Characterization of Natural Reinforcements and their Composites

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Abstract: In this study, the mechanical properties of flax, jute and jute/carbon woven fabrics, and their composites were investigated and compared with 3K carbon fabric composites. Mechanical properties of yarn, fabric and composites were separately investigated and compared for each scales. In addition, yarn and fabric structures were characterized. It was found that, fabric structure, yarn physical properties and fiber cross-section and fiber molecular structure parameters of reinforcement have seriously effect on the composite mechanical properties. It can be concluded that fabric tensile strength attribute to composite tensile strength, but there was not a direct relation between fabric tensile strength and composite tensile strength. The tensile strength of natural fiber fabrics were determined to be significantly reduced depending on the temperature increasing. This condition should be considered as a important limitation for composite applications of natural fibers. Mechanical test results are proved that natural fiber composites not to be an important alternative to conventional composites.

Keywords: Natural fiber composites, Mechanical properties, Impact properties.

1. INTRODUCTION

In the recent decades, natural fibres used as an alternative reinforcement material in polymer composites have attracted the attention of many researchers and scientists due to their advantages over conventional glass and carbon fibres [1]. These natural fibers include flax, hemp, jute, sisal, kenaf, coir, kapok, henequen and many others. The various advantages of natural fibres over man-made glass and carbon fibres are low cost, low density, comparable specific tensile properties, nonabrasive to the equipments, non-irritation to the skin, reduced energy consumption, less health risk, renewability, recyclability and biodegradability [2]. These composites materials are suitably applicable for aerospace, leisure, construction, sport, packaging and automotive industries, especially for the last mentioned application [2, 3].

In recent times the natural fiber composites have had a huge growth in the automotive industry due to the advantages of renewability, reduced emission of pollutants and improved fuel efficiency because of reduced weight of the components [4-6] In spite of their favorable properties natural fibers possess disadvantages like lack in thermal stability, strength degradation, water absorption and poor impact properties [7-9].

Owing to adverse effects on environment, high cost, etc. researchers started exploring natural fiber based hybrid composites. Hybrid composites, which are obtained by combination of synthetic–natural fibers, are developed to overcome thus type of handicap. Natural fibers themselves can be treated as composites which makes them more tougher when compared to synthetic fibers, more over a rightly configured high quality natural fiber reinforced hybrid composites possess good strength and stiffness values nearer to glass fiber reinforced composites [10]. It was observed that partial replacement of artificial fibers with natural fibers led to an artificial–natural based hybrid composites, which show intermediate characteristics between pure natural and pure synthetic fiber based composites [11, 12]. Researchers substantiated that improved properties can be achieved by hybridizing natural fiber based composites with glass fibers [13-15].

There are many factors that can influence the performance of natural fiber reinforced composites. Apart from the hydrophilic nature of fibre, the properties of the natural fibre reinforced composites can also be influenced by fibre volume fraction. In general, high fibre content is required to achieve high performance of the composites. Therefore, the effect of fibre content on the properties of natural fibre reinforced composites is particularly significance. It is often observed that the increase in fibre loading leads to an increase in tensile properties [16].

The mechanical properties of the natural fibres show serious variability since the age of the plant, the

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geographical and climatic growth conditions, the harvesting method, the retting and the combing technique etc [17], on the contrary of synthetic fibres. The variability of these mechanical properties, the compatibility between matrix and natural fibre and the moisture absorption [18] are the principal disadvantages which may prevent natural fibre composites from large-scale production [19]. Many review articles study at the fibre scale the properties of the most widely considered natural fibres such as flax, hemp, jute, sisal, kenaf etc. [1, 20-22].

Between the two scales, (fibre, composite) few studies, according to our knowledge, deal with the mechanical behaviour of natural fibre assemblies such as strands, tows and dry reinforcement fabrics on the contrary to the numerous studies dealing with the subject for synthetic materials. Indeed, for structural application in the automotive or aeronautical industries numerous publications [23, 24] study the mechanical characteristics of carbon or glass reinforcements in conjunction to the manufacturing process. These studies concern the scale of fibre and the scale of reinforcements.

It is clear that, despite the significant advantages of natural fibers because of their limited mechanical properties, they are not favored to use alone in composite materials to obtain adequate reinforcement. Therefore, hybridizing with conventional carbon and glass fibers may form good results. Unlike the synthetic fibers, mechanical properties of natural fibers show a wide range of variation, therefore, it is more critical to determinate properties of these materials (fiber or yarn) in fabric and composite. Since, properties of the composite plate can also show variations depending on the properties of yarn and fabric in it. In this study, the mechanical properties of flax, jute and jute/carbon woven fabrics and their composites were investigated and compared with 3K carbon fabric and composites. Mechanical properties of yarn, fabric and composites were separately investigated and compored for each scale. In addition, yarn and fabric structures were characterized. It is well known that fabric structure, yarn physical properties and fiber cross-section parameters of reinforcement have seriously effect on the composite mechanical properties. Because of that these parameters were examined and identified.

2. MATERIALS AND EXPERIMENTS

2.1. Materials

The properties and production parameters of the jute, flax, jute-carbon and carbon woven fabrics and fibers that were used in this study are presented in Table **1** and Table **2**. The properties of jute and flax yarn and fabrics were experimentally determined. The

Table 1: Parameters of the Woven Fabrics used in this Study

Reinforcement Definition	Flax Fabric	Jute-carbon Hybrid Fabric	Jute Fabric	Carbon Fabric
Reinforcement Code	**K1**	**K2**	**K3**	**K4**
Weave type	Plain woven	Plain woven	Plain woven	Plain woven
Number of threads per unite length (threads/cm)				
Weft yarn	12	6	7	6
Warp yarn	12	6	7	6
Yarn linear density (Tex)				
Weft yarn	46	250	230	200
Warp yarn	46	200	230	200
Yarn type	Ring spinning yarn	Filament yarn (warp yarn) ring spinning yarn (weft yarn)	Covered yarn by twist (Core yarns: 196 Tex ring spinning Jute yarn+18 Tex filament PET yarn, sheath yarn: 18 Tex filament PET yarn)	Filament yarn
Yarn definition and composition				
Weft yarn	100% flax	100%Jute	83% Jute+17%PET	100% Carbon
Warp yarn	100% flax	100% Carbon	83% Jute+17%PET	100% Carbon
Mass per unite area (g/m^2)	120	151	303	210

Table 2: Parameters of the Fibers used in the Study

Parameters	A-38 Carbon*	Flax [1]	Jute [1]
Fiber diameter, μm	7	15-50	40-350
Fiber Young modulus, GPa	240	27	26.5
Fiber strength, MPa	3800	500-1500	393-773
Fiber ultimate elongation, %	1.6	2.7-3.2	1.5-1.8
Fiber density, g/cm3	1.78	1.53	1.3

*: manufacturer data sheet.

3 K carbon yarn was purchased from Dow-Aksa. All woven fabrics were produced under the same production conditions and with the same weaving machine. The hybrid fabrics were produced at the same yarn density with 100% carbon fabrics. In hybrid fabrics, whereas warp yarns are carbon, weft yarns are jute. Araldit LY 564 type epoxy resin and XB 3486 hardener were used for composite production. The mixture ratios between the resin and the hardener were taken as 100:34 as weight ratio.

2.2. Composite Production

The fabrics used in the production of the composite materials were cut into 50x50 cm pieces. Table **3** showed the main production parameters of composite samples such as ply arrangements, number of fabric plies and thickness of composite plates. Thicknesses were measured from the finished samples using a caliper. The vacuum assisted resin infusion method was used to produce the composite plates. All samples were produced on a glass plate. The samples were held under vacuum to harden for a minimum of 12 hours after resin infusion and were the post-cured at 80ºC for 4 hours in an oven.

The end (ends/cm) and the pick count (picks/cm) of fabrics used in this study may differ from one another. Resulting from this, the fabric is slightly unbalanced with respect to the total fiber volume content in the warp and weft directions. In order to reach the overall balance of warp- and weft-directional fibers in composite laminate, the fabric layer orientation was alternated when laying the half-ply of samples.

The fiber volume fraction (V_f) given in Table **3** was obtained based on the fabric weight and plate thickness as follows:

$$V_f = \frac{n.m}{\rho.h} \quad (1)$$

Where n is the number of fabric plies, m is the fabric areal weight, ρ is the fiber density and h is the plate thickness. The fiber volume fractions are calculated for all plates separately.

2.3. Experimental Method

Thermal Gravimetric Analysis (TGA)

Perkin Elmer, STA 600 model thermo-gravimetric analyzer (TGA) was used for TGA analysis. The initial temperature of TGA was 50 °C, and the final temperature was 900 °C, heating rate was 30 °C/min, purge gas was nitrogen until 600 °C afterwards changed to oxygen.

Tensile Properties of Reinforcement Fabric and Yarns

Tensile strength and strain of the fabrics were tested according to EN ISO 13934-1 using a universal tensile tester Shimadzu Autograph AGS-X with 5000 N

Table 3: Properties of the Composite Plates

Sample Code	C1	C2	C3	C4
Reinforcement Type	K1	K2	K3	K4
Fabric Ply Number	12	12	12	24
Stacking direction	0°/90°	0°/90°	0°/90°	0°/90°
Plate thicknesses (mm)	4.93±0.19	8.72±0.15	10.58±0.11	6.32±0.032
Fiber Volume Fraction (%)	43	45	40	52

load cells. Four specimens were tested for each sample both at room temperature as in the standart and also at 75 °C and 150 °C. The gauge length was 100 mm. The crosshead speed was 100 mm/min. The maximum load was used for tensile strength calculation. Tensile strain was measured at maximum load.

Tensile strength and strain of the yarn were tested according to ISO 2062 using a universal tensile tester Shimadzu Autograph AGS-X with 5000 N load cells. The test specimen preparation was made as yarns were pulled out from reinforcement fabric. Five specimens were tested for each sample. The gauge length was 100 mm. The crosshead speed was 100 mm/min. The maximum load was used for tensile strength calculation. Tensile strain was measured at maximum load.

FT-IR Analysis

FT-IR spectra were obtained by using Thermo scientific-Nicolet i550 FTIR model device with Smart Orbit-Diamond model ATR auxiliaries in transmission mode. The spectra were taken between 4000–550 cm^{-1} wave numbers with a resolution of 4 cm^{-1}. The absorption bands in FTIR spectra were analysed by Omnic 9 software. An average of 16 scans was accumulated for each spectrum.

Microscobic Analysis

The study of cross-section of yarns was made by using Leica DM 2500 research microscope. The surface of the yarns was investigated by Leica M 125 stereo microscope. Images were obtained at a magnification of 5,5X and 22X in Leica DM 2500, and 1,3X and 1,6X in Leica M 125.

Physical Properties of Reinforcement Fabric

Physical properties of reinforcement fabrics were calculated according to EN 12127 (mass per unite area of fabric), ISO 7211-2 (number of threads per unite length), ISO 7211-5 (yarn linear density).

Tensile Properties of Composite

The tensile tests were performed in an Instron 4505 test device with a crosshead speed of 5 mm/min in accordance with ASTMD 3039 standard. The samples were cut into 25x250 mm size using a water jet, and aluminum end tabs were stuck to the ends of the samples using epoxy glue. A video extensometer was used in the tests as an optical extensometer with a precision of approximately 0.01% strain. The tensile tests were conducted in the weft and warp direction depending on the type of sample. The stress-strain curve provides the elastic modulus E, which is the initial slope of the curve; the ultimate stress, which is the maximum stress reached during the test; and the ultimate strain, which is the strain corresponding to. The corrected average strain values, which depend on the applied load, were determined using the video extensometer system.

Impact Behavior of Composite

Impact behavior of composite was performed according to (ASTM D256) at room temperature. Izod and Charpy impact tests were used for testing polymeric materials.

In this test, the calculation of the impact strength and fracture toughness was depended on the calculation of the required energy for fracture. Impact strength was calculated from the following equation:

$$G_C = \frac{U_C}{A} \quad (2)$$

Where,

G_C: Impact strength of material (J/m^2).

Uc: Absorbed energy (J).

A: cross- sectional area of specimen (m^2).

Fracture toughness, which describes the ability of a material containing a crack, to resist fracture, can be expressed as:

$$K_C = \sqrt{G_C E} \quad (3)$$

Where:

Kc: Fracture toughness of material ($MPa.m^{1/2}$).

E: elastic modulus of material (MPa).

Water Absorbtion Properties of Composite

Water absorption properties of samples were determined according to BS EN ISO 62. The samples were cut to a size of 10x10 mm. Water absorption tests were conducted by immersing the composite specimens in a deionised water bath at 25 ◦C; until the samples reached near saturation. After immersion for 2 and 24 h, the specimens were taken out from the water and all surface water was removed with a clean dry cloth and the specimens were weighed. The percentage of water absorption in the composites was calculated by weight difference between the samples immersed in water and the dry samples.

Density and Specific Gravity of Composites

Density and specific gravity of fabrics were determinated according to ASTM D 792. Five specimens were tested for each sample. The density of the fabrics calculated as grams per square centimetre using the formulation given in the standart.

3. RESULTS AND DISCUSSION

According to FTIR spectra of K1, it can be determined weft and warp yarns of K1 fabric composed of cellulosic fiber (Figure **1**). The cross-section and surface images of fiber implies that this fiber is pure flax fiber (Figure **2**, **3**). The broad peak on the 3344 cm^{-1} and the broad but less intensive peak on the 1648

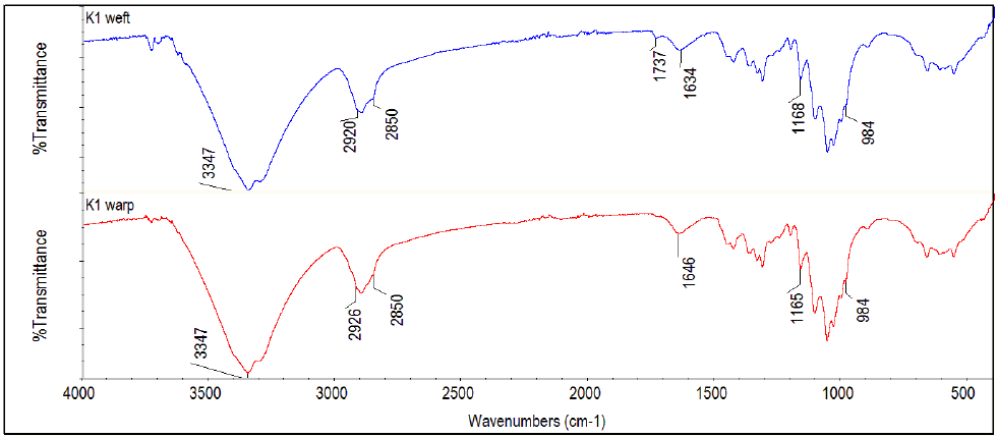

Figure 1: FTIR spectra of flax fabric (K1).

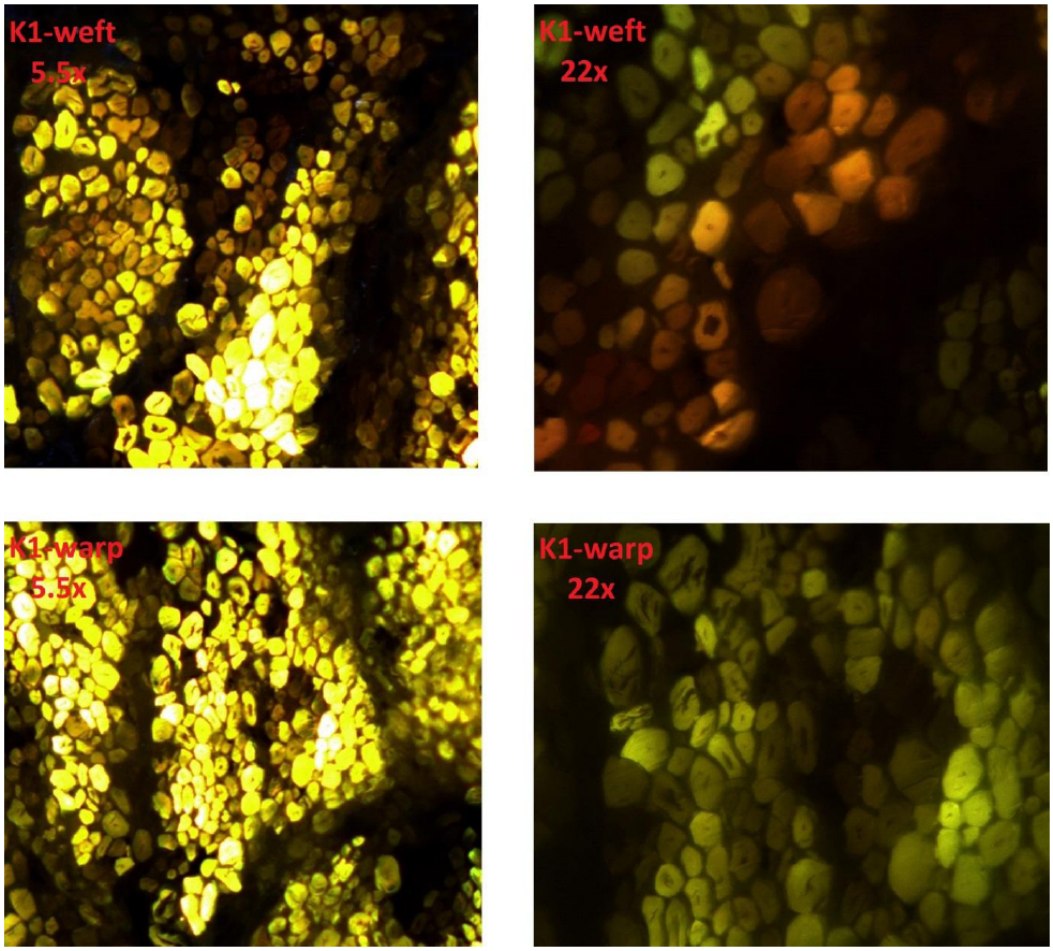

Figure 2: Cross-sections of yarns, used in flax fabric (K1).

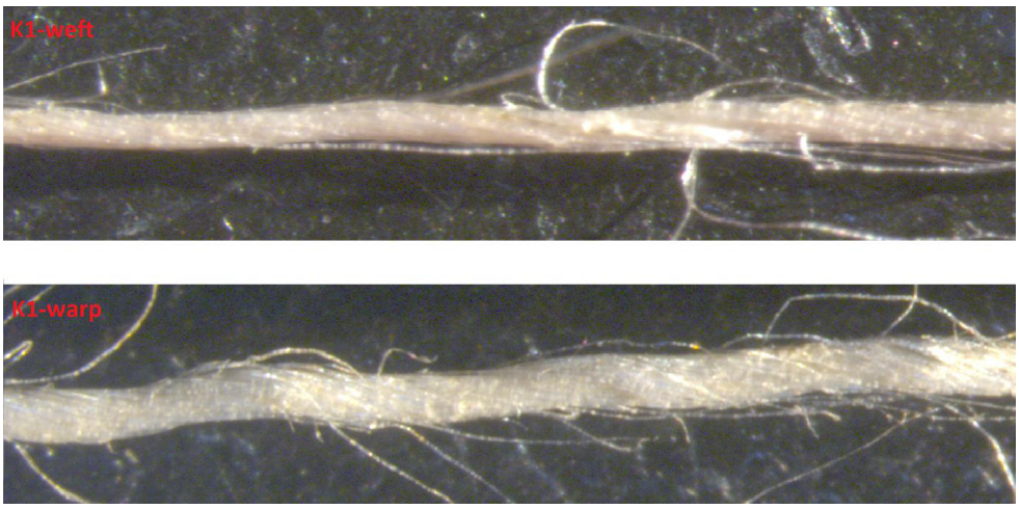

Figure 3: Surface of yarns, used in flax fabric (K1).

cm^{-1} are releated to OH chemical units of cellulosic molecule structure and water molecule. The series of peak between 2819 cm^{-1} and 2849 cm^{-1} belongs to CH_2 groups in the cellulose molecule structure. The peak series between 1662 cm^{-1} and 982 cm^{-1} are releated to cellulosic group. The spectrum of weft yarn involves a peak at the 1736 cm^{-1}, contrary to warp yarn. Thus peak are related to C=O result from damage of cellosic molecular structure in the form of ring opening. This type of damage does not affect tensile strength of the fiber.

The warp yarn spectrum of K2 looks like carbon spectrum, which include any peak (Figure **4**). Also cross section of carbon yarn supported this spectrum (Figure **5**). Weft yarn spectrum of fabric showed that thus yarn composed of cellulosic fiber. This fiber can be determined as a jute yarn from fiber cross section and surface images of the K2 weft yarn (Figure **5**, **6**). The spectrum of K2 weft yarn also include C=O peak at 1730 cm^{-1} due to damage of cellulose molecule as a ring opening.

The FTIR spectra of weft and warp yarns of K3 are similar in view of peak position and spectra shape (Figure **7**). Both spectrum include deformed cellulose molecule structure peak group between 1100 and 1012 cm^{-1}, OH group at 3343 cm^{-1}, CH2 and CH3 peak groups between 2959 cm^{-1} and 2850 cm^{-1}, C=O peak at 1722 cm^{-1}. Also, thus spectra involve peaks at 1505 cm^{-1} and 728 cm^{-1}. It can be observed easily from Figure **8** and supported with Figure **9**, the yarn composed of two different fibers, one of them was Polyethylene terephthalate (PET) filament yarn, and other one was jute yarn. The peak at 3343 cm^{-1}, the peak series between 1100 and 1012 cm^{-1}, and the peak series between 2859 cm^{-1} and 2850 cm^{-1} come from cellulose molecule structure. The peak at 1722 cm^{-1}, 1500 cm^{-1}, 1244 cm^{-1}, 728 cm^{-1} and the peak series between 2859 cm^{-1} and 2850 cm^{-1} come from

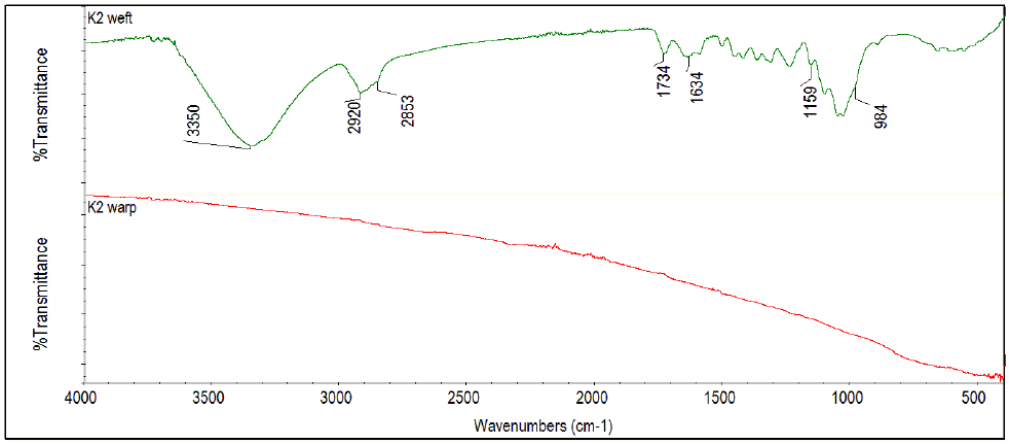

Figure 4: FTIR spectra of jut-carbon hybrid fabric (K2).

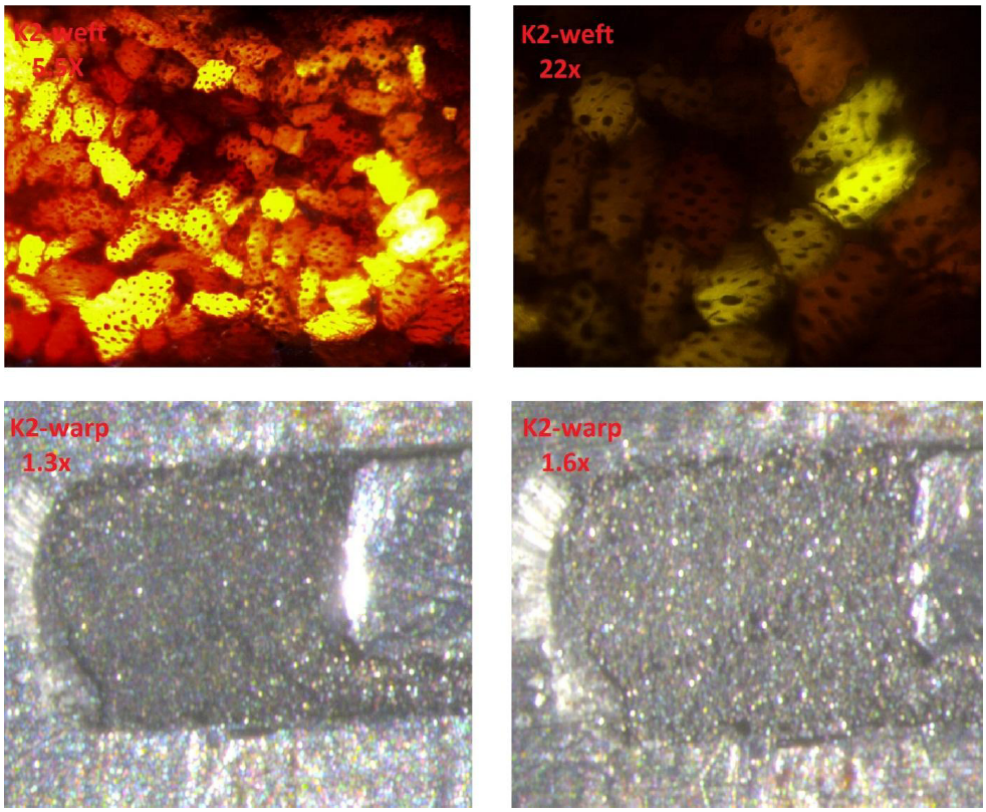

Figure 5: Cross-sections of yarns, used in jut-carbon hybrid fabric (K2).

Figure 6: Surface of yarns, used in jut-carbon hybrid fabric (K2).

PET molecule structure. The C-O bond gives series of peaks between 1100 cm^{-1} and 1012 cm^{-1} which deformed cellulose peak shape.

TGA thermogram of K1 fabric includes three thermal weight loss point (Figure **10**). The first one occured between 54 °C and 213 °C. This thermal event was releated with loss of water molecule, which was in the fiber structure. Thermal decomposition took place between 217 °C and 437 °C formed second weight loss point. The third one was releated to decomposition of carbon black under oxygen atmosphere condition. This event was occured between 567 °C and 727 °C. Decomposition of organic matter caused carbon black formation. The amount of loss of water was %3.6, the amount of loss matter which formed during decomposition was %74.8, and %15.7 matters lost

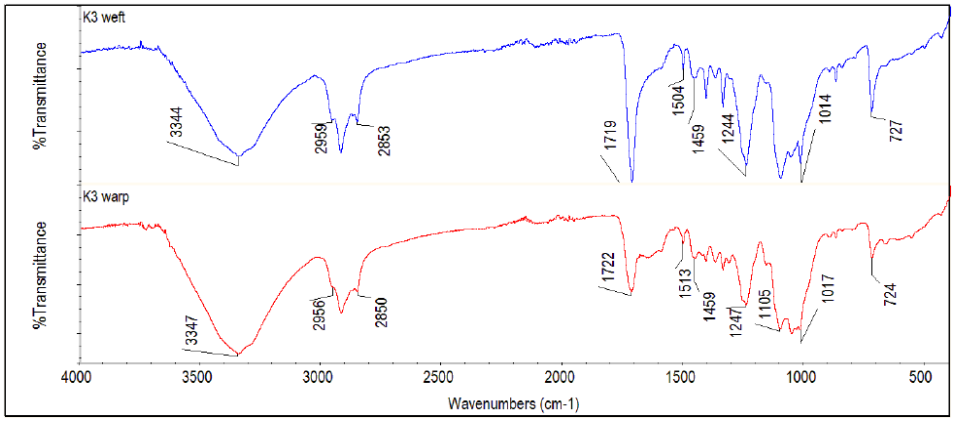

Figure 7: FTIR spectra of jute fabric (K3).

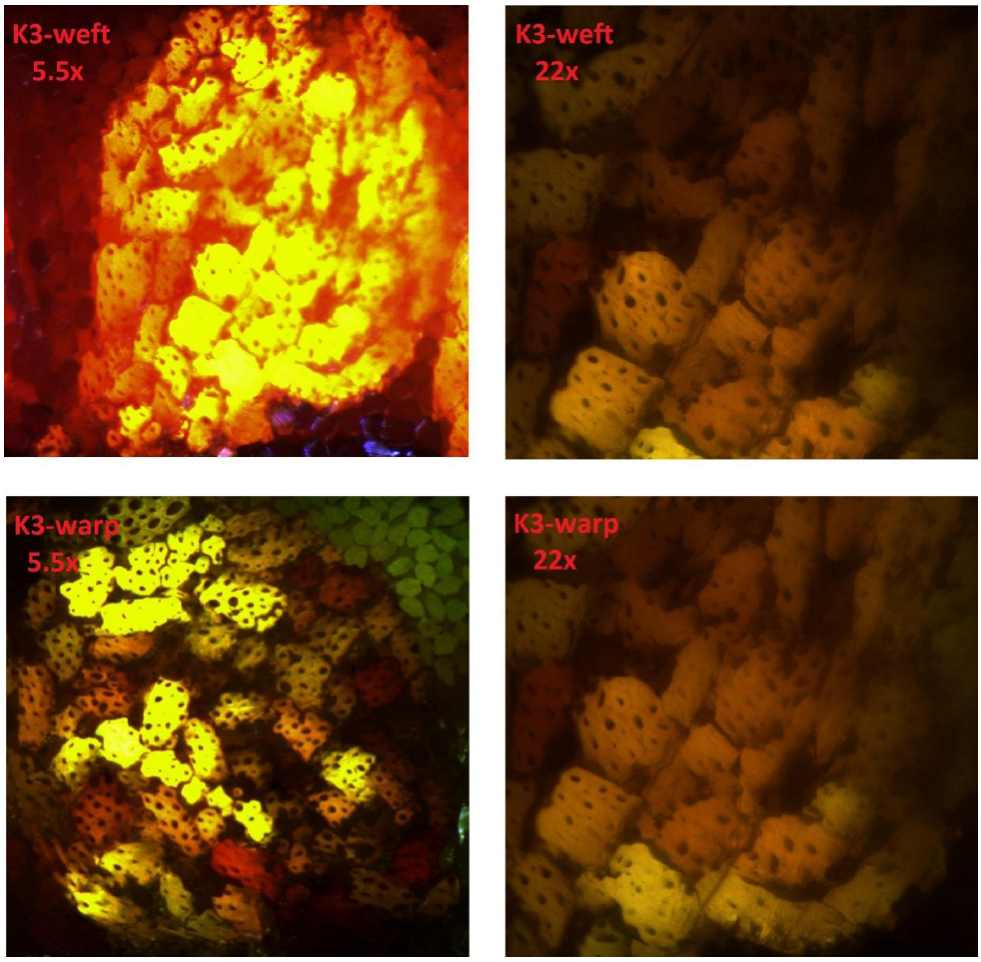

Figure 8: Cross-sections of yarns, used in jute fabric (K3).

during carbon black decomposition. The residue ratio was %6.

The TGA thermogram belongs to K2 fabric includes four thermal weight loss point (Figure **11**). The first one was occurred between 57 °C and 154 °C. This thermal event was releated to loss of water molecule, which was in the jute fiber structure. While the thermal decomposition of jute fiber started at 219 °C in second weight loss point, it continued in the third weight loss point which was also releated to thermal decomposition of carbon fiber. The last one was releated to decomposition of carbon black under oxygen athmosphere condition. This event was occurred between 563 °C and 886 °C. The amount of loss of water was %1.2, the amount of loss matter which

Figure 9: Surface of yarns, used in jute fabric (K3).

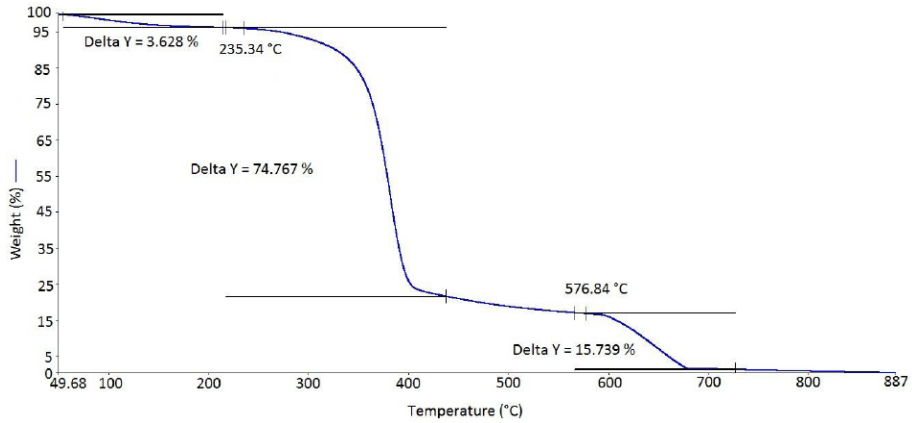

Figure 10: TGA thermogram of flax fabric (K1).

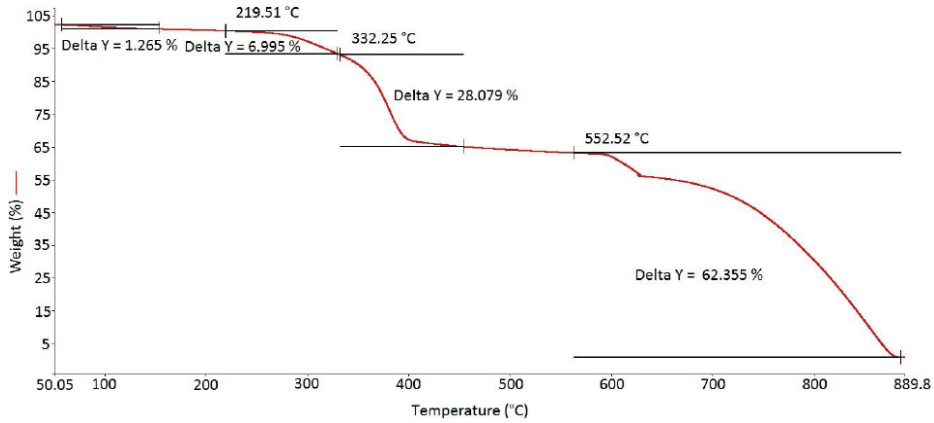

Figure 11: TGA thermogram of jut-carbon hybrid fabric (K2).

formed during decompositions were %7 and %28, and %62 matter lost during carbon black decomposition. The residue ration was %1.8.

K3 fabric gave four weight loss points on the TGA thermogram (Figure **12**). The first one was releated to loss of water molecule, which was in the jute fiber structure and occurred between 55 °C and 158 °C. The second weight loss point was releated to thermal decomposition of jute fiber. The third one was occurred between 410 °C and 528 °C and releated to thermal decomposition of PET fiber. The last one was releated to decomposition of carbon black, which was caused

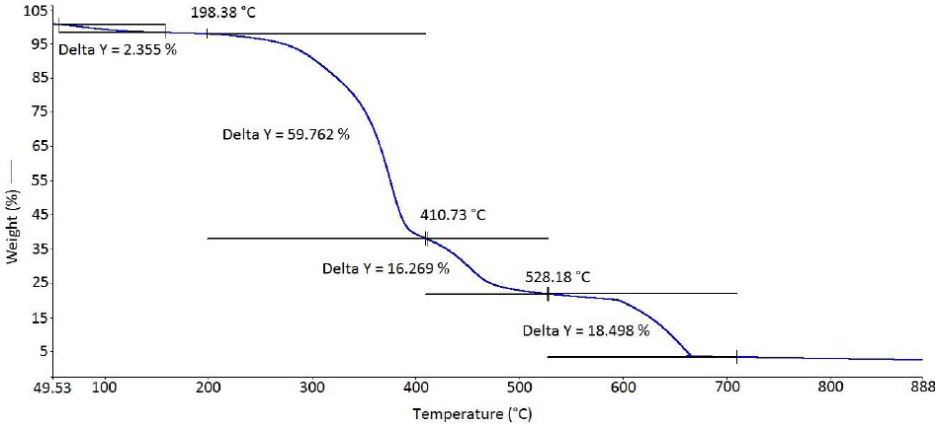

Figure 12: TGA thermogram of jute fabric (K3).

Table 4: Reinforcement Tensile Properties

Reinforcement Definition	Flax fabric	Jut-carbon Hybrid Fabric	Jute Fabric	Carbon Fabric
Reinforcement Code	**K1**	**K2**	**K3**	**K4**
Fabric tensile behavior at room condition				
Strength (MPa)				
Weft direction	11,80±0,97	12,70±1,79	11,02±0,63	19,46±2,10
Warp direction	11,64±0,70	43,24±4,43	15,60±0,53	22,36±5,09
Strain (%)				
Weft direction	4,5±0,08	4,0±0,19	7,0±0,36	1,2±0,12
Warp direction	8,6±0,35	8,9±0,32	9,5±0,23	1,5±0,41
Fabric tensile behavior at 75℃ temperature				
Strength (MPa)				
Weft direction	10,16±0,82	10,80±0,76	9,42±0,56	21,62±5,26
Warp direction	9,16±0,75	25,64±6,80	11,06±1,47	15,62±1,05
Strain (%)				
Weft direction	4,0±0,22	1,9±0,08	6,7±0,32	2,0±0,14
Warp direction	7,7±0,29	7,1±1,03	9,4±0,52	1,4±0,15
Fabric tensile behavior at 150 ℃ temperature				
Strength (MPa)				
Weft direction	7,00±1,34	5,74±0,68	7,32±0,06	17,38±3,23
Warp direction	6,64±1,30	25,16±7,90	8,38±0,74	15,90±2,99
Strain (%)				
Weft direction	4,1±0,32	2,0±0,71	6,8±0,35	1,8±0,57
Warp direction	8,3±,087	7,5±1,14	8,9±0,79	1,4±0,62
Yarn tensile strength (cN/dtex)				
Weft yarn	12,4±3,45	40,5±4,49	24,7±3,94	45,2±6,23
Warp yarn	12,8±3,44	44,2±7,48	20,4±2,43	46,0±6,84
Strain (%)				
Weft yarn	1,5±0,32	1,2±0,13	1,0±0,25	0,3±0,07
Warp yarn	1,7±0,31	0,3±0,08	0,8±0,16	0,4±0,08

from jute and PET fibers, under oxygen athmosphere condition. This event was occurred between 528 °C and 709 °C. The amount of loss of water was %2.3, the amount of loss matter which formed during decompositions were %59.7 and %16.3, and %18.5 matter lost during carbon black decomposition. The residue ration was %3.2.

Tensile strenght and strain of all reinformencent fabrics were given in the Table **4**. The tensile curves of

fabrics in both directions were given in the form of stress versus strain in the Figure **13a-d**. Tensile strength of K4 in warp direction was less than tensile strength of K2 in same direction. Although they were produced from same yarn and in same yarn density in warp direction, these differences were meaningful. As seen Figure **13.b** and Figure **13.d** in warp direction, the brekage of yarn in the fabric occurred sharply in K2 but the brekage of yarn occurred widely in K4. These situations implay that contrary to the K4 fabric in which yarns and filament in the yarns broke separately, all yarns and some of filament in the yarn broke together in K2 fabric. The reason of together breakage of all yarns in K2 was high-level friction force between carbon and jute yarns. There is also friction force between carbon-carbon yarns, but the more friction force between carbon-jute yarns result from roughly surface of jute yarn and woven structure. As the reinforcement fabric was enclosed in the resin system in the composite materials, the yarn in the fabric could not glade over each other. Because of that, the tensile strength of C4 was more than C2 in the form of composite as seen in Figure **14.b** and Figure **14.d**.

The strain ratios of warp direction in all fabrics were more than the strain ratio in the weft direction (Figure **13a**, **b**, **c**). The crimp amount on the yarn results from interlaying of the yarns in the weaving procedure cause this type of extra strain. There was no difference between strain ratio of weft and warp direction in K4, because the yarns in the K4 have no crimp.

The tensile strength of all fabrics in both directions decreased with increasing temperature, except K4. There was not meaningful change in the tensile strength of K4 according to temperature raise. Because carbon yarn does not effect from temperature change between room temperature - 150°C. Although the warp direction of K2 composed of carbon yarn, the decrease of tensile strength in the warp direction of K2 resulted from surface change of the jute yarns. The change of jute yarns surface caused decrease friction force between carbon and jute yarns, because of that some carbon yarn broke separately in the fabric as seen in Figure **14** in warp direction. It was assumed that, the decrease on the tensile strength with increasing temperature resulted from morphological chance in the fiber of the yarn. The tensile strength of cellulosic fiber is effected temperature and moisture change [25].

The tensile strength of K1 in weft direction was 13,9% and 40,7% decrease when the temperature was increased room temperature to 75 °C and 150 °C, respectively. There was much decline in warp direction

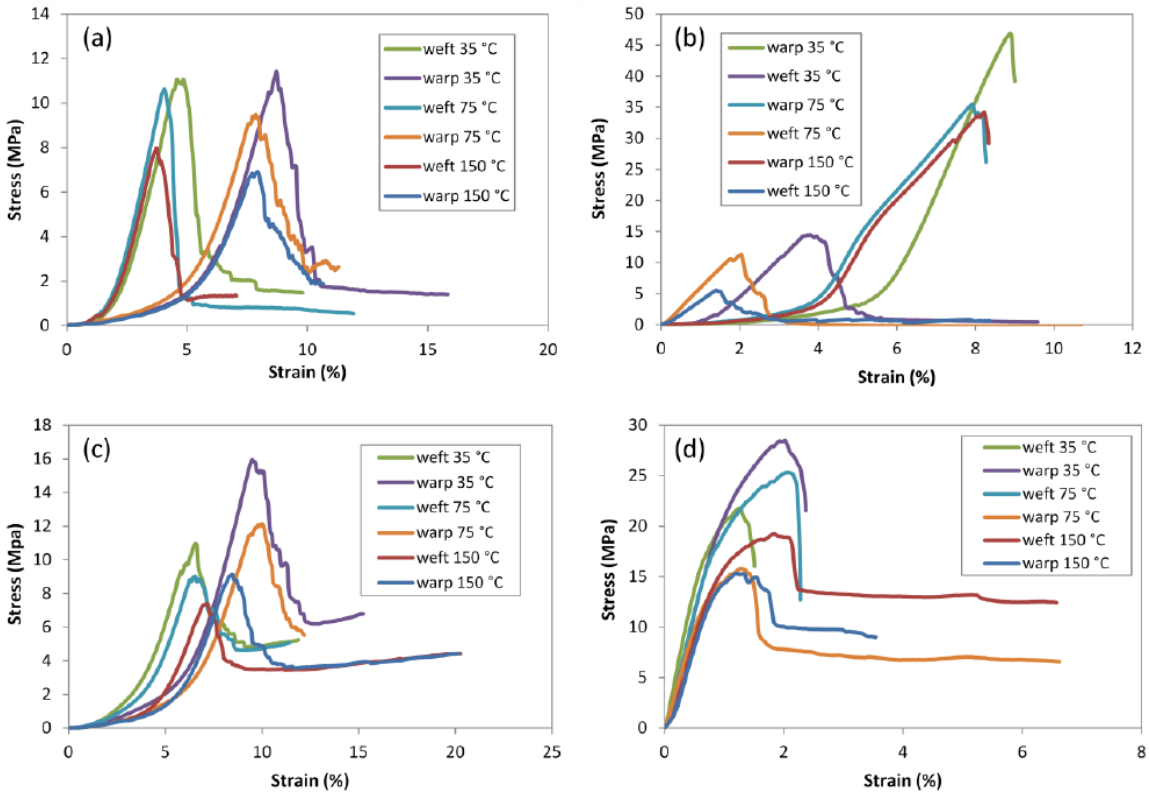

Figure 13: Stress-strain variations of different woven fabrics: (**a**) Sample K1; (**b**) Sample K2; (**c**) Sample K3; (**d**) Sample K4.

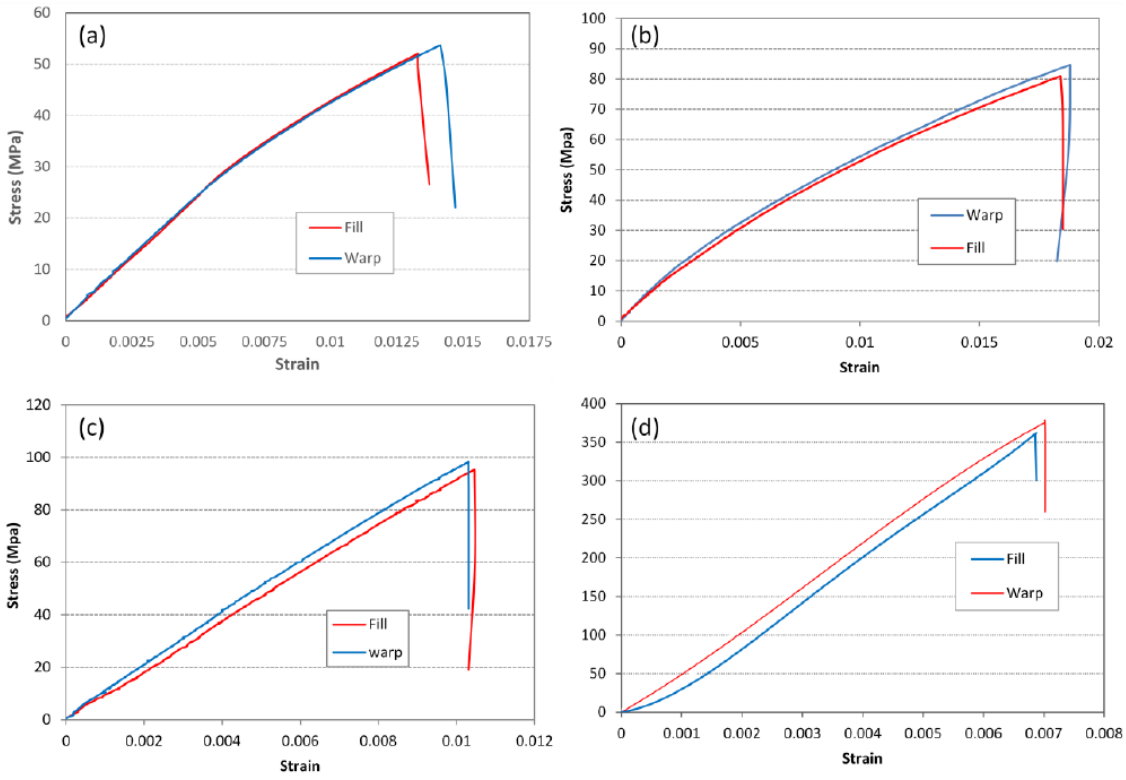

Figure 14: Stress-strain variations for different composite materials: (**a**) Sample C1; (**b**) Sample C2; (**c**) Sample C3; (**d**) Sample C4.

with temperature in warp direction. The tensile strength of K1 in warp direction was 21,3% and 75,3% decrease when the temperature was increased room temperature to 75 °C and 150 °C, respectively.

The tensile strength of K2 in weft direction was 14,96% and 54,8% decrease when the temperature was increased room temperature to 75 °C and 150 °C, respectively. The tensile strength of K2 in warp direction was 40,7% and 41,81% decrease when the temperature was increased room temperature to 75 °C and 150 °C, respectively.

The tensile strength of K3 in weft direction was 14,52% and 33,57% decrease when the temperature was increased room temperature to 75 °C and 150 °C, respectively. The tensile strength of K3 in warp direction was 29,1% and 46,28% decrease when the temperature was increased room temperature to 75 °C and 150 °C, respectively.

The tensile strength of K4 in weft direction was firstly 11,1% increase with the temperature increase room temperature to 75 °C, but when the temperature was increased to 150 °C there was 10,68% decrease in tensile strength of K4 according to room temperature value. The tensile strength of K4 in warp direction was 30,14% and 28,89% decrease when the temperature was increased room temperature to 75 °C and 150 °C, respectively.

The sequences according to tensile strength of fabrics in weft direction at room temperature were K4, K2, K1, and K3. Tensile strength of K2 was %35, K1 was %40, and K3 was %44 less than K4. The sequences according to tensile strength of fabrics in warp direction at room temperature were K2, K4, K3, and K1. Tensile strength of K2 was %95 more than K4. Tensile strength of K3 was %31, and K1 was %48 less than K4.

The tensile strentgth test result in case of under 75 °C condition was sorted decending as K4, K2, K1, and K3 for weft direction. Tensile strength of K2 was %50, K1 was %53, and K3 was %57 less than K4. The sequences according to tensile strength of fabrics in warp direction at 75 °C were K2, K4, K3, and K1. Tensile strength of K2 was %64 more than K4. Tensile strength of K3 was %29, and K1 was %41 less than K4.

The sequences according to tensile strength of fabrics in weft direction at 150 °C were K4, K3, K1, and K2. Tensile strength of K3 was %58, K1 was %60, and

K2 was %67 less than K4. The sequences according to tensile strength of fabrics in warp direction at 150 °C were K2, K4, K3, and K1. Tensile strength of K2 was %58 more than K4. Tensile strength of K3 was %48, and K1 was %58 less than K4.

The tensile strength of jute yarn of K2 was more than jute yarn of K3. Although jute yarn properties in both fabrics were same in scope of fiber properties and twist, the difference between tensile strength came from composite structure of the jute yarn in the K2 fabric. As seen in Figure **6** and Figure **9**, the yarns in K3 is composite yarn composed of jute yarn and filament PET yarn, but the jute yarn in the K2 is not composite yarn. The main reason for less strength of K3 is twist opening on the jute yarn during coupling of jute yarn with filament PET yarn. Tensile strength of flax yarn in the K1 had less tensile strength than jute and carbon yarns in K2, K3, and K4.

Tensile Strength of Composite

The results of the tensile tests were given in Table **5** and Figure **14 a**-**d** as a diagram of stress vs. strain for the warp and weft directions.

The sequences according to tensile strength of composites in weft direction were sample C4, sample C2, sample C3 and sample C1. Tensile strength of sample C2 was %74, sample C3 was %78, and sample C1 was %85 less than sample C4. The sequences according to tensile strength in warp direction were sample C4, sample C2, sample C3, and sample C1. Tensile strength of sample C2 was %73, sample C3 was %77, and sample C1 was %85 less than sample C4.

Samples have almost identical properties in warp and weft directions, so the tensile properties in both directions are quite close to each other. The strength of flax-reinforced composite was determined approximately 52-53 MPa, which was very low compared with glass or carbon reinforced composites [26, 27].

In case of flax-epoxy composite, a serious non-linearity can be seen on the stress-strain curve, after a certain strain value (Figure **14.c**). It was thought that this fact related to initiating damage on the flax yarn. Young-module of the flax-epoxy composite was 5 GPa. There was a non-linearity on stress-strain curve after 0.5% and it increased gradually. Young module was 3.1 GPa thereby approximately 35% decreasing between 0.5% and ultimate strain values.

Tensile properties of 100% carbon composite material, is stated in order to compare with, hybrid composites. Tensile strength and module of carbon composite was shown at Table **5**. Also stress-strain curve was given as a Figure **14.c**. At the beginning, a linear curve characteristic is observed. However, as the loading level increases curves become non-linear and show stiffening effect. This situation is a charasteristic result of carbon fibers and stated by many reserarchers [28-31].

Tensile strengh of carbon composites was higher 6 times of flax composites' and 3,5 times of jute composites'. Similarly, Young Module values are 10 times of flax composites' and 7 times of jute

Table 5: Properties of Composites

Parameters	C1	C2	C3	C4
Tensile Strength (MPa)				
Weft direction	53,410	95,740	80,340	372,300
Warp direction	52,340	97,820	84,740	363,100
Strain at break (%)				
Weft direction	1,400	1,030	1,840	0,67
Warp direction	1,520	1,040	1,910	0,63
Impact Energy (J)	0,727	1,101	0,289	1,723
Impact Strenght (kJ/m^2)	6,291	12,059	7,292	25,843
Water Absorption (%)				
After 2 hr immersion	0,192	0,200	0,376	0,041
After 24 hr immersion	0,499	0,686	0,775	0,050
Density (g/cm^3)	1,183	1,210	1,205	1,350

composites'. This situation shows that mechanical properties of natural fiber composites are too low as not to be compared with carbon composites.

Results about carbon-jute composites are lower than expected. Values related to carbon-jute composites were given in Table **5** and stress-strain curves can be seen at Figure **14.b**.

Young Module and tensile strengh of carbon-jute hybrid composites are higher than 100% jute composite, however, it is lower than expected. For carbon-jute hybrid composite material Young Module and tensile strengh values respectively, compared to 100% jute composite, are only increased about 35% and 15%. Young module and tensile strength values of hybrid composite are respectively 4,8 times and 2,7 times lower than 100% carbon composite material. A similar behavior for carbon-flax composites is reported by Dhakal et. al. [32]. Although, by hybridizing tensile strength and Young Module can increase to a certain level, this situation is valid for the fibers which have similar tensile strength and Young Module values. Combining a fiber which has high strength and Young Module values to another which has lower strengh and module values can not provide expected hybrid effect. This situation can be attirubuted to earlier split of weak fibers which ends their load carry ability. Consequently, it is obvious that combining fibers with high module and fibers with low module can not increase their tensile properties as expected.

For natural fiber reinforced composites one of the most used materials is jute fibers. Results of tensile test applied to jute-epoxy woven composites was given in the Table **5**, and stress-strain curves for warp and fill directions are given at the Figure **14.d**. According to these results tensile strength of jute-epoxy composites is measured about 82 MPa and Young Module is measured about 7 GPa. If these results are compared with flax composites, tensile strength of jute-epoxy composites is higher 36% and Young module is higher 20%. This situation is related to both jute fibers' higher strength and structure of yarn which is shown at Figure **9**. Surface of jute yarn is covered with continuous filament polyester and this situation supports the strength of yarn. But difference between yarn strength and fabric strength occurred at the jute-epoxy composites too. Strength of jute yarn is showed at Table **4**. When these values are compared with strength of the composite materials, a serious decrease is observed. Tensile strength, compared to yarn strength, falls to 1/3 of the first value. This situation can be explained with effect of the yarn curves on woven structure [33, 34].

Impact Properties of Composite

The impact energy sequences of composites were sample C4, sample C2, sample C1, and sample C3. The impact energy of sample C2 was %36, sample C1 was %58, and sample C3 was %83 less than sample C4. The impact strenght sequences of composites were sample C4, sample C2, sample C3, and sample C1. The impact strenght of sample C2 was %53, sample C3 was %72, and sample C1 was %76 less than sample C4.

As a result of izod charpy tests impact strength and fracture toughness values are calculated with equations 2 and 3. Results were shown at Table **5**. Impact test results are very similar to tensile test results. Flax-epoxy composites' impact strength and toughness values, are 16% and 27% lower than jute-epoxy composites'. Carbon-epoxy composites have the highest impact strengh value. Compared to 100% flax-epoxy composites, respectively its strength and fracture toughness values are 3,1 and 5,8 times higher. Also carbon-epoxy composites' impact strength and

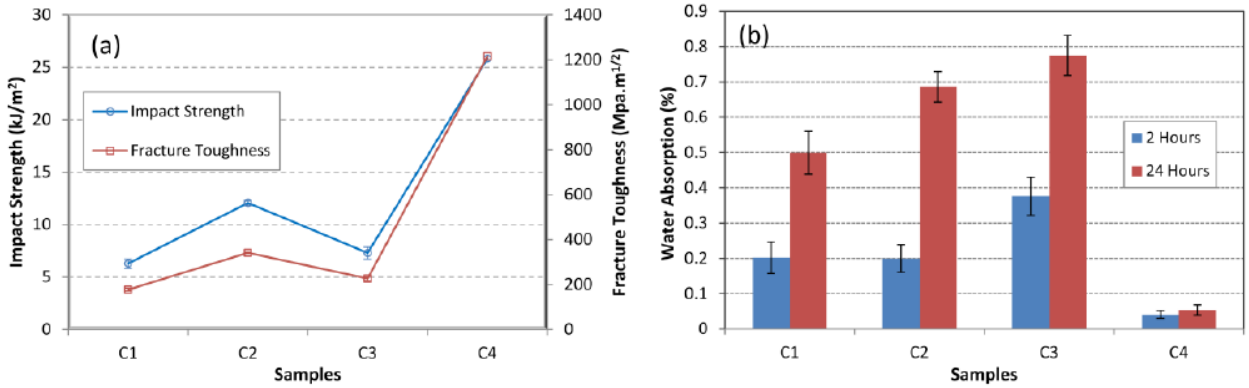

Figure 15: (**a**) Izod charpy impact and (**b**) water absorbtion properties of different composite samples.

fracture toughness values are 2,5 and 4,4 times of jute epoxy composites'. These results show that carbon-epoxy composites with high module and strength values have also sudden impact strength which is extremeley higher than natural fibers' [7].

By hybridizing, impact strength and fracture thoughness values increased a certain amount. Results prove that by hybridizing, impact properties show more increment than tensile properties. So it can be stated that jute fibers slightly increases thoughness of composite materials. Jute-carbon hybrid materials' impact strength and fracture thoughness, compared to 100% jute composite material, improved 65% and 51% respectively. However, jute-carbon hybrid composite materials' impact strength and fracture thoughness values, compared to 100% carbon composites, are lower 1,11 and 2,56 times respectively. Figure **15.a** shows the impact properties of all samples.

Water Absorbtion

The water absorbtion sequences of composites after 24 hr immersion were sample C4, sample C3, sample C2, and sample C1. Water absorption of sample C3 was %46, sample C2 was %52, and sample C1 was %65 less than sample C4.

Due to the extreme hydrophilic character of natural cellulosic fibers, their water absorbtion properties effect on mechanical properties is a common research topic. While the water absorbtion generally improves the mechanical properties of cellulosic fibers in yarn form, it causes a decrease when they used in composite materials. In composite form absorbed water diffuses to fiber-matrix interface and decrease the adhesion force that cause a serious decrease mechanical properties of composite material [35]. There were comprehensive studies about this situation [1, 18].

Water absorption properties of composites were given in Table **5**. Water absorption properties were evaluated according to differences between dry weight and the weight after 2 and 24 hours soaking of composite materials. Water absorption values of composite were given proportionally because of the differences in thickness of the samples and fiber volume fraction in composite samples. According to results, natural fiber reinforced composites have very high water absorption value. Water absorption value of flax reinforced composites were 0,15% and 0,27%, for 2 hour and 24 hour soaked composites, respectively. Water absorption value of jute reinforced composite was higher than flax reinforced composite. Water absorption values of jute reinforced composite was 86% and 55% more than flax reinforced composite ones for 2 and 24 hour soaking times, respectively.

Water absorption values of carbon-epoxy composites were very low. Their water absorption values were 3,9 and 8,2 times less than flax reinforced composites ones for 2 and 24 hour soaking times, respectively. Similarly, water absorbtion values of carbon-epoxy composites were 8 times and 13 times less than values of jute composites for 2 and 24 hour soaking times, respectively. There was some progress in water absorption value with hybridization. Water absorption value of hybrid composites were 88% and 12% less than jute reinforced composites for 2 and 24 hour soaking times, respectively. Water absorption value of hybrid composite was too high compared with carbon composites. Water absorption values of hybrid composites were 3,8 and 11,7 times more than carbon composites for 2 and 24 hour soaking times, respectively.

Comparative water absorption values of all composites were given in Figure **15.b**. It was known that water absorption has significantly negative effect on the mechanical properties of composite material [35]. In this case, such materials would not be suitable for applications which have direct contact with water.

4. ADDITIONAL DISCUSSION

The fibers used in this study can be sort with respect to tensile strength decline as carbon, flax, and jute (Table **2**).

Tensile strength of K4 weft and warp yarns, and K2 warp yarn composed of carbon fiber were approximately similar to each other. These yarns were called as carbon yarn. Tensile strength of K1 weft and warp yarns also similar to each other, and these yarns were called as flax yarn. K2 weft yarn was called as jute yarn. K3 weft yarn was called as PET covered jute weft yarn. K3 warp yarn was called as PET covered jute warp yarn. In terms of tensile strength, the yarns were ranked in the following order: carbon, jute, PET covered jute weft, PET covered jute warp, and flax yarns.

Although it is expected that the tensile strength of PET covered jute yarn was higher than jute yarn's tensile strength, jute yarn's tensile strength was measured higher than PET covered jute yarn. Tensile test procedure and calculation of tensile strength caused this situation. During tensile test, yarn was broken down completely in case of jute yarn, but in

case of PET covered jute yarn only jute part of the yarn was broken down. Tensile strength value was calculated via dividing yarn linear density to maximum force. Total yarn linear density of PET covered jute yarn was more than jute yarn's, but jute yarn part of PET covered jute yarn was similar to jute yarn. Taking into consideration of this condition, this difference came from calculation of tensile test strength according to standart test method. Although the fiber tensile strength of flax fiber is more than jute fiber's, the tensile strength of flax yarn was less than jute yarn's. This contraction may be result from twist on the yarn. According to the many study tensile strength of yarn increase with increasing twist amount on the yarn [36, 37].

The sequences of fabrics according to tensile strength were K2 warp > K4 warp > K4 weft > K3 warp > K2 weft > K1 weft > K1 warp > K3 weft. But the sequence of composite according to tensile strength were C4 weft > C4 warp > C2 warp > C2 weft > C3 warp >C3 weft > C1 weft > C1 warp.

Although K4 fabric (weft and warp directions) and warp direction of K2 fabric consist of carbon yarn, there was a difference in tensile strength of fabrics. Tensile strength of K2 warp direction more than both tensile strength of K4 weft and warp directions. K4 weft and warp direction tensile strength can be assumed as similar. Althought the yarn strength of flax yarn less than jute yarn, tensile strength of K3, K2 weft direction and, K1 were approximately similar to each other. The reason of this situation was more number of threads per unite length in K1 fabric. Covering of the jute yarn with filment yarn by twist decrease yarn tensile strength, but any decrease on the tensile strength occur in the fabric form. The reason of not changing on the tensile strength of the fabric in case of both situations is that, the weakest yarn determines the tensile strength of a fabric. Decrease on the yarn tensile strength arised from the tensile test procedure. Decrease on the composite tensile strength result from strain differences between jute yarn and PET yarn. The difference in strain caused that applied load directly effect the jute yarn, in state of total yarn.

While a similar sorting was assumed both in the case of being fabric and composite, the sorting was change when fabrics used as a reinforcement material in a composite. This alteration can be arised from tensile test procedure, and fabric structure.

Even though the number of threads per unite length were similar in K2 and K4 fabric, and K4 warp and weft yarn's properties were similar with K2 warp yarn's, there was difference in tensile strength consequence of weft yarn properties of K2 fabric. During tensile test procedure carbon yarn slided over the other yarn laid through other direction and flamentation took place. Carbon yarn can easily slided over carbon yarn result from less friction between yarns, because carbon yarn was flat filament yarn with lack of twist. The sliding degree was less if carbon yarn slided over staphel yarn like jute yarn result from more friction force between yarns. More sliding and flamentation causes less tensile strength measurement. Carbon yarns were embedded to resin in composite structure, because of that yarns cannot be slided and filamanted during tensile test. This situation, result in more tensile strength when carbon fabric used as a reinforcement material.

Although tensile strength of K1 was similar to K3 in the form of fabric, tensile strength of K1 reinforced composite less than K3 reinforced composite. This contraction arises from less mass per unit area result from using thinner yarn in the K1 fabric. Using thinner yarn even more number of threads per unit length decrease load carrying capacity of reinforcement.

5. CONCLUSIONS

In this study, the properties of natural fiber woven fabrics and their composites were investigated experimentally. FTIR and TGA thermogram analysis were applied to the fabrics to characterize them. The results were supported with microscopy images. The results are as follows:

Tensile strength of the natural fiber fabrics effected from the temperature changes. while the flax fiber fabric was lost about 75% of its' tensile strength, jute fiber fabric was lost about 35% of its' tensile strength on 150°C temperature. This prove that the thermal stability of natural fiber is very poor. But carbon fabric was not affected from temparature increasing as expected.

Mechanical properties of composite affected from reinforcement material type and form. It can be concluded that fabric tensile strength attribute to composite tensile strength, but there was not a direct relation between fabric tensile strength and composite tensile strength.

Tensile strength of jute-epoxy composites is higher 36% and Young module is higher 20% than flax-epoxy composites ones. Tensile strengh of carbon composites was higher 6 times of flax composites' and

3,5 times of jute composites'. Similarly, Young Module values are 10 times of flax composites' and 7 times of jute composites'. This situation shows that mechanical properties of natural fiber composites are too low as not to be compared with carbon composites.

Young Module and tensile strengh of carbon-jute hybrid composites are higher than 100% jute composite, however, it is lower than expected. For carbon-jute hybrid composite material Young Module and tensile strengh values respectively, compared to 100% jute composite, are only increased about 35% and 15%.

Flax-epoxy composites' impact strength and toughness values, are 16% and 27% lower than jute-epoxy composites'. Carbon-epoxy composites have the highest impact strengh value. Compared to 100% flax-epoxy composites, respectively its strengh and fracture toughness values are 3,1 and 5,8 times higher. Also carbon-epoxy composites' impact strengh and fracture toughness values are 2,5 and 4,4 times of jute epoxy composites'. Jute-carbon hybrid materials' impact strengh and fracture thoughness, compared to 100% jute composite material, improved 65% and 51% respectively.

Water absorption value of flax reinforced composites were 0,15% and 0,27%, for 2 hour and 24 hour soaked composites, respectively. Water absorption values of jute reinforced composite was 86% and 55% more than flax reinforced composite ones for 2 and 24 hour soaking times, respectively. There was some progress in water absorption value with hybridization. Water absorption value of hybrid composites were 88% and 12% less than jute reinforced composites for 2 and 24 hour soaking times, respectively.

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