingled yarns that exhibit the constituents of the fibers (PET/ GF)

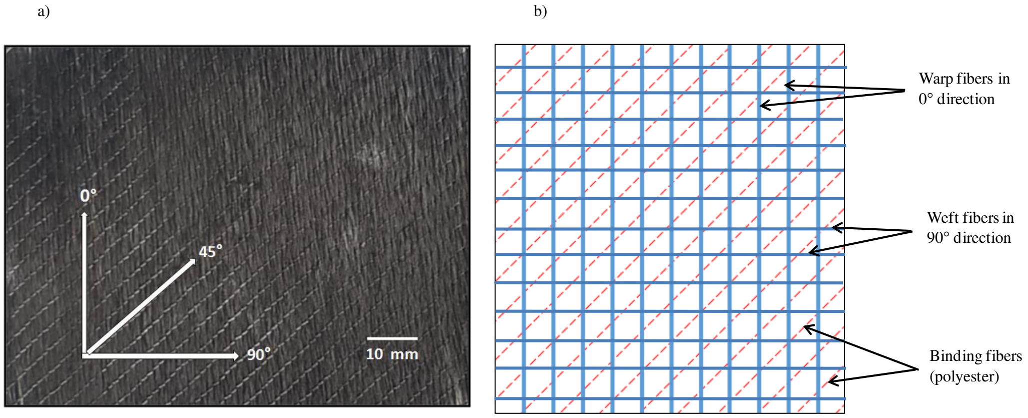


Figure 4.2. The commingled yarns and binding fibers orientation in NCF (a) real image of the biaxial NCFs, (b) schematic drawing of the biaxial NCFs

Table 4.1. Specifications of NCFs of PET

	Biaxial yarn +45° (warp) fibers	**Biaxial yarn -45° (weft) fibers**	**Binding fibers**
Weight composition	60% glass fibers 40% PET fibers	60% glass fibers 40% PET fibers	100% polyester
The color	Natural white	Natural white	Natural white
The weight (g/m^2)	380	380	5.0
Fiber yarn count (TEX)	525	525	7.6

Table 4.2. Properties of (MWCNTs)

Parameter	Value
The outer diameter (nm)	10–20
The interior diameter (nm)	5–10
The length (mm)	10–30
The surface area (m^2/g)	>200
The color	Black
The ash	Mass<%1.5
The electrical conductivity (S/cm)	>100
The density (tap) (g/cm^3)	0.22
The density (true) (g/cm^3)	2.1

Table 4.3. Properties of (MWCNTs-COOH)

Parameter	Value
The content of-COOH (wt %)	2
The outer diameter (nm)	10–20
The interior diameter (nm)	5–10
The length (mm)	10–30
The surface area (m^2/g)	>200
The color	Black
The ash	Mass<%1.5
The electrical conductivity (S/cm)	>100
The density (tap) (g/cm^3)	0.22
The density (true) (g/cm^3)	2.1

4.2. Magnetic Stirrer

The first step of dispersing of the MWCNTs in ethanol liquid begins with the device called magnetic stirrer that illustrated in Figure 4.3. A magnetic stirrer an instrument that uses a rotating magnetic field that moves a bar obscured in the liquid (ethanol) to spin quickly and stirring it.

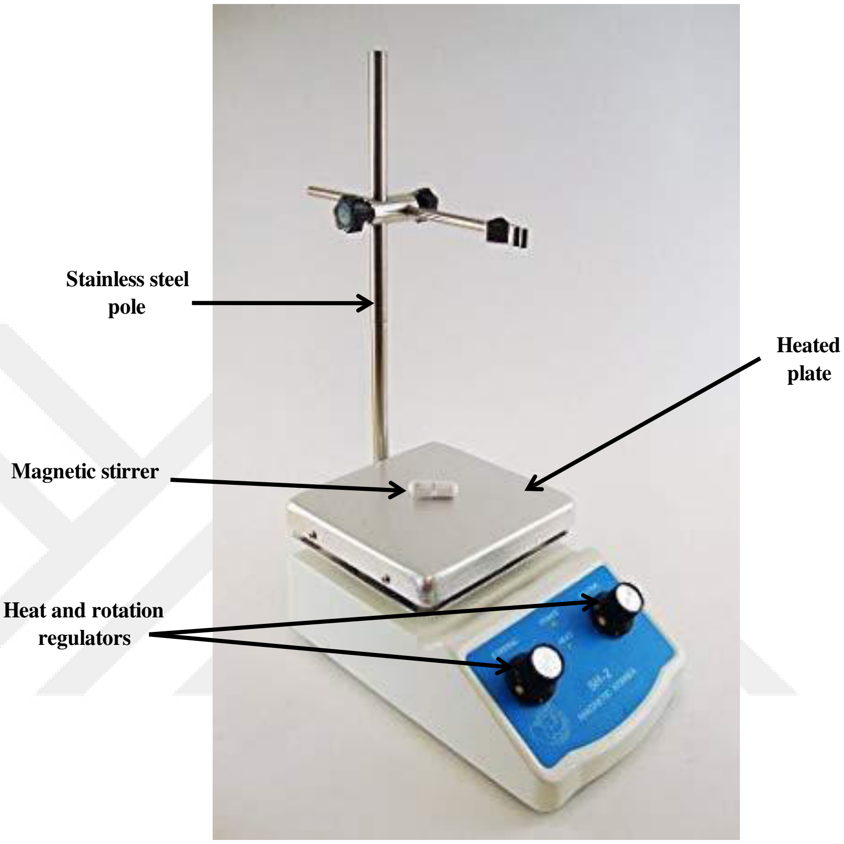
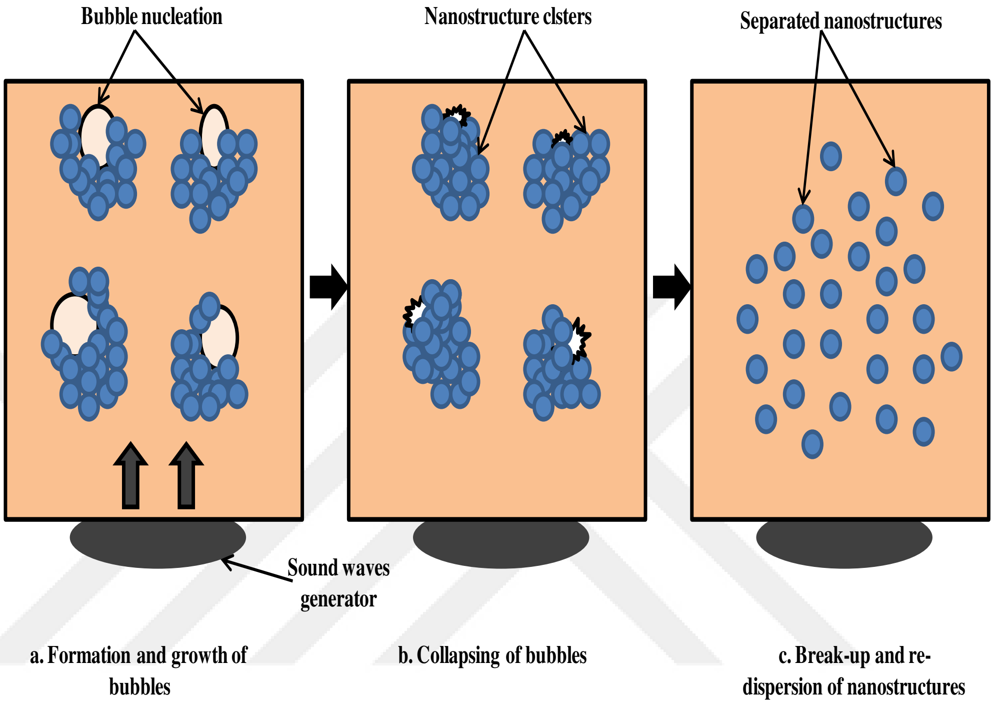


Figure 4.3. Magnetic stirrer instrument

4.3. Ultrasonic Dispersing of MWCNTs

As mentioned previously, CNTs are highly coherent. The process of dispersing it in various liquids like ethanol, water and even polymers. The ultrasonic dispersing method is so efficient technique for obtaining separated single dispersion of CNTs. The various dispersion techniques and the ultrasonication is one of a suitable method to reduce the CNTs agglomeration as mentioned in many studies. In ultrasonication method, the sound waves propagate into the liquid media that lead in alternating low and high pressures cycles. Through the cycle of low pressure, high intensity ultrasonic wave make a small voids or vacuum bubbles in the liquid. These bubbles when reach a size that can no longer absorb energy, they breakdown strongly during the cycles of high pressure. This phenomenon can be termed as cavitation that shown in Figure 4.4.



a. Formation and growth of bubbles

b. Collapsing of bubbles

c. Break-up and re-dispersion of nanostructures

Figure 4.4. Ultrasonic dispersing method Zhou et al. (2014)

4.4. Hot-Press Manufacturing Process

In this machine, ten layers (NCFs from PET) symmetrical of the +45°/-45° biaxial NCFs were placed in a mold; the mold must withstand high temperatures, so it is made of copper and putted between two steel heaters. The molding temperature and pressure were 205 °C and 13 bar respectively. After that, samples were cooled until reached room temperature. The same pressure and temperature values were applied for the all manufactured samples. In Figure 4.5 illustrates a schematic drawing of a hot-press machine which showes the main parts.

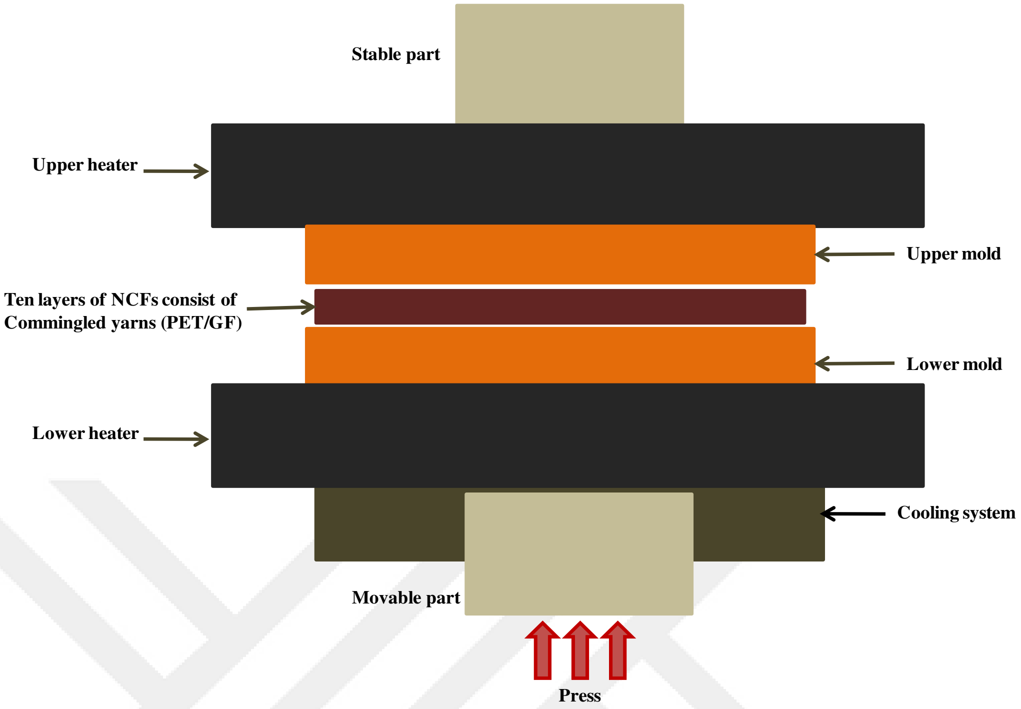


Figure 4.5. Schematic drawing of the hot press-machine which showes the main parts

4.5. Method

4.5.1. MWCNTs solution and NCFs preparation

At the first ethanol was used such as a dispersing agent of the solution because of its compatibility with the MWCNTs and PET/GF. As we maintioned, the first stage of MWCNTs dispersion in ethanol begins with a magnetic stirrer, in which distribution by using a magnet bars and stirred through magnetic field. The next step of dispersion is by means of a technique called ultrasound, in this procedure MWCNTs dispersed homogenously in the ethanol Park et al. (2008).

In our study, we used a fixed percentage of MWCNTs (0.9wt %), Figure 4.6 display the process of preparing of NCFs and the process of its coating with MWCNTs and MWCNTs-COOH materials. The dimensions of the NCFs were 20 x 20 cm^2. We coated the two faces of the NCFs with the prepared solution previously for the ten layers that used in the fabrication of thermoplastic composites as shown in Figure 4.7, the specimen before and after coating them successively. After the coating process we left the ten layers for a period three days at the room temperature to ensure the ethanol is fully evaporated.

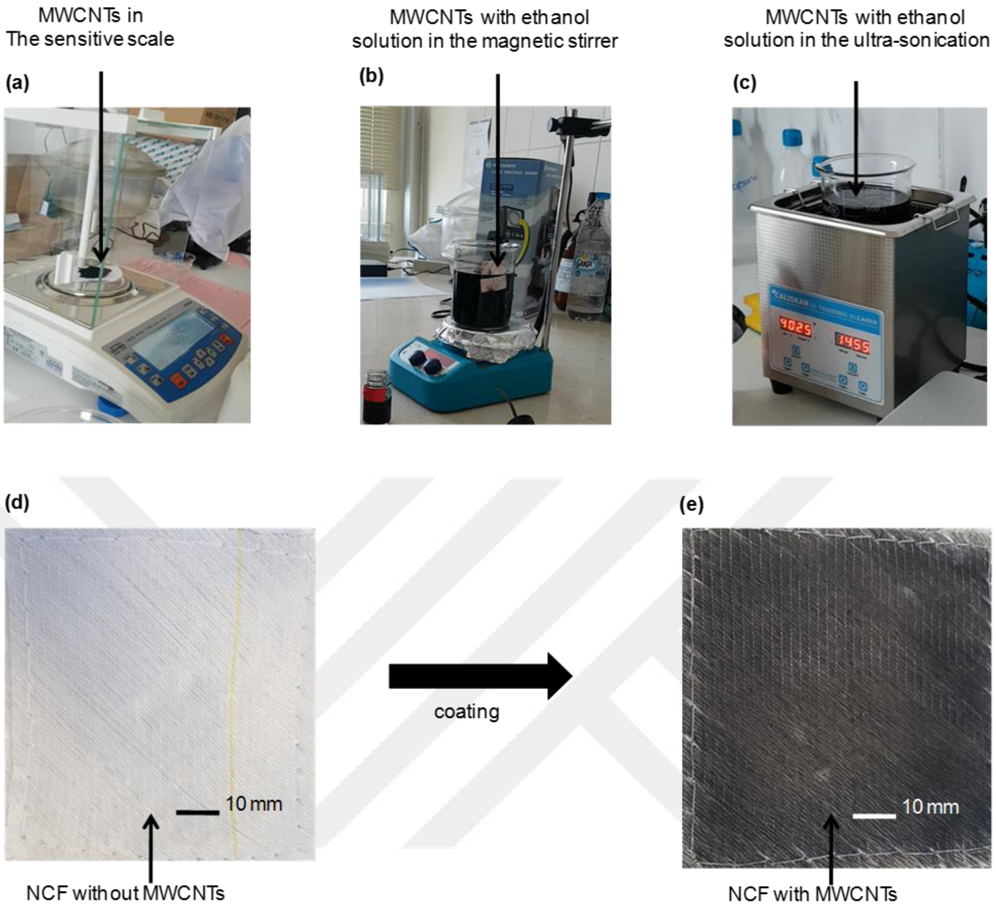
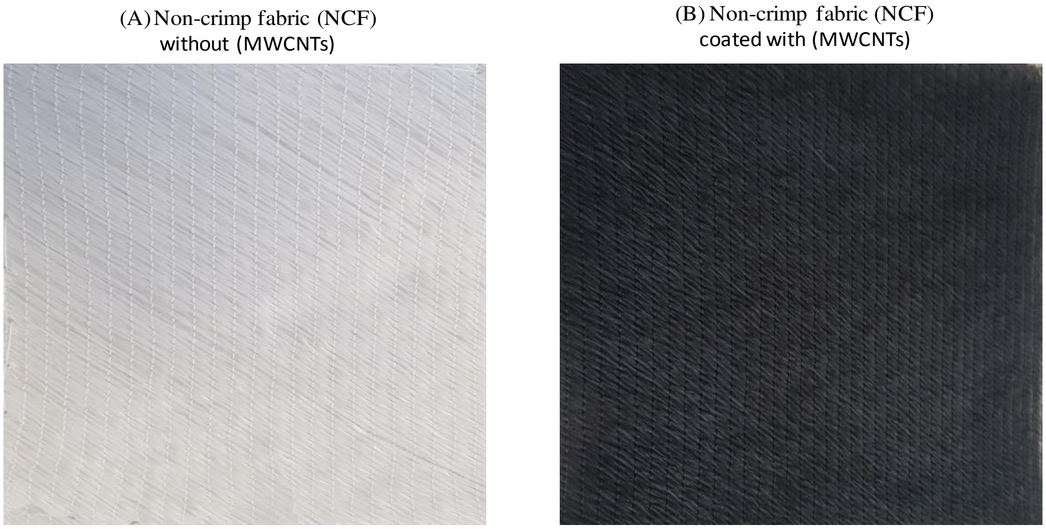


Figure 4.6. Sequential operations of coating NCFs with MWCNTs


(A) Non-crimp fabric (NCF) without (MWCNTs)

(B) Non-crimp fabric (NCF) coated with (MWCNTs)

Figure 4.7. (a) NCF without MWCNTs, (b) NCF coated with MWCNTs

4.5.2. Sampling method

Reinforcement orientation has a great effect on the mechanical properties of the composites like tensile and flexural properties Alves et al. (2016). The samples laminas manufactured in hot-press machine were equipped for sampling in tow various orientations of the fibers that based on reinforcement direction (PET/GF). As shown in Figure 4.8, tow samples can be identified: samples in 0°, these samples parallel depending on the reinforcement fibers direction, samples in -45°, these samples in -45° direction depending on the reinforcement fibers.

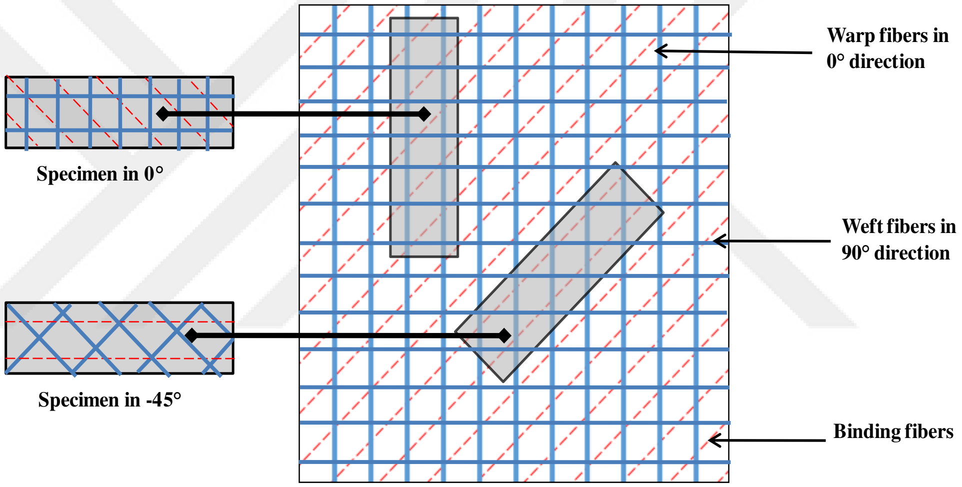


Figure 4.8. Sampling method

4.5.3. Volume and weight fraction

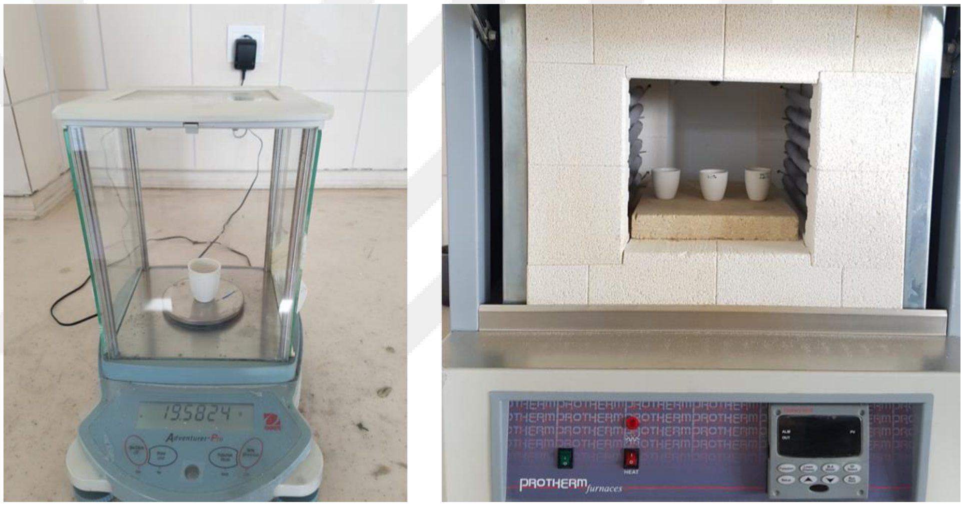
For the purpose of determining the percentages of all components of the thermoplastic composites, specifically each component separately, burn off method in the muffle furnace was used. The operation was done in accord with the American Society for Testing and Materials (ASTM) D3171–99 standards. We can shorten the process in three steps Figure 4.9:

The first, we have to find the value of the density of the samples (Pc) and the mass (Mi) of the samples and the weights of the crucibles that used. The density of the glass fiber (Pr) is constant. The second, Use the muffle furnace to burn off PET and raise a temperature of 620 °C for approximately 5 hours. Finally measure the mass of reinforcement fibers GF (Mf) that remained alone in crucibles. Use the following of the equations to calculate weight fraction (Wr) and volume fraction (Vr) of the reinforcement constituents:

$$Wr = Mf/Mi \times 100$$

$$Vr = Mf/Mi \times 100 \times Pc / Pr$$

The values of the weight and volume fraction of all of the specimens of 3-point flexural test showed in Table 4.4.



Calculate the weight of the crucibles and specimens

Specimens in the furnace and the temperature set to 620 °c

Specimens (MWCNTs-COOH, MWCNTs and PET respectively) before positioned in furnace

Specimens after positioned in furnace (pure reinforcement results)

Figure 4.9. Burn off in the muffle furnace method for calculating the reinforcement weight and volume fraction of the composites

Table 4.4. Volume and weight fractions of composites for the samples

Weight percentages of MWCNTs (MWCNTs wt %)	Weight percentages of glass fibers (GF wt %)	Volume percentages of glass fibers (GF vol %)	Density (g/cm3)	Thickness (mm)
0.0	63.38	44.47	1.824	3.42
0.9	59.86	42.00	1.824	3.64
0.9-COOH	63.85	45.64	1.858	3.42

4.5.4. Mechanical characterization

Optical Microscopic (OM) and Scanning Electron Microscopic (SEM) images were obtained in the JSM-7001F analytical field-emission SEM (Japan) and Leica DM 4500 OM apparatus (Germany). Fourier Transform Infrared (FTIR) spectroscopy analysis was completed in Bruker Tensor 27 FTIR (Germany).

The 3-point flexural tests were conducted on the samples according to ASTMD790 standard. In this tests, three specimens were tested from each type of composite plates in the size of 9 cm x 1.5 cm x thickness in the warp direction. The specimens were tested by using the INSTRON 5982 100 KN (USA) with the flexural test apparatus at Ondokuz Mayıs University (OMU) Central Laboratory (KITAM).

Figure 4.10 display the top and side views of specimens that used for the bending tests, ten layers fixed with each other from PET/GF were applied and ASTM-D790-03 standards were followed to preparing the samples. The prepared samples dimentions were 90 mm in length, 15 mm in width and approximately 3 mm in thickness. Also the span length was variable due to the thickness of the specimen; it ranged between 48 mm and 52 mm. In this test, two types of samples were tested in 0° and -45° directions for all of panel’s type.

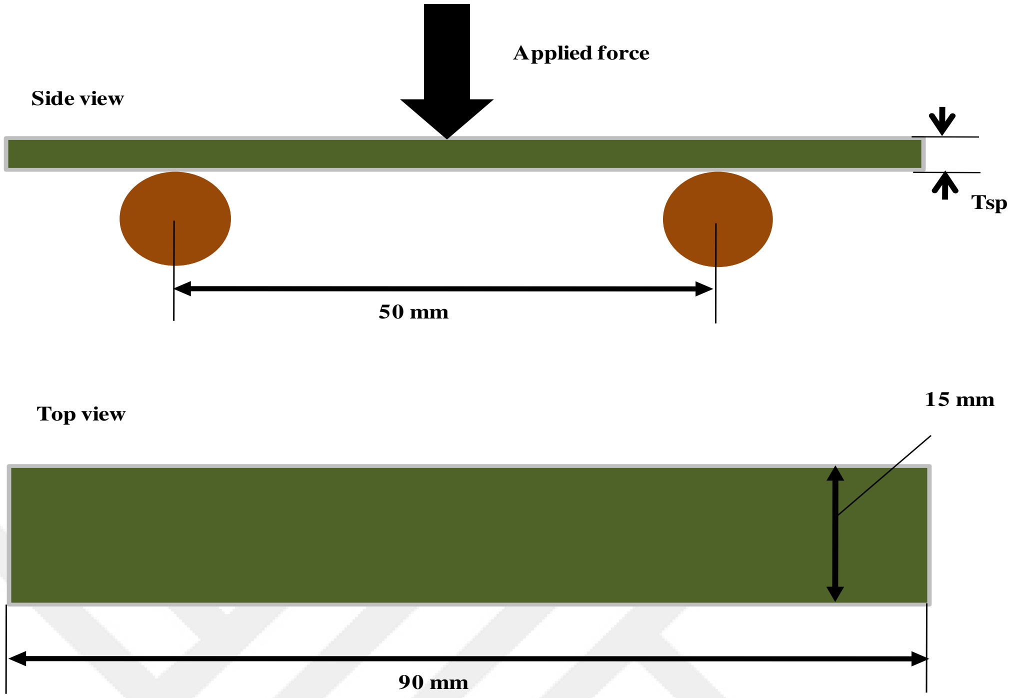


Figure 4.10. Dimensions of the specimens for bending test

5. RESULTS AND DISCUSSION

5.1. Scanning Electron Microscope

The images of the SEM microscopy of the surface morphologies of PET-GF after grafting CNTs and before fabricating it are illustrated in Figure 5.1 and Figure 5.2, they were taken to notice the distribution of MWCNTs upon the fabric.

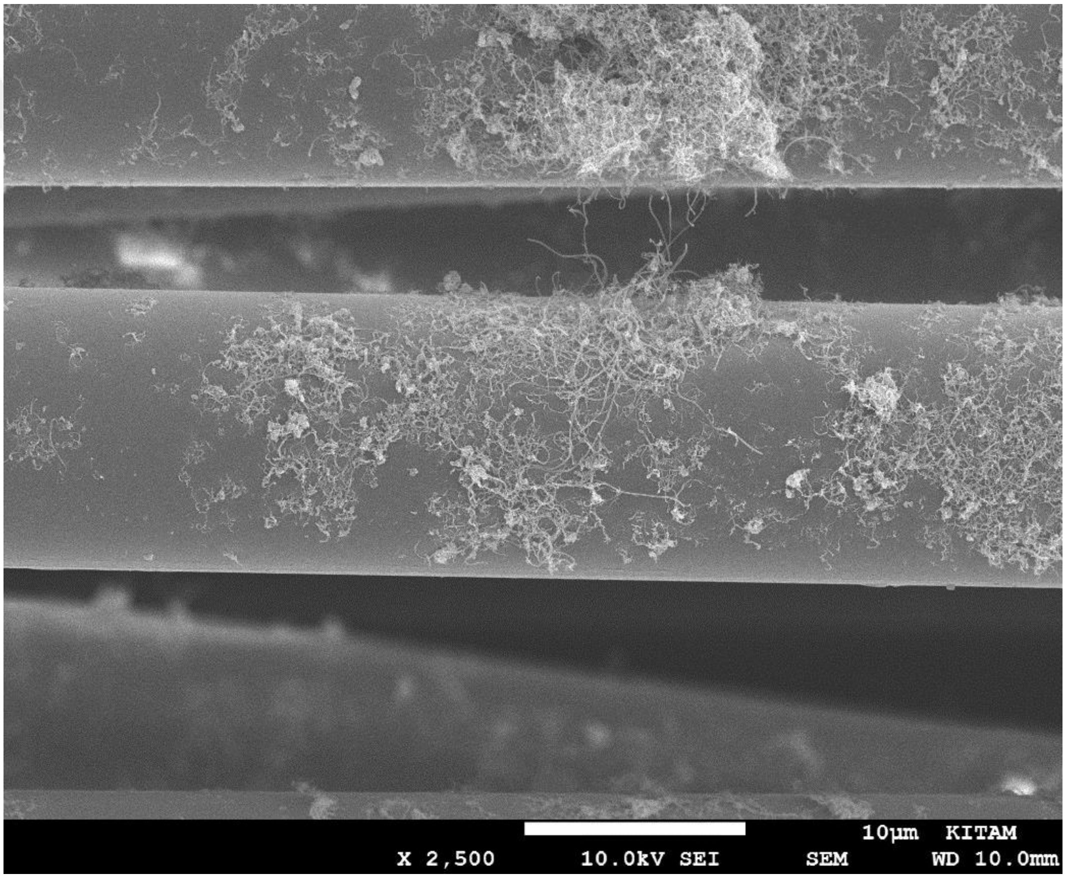


Figure 5.1. SEM image of NCFs after coating with MWCNTs before fabrication

Figure 5.2 points to the SEM image of GF after coating it with the CNTs. The GF surface was covered homogenously by CNTs.

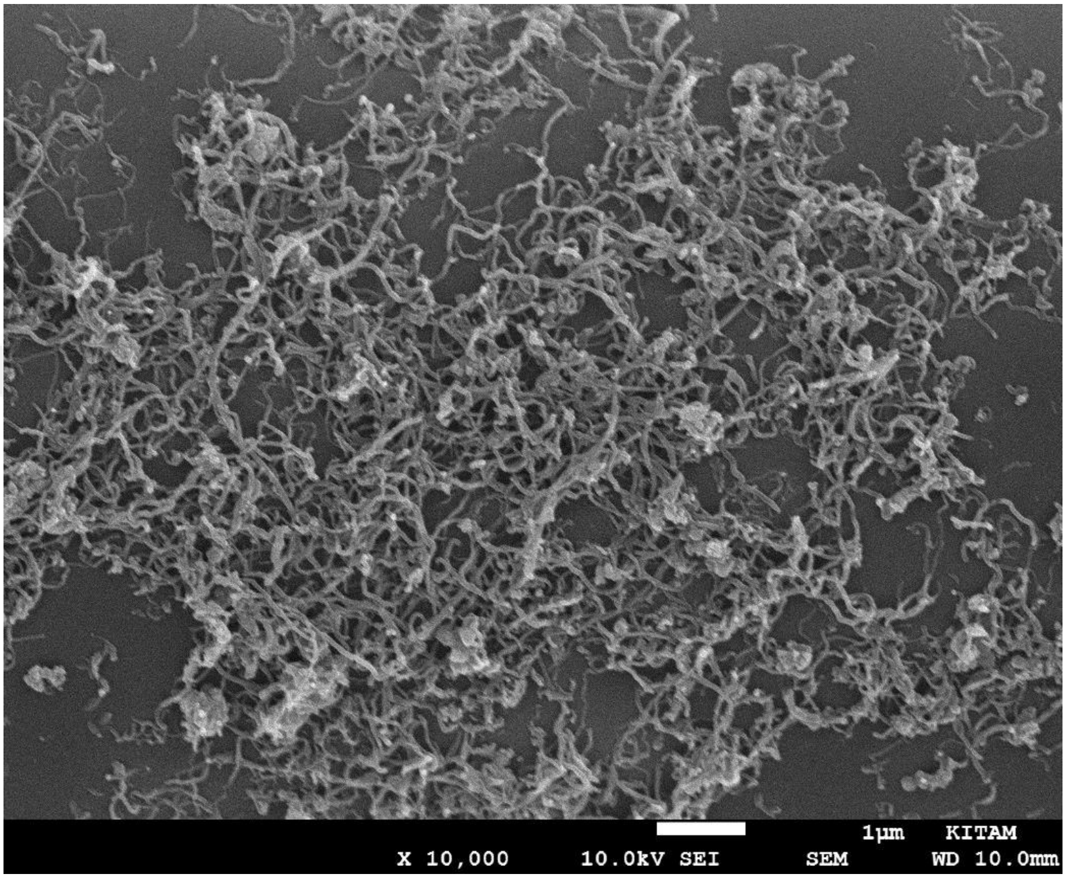


Figure 5.2. SEM image of the NCFs after coating by MWCNTs before fabrication with another magnification

The CNTs on the GF was generally distributed homogenously. In addition, rightly CNTs agglomerations were also showed in Figure 5.3. Clearly that distributed CNTs in homogeneous way play a significant role in an interfacial interactions among the matrix interface-grafted CNTs fiber and the extra power mechanisms which include CNT pull out and bridging Godara et al. (2009).

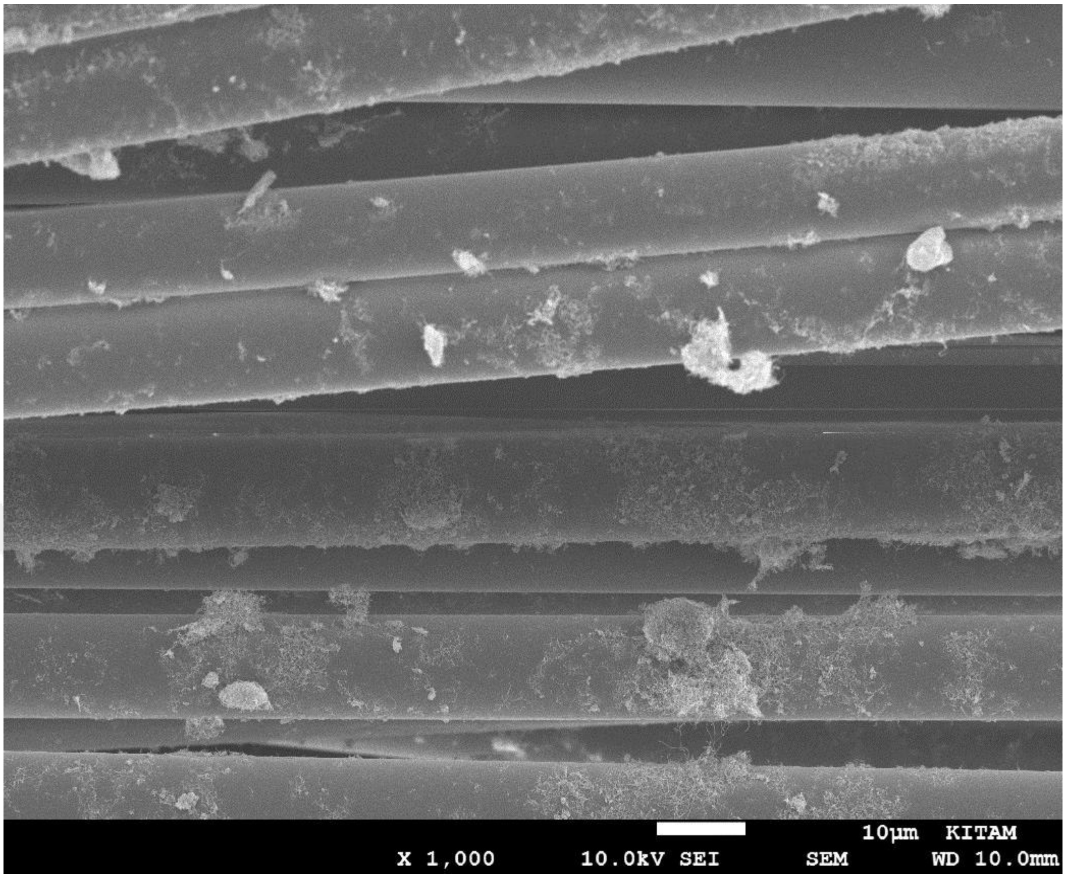


Figure 5.3. SEM image of the NCFs coated with the MWCNTs before fabrication with different magnification

5.2. Fourier Transform Infrared Spectroscopy

Fourier-Transform Infrared (FTIR) spectroscopy is a method that used to obtain an infrared spectrum of the emission or absorption of a liquid, solid or gas. At looking to the FTIR spectrum of the MWCNTs references to the existence of remarkable amount of the functional groups on the surface of nanotube as shown in Figure 5.4 (a). The peak at 3731 cm^{-1} is indicating to the free hydroxyl groups. The peaks at 2904-2989 cm^{-1} agree to the vibrations of C–H bonds showing the –CH3 adsorption on the surface of the nanotube Mallick (2007). After looking at the result of the FTIR analysis, we clearly see the appearance of four major peaks associated with the structure of the PET namely were terephthalic acid ester $C^1/_4O$ group at 1715 cm^{-1}, the asymmetric C–C–O, the O–C–C spread at 1240, stretching 1092 cm^{-1} and the last major peak appeared at C–H wagging vibrations from aromatic structures at 731 cm^{-1} Nijssen (2015). The peak at 1408 cm^{-1} corresponds to C–O stretch vibration of the free carboxylic acid groups. The peak at 872 cm-1 references to the existence of the silanol groups on the surface of the fiber Eskizeybek et al. (2017) Eskizeybek et al. (2014). With the coating of NCFs with the MWCNTs, did not observe any changes on the wave numbers, characteristics and intensities of spectrum, just a physical interaction between MWCNTs and NCFs as shown in Figure 5.4 (c).

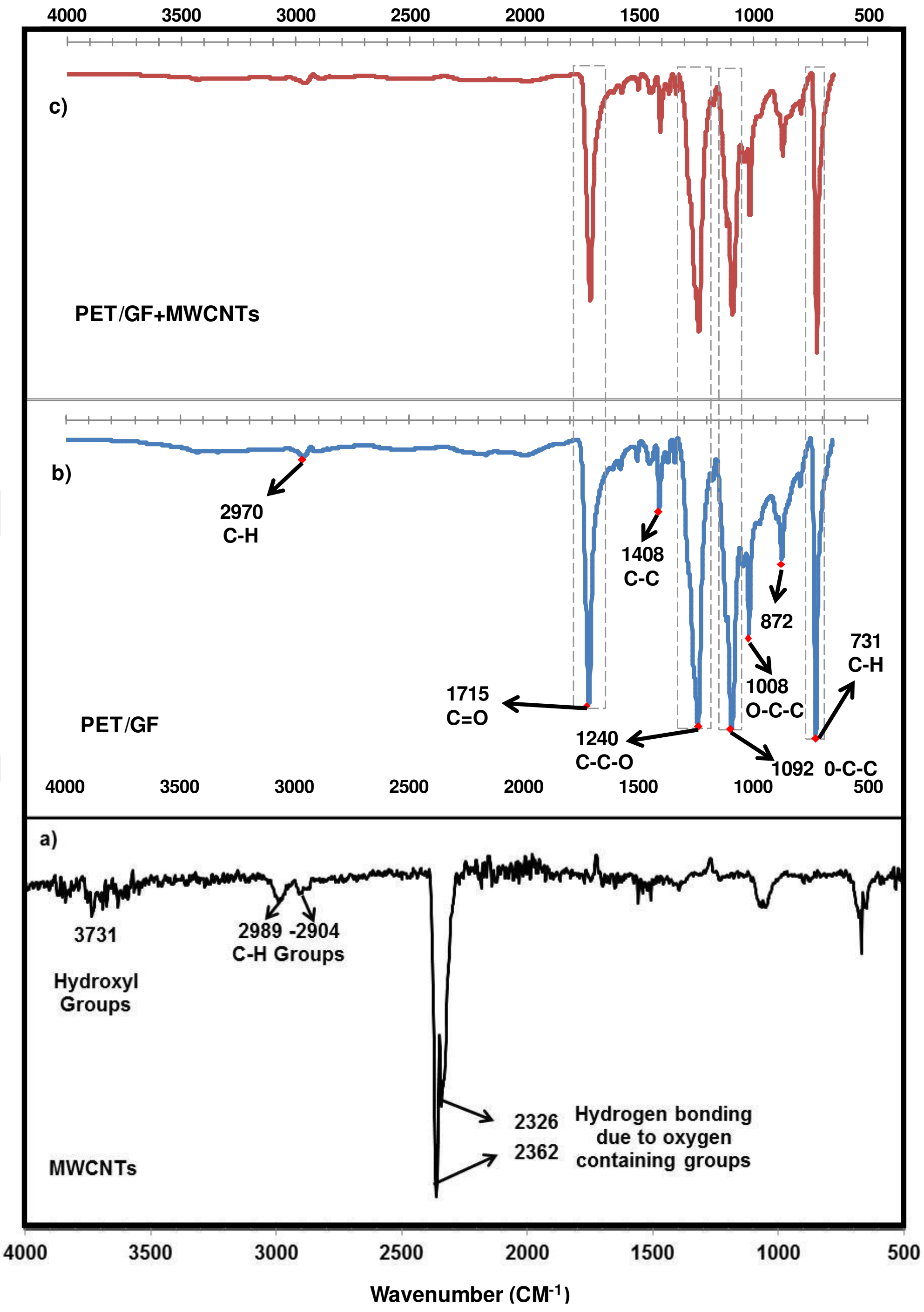


Figure 5.4. Results of FTIR characterization for the tested samples from bending test

5.3. Testing of 3-Point Flexural

Simplified definition of flexural stress is the ability to resist deformations when it is under the bending force Curtis et al. (2009). Figure 5.5 (a) and (b) illustrated the curves of the stress–strain that obtained from the 3-point bending test. In Figure 5.5 (a) and (b), the composites with MWCNTs-COOH had greater flexural stress than the other samples, however the composites which without being added to it CNTs (0 MWCNTs) obtained lowest flexural stress for both orientation 0° and -45°. Figure 5.6 shows the results of flexural modulus and flexural strength of all of the samples together (MWCNTs-COOH, MWCNTs and without MWCNTs). The flexural strength and modulus of the specimens were improved with addition with 0.9wt% of MWCNTs-COOH and MWCNTs. Whatever the direction of the samples, the MWCNTs-COOH had the best and highest flexural strength and modulus between the other specimens. The samples in 0° direction with addition of MWCNTs-COOH in the rate of 0.9-wt% MWCNTs-COOH had the best and highest results of flexural strength and modulus (11 GPa and 288 MPa, sequentially) with an improvement of about 14% flexural strength and about 58% flexural modulus compared to that samples without MWCNTs-COOH in 0° direction. The samples without MWCNTs in direction of 0° had better flexural modulus and flexural strength (7 GPa and 252 MPa) if we compared them to that specimens was in -45° direction (5.7 GPa and 119 MPa). The composites that have been tested in 0° direction had a greater flexural strength and modulus than the other specimens those in -45° direction. In addition, the tests showed that the samples containing MWCNTs-COOH were distinguished by stronger strength and tensile strength than those samples that did not added to them MWCNTs-COOH whether it is toward 0° or -45° directions. Also composites with MWCNTs in both 0° and -45° directions had the second best results of flexural modulus and flexural strength and the lowest results showed from the specimens without MWCNTs (0.0-wt%). The tested samples with 0° direction obtained higher results if we compared it with the other samples. Several of reinforcement fibers were perpendicular and the others were parallel against the applied loads as shown in Figure 4.8. After we conducted the tests on all specimens in both directions 0° and -45°, it was found that the samples towards 0° were stronger and better, and the results showed that the flexural strength and modulus is better than the specimens in -45° direction and this proves that the perpendicular orientation of the fibers against the applied force positively increases the results compared to its counterparts.

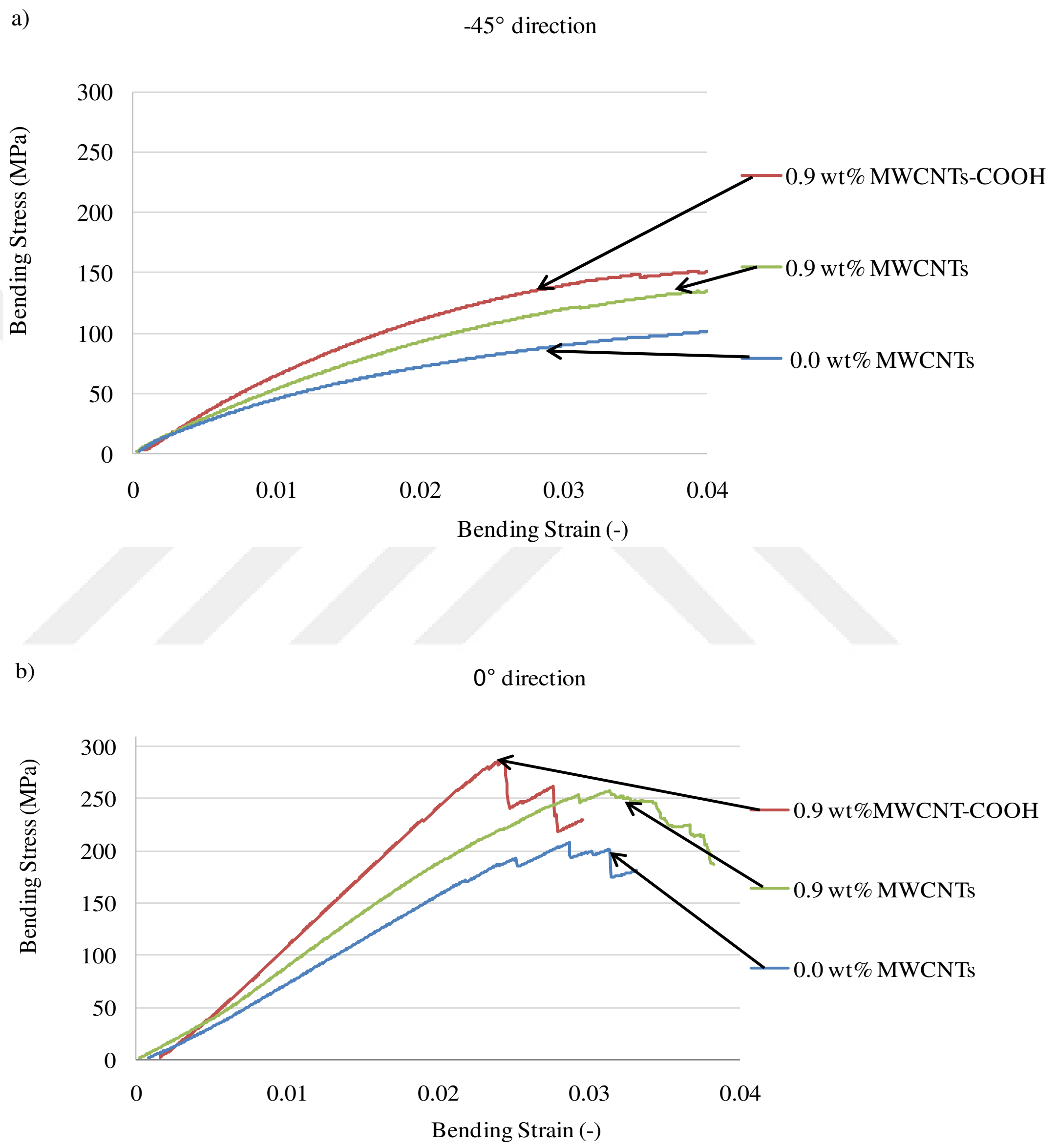


Figure 5.5. The curves of the stress–strain obtained from the 3-point flexural test (a) in -45° direction, (b) in 0° direction

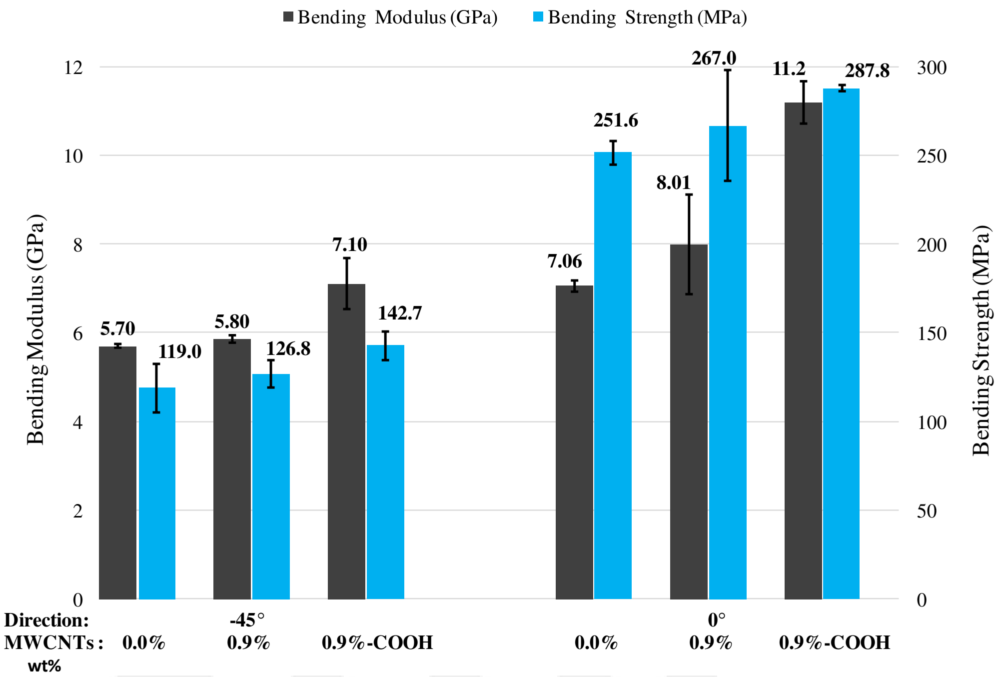


Figure 5.6. Flexural modulus and strength results of all types and directions of the specimens from 3-point flexural test

Figure 5.7 and 5.8 appears the SEM images of tested samples with 0.9wt% MWCNTs from flexural test; we can see covalent interactions between the the matrix and the outer walls of the CNTs, also in Figure 5.9 appears SEM image of a surface of tested samples with 0.9wt% MWCNTs that showed good presence of MWCNTs.

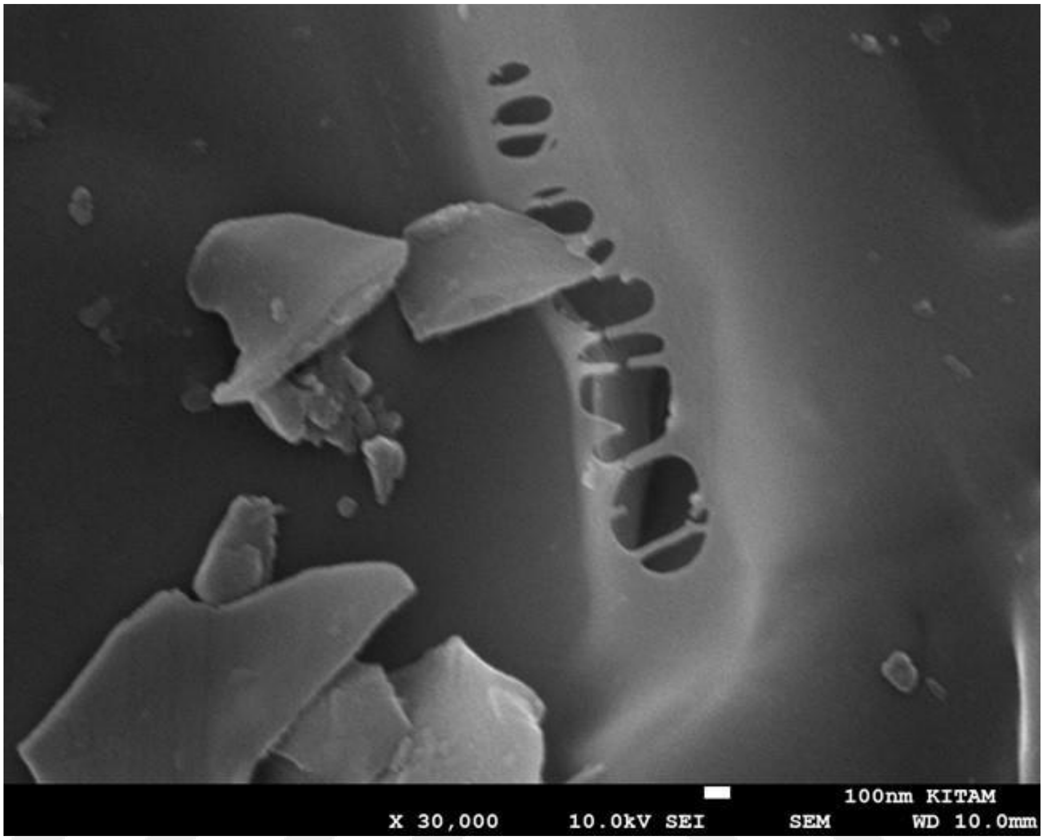


Figure 5.7. SEM image of the specimen after fabricating MWCNTs in scale of 100 nm

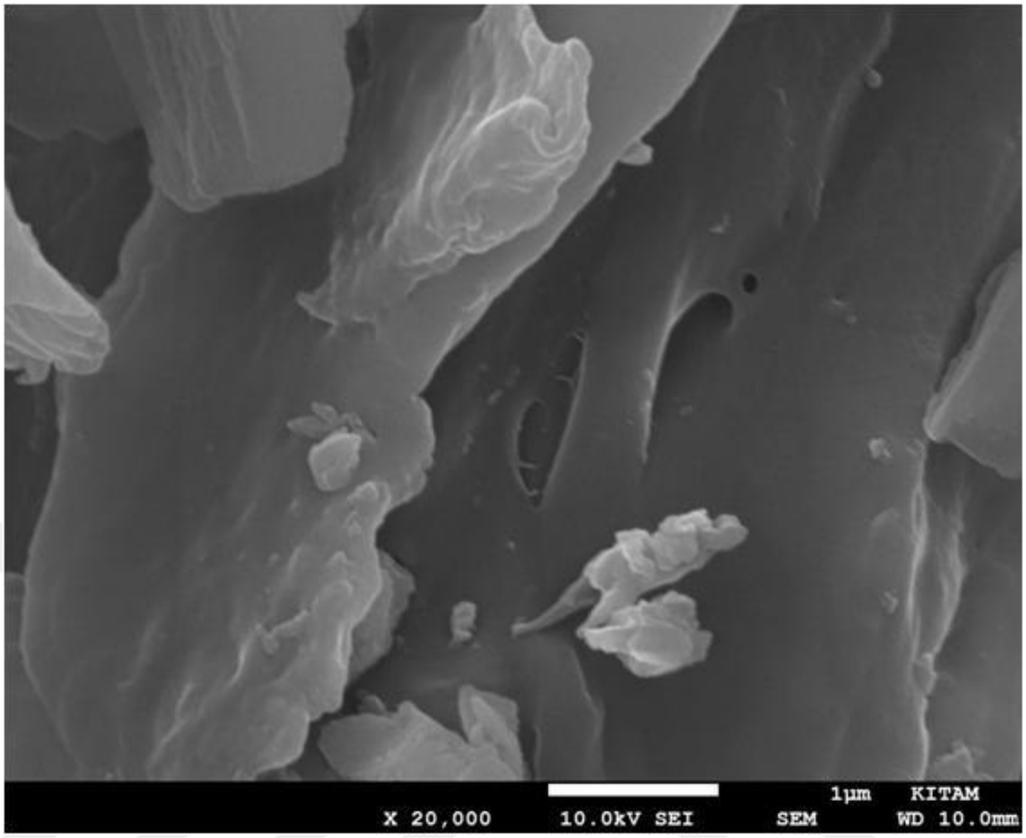


Figure 5.8. SEM image of specimen after fabricating MWCNTs with lower magnification

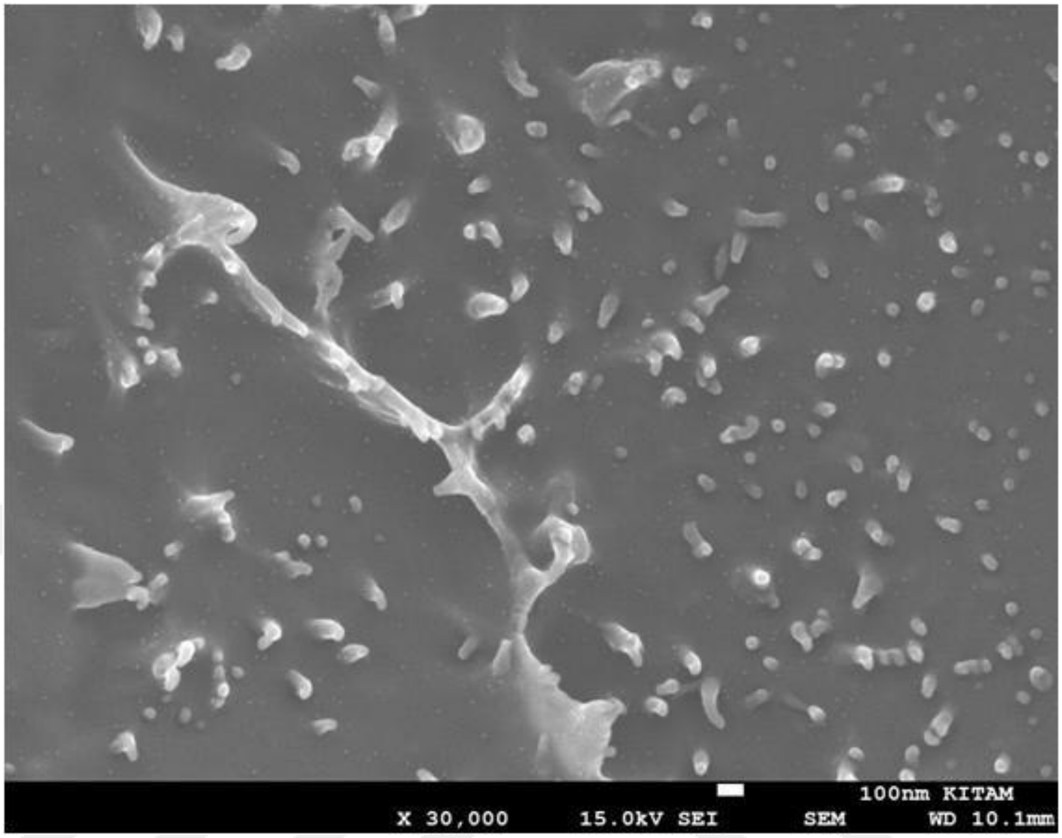


Figure 5.9. SEM image of a surface of the sample that showed good presence of MWCNTs

5.4. Optical Microscope

Figure 10 (a, b) illustrates the fracture aspects of the optical microscope (OM) from the bending tested samples in 0° direction. In Figure 10 (a) the formation of cross-section of the composite sample (0 percentages of MWCNTs) after the fracture under bending force. Delaminations were showed so clearly in fractographic analysis.

Figure 10 (b) shows the cross-sections of the composite sample with 0.9 percentages of MWCNTs. Delaminations were not appeared in the fractographic analysis. It is approved from optical imaging that the integrated thermoplastic PET/GF can be greatly improved after adding the MWCNTs. More important, no delaminations and little cracks arises after confirms to the well interfacial bonding between PET/GF due to the added MWCNTs, composite showed superior mechanical properties compared to that composite without CNTs in 0° direction. The enhanced mechanical properties of PET/GF integrated thermoplastic composite can be attributed to the completely exploited reinforcement effect from MWCNTs by a good dispersion Zanjani et al. (2016).

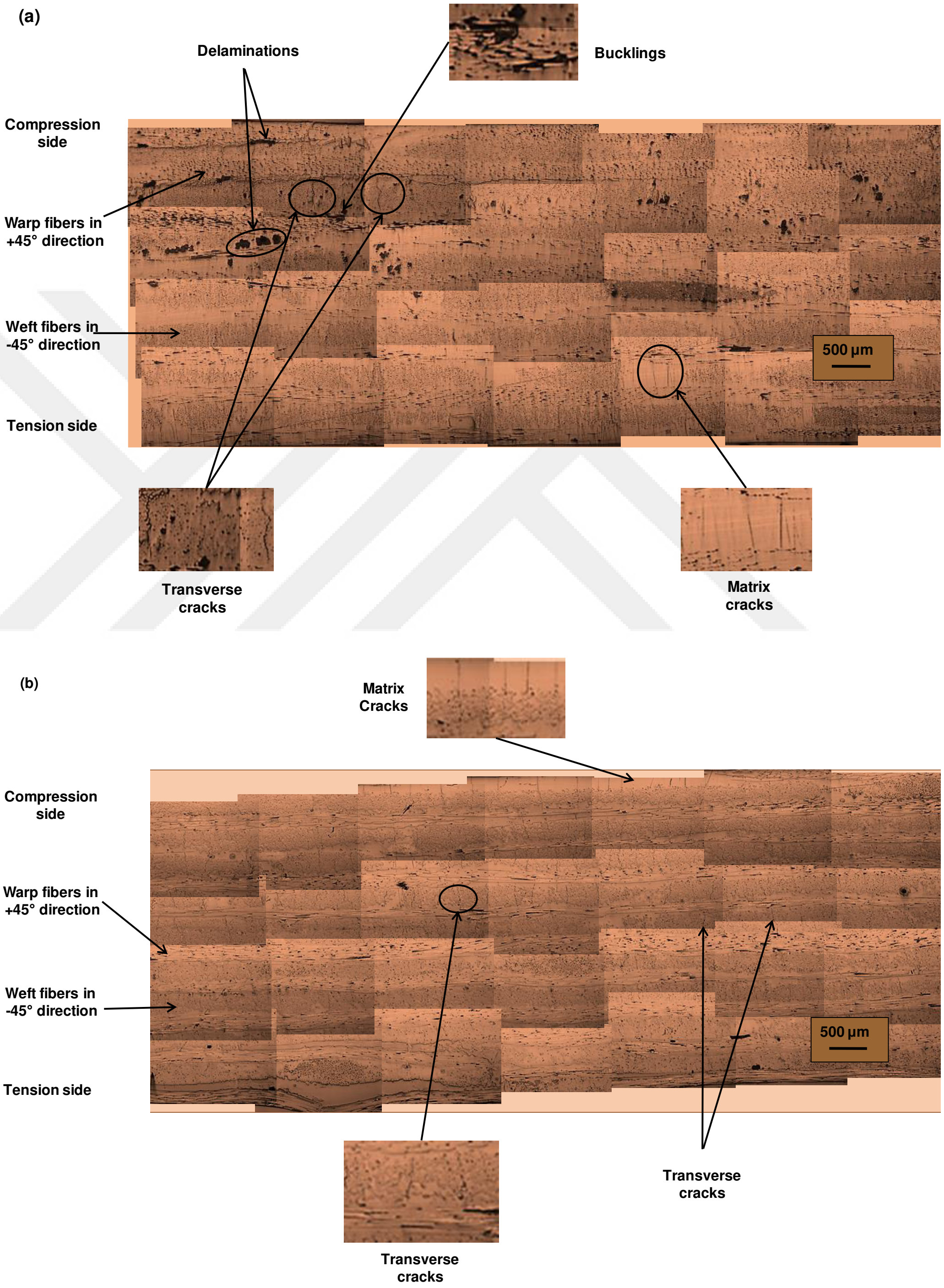


Figure 5.10. Fracture areas of the (OM) from flexural tested samples (a) without addition of MWCNTs and (b) with addition of 0.9wt% of MWCNTs.

6. CONCLUSIONS

Our study presented and revealed that the 3-point flexural properties of thermoplastic composites with PET/GF commingled fibers could be enhanced by adding good amount of MWCNTs at the ten layers of fabrics. The samples with (MWCNTs-COOH) obtained the highest and best results in the flexural strength and modulus between the other samples, the specimens with (MWCNTs) came with the second best results and the specimens without MWCNTs obtained the lowest results. The results showed that samples with 0.9-wt% of (MWCNTs-COOH) in direction of 0° had the best and highest results of the properties with an improvement approximately 14% flexural strength and about 58% flexural modulus if we compared to another samples that without MWCNTs in 0° direction given the to increase the interfacial adhesion because of the existence of the MWCNTs-COOH.

Our study also provided that after we conducted the tests on all specimens in both directions 0° and -45° regardless of whether or not CNTs is added to samples, it was found that the samples towards 0° were stronger and better, and the results showed that the flexural strength and modulus is better than the specimens in -45° direction and this proves that the perpendicular orientation of the reinforcement fibers against the applied force positively increases the results compared to its counterparts.

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