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Characterization of Carbon Fiber Micro- and Nanostructure using Electron Microscopy Image Processing

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วิทยาลัยนานาชาติ

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ABSTRACT

In automotive field, material is one of the way to reduce fuel consumption and emission by reduce weight of vehicles. Among several materials in automotive field, composite material is one of the most effective material to reduce weight. In composites, carbon fiber and glass fiber composite are found as the most effective composite and the most flexible material to reduce weight. Those are the most effective material to reduce weight. In current research, two types of carbon fiber and two types of glass fiber were choose to study in both fabric alone and composite. Epoxy resin was used a matrix in this composite. Hand lay up fabrication process was used to make composite. Carbon fiber composites frequently used composite in these days. X-ray diffraction (XRD), Raman Spectroscopy, Nano Indentation and Fourier Transform Infrared (FTIR) to investigate characteristic of fibers. Image processing method such as Scanning electron microscopy (SEM), field emission scanning electron microscopy (FE-SEM) and Transmission electron microscopy (TEM) are used to observe morphology of fiber and fracture mechanism of composite. Usage of composites are increased rapidly in automotive field.

Keywords: Carbon Fiber, Glass fiber, Hand lay up, Image processing

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Asst.Prof.Dr.Preechar Karin
Automotive Engineering Program, KMITL

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Chapter 1
Introduction

1.1 Research Background

In a current huge global development situation, automotive field is one of the most important thing for transportation. But carbon dioxide are increase yearly with the increase of vehicles because vehicles released several carbon-dioxide in environment. Only a few of carbon dioxide are absorbed by plants and the rest are greenhouse gas which is the cause of global warming. Therefore, several researcher are researching to reduce carbon dioxide from vehicles with several method. And found that there are several way to reduce exhaust gases. Materials are one of the effective way to reduce weight that lead to reduce carbon dioxide. Among several materials, composite of carbon fiber and glass fiber are the most effective material with 60% of weight reduce. There are only a few of composite manufacturing due to complex design and manufacturing process. The lack of knowledge of composite character is also one of the reason.

The research on optical, macro and micro are not still sufficient but needed nano scale both in fiber filament alone and interfacial bonding of fibers-matrix. To enhance the mechanical properties of carbon and glass fiber composite are much depends on the nanostructure of fiber filament. Fiber surface is also one the main important part to increase bonding structure between the matrix and fiber. Smooth surface and rough fiber surface give different properties and fracture mechanism. Matric called epoxy is also one of the main important matrix in composite. Thermosetting epoxy are mostly used in automotive field because it give high strength and high temperature resistance compare to thermoplastic matrix.

Although, several research are well conduct in carbon fiber and glass fiber fracture mechanism, current research with hand lay up process will give physiochemical characteristic, mechanical properties and fracture mechanism of carbon and glass fiber composite. And treatment of fiber surface is also one of the reason to enhance mechanical properties by increasing interfacial bonding between fiber and matrix.

1.2 Research Objectives

- To study about physical characteristic and chemical composition of carbon fiber and glass fiber in micro and nanostructure of the commercial carbon and glass fiber materials.
- To investigate mechanical properties of different woven pattern fabrics and different filament quantities within pattern in both carbon fiber and glass fiber composite.
- To study the failure mode of carbon fiber and glass fiber composite in micro and nanostructure.

1.3 Scope of Research

- Characterization of carbon fiber and glass fiber physicochemical in micro-and nanostructure for both naked fiber and composite by using engineering and material science analysis tools such as Raman Spectroscopy, X-Ray Diffraction (XRD), Fourier-Transform Infrared spectroscopy (FT-IR), Field Emission Scanning Electron Microscopy with Energy Dispersive Spectroscopy (FE-SEM-EDS), Transmission Electron Microscopy (TEM) and Carbon Hydrogen Nitrogen Oxygen Analysis (CHNO).
- Analysis of Mechanical properties of each fiber patter in fabric and composite of carbon and glass fiber by using mechanical properties analyzer such as tensile and flexural strength test. Clarification of fracture mechanism of the carbon fiber and glass fiber in micro and nanostructure by using image processing techniques from the electron microscopy image comparing the analysis results of before and after failure.

1.4 Research Methodology

- Characterization of physicochemical in micro-and nanostructure of carbon fiber and glass fiber alone without matric epoxy both mechanical properties and physical analysis by using Raman Spectroscopy, X-Ray Diffraction (XRD), Fourier-Transform Infrared spectroscopy (FT-IR), Field Emission Scanning Electron Microscopy with Energy Dispersive Spectroscopy (FE-SEM-EDS), Transmission Electron Microscopy (TEM) and Carbon Hydrogen Nitrogen Oxygen Analysis (CHNO).
- Fabricate composite by hand lay up process to investigate mechanical properties of carbon and glass fiber composite by using tensile and flexural mechanical testing machine. The failure mode of composite will be investigated by using Raman Spectroscopy, X-Ray Diffraction (XRD), Fourier-Transform Infrared spectroscopy (FT-IR), Field Emission Scanning Electron Microscopy with Energy Dispersive Spectroscopy (FE-SEM-EDS) and Transmission Electron Microscopy (TEM).

1.5 Expected Output

Current research result will be distributed as research paper in the 9th International Conference on Mechanical Engineering (TSME-ICoME2018), December 2018.

Chapter 2
Literature Review

2.1 Carbon and Glass Fiber Composites

Several researchers conduct variety of materials in deep study, several type and field in carbon fiber and glass fiber have been studied. There are several carbon fiber type base on different precursor and source raw materials. And also several different manufacturing methods make different properties of carbon fiber. Continuous fiber and short fiber are also available base on the composite fabrication type [1]. Based on the composite type, manufacturing make the bundle with different filament quantity. Carbon fiber tow and woven were made for different fabrication process. In carbon fiber, their micro and nanostructure affect much to the material properties. Well understanding micro and nano-structure might dig to the detail of carbon fiber morphologies for better composite in automotive field. Patrycja Masiol [2] represented about material structure vary base on microfibers and nanofiber with the temperature changes. Different temperature give different strength and morphologies. 92-93% containing carbon was produced into nanofiber and microfiber. 1000ºC and 2000ºC annealed micro and nanofiber have similar the ratio of integration. Annealed sample with 2800ºC of nanofiber were higher than microfiber in Raman spectra. TEM image of nanofiber was shown in **Figure 2.1**. It shows the Turbostratic structure of crystallite of carbon fibers. Graphite structure crystallite was found in nano carbon fiber at 2,800ºC annealed fiber with d_{002}=0.335nm. Lc, La and spacing was calculated from X-ray diffraction data.

In composites, there are two main functions those are fiber and matrix. Fiber is the main product in the composite and matrix is one of the material that can create bonding strength between fibers [4]. Polymer matrix is the most widely used in the composite industry. There are two main matrix resins such as thermosetting and thermoplastic resins; those are the most useful resin in the composite field for laid up process laminar. Thermosetting resin is liquid form and it is irreversible resin [5]. After curing thermoset resin, the resin cannot turn back to the original liquid form and the resin can cured by chemical reaction at room temperature. Among several resin types in thermoset, epoxy is the most useful matrix because the matrix can lead composite to the best material of high bonding strength [6]. The composite need higher strength to resist the force and epoxy have to transfer stresses to fibers. Most of the composite starts to crack from matrix de-bonding, fibers delamination and pull out fibers from the matrix failure because matrix is not wet enough to bond one to another fiber. Then matrix cannot distribute the load uniformly to the fibers [7]. Dany Arnoldo Hernandeza [8] observed the main fracture of the composite is come from the interface zone, area between resin and fiber, which is affected by the tensile stress concentration on resin. It makes a crack initiation at the resin area, and then the force and crack are distribute to the fibers. Therefore, fiber is pull out then leads to break fibers.

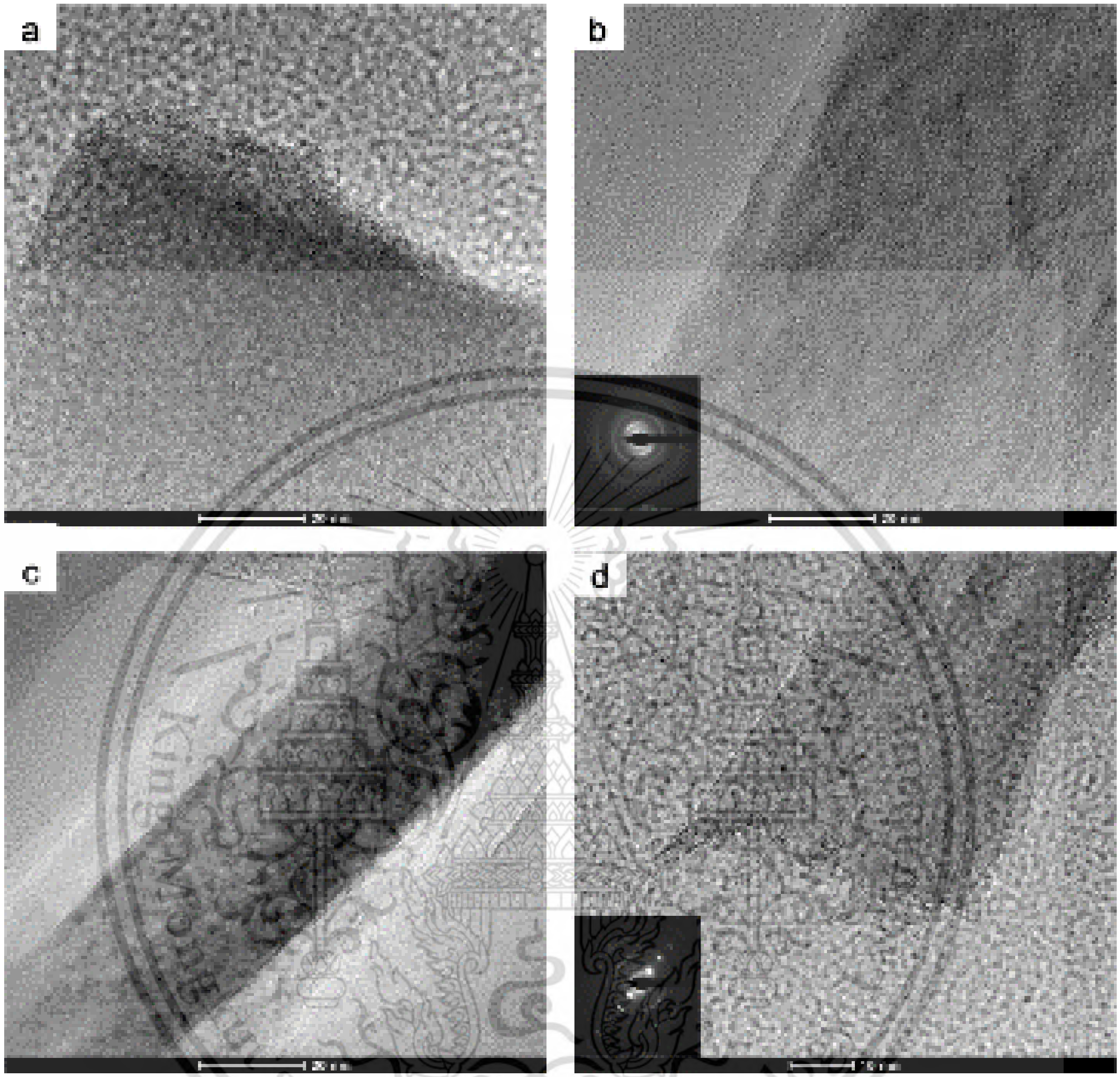


Figure 2.1 HR-TEM images of CNF annealed at (a) 1,000 °C, (b) 2,000 °C, and (c) and (d) 2,800 °C.

Issa A. Hakim [9] studied the porosity of the composite according to different vacuum poor, moderate and high vacuum. As the result, the poor vacuum composite has the highest quantity of porous that can make lower strength with faster crack then the toughness of fibers are decreasing. Energy absorptions are drop compare to moderate and high vacuum. From the view of an image, it is quite important to investigate the porous inside fiber and the structure of each fiber that can affect mechanical properties and fracture of composite. Glass fiber are produced base on Silica, however variety of different chemical composite glass fiber are available commonly. Most of glass fibers are based on Silica with the highest amount of Silica including some element of Calcium, Sodium, Aluminum and Iron [9]. There are several types of glass fibers based on different chemical composition such as E-Glass, S-Glass and C-Glass with different properties. In this research, E-Glass fiber with around 55% of Silica composition are used due to its good electric insulator and reasonable modulus strength. Thermosetting resin are liquid form and it is irreversible resin [10]. After cured thermoset resin, the resin cannot turn back to the original liquid form and the resin can cure by chemical reaction at room temperature. There are several type of resin in thermoset, in my research, epoxy type was used as matrix lead to the best material to make stronger bonding and wetting enough to the fiber [11]. The composites needs higher strength to resist the force enough and epoxy transfer the stress to the fibers, therefore well distribute bonding and wetting are needed to sustain the fiber by epoxy's bonding strength. Most of the composite are start to crack from matrix deboning, delamination and pull out fibers come from the matrix failure due to wetting are not enough to bond and transfer the load to the fibers.

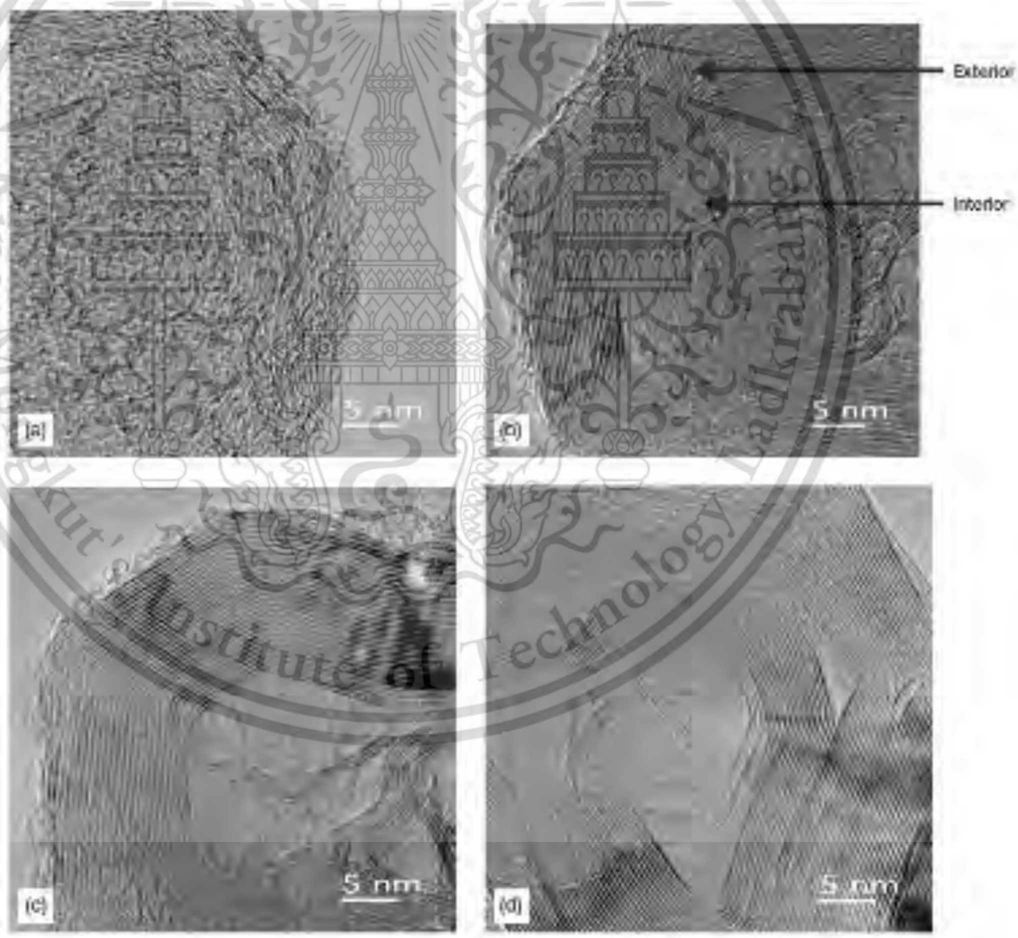


Figure 2.2 HR-TEM images of the carbon black prepared by heat treatment at temperatures (a) 1350 °C, (b) 1950 °C, (c) 2300 °C and (d) 3000 °C.

The morphology of fiber and crystal are one of the important part in composite because it effect much to the composite. Po-Yuan Chen [12] observe the crystal size of the material in carbon nanotube by using X-ray diffraction. And also he observe the bonding element and element of material by using FT-IR [13]. The material type can also be decided by Raman spectroscopy. The wavelength of atom show the type of fiber and crystal type and the bonding structure with G and D band. D band is call disorder band which come from the defected atom without hexagonal shape but G band imply to the good structure with hexagonal structure. Those are observed by A. Kariminejad [14]. These different tool can tell precise crystal size and spacing between the graphene layers. Now a days, several method and way are available to detect the material. However, in case of composite reinforced with carbon and glass fibers in micro and nanostructures are not understand well. It induces to investigate the properties and fracture mechanism of composite with different type of base material. In composites, there are two main functions those are fiber and matrix. Fiber is the main product in the composite and matrix is one of the material that can create bonding strength between fibers [15]. Polymer matrix is the most widely used in the composite industry. There are two main matrix resins such as thermosetting and thermoplastic resins; those are the most useful resin in the composite field for laid up process laminar. Thermosetting resin is liquid form and it is irreversible resin [16]. After curing thermoset resin, the resin cannot turn back to the original liquid form and the resin can cured by chemical reaction at room temperature. Among several resin types in thermoset, epoxy is the most useful matrix because the matrix can lead composite to the best material of high bonding strength [17]. The composite need higher strength to resist the force and epoxy have to transfer stresses to fibers. Most of the composite starts to crack from matrix de-bonding, fibers delamination and pull out fibers from the matrix failure because matrix is not wet enough to bond one to another fiber. Then matrix cannot distribute the load uniformly to the fibers [18]. Dany Arnoldo Hernandeza [19] observed the main fracture of the composite is come from the interface zone (area between resin and fiber) which is affected by the tensile stress concentration on resin. It makes a crack initiation at the resin area, and then the force and crack are distribute to the fibers. Therefore, fiber is pull out then leads to break fibers.

Chapter 3
Experimental Set up and Methodology

3.1 Materials Preparation

Two type carbon fibers and two type glass fibers were used in this research as shown in F**igure 3.1**. The material properties are summary in **Table 1**. Fabric are different in woven pattern. First of all, the fabrics were test in tensile test to investigate mechanical properties of fibers alone without matrix epoxy. The fabric are cut into rectangular shape of specimens with 127 mm length, 12.7 mm width and thickness are depend on the supplier material thickness. The cut specimens were bond with tape at both side not to freak out the woven pattern. The tape result were subtract with tape property from the mechanical properties of fibers tensile test.

(a) Carbon fiber twill weave (b) Carbon fiber plain weave

(c) Glass fiber woven (d) Glass fiber fabric

Figure 3.1 Raw material of fibers (a) CFT, (b) CFP, (c) GFW and (d) GFF.

Table 1.1 Material properties

No.	Material	Prod Name	Short name	Type	Dia (μm)	Thickness (mm)
1	Carbon Fiber Twill	C135T	CFT	Carbon	6	0.3
2	Carbon Fiber Plain	PC6951500	CFP		6	0.3
3	Glass Fiber woven	Woven Roving N323	GFW	Glass	17	0.3
4	Glass Fiber Fabrics	Glass Cloth EW200	GFF		15	0.2
5	Epoxy (Part :A)	YD 582	-	Epoxy	-	-
6	Hardener (Part : B)	TH 7253	-		-	-

3.2 Fabrication process of composite

In this research, hand lay up process are used to fabricate the composite. Carbon fiber and glass fiber were used as the fiber and epoxy resin was used as the matrix on the composite. Carbon fiber and glass fiber were cut in to 300 x 300 mm and weighting by using weight machine. Base on the weight of fiber epoxy were calculated by using equation (1) - (3) to mix fiber and matrix composite. The fabric were plied one by one layers within the thickness of 3.2 mm +/- 15%. The layers of the composite are based on the thickness or fabric of glass and carbon fibers. In epoxy, there are two type of product 1) Epoxy and 2) hardener. The mixing ratio of the epoxy and hardener are calculated base on equation (1-3). The fabrication of composite are as shown in **Figure 3.2.**

$$Hardener\ weight\ (g) = \frac{Weight\ of\ Fibers\ (g)}{4} \tag{1}$$

$$Epoxy\ weight\ (g) = \ weight\ of\ hardener\ (g)\ x\ 3 \tag{2}$$

$$Epoxy\ and\ hardener\ ratio = 3:1 \tag{3}$$

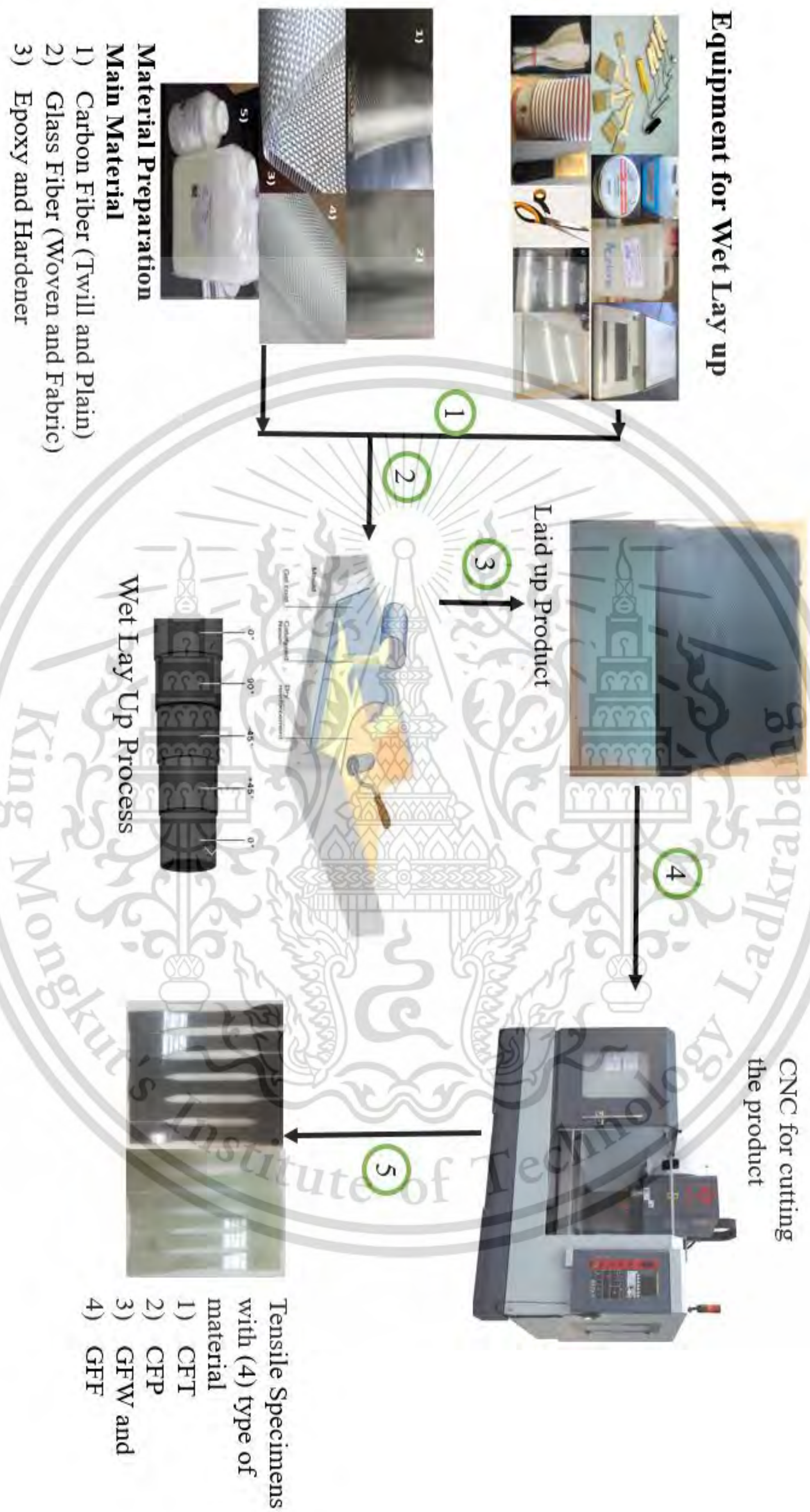
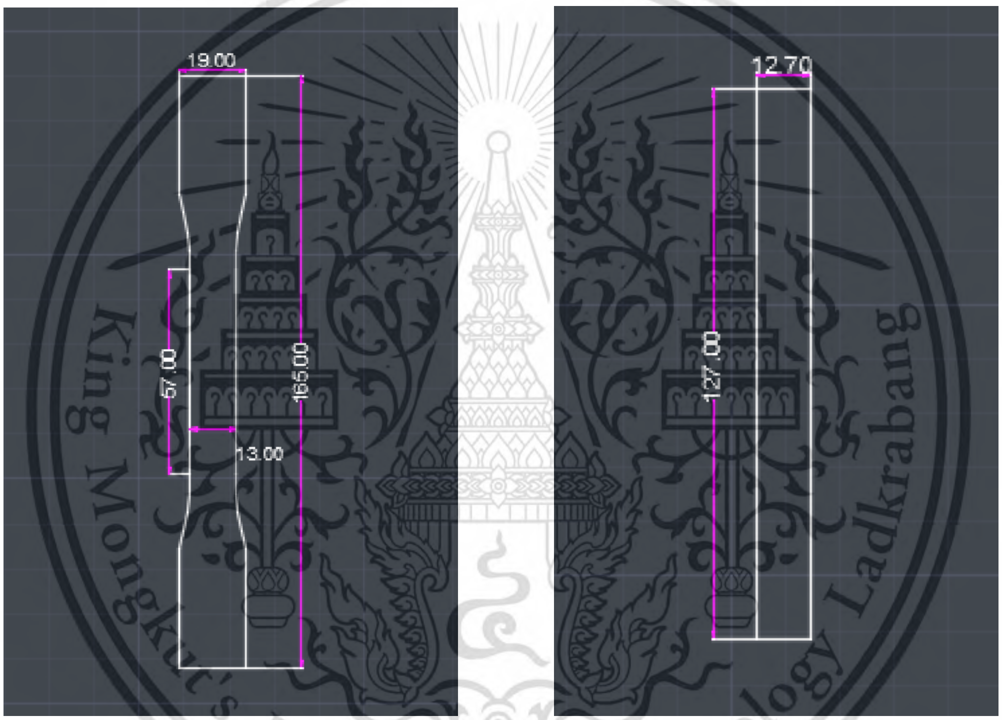


Figure 3.2 Composite preparation and fabrication process.

3.3 Mechanical specimen on composite

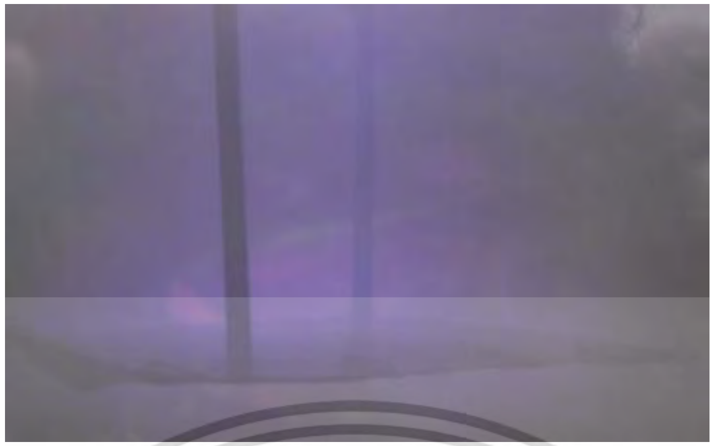
After fabrication process are done, the preparation for mechanical test sample are arrange for the composite material by using CNC (computer numerical control) machine Mazak FJV-20 with the situation of spindle speed 150 mm/min and feed speed 90-100 mm/min. Three type of mechanical testing are performed in this research. Those are 1) Tensile test, 2) Flexural test and 3) Creep test. Tensile test and creep test specimens are prepared based on ASTM 638 and flexural specimens are based on ASTM 790. The specimens drawing are as shown in **Figure 3.3**.



(a) Tensile Test Specimen (b) Flexural Test Specimen

Figure 3.3. Tensile and Flexural test specimens.

The specimens were test on a tensile test machine INSTRON 8801 with load cell 95KN, test speed 5mm/min for all composite with the same testing function at temperature 24 degrees Celsius with 47% RH. Another mechanical flexural test (three-points bending) is perform at 24C temperature and 49% RH with INSTRON 55R4502 machine. Testing rate speed is 5.2mm/min with cell load 10KN. Creep test performs with the machine INSTON 8501, Cell load 100KN, one cycle for 24hrs at 18’C without temperature elevated. All of the sample are test with two condition 1) at room temperature and 2) sample after cured at Oven for 6 hrs with 80C temperature to investigate the effect of temperature to the samples.



(a) Plasma assistance vapor chemical deposition.

(b) Glass fiber after treatment

(c) Glass Fiber After deposited DLC

Figure 3.4. PAVCD of glass fiber (a) PAVCD machine, (b) glass fiber before deposited and (c) glass fiber after deposited.

3.4 Treatment fabric and deposited (Diamond like carbon) DLC by PACVD machine

The fibers filament from carbon and glass fibers have several defects and particle in the surface of filament. Mainly those are come from sizing materials by epoxy while the filament are producing. That is one of the reason to make weakness in bonding between fibers and matrix. Therefore, one of the method to remove sizing material from the fiber surface is treatment method. Those are several method to make treatment in fiber. The same four type fabric pattern of fibers are prepared by cutting with scissor and covered by tape not to freak out the pattern of fibers while treatment are performing. Firstly, the cut fabrics are put in the bowl and applied ethanol to sock out unclean particles from the surface of fiber for 30 minutes and clean with distilled water for 10 minutes. Then cleaned fabric are put into oven to cure at 80° C for one and half hours as shown in **Figure 3.4**. After cured, fibers are fit to the holder of the sample. Cleaned with Argon (Ar) for 10 mins with flow rate 20 SCCM, pressure 3Pa and voltage 3.5kV in PACVD machine. After cleaned with argon, applied Acetylene (C2H2) for 30 minutes with flow rate of 20 SCCM, 3Pa pressure with 3.5kV voltage. The deposited fibers are cut with same shape of fabric to test in mechanical tensile test.

3.5 SEM, FE-SEM and TEM Image analysis of fiber.

The defective surface on the fiber and cross section area are found by using SEM/EDX (JEOL - JCM 6000) with 15kV, FE-SEM and TEM observed the behavior of fibers and their chemical composition. All of the fiber type such as fabric alone, composite and deposited fibers were make investigation.

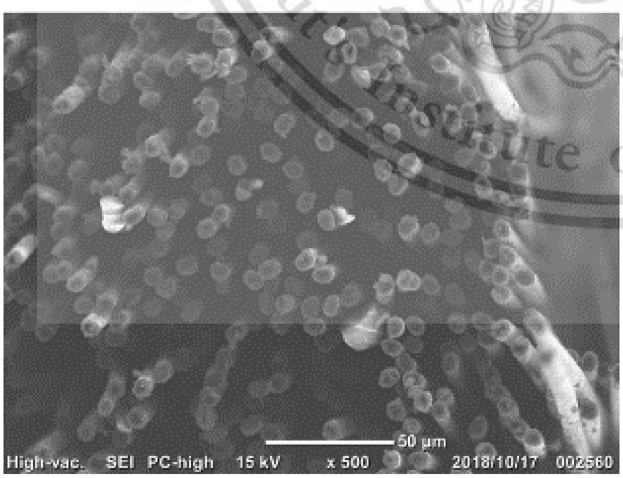
Chapter 4

Result and Discussion

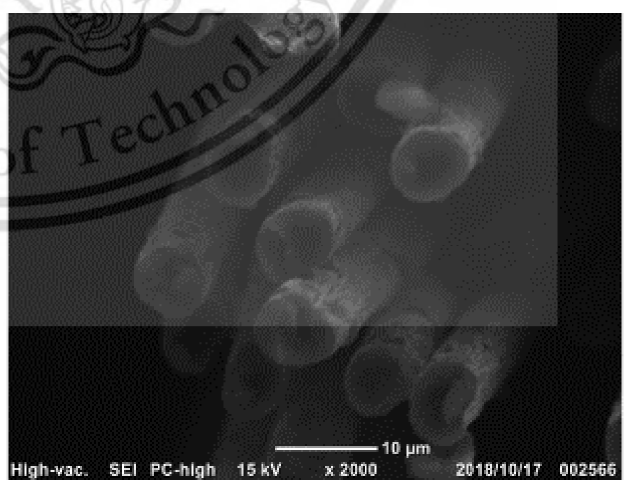
4.1 SEM-EDS Characterization of Carbon and Glass Filament of Fiber

All fabric of glass and carbon fiber are analysis using SEM/EDS and TEM to investigate the surface and cross section behavior. All of the fiber have several defective on the surface of each fibers. That can make the interfacial de-bonding between fiber and matrix in the composite. Both of carbon fiber does not show porous on the cross section of the fiber. But in the case of glass fiber, several porous are found on the cross section with porous diameter size of 0.8 μm to 2.2 μm as shown in **Figure 4.1**. It may bring the weakness strength not only in fabric but also at the composite. SEM/EDS show chemical element composition of all fibers filament. In both carbon fiber CFT and CFP, carbon (C) containing is the highest with approximately 92% and oxygen (O2) as shown in figure 8 (a) and (b).

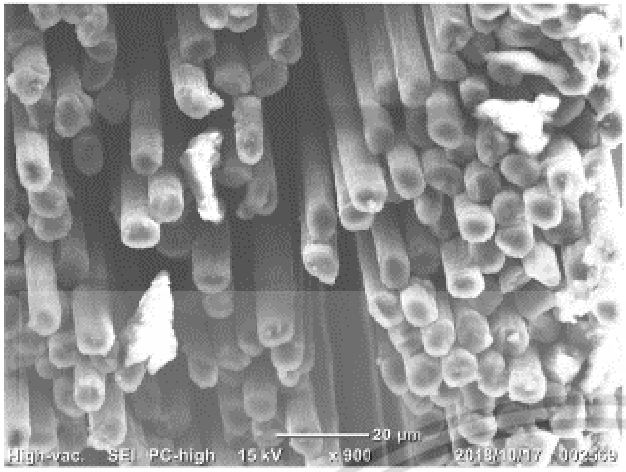
In glass fibers, both GFW and GFF have the same amount and the same element are bonding. The highest percentage is silica (Si) Oxygen (O2) and Carbon (C). Another small amount of element are also contain such as magnesium (Mg), chloride (Cl) and calcium (Ca) in this filament as shown in **Figure 4.2** (c) and (d). Au (sputtering gold) and Al (sample holder) need to be neglected.



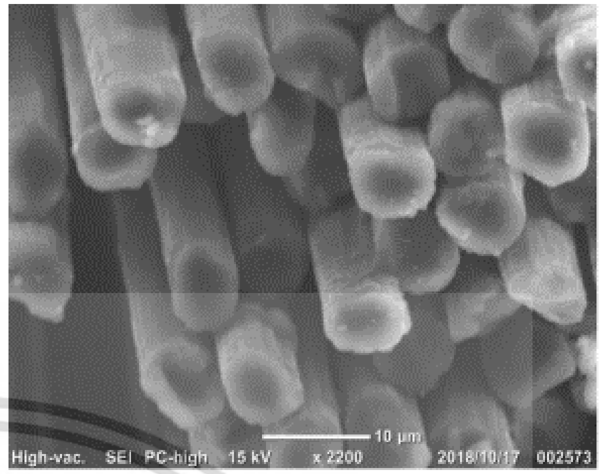
(a) CFT 500 magnification



(b) CFT weave with 2000 Magnification



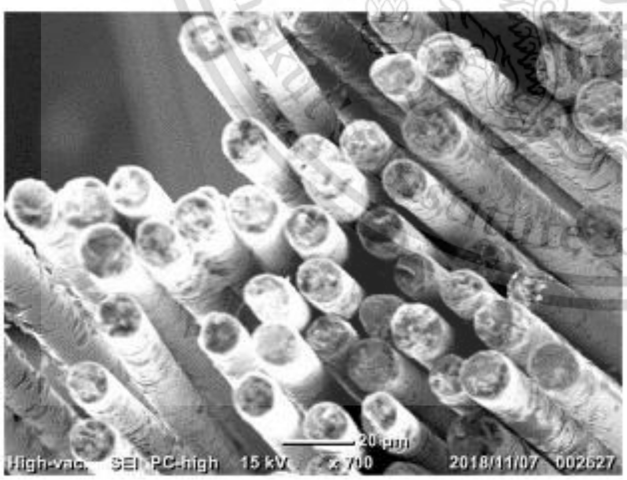
(c) CFP Surface at 900 Magnification



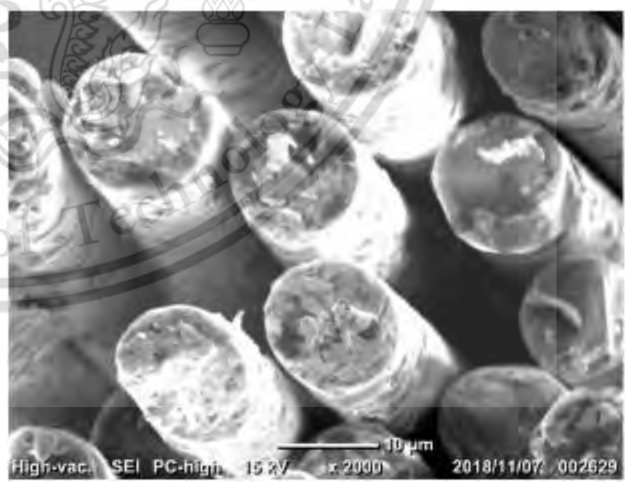
(d) CFP Surface at 2200 Magnification

(e) GFW surface at 440 magnification

(f) GFW Surface at 2200 Magnification

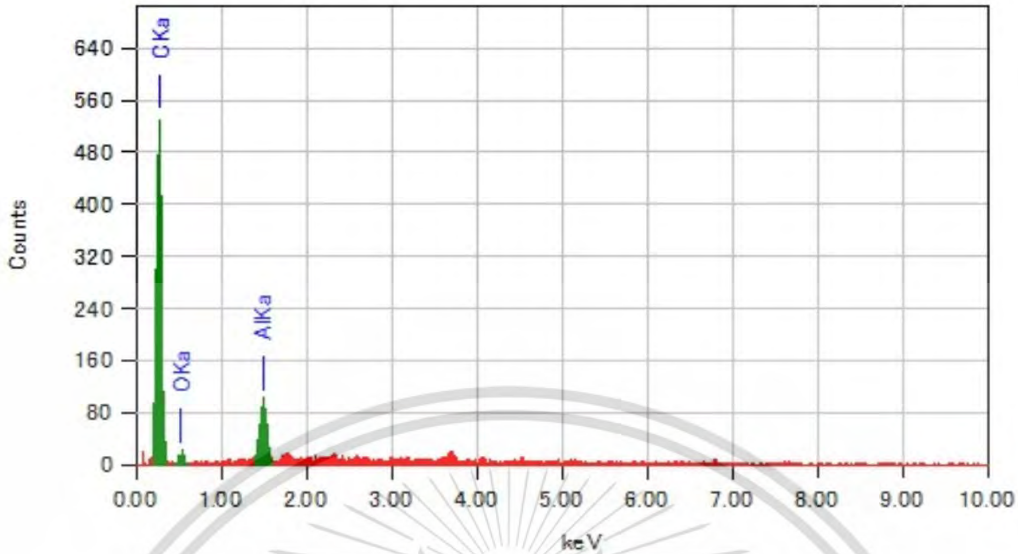


(g) GFF Surface at 700 magnification

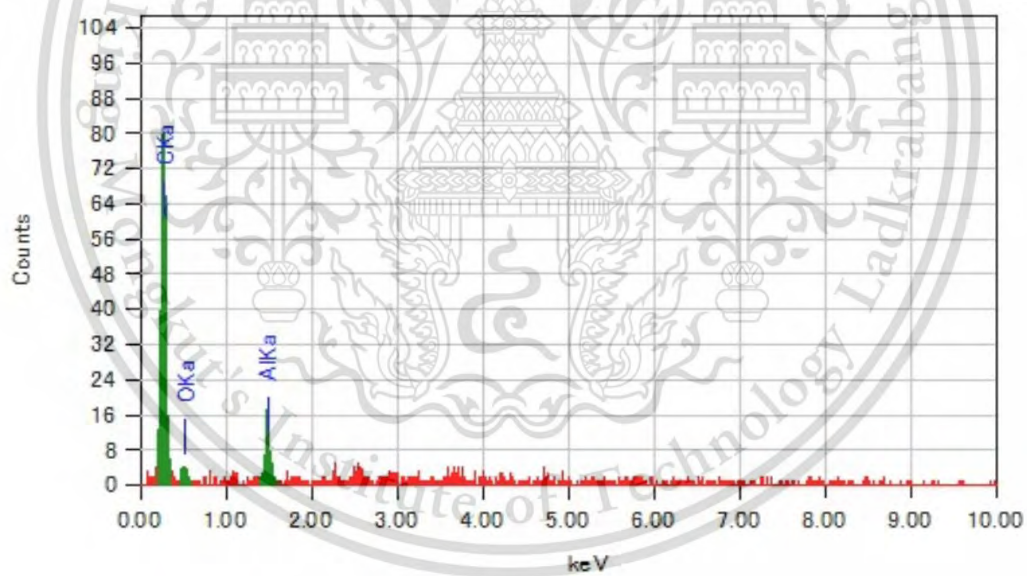


h) GFF surface at 2000 magnification

Figure 4.1. SEM image for raw fiber of (a) & (b) CFT, (b) & (c) CFP, (e) & (f) GFW and (g) & (h) GFF

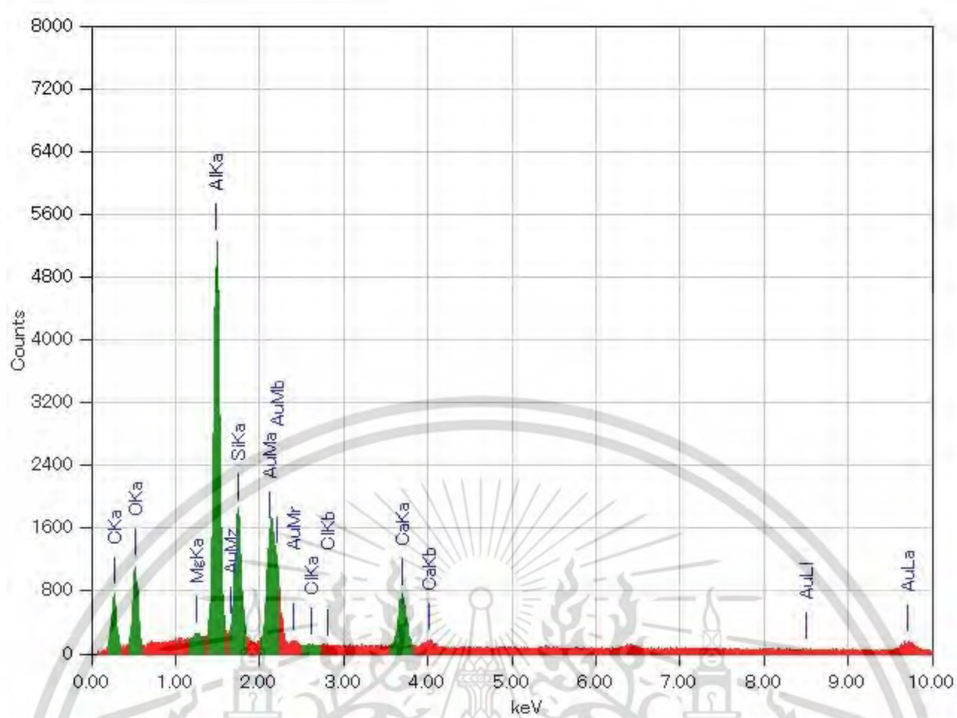


(a) EDS analysis on CFT

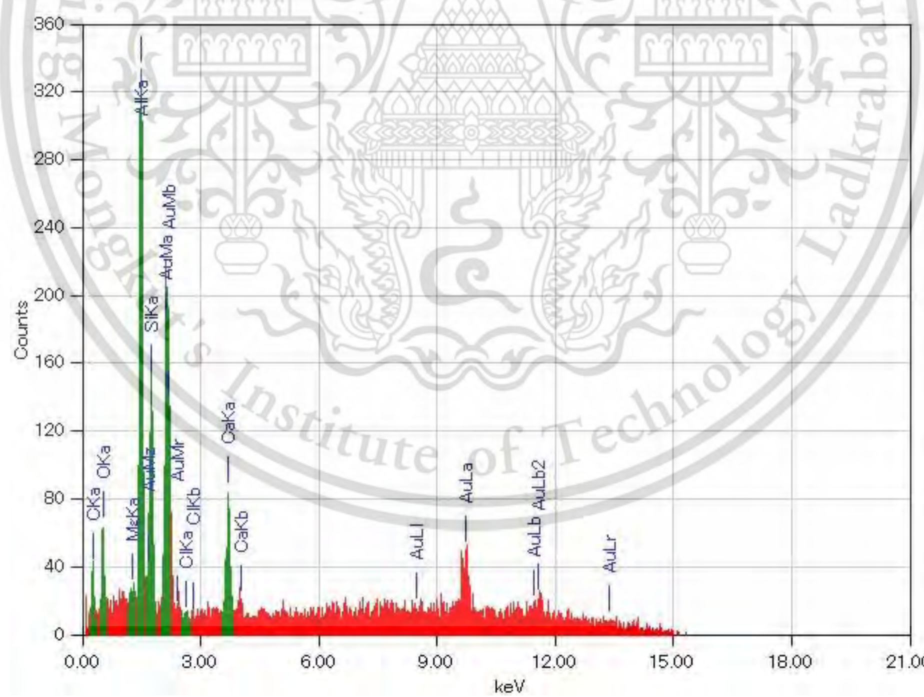


(b) EDS analysis on CFP

Figure 4.2 SEM-EDS analysis on fiber filament of (a) CFT, (b) CFP, (c) GFW and (d) GFF.



(c) EDS analysis on GFW

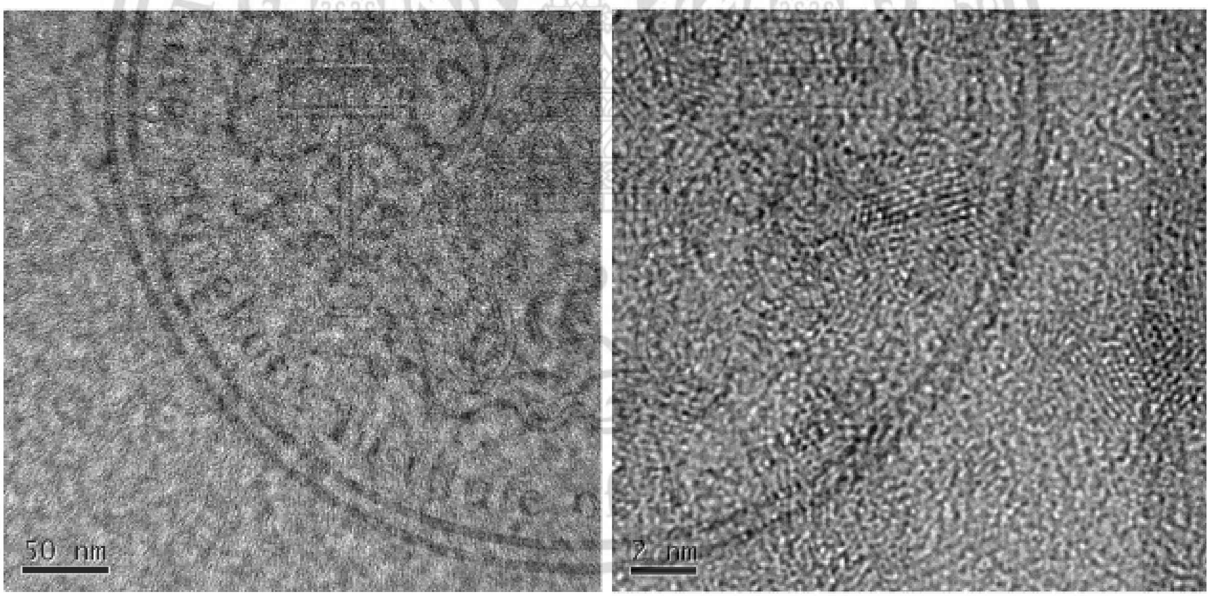


(d) EDS analysis on GFF

Figure 4.2 SEM-EDS analysis on fiber filament of (a) CFT, (b) CFP, (c) GFW and (d) GFF.

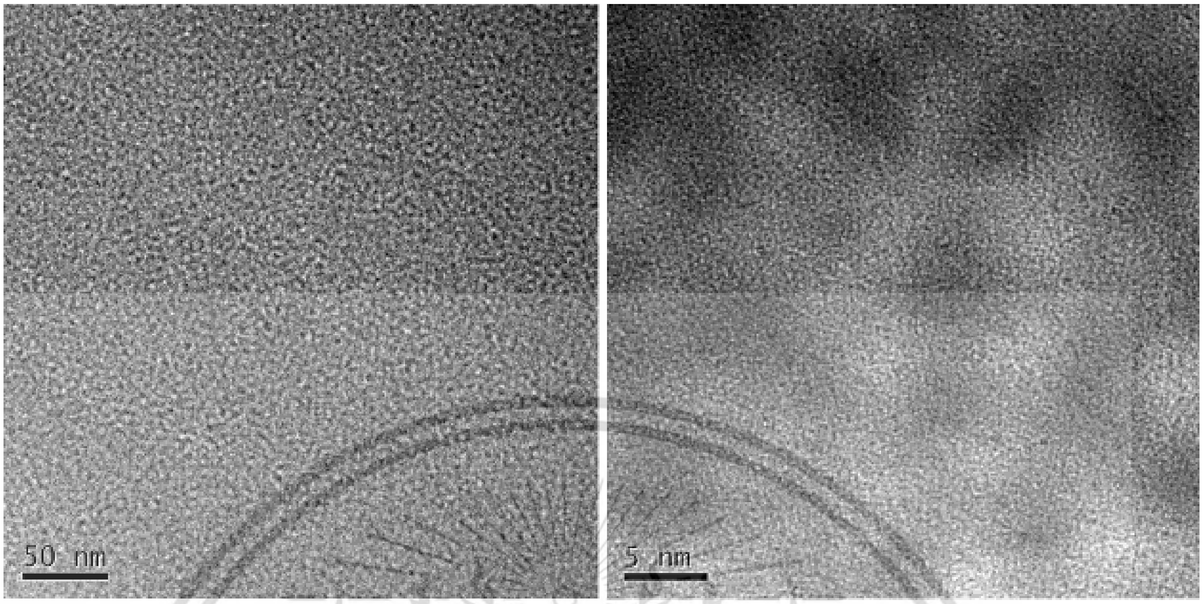
4.2 Transmission Electron Microscopy (TEM)

TEM is used to investigate cross section area of carbon and glass fiber filament. The specimens of carbon and glass fiber were prepared by focus Ion Beam (FIB) apply epoxy to the whole filament surface and leave a while to dry. After the epoxy are dry, the specimens were cut by FIB. The specimens were cut more than 100nm square meter. The cutting process are not quite smooth because SEM detected several porous inside the filament that can bring shifting graphene layer. Both of carbon and glass fiber didn’t show any of crystal or graphene layers for 50nm magnification sample. It can not show any layer or graphene on the fibers. Therefore, increase to higher magnification to detect detail in both carbon and glass filament as shown in **Figure 4.3** (b) and (d). As a result, some part of carbon fiber shows graphene layer of crystal and some part of fiber show no any graphene. It indicate disorder crystal arrangement and the graphene of crystal also lay randomly. Therefore, graphene layer cannot detect the whole fiber filament of carbon fiber. As a contrast in glass fiber, the images were not shown any structure.



(a) Carbon fiber with low magnification (b) Carbon fiber with high magnification

Figure 4.3 TEM Image of (a) & (b) Carbon Fiber and (c) & (d) Glass Fiber.

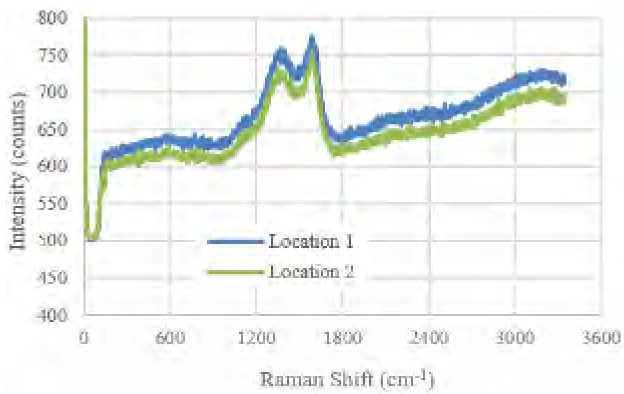


(c) Glass fiber with low magnification (d) Glass fiber with high magnification

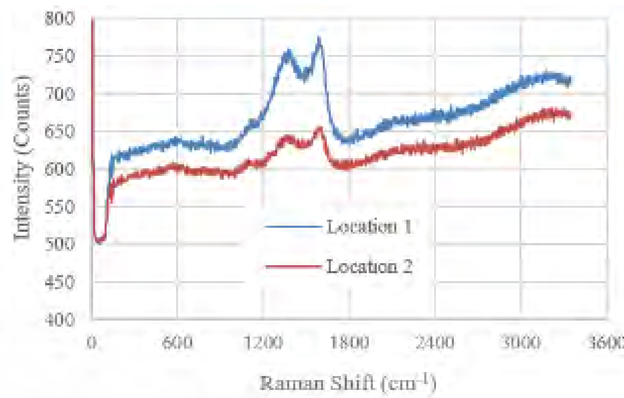
Figure 4.3 TEM Image of (a) & (b) Carbon Fiber and (c) & (d) Glass Fiber.

4.3 Raman Spectroscopy on Fibers

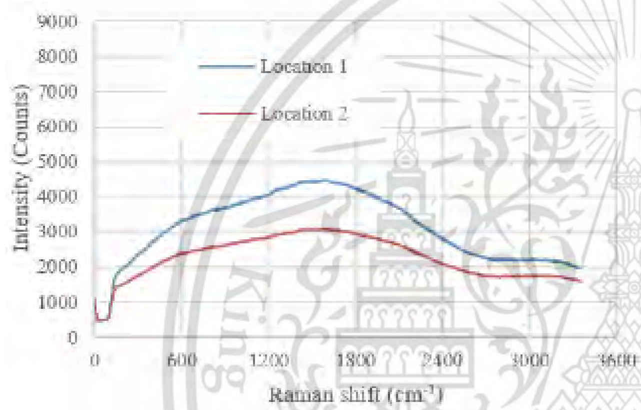
Raman spectroscopy is one of the main tool that can give the information about the structure with the changes of wavelength. The wavelength of D band is the structure of defect crystal with the bonding structure are not symmetric. Disorder band in this research is around 1350 cm^{-1} for carbon fiber and 1580cm^{-1} is for Graphite peak with widen peak. The peak intensity are not very high. Carbon fiber raw fabric and composite are the same at peak area in this Raman spectroscopy. On the other hand, glass fiber have some different peak with the information of the structure are not well bonding with correct structure. Raman spectroscopy give the same information for all composite materials. Assume the peak between 3000 cm^{-1} and 3200 cm^{-1} are come from epoxy that can bonding with C-O-C bonding in the composite material. But in carbon fiber composite, there are still D band and G band are shown in **Figure 4.4**.



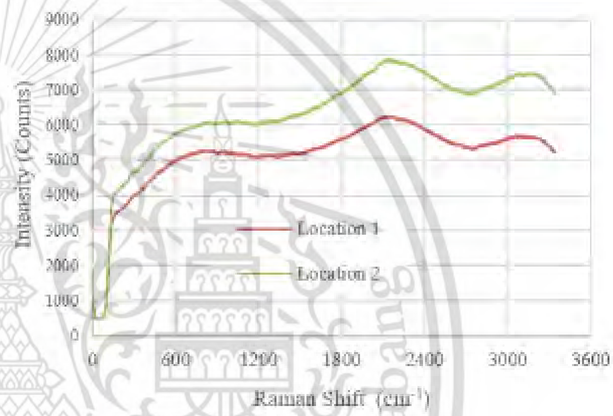
(a) Raman Shift of Raw CFT



(b) Raman shift of raw CFP



(c) Raman Shift of raw GFW



(d) Raman Shift of raw GFF

Figure 4.4 Raman Spectra Graph of (a) CFT, (b) CFP, (c) GFW and (d) GFF.

4.4 X-Ray Diffraction

XRD is one of the tool that can reveal the structure and behavior of carbon fiber and glass fiber. The fabric and composite both are test in the XRD machine with wavelength 1.5418 cm^{-1} and angle are 2thelta. As the result, the raw fiber peak of carbon fiber are sharp and very high with graphite structure. Main peak of carbon fiber in the graph is at around 2ϑ. In the case of glass fiber, there is no peak in the graph that can give the information about its structure was amorphous structure with random of bonding. Fabrics and composite both give the same information about glass and carbon fiber in **Figure 4.5**. In this XRD test, the peak is only for carbon fiber, it means the graphite structure of carbon bonding are in the fiber at 25 degree with the range measurement of 2thelta degrees. By using the data of XRD, crystal size and the spacing can be determine according to Bragg's equation.

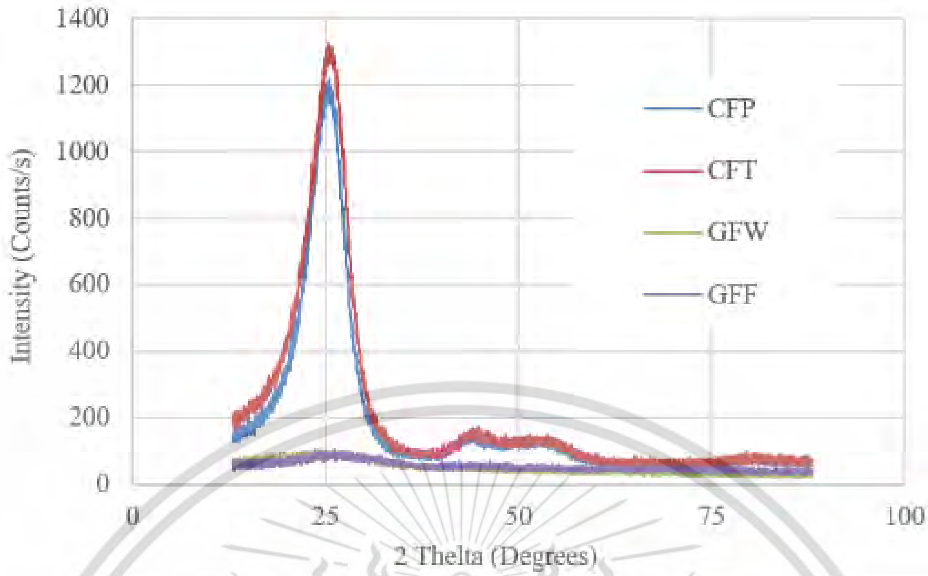


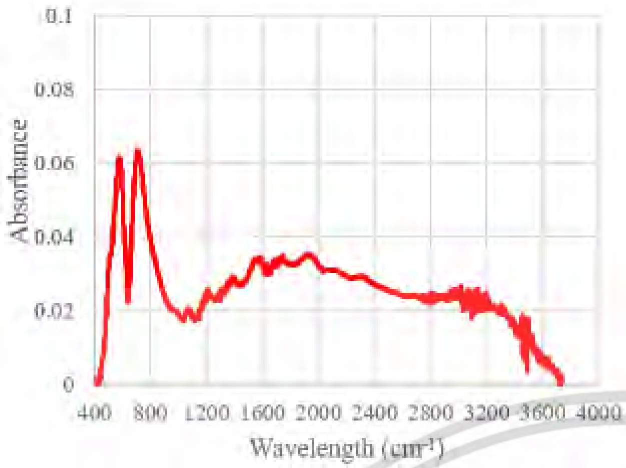
Figure 4.5 XRD graph for all carbon fiber and glass fiber.

4.5 Fourier-Transform Infrared Spectroscopy (FT-IR)

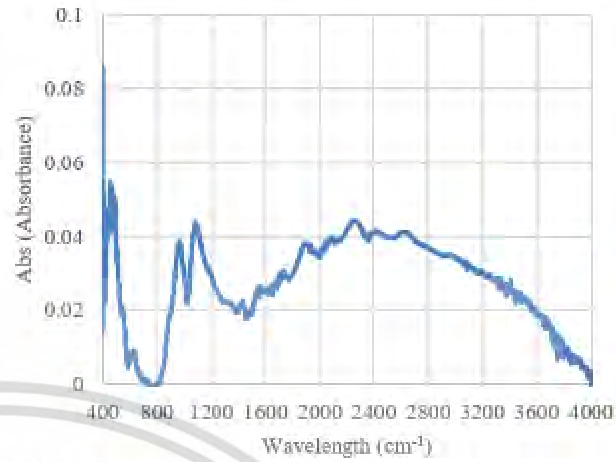
This is one of the tool that can give the chemical bonding of carbon fiber and glass fiber inside the filament and also in the composite. FTIR shows the bonding element at different wavelength peak as shown in **Figure 4.6**.

4.6 Tensile Test of Fabric

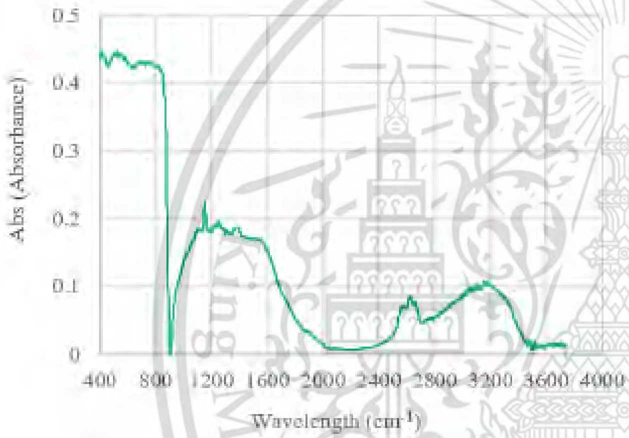
Figure 4.7 shows the breakage of fiber while tensile test are performing. After break the tape, verticals axis of carbon fiber are reduce in diameter that bring to break fiber. The main direction that can resist external tension force is vertical axis fiber. With the help of tape, horizontal laid fabrics are stick together with vertical axis fiber. The mechanical properties of each fiber are as shown in **Figures 4.8**. Graph shows CFT have the highest force with around 430N in average while CFP is around 200N. Different patterns much affect to the properties of material. More than half of force is reduce in CFP compare to CFT. Therefore, twill weave pattern of fabric leads to the better properties. In glass fiber, the results are not much different between two fibers. GFW is almost 300N force while GFF is around 310N. GFF has higher force because of the fiber bundles of GFF are smaller than GFW. Therefore, more fiber bundles were placed in the same size specimen, it brought to the higher tensile force. In the case of elongation displacement, all of materials are almost the same displacement around 5mm elongation.



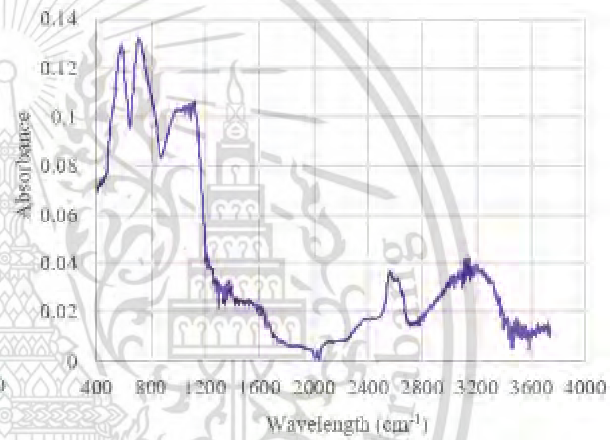
(a) FT-IR graph of CFT



(b) FT-IR graph of CFP

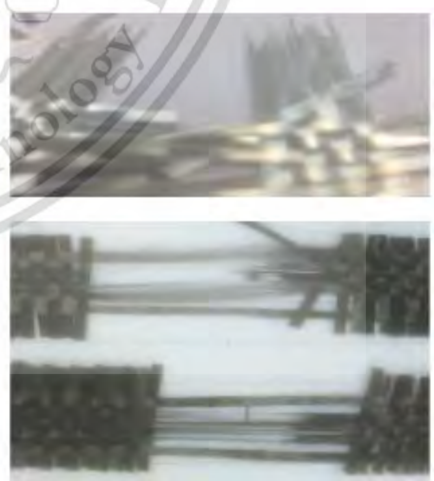


(c) FT-IR graph of GFW



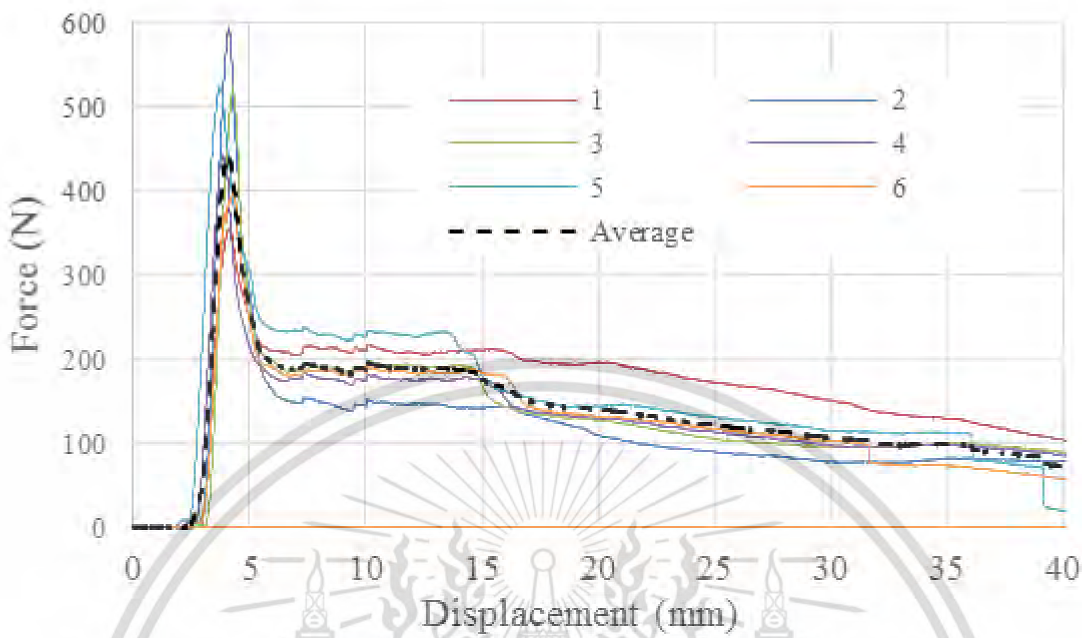
(d) FT-IR graph of GFF

Figure 4.6. Fourier Transform Infra graph of (a) CFT, (b) CFP, (c) GFW and (d) GFF.

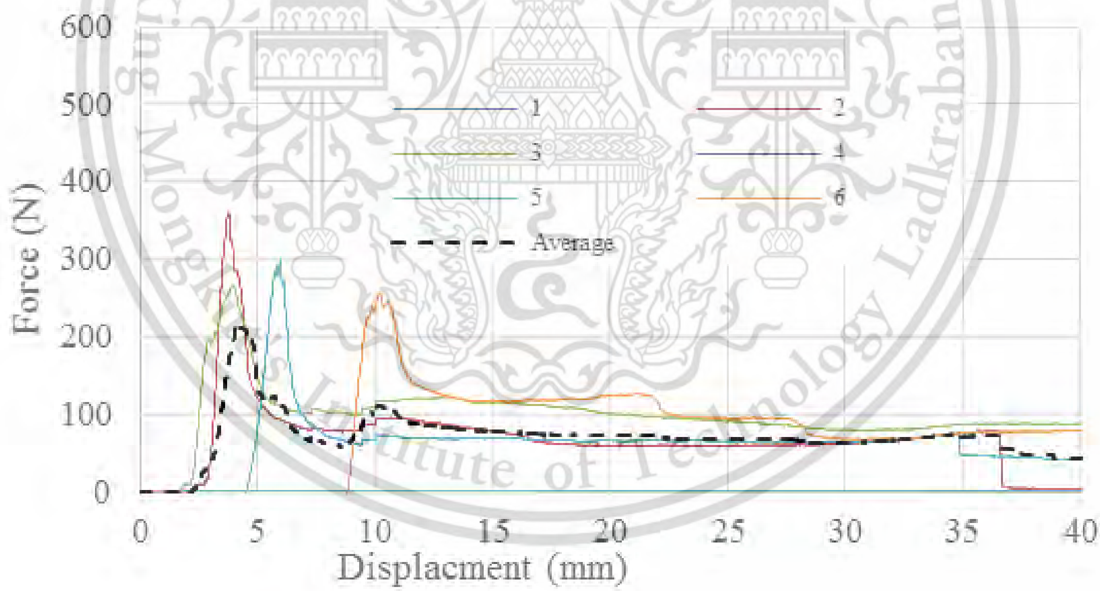


(a) GFF (b) CFP (c) GFW & CFT

Figure 4.7 Fracture of fiber after tensile test (a) GFF while tensile test, (b) CFP while tensile test and (c) GFW & CFT after tensile test.

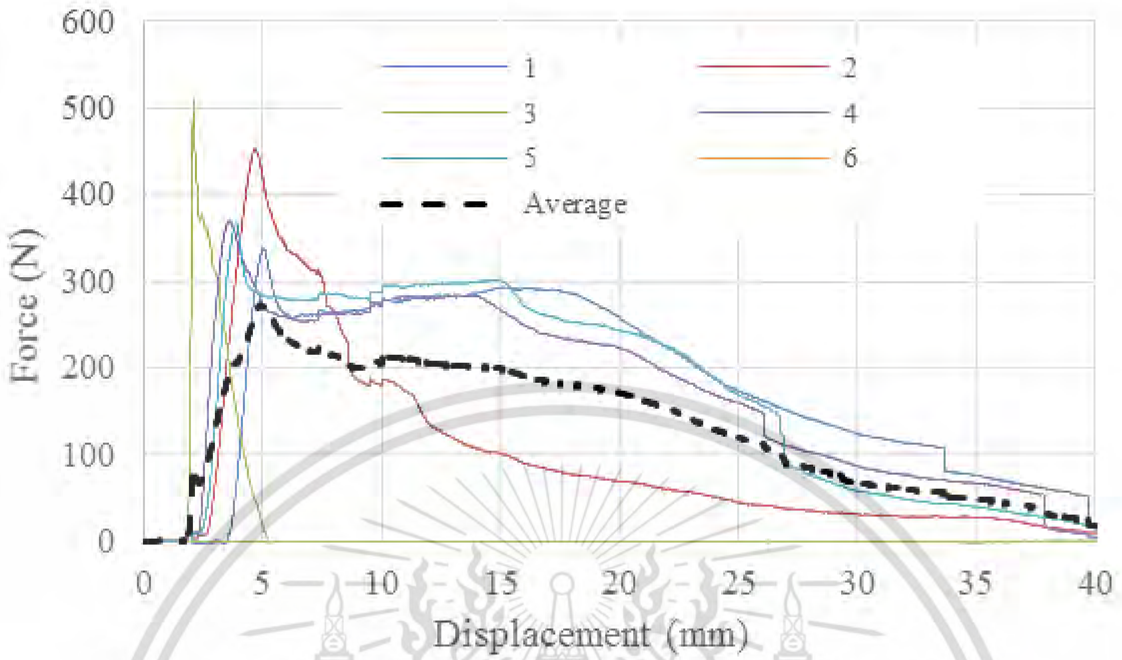


(a) Force - Displacement curve of CFT

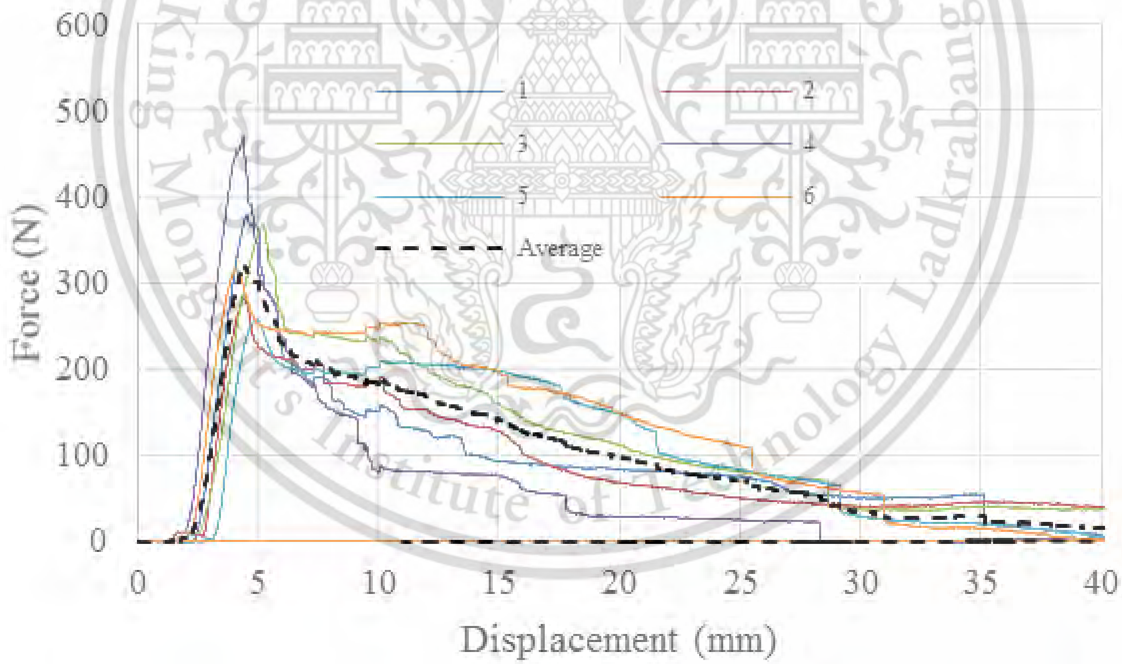


(b) Force - Displacement curve of CFT

Figure 4.8 Tensile test result for all naked fiber Force (N) and displacement (mm) curve of (a) CFT, (b) CFP, (c) GFW and (d) GFF.



(c) Force - Displacement Curve for GFW



(d) Force - Displacement Curve of GFF

Figure 4.8 Tensile test result for all naked fiber Force (N) and displacement (mm) curve of (a) CFT, (b) CFP, (c) GFW and (d) GFF.

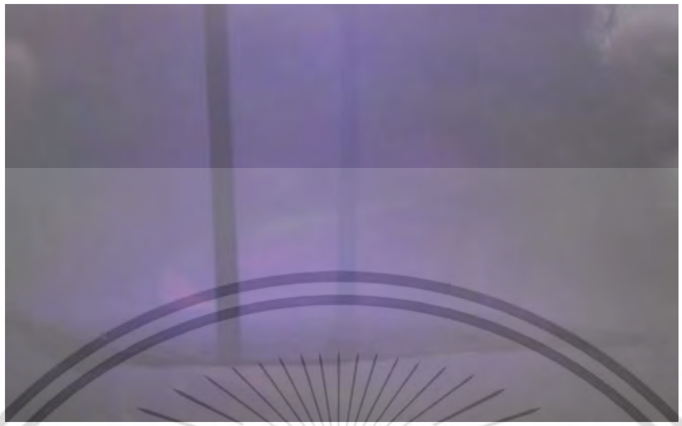
4.7 Diamond Like Carbon (DLC)

The materials of fiber are used to make a treatment and deposited diamond like carbon (DLC) by using plasma assistance chemical vapor deposition (PACVD) to investigate mechanical properties and surface morphology. Two types of fiber CFT and GFW were deposited DLC. Deposited fibers were tested in tensile machine to know their properties. The same fabric pattern of fiber are prepared by cutting with scissor and covered by tape not to freak out the pattern of fibers while treatment are performing. Firstly, the cut fabrics are put in the bowl and applied ethanol to sock out unclean particles from the surface of fiber for 30 minutes and clean with distilled water for 10 minutes. Then cleaned fabric are put into oven to cure at 80° C for one and half hours. After cured, fibers are fit to the holder of the sample. Cleaned with Argon (Ar) for 10 mins with flow rate 20 SCCM, pressure 3Pa and voltage 3.5Kv in PACVD machine. After cleaned with argon, applied Acetylence (C2H2) for 30 minutes with flow rate of 20 SCCM, 3Pa pressure with 3.5 Kv voltage.

DLC fiber are test in mechanical test and compare to the naked fiber properties. The mechanical properties of carbon fiber and glass fiber woven are shown in **Figure 4.10** (a) and (b). In Carbon fiber, average maximum force is around 300N with approximately 5mm elongation while glass fiber woven are 265N maximum force with around 5mm elongation. The fiber failure mode are same as before naked fabric. The diameter of filament become smaller and smaller that bring to the weakness fiber until break fiber. One of the weakness point of deposition of fiber is the whole filament diameter cannot wet well by the plasma coating DLC. Inside of the fabric pattern are not wet well with DLC. That cannot make the fiber to reinforce more than original naked fiber.

Figure 4.10 (c) is the summary result of carbon fiber twill weave and glass fiber woven in naked and DLC coated. Based on the result, DLC coated fabric maximum forces are less than naked fiber while elongation are almost same in both carbon fiber and glass fiber. In carbon fiber twill weave, the maximum force of DLC coated fiber are dramatically decrease to be around 36% from naked material tensile test result. And around 3.5% maximum force are decrease in glass fiber woven. The main failure mode of coated fiber are due to the treatment process. In treatment process, the fibers are put into ethanol for 30 min to sock all of the defective and sizing material. Therefore the diameter of carbon fiber are decrease and all of foreign element on fiber surface are remove from filament surface. That bring weakness in fabric test. But it might enhance bonding behavior between fibers and matrixes.

Both naked and coated fiber of carbon and glass fiber woven were investigated by using SEM image analysis to observe the difference of coated and uncoated DLC. **Figure 4.11** shows uncoated naked fiber have several defects on the surface of fiber. In contrast, coated fiber are smoother and reduce defective on the surface, but coated DLC become small particle on the surface of fiber as shown in Figure 4.11 (b) and (d).

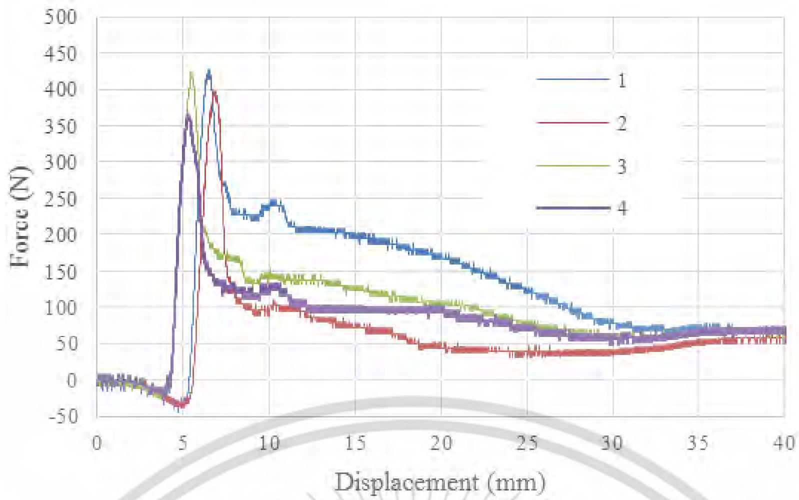


(d) Plasma assistance vapor chemical deposition.

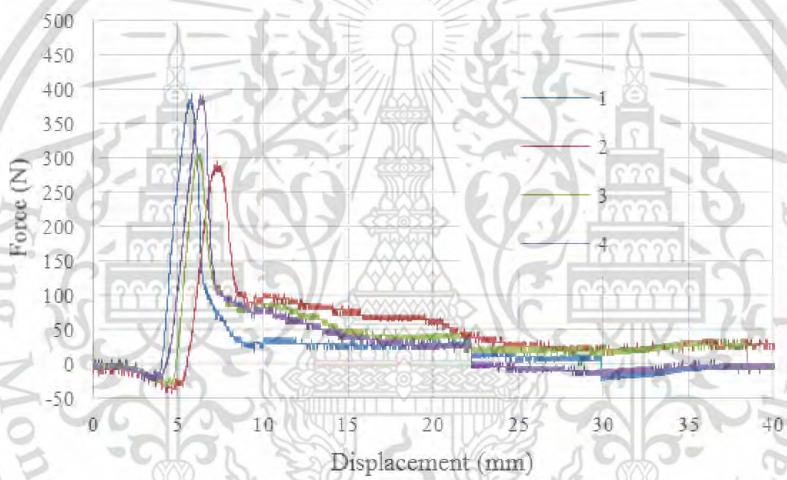
(e) Glass fiber after treatment

(f) Glass Fiber After deposited DLC

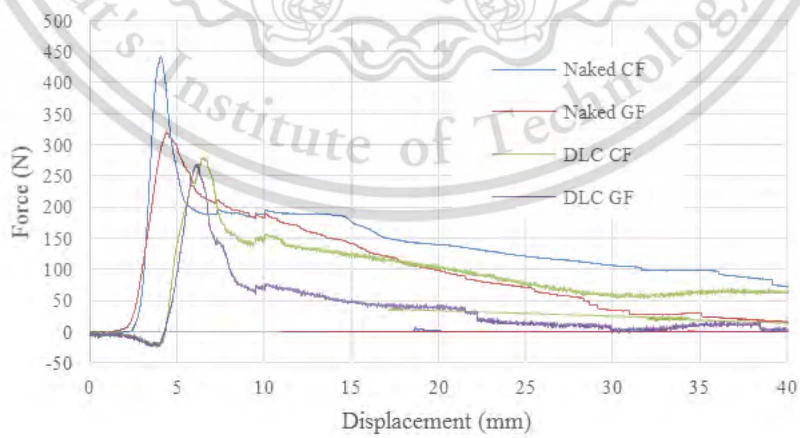
Figure 4.9 Deposited DLC of glass fiber of (a) plasma, (b) treatment glass fiber and (c) deposited glass fiber.



(a) DLC coated Carbon fiber

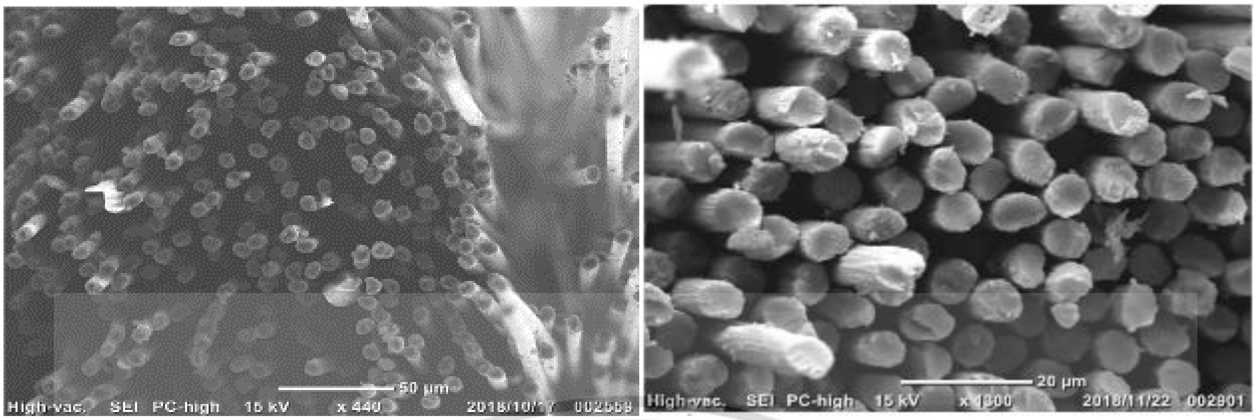


(b) DLC Coated Glass fiber

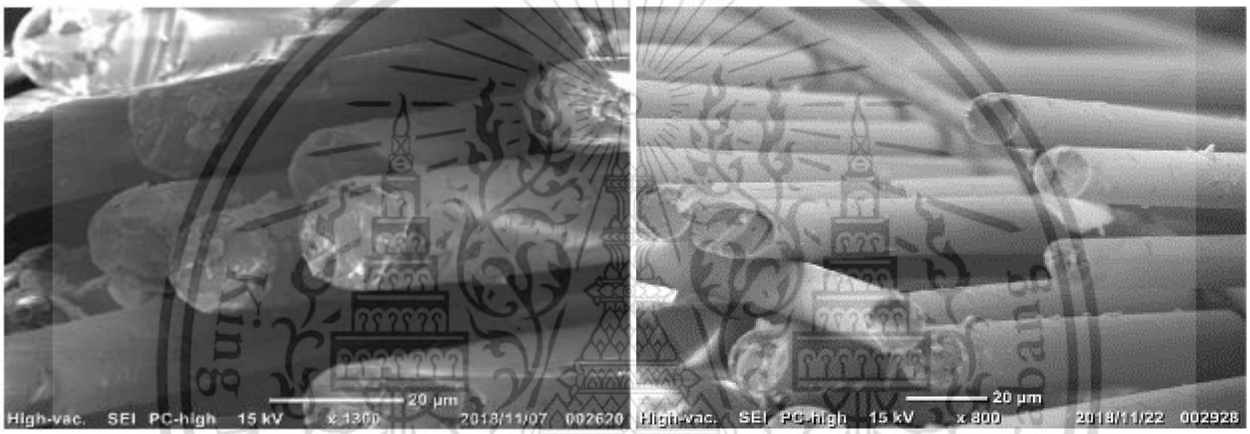


(c) Average result of naked carbon/glass and DLC coated carbon/glass fiber

Figure 4.10 Tensile test of DLC coated carbon and glass fiber.



(a) Carbon fiber before coated DLC (b) Carbon fiber after deposited DLC

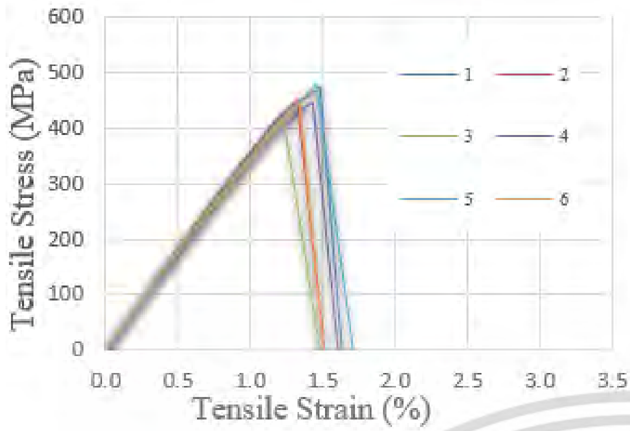


(c) Glass fiber woven before coated (d) Glass fiber woven after deposited DLC

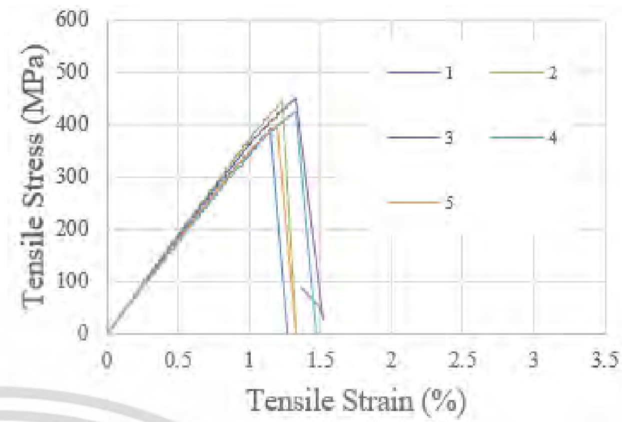
Figure 4.11 SEM image of glass fiber (a) naked CF, (b) DLC coated CF, (c) naked GF and (d) DLC coated GF.

4.8 Tensile Test Composite

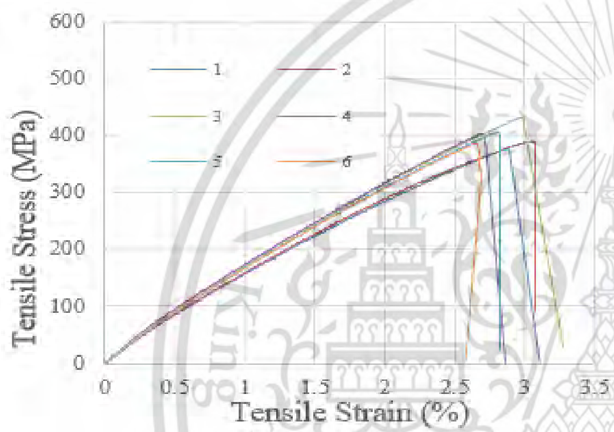
All of composites made of carbon fiber (twill and plain weave) and glass fiber (woven and fabric) were cut by computer numerical control (CNC) process based on ASTM 638. The cut specimens are test in tensile machine INSTRON 8801 with the parameter of load cell 95KN, test speed 5mm/min for all composite with the same testing function at temperature 24 degrees Celsius with 47% RH. In tensile test, CFT have the highest tensile strength with 480MPa as shown in **Figure 4.12** (a). Glass fiber composite, GFW and GFF are slightly drop from carbon fiber composite. On the other hand, glass fiber strain is higher strain compare to carbon fiber more than 50%. Fracture mechanism of composite are shown in **Figure 4.13**. Different fracture mechanism are found in composite. Fracture of carbon fibers composite are at small area with opposite of glass fiber composite with large fracture area. Carbon fiber didn’t alert for crack, it break immediately. But glass fiber is not break immediately, firstly strain was elongate as much as possible. Start to break when strain cannot elongate anymore from the composite. Glass fiber crack are quite complicated than carbon fiber.



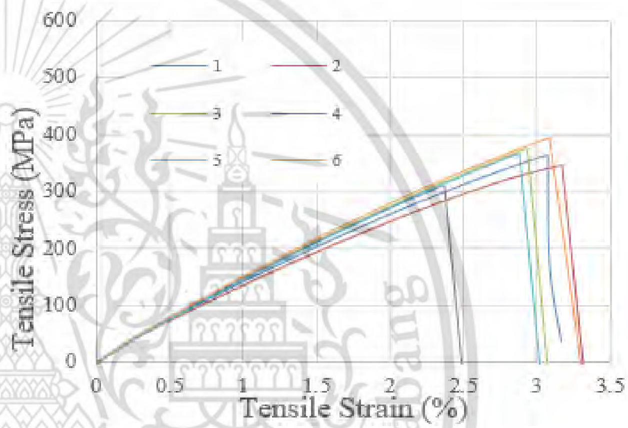
(a) Stress - strain curve of CFT



(b) Stress - strain curve of CFP



(c) Stress - strain curve of GFW



(d) Stress - strain curve of GFF

Figure 4.12 Stress-strain relationship of tensile test data of CFT, CFP, GFW and GFF.

4.9 SEM/EDS of composite

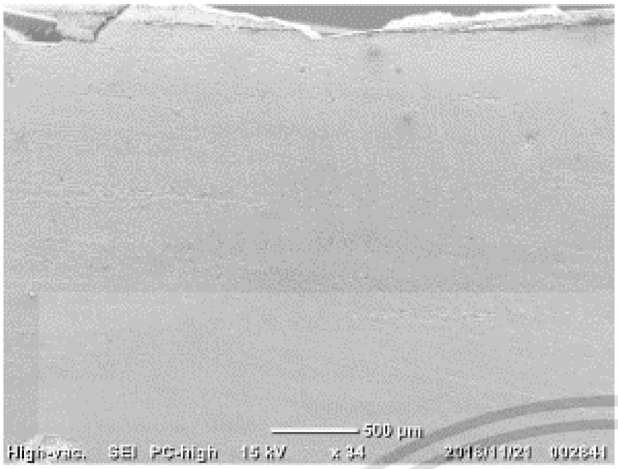
All of composite are investigated using SEM/EDS before and after fracture mechanism. **Figure 4.14** shows composite of all of materials. The figure shows the fiber and matrix layers. Especially, glass fiber composite shows each layers of fiber clearly between matrixes. In composite, some bubbles and several porous can see clearly that can make weaker in tensile strength. The composite were polished with sand papers grain size 120. **Figure 4.15** shows higher magnification of composite and their differences. The matrix and fibers are tightly hold each other especially at interfacial area. Most of fibers are break at near tight matrix while polish for smoother surface in carbon fiber. In glass fiber composite, most of fibers are pull out from tight matrixes.

The fracture of composite shows their different characteristic of fracture of composite after tensile test. In carbon fiber composite fracture, fibers are pull out from vertical axis of tensile test and horizontal axis fiber are delaminate after matrix between fibers are damage. Some of bubbles or porous are also one of fracture crack initiator of composite. In glass fiber composite, the matrix between fibers are damage and crack propagation are spread between fibers filament. Therefore, some fibers starts to pull out and easy to break after the bundles of fibers are spread to stand alone. Some of bubbles are also one of the reason to initiate crack in composite as shown in **Figure 4.16**.

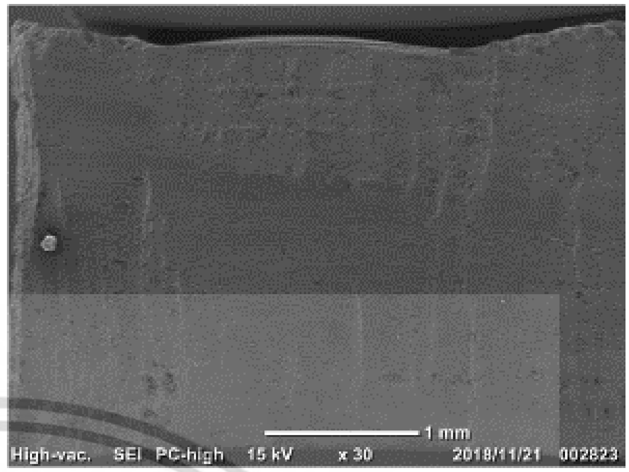
(a) CFT fracture specimens (b) GFW fracture specimens

(c) CFP fracture Specimens (d) GFF fracture specimens

Figure 4.13 Fracture mechanism of composite (a) CFT, (b) CFP, (c) CFP and (d) GFF.

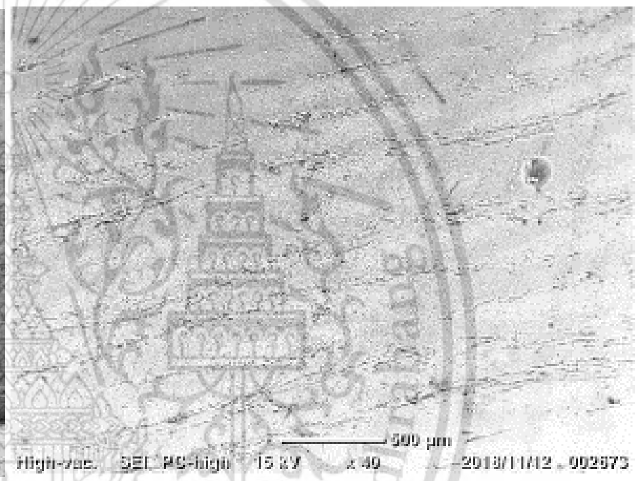


(a) Composite of CFT



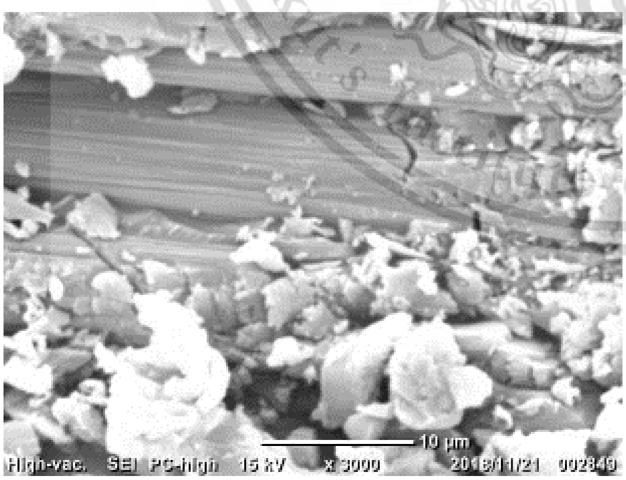
(b) Composite of CFP

c) Composite of GFW

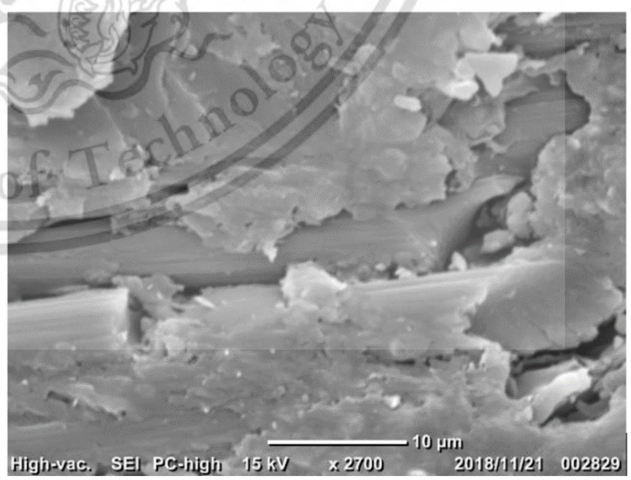


d) Composite of GFF

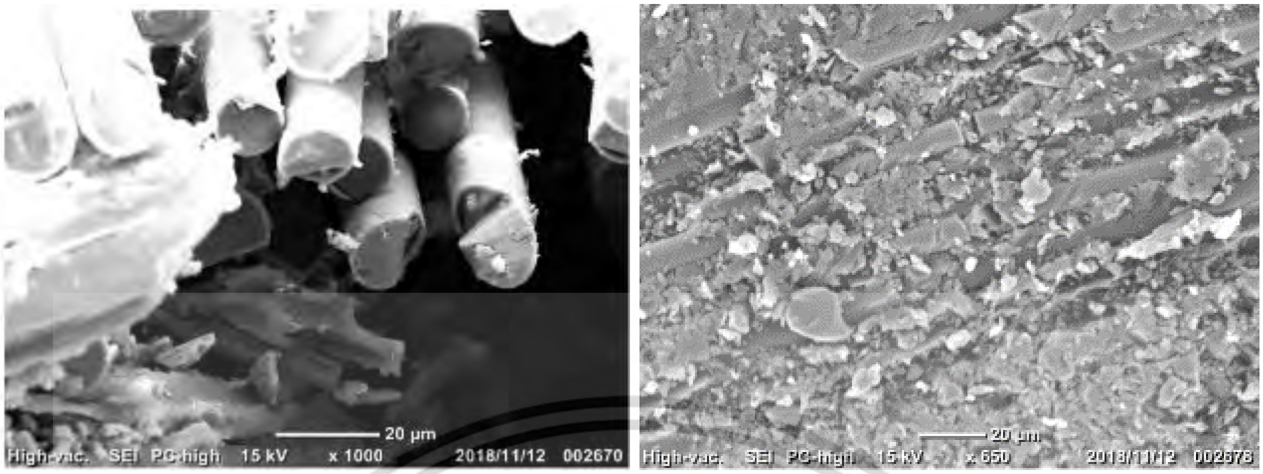
Figure 4.14. SEM image of Composite of (a) CFT, (b) CFP, (c) GFW and (d) GFF.



(a) Composite of CFT

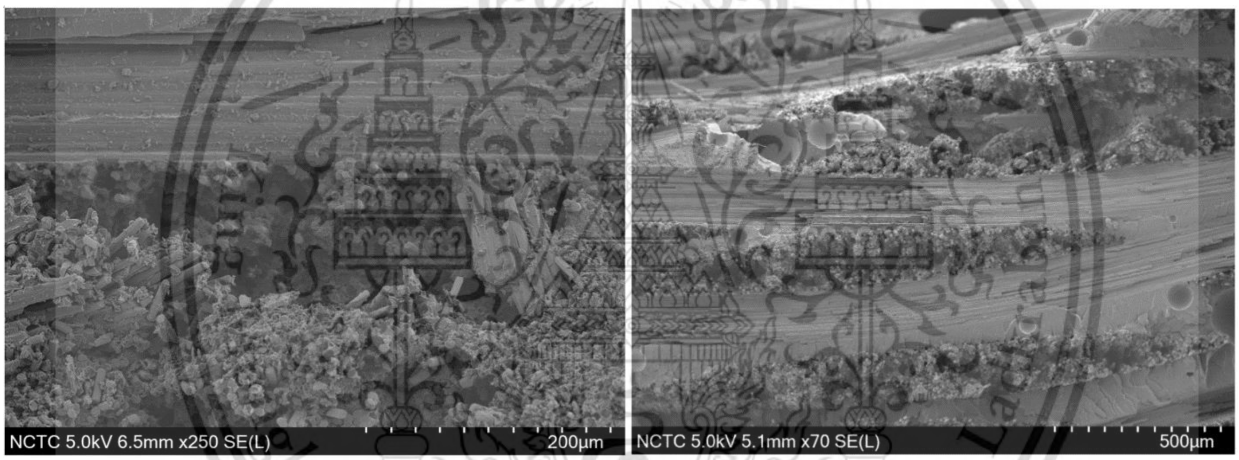


(b) Composite of CFP

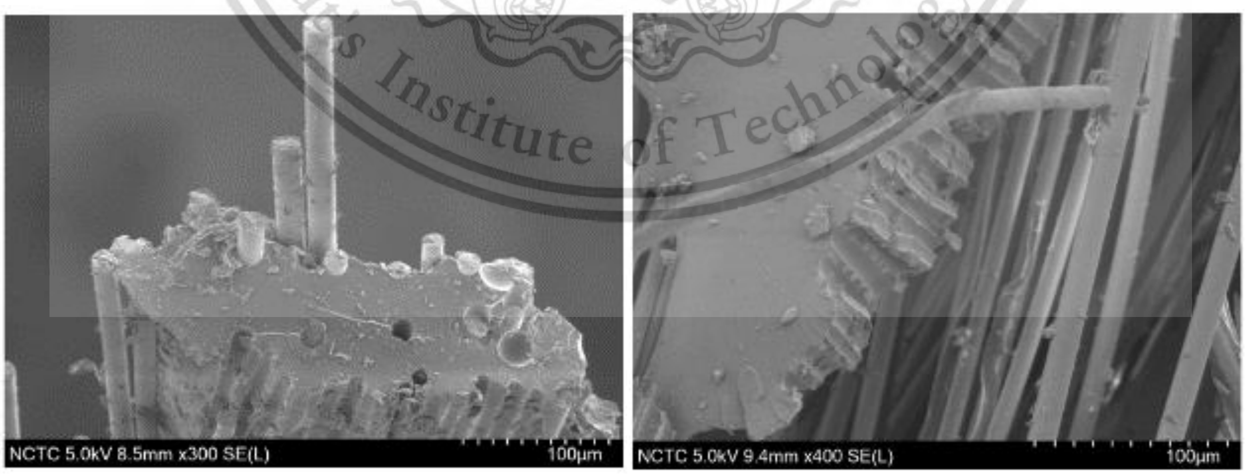


(c) Composite of GFW (d) Composite of GFF

Figure 4.15 SEM image of Composite (a) CFT, (b) CFP, (c) GFW and (d) GFF.



(a)Fracture mechanism of CFT (b) Fracture mechanism of CFP

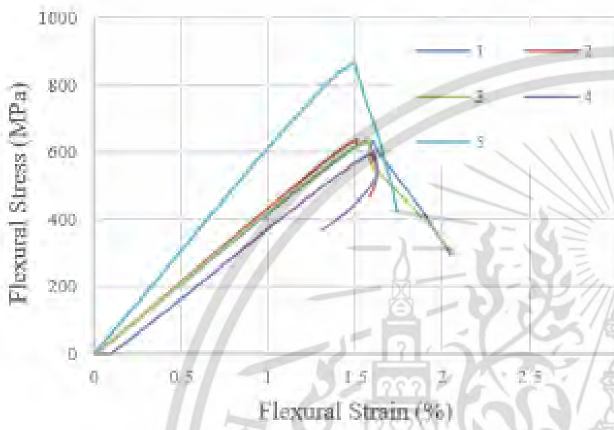


(c) Fracture mechanism of GFW (d) Fracture mechanism of GFF

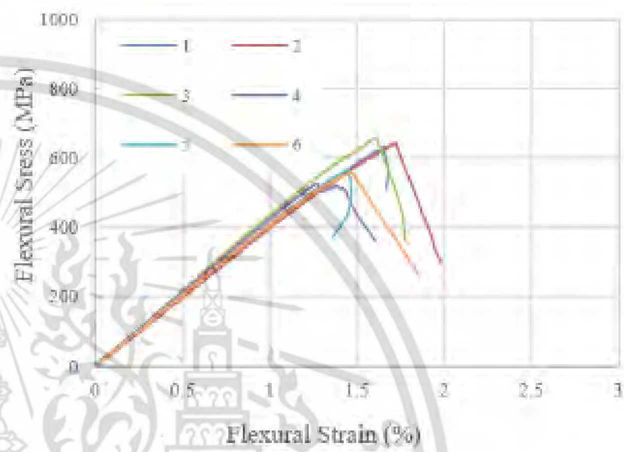
Figure 4.16 FESEM image of fracture mechanism after tensile test of (a) CFT, (b) CFP, (c) GFW and (d) GFF.

4.10 Flexural test and their fracture mechanism

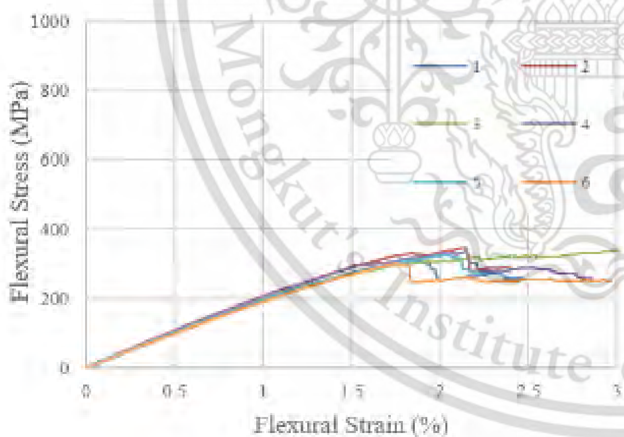
Flexural test are performed on the specimens of composite that were cut according to ASTM D790 with 12.7 mm (with) x 127 mm (length) dimensions square shape of sample. The tested parameter is at 2 mm/min with 10KN cell load. In flexural test, CFT have the highest flexural test with 630 MPa and flexural stress of CFP is slightly low than CFT. Glass fiber flexural stress of composite are almost 50% lower than carbon fiber with around 320 MPa for GFW.



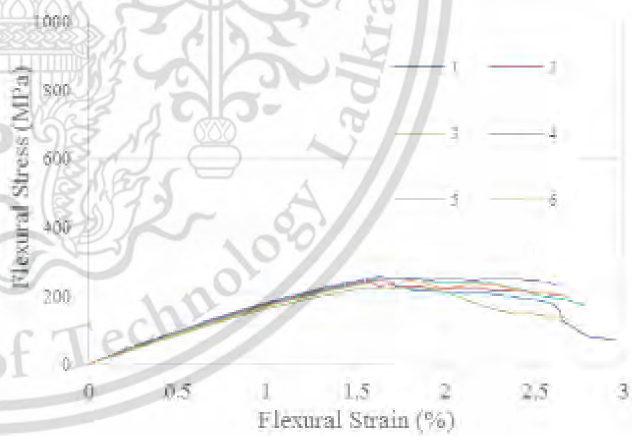
(a) Stress - strain curve of CFT



(b) Stress - strain curve of CFP



(c) Stress - strain curve of GFW



(d) Stress - strain curve of GFF

Figure 4.17 Flexural tensile test of (a) CFT, (b) CFP, (c) GFW and (d) GFF.

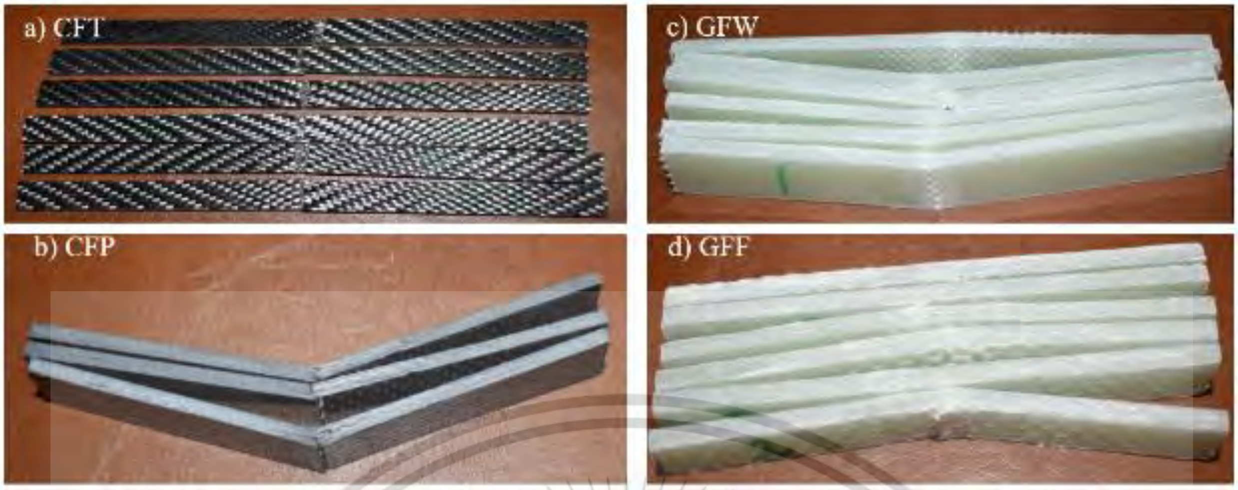
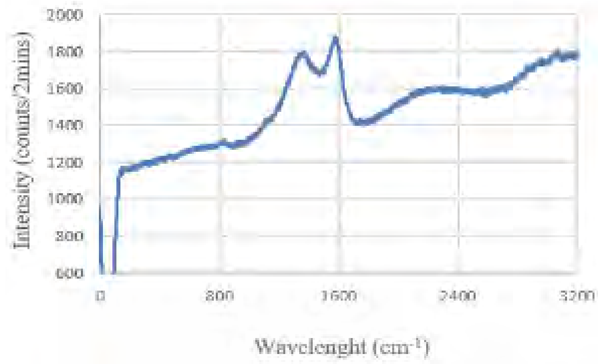


Figure 4.18 Flexural fracture image of (a) CFT, (b) CFP, (c) GFW and (d) GFF.

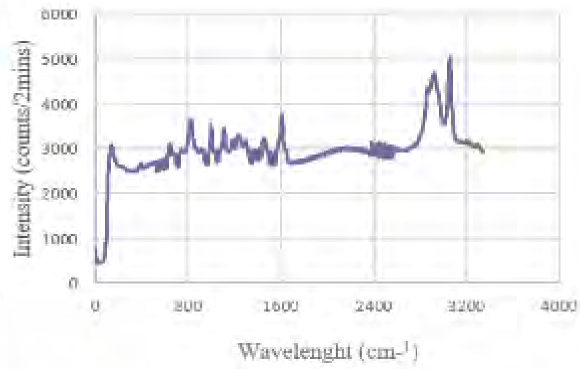
As a contrast, flexural strain of glass fiber are 25% percent higher than carbon fiber while carbon fiber is 1.5% strain, glass fiber is 2% at maximum flexural stress as shown in **Figure 4.17** (a),(b), (c) and (d). In fracture mechanism of all composite, the failure mode are almost similar for all. The flexural actuator touching surface are applied with compression force of flexural and another surface are hit by tension force. Most of composite are break at tension force applying side. Compression side are break after tension side damage in some specimens of carbon fiber. But in the case of glass fiber, the specimens are not break as mention in Figure 4.18 Most of the specimens of glass fiber are bending at the actuator area.

4.11 Raman spectroscopy of composite

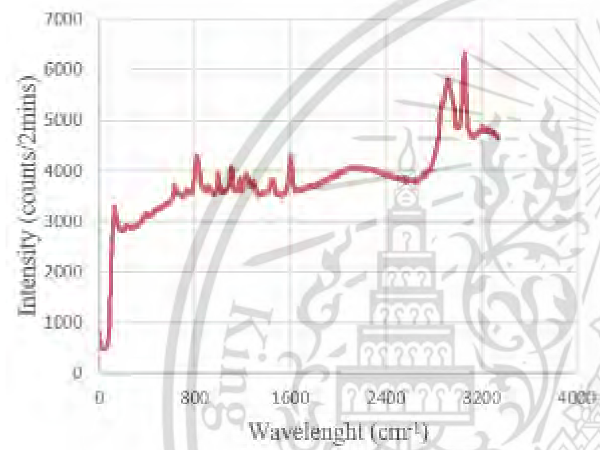
The composite of carbon fiber and glass fiber are check with Raman spectroscopy to observe the behavior of carbon fiber and glass fiber. In this composite, the graph of Raman spectroscopy show almost similar to the raw fabric fiber characteristic. Carbon fiber show peak at D band and G-band which refer to the crystal of disorder crystal and graphite peak. Additionally, there are sharp peak at 3000cm^{-1} for every graph of carbon fiber and glass fiber composite. It may come from Epoxy chemical bonding.



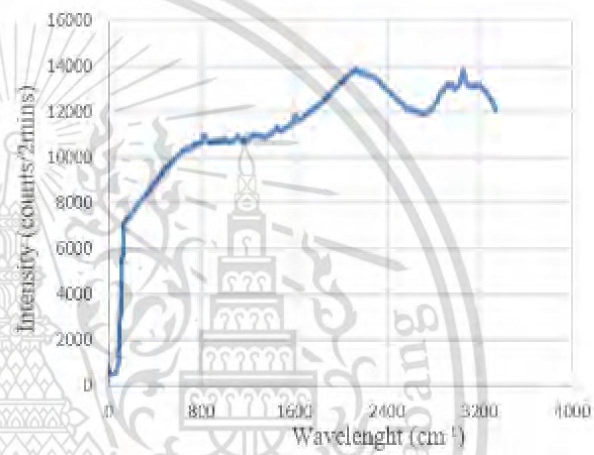
a) Raman Shift of CFT-Composite



b) Raman Shift of CFP-Composite



(c) Raman Shift of GFW Composite



(d) Raman Shift of GFF Composite

Figure 4.19 Raman Spectroscopy of composite of (a) CFT, (b) CFP, (c) GFW and (d) GFF.

4.12 Nano Indentation

The indentation test was performed in composite material to know the properties of composite with different fiber pattern and lay up process. Nano indentation test was conduct with the machine of Elionix ENT1100a. The test condition are set up with max load 200mN and the depth are not fix, then testing time is 10,000 msec and divide into 500 steps of testing position. **Figure 4.20** shows the indentation area and properties graph. Table 4.1 shows, the indention summary for four different composite. Base on the graph, CFT have different graph than other due to pumping while the test are perform. It shows that there are several porous in Carbon fiber composite more than glass fiber. This porous will affect to the mechanical properties.

The elongation of depth, hardness and modulus are shown in Table 2. In an indentation test, the highest hardness is 531.06MPa for GFW and the highest modulus is about 15900MPa for GFF. And the max depth of composite is 6.4µm for CFT. Base on the result, different properties are investigated with different pattern of fabric. GFW fabric is big amount of fibers and filament are bigger than other, therefore the hardness are higher among composite. GFF indentation result for Young Modulus is the highest one in this research. Indenter cannot penetrate the composite deeper due to the pattern of fabric and fabric layers are very thin it make to ply several layers with 16 ply. Therefore the depth are very small among other composite with the value around 4.4µm.

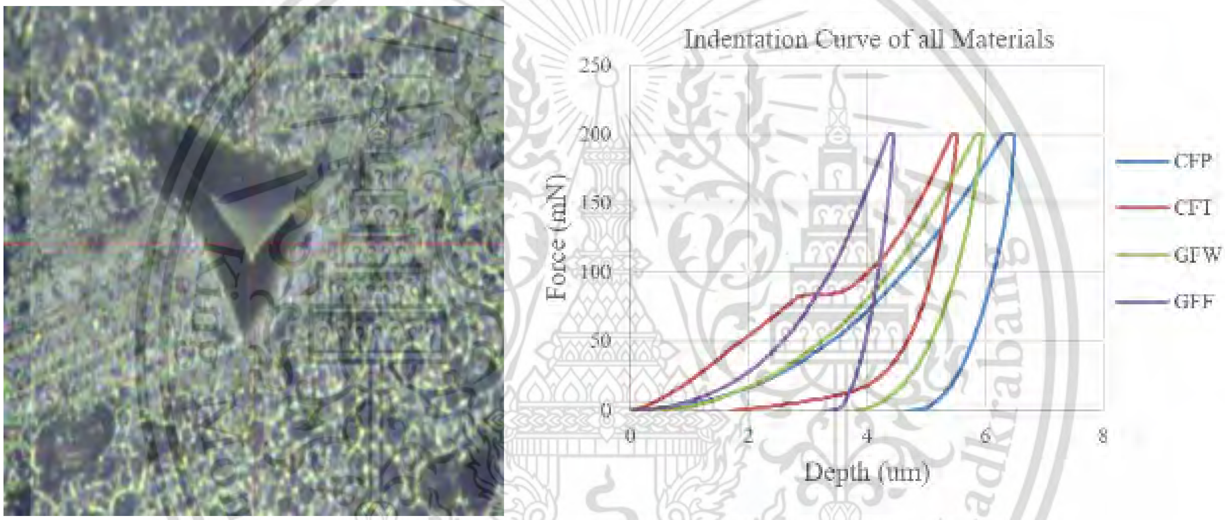


Figure 4.20 Indentation point and the summary of Carbon and glass fiber properties.

Table 4.1 Indentation properties of composite.

Composite Properties	CFP	CFT	GFW	GFF
Hardness (Mpa)	219.49	334.13	531.06	473.96
Young Modulus (Mpa)	9725.23	10853.79	15337.61	15921.93
Max Force (mN)	200	200	200	200
Max depth (µ m)	6.41	5.5	5.9	4.4

Chapter 5

Conclusions

Tensile test of fabric show CFT have the highest strength among all of fabric types. Composite of CFT also have the highest tensile test with the value of 480MPa while GFW is around 400MPa tensile strength.

In Raman spectroscopy, carbon fiber show the structure of graphite structure with two peak in Raman shift (in wavelength) as D band and G band. Disorder (D) band shows the disorder crystal with defected crystal at 1358cm-1 peak. Graphite (G) Band shows the hexagonal crystal structure at 1580cm-1 peak on Raman shift.

SEM images show carbon fiber have smoother surface than glass fiber. Several defects from SEM prove that glass fiber make the fiber pull out from the matric in composite because there is several defects sacra are in the fiber's filament surface. SEM/EDS detect element of carbon fibers and glass fiber.

X-ray diffraction shows peak that can use to calculate crystallite dimension and spacing in carbon fiber. But there is no peak for glass fiber.

TEM observe graphene layer of carbon bonding crystal with the same spacing in some part. Some parts of area show turbostratic crystallite structure of carbon fiber with higher magnification.

Chapter 6
Publication

T. Cuaiman, P. Karin, N. Ohtake, H. Akasaka, P. Larpsuriyakul, N. Prakymoramas, J. Rojsatean, D. Thanomjitr and S. Kaewket, "Mechanical property and fracture mechanism of glass fiber reinforced polymer and carbon fiber reinforced polymer", The 9th TSME International Conference on Mechanical Engineering, AMM0007, 11-14 December 2018, Phuket, Thailand.

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Appendix

Appendix A

Research Publications

T. Cuaiman, P. Karin, N. Ohtake, H. Akasaka, P. Larpsuriyakul, N. Prakymoramas, J. Rojsatean, D. Thanomjitr and S. Kaewket, “Mechanical property and fracture mechanism of glass fiber reinforced polymer and carbon fiber reinforced polymer”, The 9th TSME International Conference on Mechanical Engineering, AMM0007, 11-14 December 2018, Phuket, Thailand.

The 9th TSME International Conference on Mechanical Engineering
11-14 December 2018
Phuket, Thailand

AMM0007

Mechanical property and fracture mechanism of glass fiber reinforced polymer and carbon fiber reinforced polymer

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Abstract. In the automotive field, most of the manufacturers are looking to replace the material steel, aluminium with lightweight material like carbon fiber or glass fiber composite. The purpose are due to their relatively high strength, higher chemical resistance, flexible usage temperature and higher stiffness than steel. In this study, mechanical properties of carbon fiber and glass fiber reinforced polymer were investigate. It was find that the tensile strength of carbon fiber composite is approximately 11% higher than that of glass fiber, almost twice in Young's modulus than that of glass fiber. Carbon fiber is two times higher than glass fiber in both flexural stress and young modulus of flexural three points bending test. Image analysis of fracture and damage were detect by field emission scanning electron microscopy (FESEM) in microstructure scale to observe the fracture mechanism. Observed different failure mode in fiber and resin. Chemical composition of composite and fibers were investigated by using electron dispersive x-ray (EDX) spectroscopy that gave out in 88 w.t % of carbon and 12 w.t % in carbon fiber twill (CFT) composite. On the other hand, glass fiber woven (GFW) composite contained 72.7 w.t % of C, 20.7 w.t % of O_2, and the rest contained Si, Ca, Al, Mg and Cl.

Keywords: Carbon fiber, Glass Fiber, Fracture Mechanism, Mechanical Properties

1. Introduction

Nowadays, most of the automotive manufacturer deeply invested to make research on carbon fiber and glass fiber due to their lightweight properties. The purpose of lightweight vehicles is for future automotive fields [1]. Vanishing of CO_2 footprint and preventing the particles matters (PM) emission from vehicles in our environment are also one of the most important point. Carbon fiber and glass fiber are the most popular materials not only in the automotive field but also in the field of marine, aircraft, military vehicles, sports, rockets and etc [2]. The main properties are lightweight, high stiffness, high temperature resistance and high strength compare to the same weight [3,4]. In composites, there are two main functions those are fiber and matrix. Fiber is the main product in the composite and matrix is one of the material that can create bonding strength between fibers [5]. Polymer matrix is the most widely used in the composite industry. There are two main matrix resins such as thermosetting and thermoplastic resins; those are the most useful resin in the composite field for laid up process laminar. Thermosetting resin is liquid form and it is irreversible resin [6]. After curing thermoset resin, the resin cannot turn back to the original liquid form and the resin can cured by chemical reaction at room temperature. Among several resin types in thermoset, epoxy is the most useful matrix because the matrix can lead composite to the best material of high bonding strength [7]. The composite need higher strength to resist the force and epoxy have to transfer stresses to fibers. Most of the composite starts to crack from matrix de-bonding, fibers delamination and pull out fibers from the matrix failure because matrix is not wet enough to bond one to another fiber. Then matrix cannot distribute the load uniformly to the fibers [8]. Dany Arnoldo Hernandeza [9] observed the main fracture of the composite is come from the interface zone (area between resin and fiber) which is affected by the tensile stress concentration on resin. It makes a crack initiation at the resin area, and then the force and crack are distribute to the fibers. Therefore, fiber is pull out then leads to break fibers. Issa A. Hakim [10] studied the porosity of the composite according to different vacuum poor, moderate and high vacuum. As the result, the poor vacuum composite has the highest quantity of porous that can make lower strength with faster crack then the toughness of fibers are decreasing. Energy absorptions are drop compare to moderate and high vacuum. From the view of an image, it is quite important to investigate the porous inside fiber and the structure of each fiber that can affect mechanical properties and fracture of composite. P. Karin [11] observed particle matters (PMs), average agglomerated particle diameter sizes are in the range of 50-500 nm size and average nanoparticle diameter size are in the range of 20-50 nm respectively. He used (TEM) transmission electron microscopy to investigate the size of PM. P. Karin [12] used TEM to observe particle matters size from biodiesel engine and diesel engine with different speed RPM. He investigated the average of nanoparticles size in approximately 48, 34 and 32 nm for carbon black for biodiesel and diesel engine's PMs respectively. P. Karin [13] has investigated carbon black by using electron microscopy analysis. Therefore, electron microscopy is one of the most important tool to study fracture mechanism. However, in case of composite, micro and nanostructures are not understand well, it induces to investigate the properties and fracture mechanism of composite with different type of base material.

2. Materials and Methodology

2.1. Materials

In this research, two types of materials were used with epoxy resin matrix; carbon fiber (twill weave and plain weave) based on polyacrylonitride (PAN) [8, 9] and E-glass fiber (woven roving and fabrics). Epoxy YD 582 and hardener TH7253 are use as the matrix in this composite. Listed materials in table 1 are supply by concrete composite.

Table 1. Materials type

No.	Material	Prod name	Composites name in this paper	Type
1	Carbon fiber twill	C135T	CFT	
2	Carbon fiber plain	PC6951500	CFP	Carbon
3	Glass fiber	Woven roving N323	GFW	
4	Glass fabrics	Glass cloth EW200	GFF	Glass
5	Epoxy (part: A)	YD 582		
6	Hardener (part: B)	TH 7253		Resin

2.2. Sample preparation

Orientation for all of the materials are bidirectional 0/90 degree. The fabrication process are wet lay up process based on the weave fibers pattern from manufacture. All of the fibers are lay up in the same orientation. In epoxy mixing ratio, there are two parts, part A: epoxy and part B: hardener are mix for 3:1 ratio based on fiber ratio and equations (1-3). The thickness of composite were control based on the fabric thickness of each layer. The same method is use for all composites with wet lay-up process. All of laid up conditions can see in table 2.

$$Hardener\ weight\ (g) = \frac{Weight\ of\ Fibers\ (g)}{4} \quad (1)$$

$$Epoxy\ weight\ (g) = \ weight\ of\ hardener\ (g)\ x\ 3 \quad (2)$$

$$Epoxy\ and\ hardener\ ratio = 3{:}\,1 \quad (3)$$

Composite was cut by computer numerical control (CNC) machine Mazak FJV-20 with the situation of spindle speed 150 mm/min and feed speed 90-100mm/min. Samples are prepared according to ASTM 638 for tensile test and ASTM 790 for flexural test specimens. Fabricated composite information of composites.

Table 2. Material ply and lay up status

No.	Material	Fabric layers	Fabric thickness (mm)	Fibers w.t (g)	Composite size (mm)	Comp w.t (g)
1	CF twill	10	0.31	261.1	320x320x3.2	512
2	CF plain	9	0.3	343.29	240x280x2.9	429
3	GF woven	10	0.3	408.1	320x320x3.2	636.06
4	GF fabrics	16	0.2	343.62	320x320x3.2	574.167

2.3. Mechanical testing

The specimens were test on a tensile test machine INSTRON 8801 with load cell 95KN, test speed 5mm/min for all composite with the same testing function at temperature 24 degrees Celsius with 47% RH. Another mechanical flexural test (three-points bending) is perform at 24C temperature and 49% RH with INSTRON 55R4502 machine. Testing rate speed is 5.2mm/min with cell load 10KN.

3. Result and Discussion

3.1. Tensile test results with different materials CFT, CFP, GFW and GFF

Figure 1 shows the average value of each composite. CFT/CFP has the highest tensile strength than that of GFW/GFF. The tensile strain of glass fiber is two times longer than carbon fiber elongation. CFT is the peak tensile stress around 450MPa while CFP is around 420MPa at the same tensile strain 1.3%. Maximum strength of GFW and GFF are decrease particularly compare to CFT /CFP. The elongation at break point are 1.37% for CFT and 1.31% for CFP respectively, while GFW and GFF elongation are 2.85% and 2.91% respectively. Young modulus is the main important point in mechanical test and properties. Therefore, the highest young modulus is around 37 GPa from CFP and it is almost similar to CFT composite with the value of 36 GPa. The value of CFT and CFP are almost two times higher than that of GFW and GFF's young modulus.

Tested materials data are summarize and compare to each sample properties in table 3. The specimens are not the same thickness, but the thickness will not affect to young modulus of materials because material properties are not depends on the thickness of samples. Unlike steel or alumina, the samples are sensitive and break at several points. Therefore, strain gauge was not use in this experiment. The elongations are calculate from sample crosshead displacement because it was collect at maximum strength of sample.

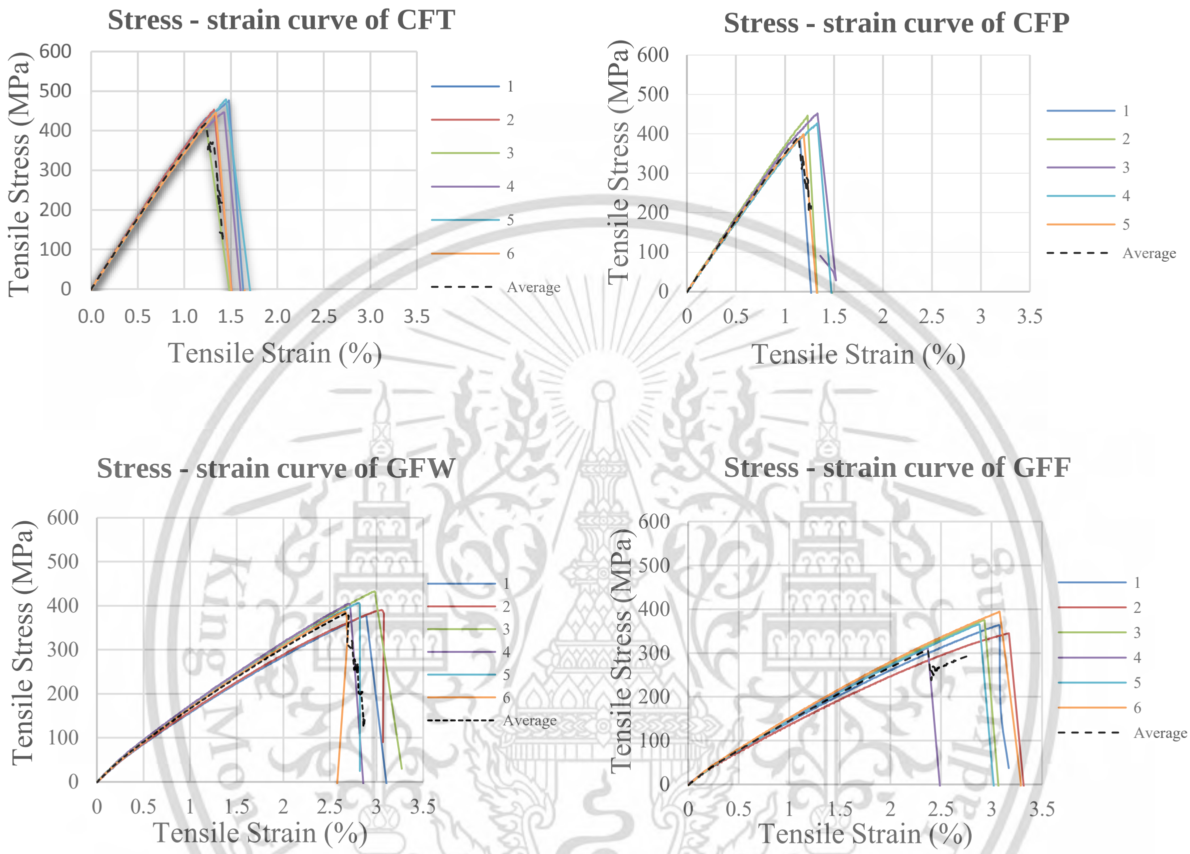


Figure 1. Stress-strain relationship of tensile test data of CFT, CFP, GFW and GFF

The specimens were disintegrate to be several pieces immediately after the peak points of tensile stress for CFT. It leads to brittle behaviour, but higher stiffness. Composite breakage of CFT and CFP are almost linear. Figure 1 also shows that stresses are immediate drop. For glass fibers, the nature of glass are flexible and higher elongation. The fracture behaviour of GFW and GFF are tougher comparable to CFT and CFP behaviour. After the maximum load are applied, the specimens break immediately in the weakest point of the sample where the fillet of specimens are located for all types of specimens. The failure mode of composite are as shown in figure 2.

Table 3. Comparison of composite material and their properties of tensile test

Samples	Thickness (mm)	Width (mm)	Grip distant (mm)	Maximum load (N)	Tensile strength (MPa)	Young modulus (MPa)	Elongation at break (%)
CFT	3.5	13.35	115	21,332.87	452.98	36,204	1.37
CFP	2.85	13.6	115	16,328.60	430.73	36,604	1.31
GFW	3.3	13.6	115	18,182.37	399.85	18,620	2.85
GFF	3.2	13.7	115	15,582.11	358.99	15,860	2.91

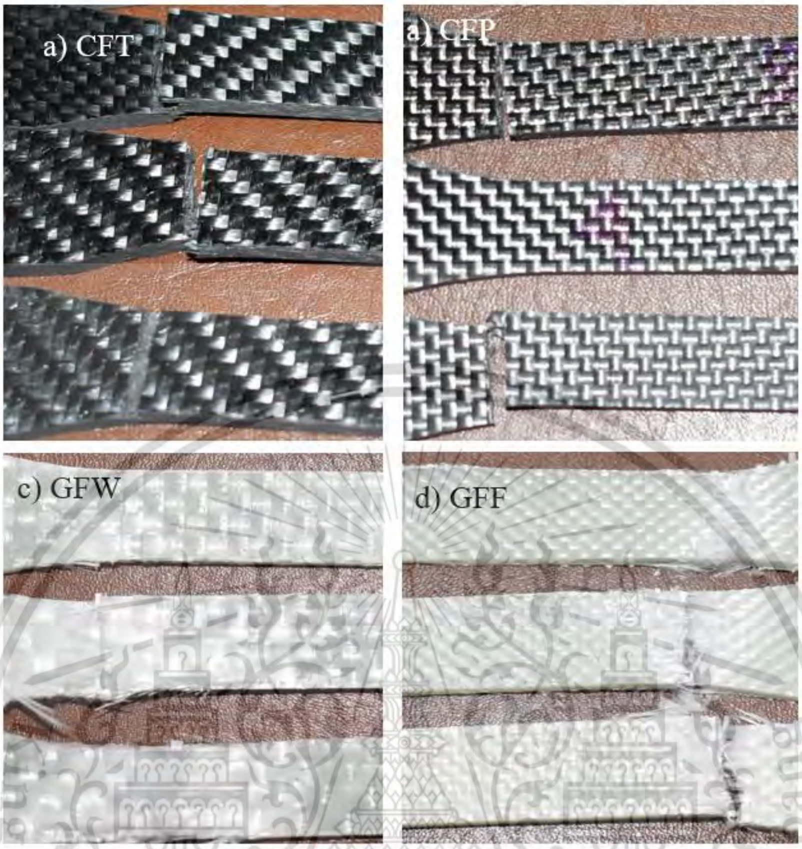


Figure 2. Fracture sample of tensile test a) CFT, b) CFP, c) GFW and d) GFF

3.2. Flexural Test

Three points bending flexural test condition are as mentioned; six pieces of each type are tested. The average flexural strength of all specimens are as shown in figure 3. Each type of samples are much different not only in flexure stress at maximum load but also in young modulus. The summary and properties of all flexural tested conditions are show in table 4. CFT and CFP have a big gap in maximum stress but almost the same flexure strain in elongation. GFW/GFF in this flexural test are drop gradually without breaking immediately. After the maximum load are applied, the fibers breaks unstably and tends to more elongation. In young modulus, CFT is the best one with the highest value of 47 GPa and the next follow by CFP with 42 GPa. Young modulus for GFW and GFF are lesser more than compare to CFT. On the other hand, glass fiber are very good in elongation that lead to the good toughness behaviour. The failure behaviour are also quite different in each type as shown in figure 4. Tension side of surface starts to crack first due to tension load and compression side are crack.

Table 4. Flexural strength and modulus of composites

Name	Maximum flexure load (N)	Flexure Stress at max load (MPa)	Modulus (automatic young's) MPa	Flexure strains at max flexure stress (%)	Thickness (mm)	Width (mm)
CFT	655.69	675.37	46,975	1.55	3.35	13.34
CFP	425.35	598.26	41,945	1.53	2.88	13.63
GFW	329.04	327.15	20,720	2.21	3.32	13.67
GFF	229.33	246.18	18,603	1.72	3.2	13.66

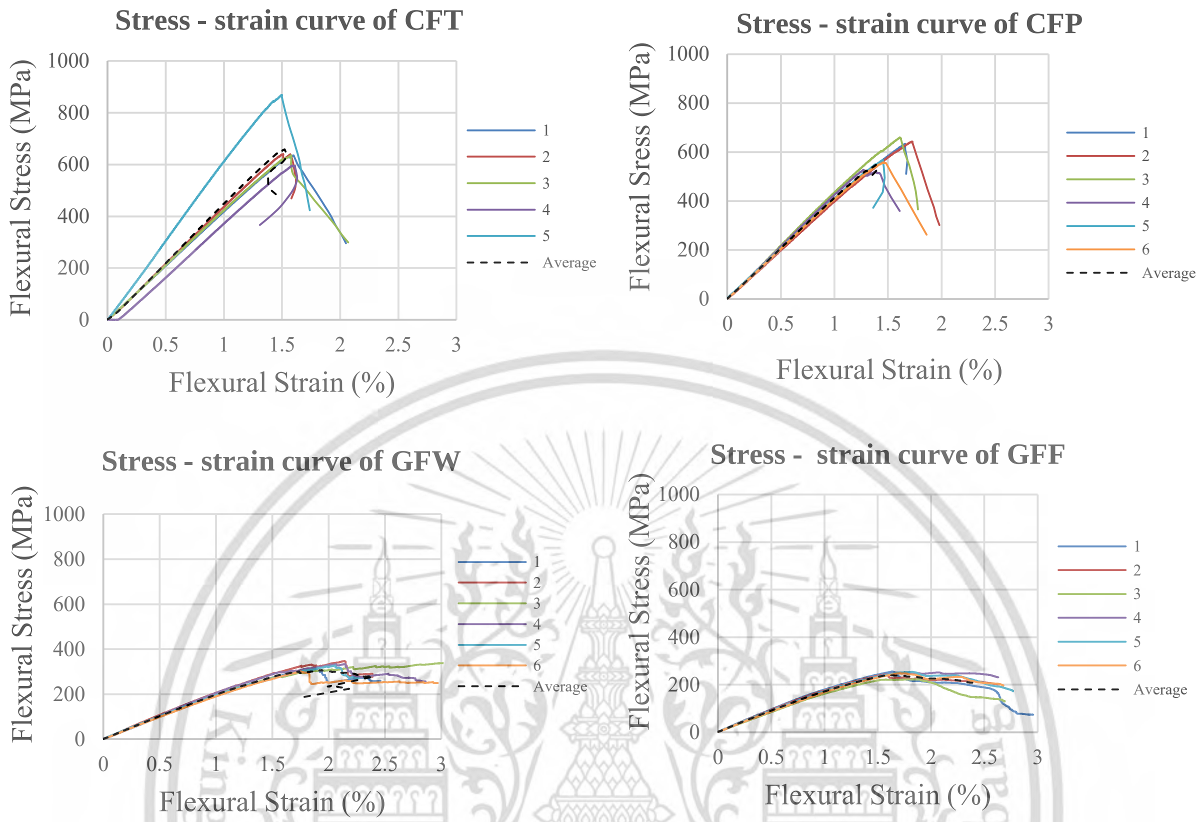


Figure 3. Flexural stress-strain curve for all composites

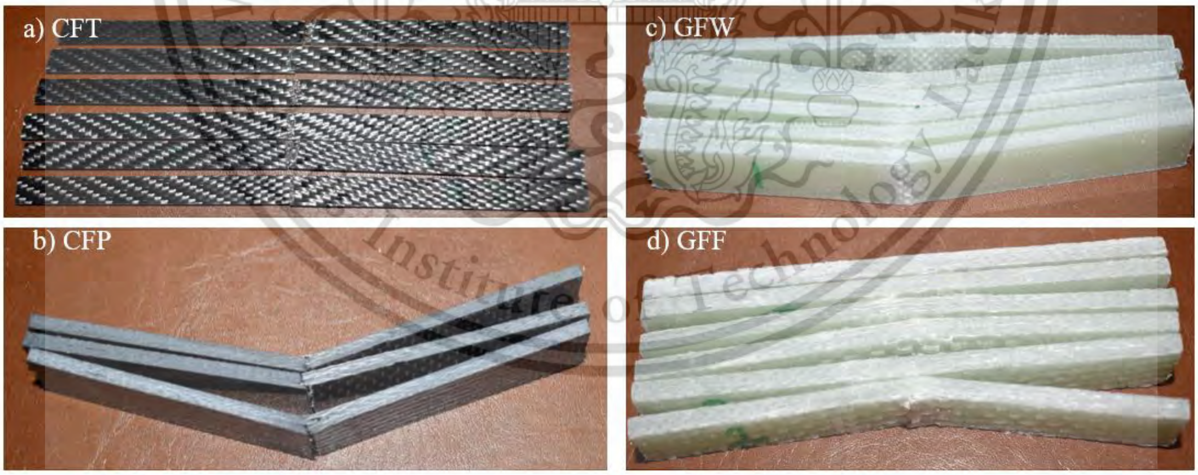
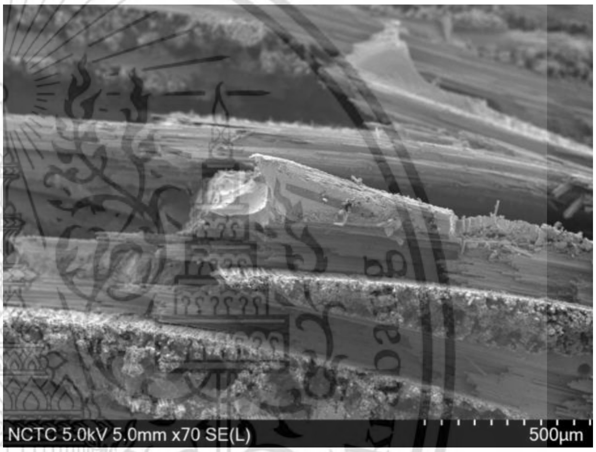


Figure 4. a) CFT, b) CFP, c) GFW and d) GFF specimens after the flexural test

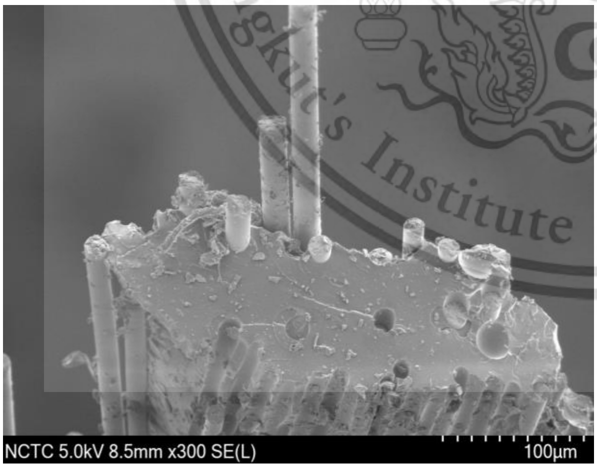
3.3. FESEM image Analysis

Fracture mechanism of materials is very important role to improve the property or strength because it is extremely depend on the microstructure of interface. In this paper, the microstructure is describe based on tensile test specimens for all four types of composite. Firstly, the main fracture of all samples are come from the smallest and the weakest area of the specimens. The fracture mechanism of glass and carbon are quite different in crack area. Small area for CFT/CFF and quite a large area for GFW/GFF with complex breakage. CFP fracture breakage shows 0 degree (the same direction with tension load) laid fiber are break almost linearly while 90 degrees across lay up fiber are break by each strand delamination in figure 5 a) and b). The main tension force of CFT and CFP are come from vertical direction laid up fibers, it lead to break resin and fiber. Longitudinal tension force pulls the fiber yarn to separate each filament that make each fiber delamination from bonding. As shown in figure 5 a), CFT is disintegrating into several pieces in the middle, but still hold together matrix and fiber on both edge sides. GFW/GFF is difficult to detect the breakage area because of breakage filament are complicated and breakage area of fibers is longer than that of carbon fibers. The main fracture behavior of GFW/GFF is delamination and pullout the fibers from the bonding matrix as shown in figure 5 c) and d). The matrix bond tightly, but the fibers are delaminate and pull out due to external from through fibers. Delamination of fiber will bring to stand alone each filament, therefore each filament are very easy to break. The middle filament are break first and the breakage are distribute to the both side of fibers, it is the main breakage of fiber in GFW and GFF. Additionally, voids can see in matrix area that comes from the fabricated process through air bubbles that didn't remove very well while lay up process are performed, it becomes voids in composite. Those voids are also one of the weak points to initiate crack in the matrix.

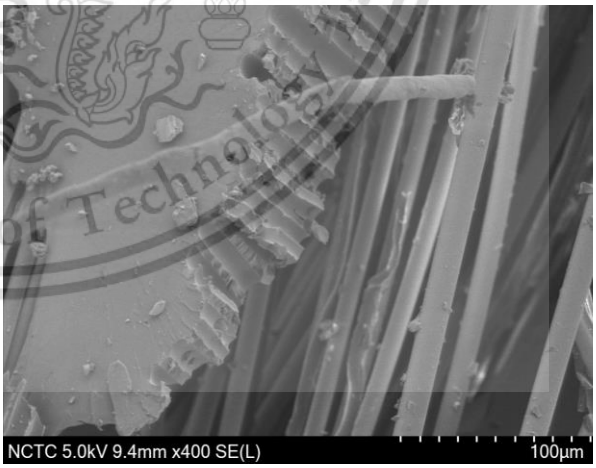
a) CFT composite



b) CFP composite



c) GFW



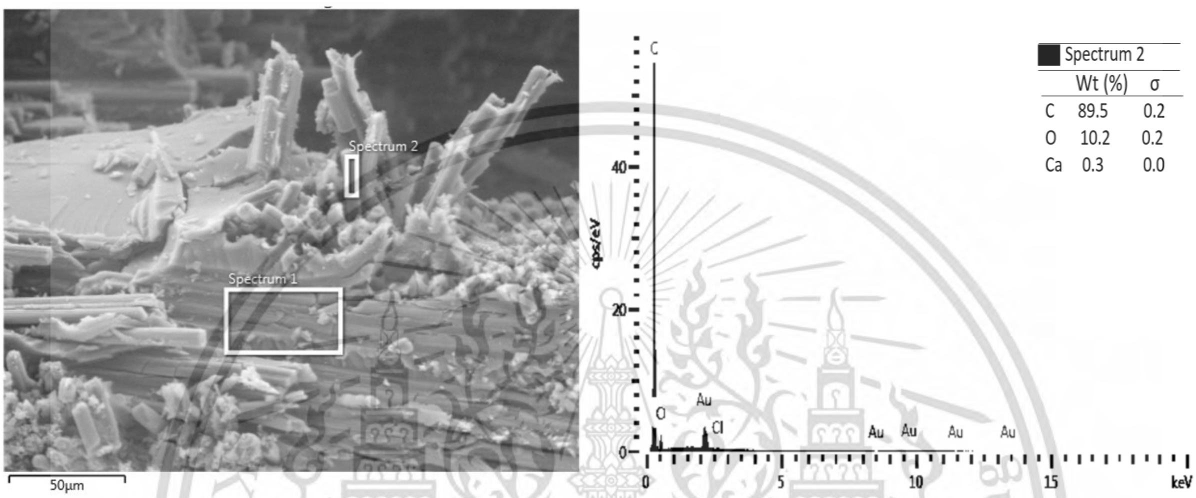
d) GFF

Figure 5. FESEM image a) CFW, b) CFP, c) GFW and d) GFF

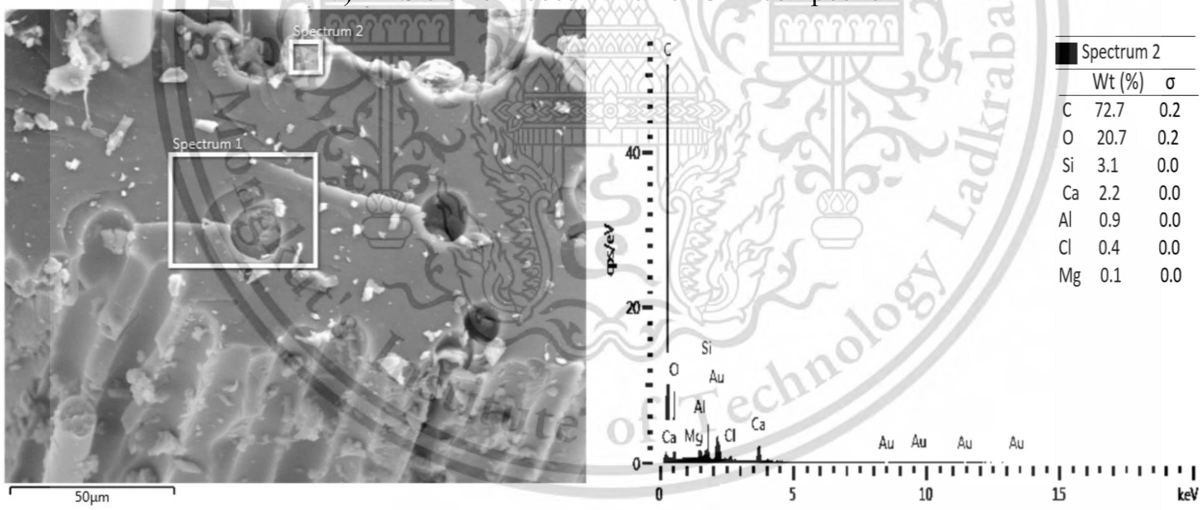
3.4. EDS Analysis

FE-SEM machine with EDS system observed the element composition on the composite CFT and GFW with 60 CPS in figure 6. a) and b). CFT composite spectrum 1 proved that 88% w.t of carbon, 11.7% of O_2 and 0.3% of calcium containing in composite. Therefore, especially carbon and oxygen are the most important element in this material to play at the main role of carbon composite.

GFW has observed 72.7% w.t of C, 20.7% of O_2, 3.1% of Si, 2.2% of Ca, and a few of AL, Cl and Mg respectively in spectrum 1. Thus, element composition of epoxy can be assumed as C, O_2 , Ca and Cl. Table 5 is the summary of EDS chemical composite in each GFT and GFW. On the other hand, breakage of CFT prove that it have brittle behaviour due to tension force to the fibers as shown in figure 5. Au containing percent is due to gold spray on sample for electron conductive purpose. Therefore, Au data was ignore in figure 6. A) and b). Al (Alumina) also EDS scanner may count from the stub, which use to stick the sample.



a) EDS element observation of CFT composite



b) EDS element observation of GFW composite

Figure 6. Element composition of a) CFT and b) GFW composite by using electron dispersive x-ray spectroscopy (FESEM-EDS)

Table 5. EDS result of CFT/GFW composite and each filament

Element/ Composite or Fiber		**Element (Weight %)**						
		Carbon	**Oxygen**	**Silicone**	**Ca**	**Al**	**Cl**	**Mg**
CFT	Spect:1	87.9	11.7	0.3	-	-	-	-
GFW	Spect:1	72.7	20.7	3.2	2.2	0.9	0.4	0.1

4. Conclusion

The composite of carbon fiber and glass fiber reinforced polymer with an epoxy matrix were test in tensile testing machine, the results show carbon fiber composite (CFT/CFP) was the highest modulus and tensile strength. Approximately 11% of tensile strength are higher than that of GFW/GFF and almost double modulus are achieve in CFT and CFP with 36, 204MPa and 36,604MPa respectively.

Flexural test shows higher modulus than a tensile test with value 46,975 MPa and 41,945MPa for CFT and CFP respectively, meanwhile GFW and GFF are lower than CFT and CFP almost half.

Fracture surface shows, the main character of CFT/CFP are peel off fiber by each bundles and break therefore the breakage area are almost linear in each bundles. This experiments show that CFT/CFP have brittle behaviour. As a contrast, GFW and GFF are delaminate in each filament then each filament are crack after matrix transfer the load. Then the whole fibers are leads to failure. GFW/GFF has a lesser brittle deformation behaviour than CFT/CFP.

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Appendix B

Research Budget

บันทึกรายการรับ-จ่ายเงิน โครงการวิจัย สัญญาเลขที่ 2561-0111005 ตั้งแต่วันที่ 1/4/2561 ถึงวันที่ 30/9/2561

แหล่งทุน: เงินรายได้ วิทยาลัยนานาชาติ สจล.
ชื่อโครงการ :การวิเคราะห์โครงสร้างไมโครและนาโนของคาร์บอนไฟเบอร์ด้วยการประมวลผลภาพถ่ายจากกล้อง จุลทรรศน์อิเลคตรอน
ชื่อหัวหน้าโครงการ: ผศ.ดร.ปรีชา การินทร์

ว/ด/ป	รายการ	เลขที่อ้างถึง	รายการรับ - จ่าย			รายรับ	รายจ่าย						รวม
							งบบุคลากร	งบดำเนินงาน				งบลงทุน	รายจ่าย
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	งบประมาณที่ได้รับการอนุมัติ (ตามแผน)		100,000.00										-
	จำนวนเงินที่ได้รับ (งวดที่ 1 = 85%)		85,000.00			24.13							
	จำนวนเงินที่ได้รับ (งวดที่ 2 = 15%)		15,000.00			0							
	หัก ค่าใช้จ่าย (ครั้งที่ 1)			103,775.54			-	-	56,232.50	47,543.04	-	-	103,775.54
	ค่าใช้จ่าย (ครั้งที่ 2)			-			-	-	-	-	-	-	-
	งบประมาณคงเหลือ		100,000.00		- **3,775.54**	**24.13**							
	รายละเอียดค่าใช้จ่าย												
ครั้งที่ 1													
19 ก.ค. 61	Carbon Fiber	C61070637								6,896.15			6,896.15
4 ก.ค. 61	ใยเสริมความหนา	C61070133								5,378.89			5,378.89
16 ส.ค. 61	Carbon Fiber	C61080505								8,025.00			8,025.00
7 ส.ค. 61	SEM Analysis	353								7,757.00			7,757.00
6 ก.ย. 61	SEM Analysis (susan)	27								5,136.00			5,136.00
14 ก.ย. 61	XRD Analysis	244								6,000.00			6,000.00
17 ก.ย. 61	TEM Analysis	40							8,613.50				8,613.50
18 ก.ย. 61	TGA Analysis	373							14,980.00				14,980.00
26 ก.ย. 61	SEM EDS Analysis	400								8,350.00			8,350.00
9 พ.ย. 61	TEM EDS Analysis	178							8,346.00				8,346.00
9 พ.ย. 61	TEM EDS Analysis	179							7,597.00				7,597.00
9 พ.ย. 61	TGA Analysis	439							7,276.00				7,276.00
9 พ.ย. 61	TGA Analysis	438							6,420.00				6,420.00
9 พ.ย. 61	TSME-ICoME-IOP								3,000.00				3,000.00
	รวมครั้งที่ 1		-	-	-	-	-	-	56,232.50	47,543.04	-	-	103,775.54
ครั้งที่ 2													
													-
	รวมครั้งที่ 2		-	-	-	-	-	-	-	-	-	-	-

ลงชื่อหัวหน้าโครงการ .... วันที่ ....

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