POST-FIRE MECHANICAL PROPERTIES OF NATURAL AND SYNTHETIC FIBRE COMPOSITES

By

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ENDORSEMENT

I, Engku Afif Akramin bin Engku Muhammad Nazri hereby declare that all corrections and comments made by the supervisor and examiner have been taken consideration and rectified accordingly.

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DECLARATION

This thesis is the result of my own investigation, except where otherwise stated and has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any other degree.

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POST-FIRE MECHANICAL PROPERTIES OF NATURAL AND SYNTHETIC FIBRE COMPOSITES

ABSTRACT

Sustainability is an important aspect in engineering design. Manufacturers are looking to find more sustainable materials as an alternative to synthetic fibres in composite. Natural fibres seem to be a great alternative to replace synthetic fibres in composite materials applications. However, the mechanical properties of the composite materials after exposure to fire needs to be considered in the design process. This study fills the research gap whereby the post-fire mechanical properties of natural fibre reinforced polyester and glass fibre reinforced polyester can be compared and analysed. In this study, jute fibre reinforced polyester and glass fibre reinforced polyester are fabricated by using wet hand layup method. Then, the physical appearance of the two composites after exposing it to fire for a certain duration are investigated and lastly the mechanical properties of room temperature and post-fire composites are compared by running a tensile test. The result of the study shows that in general, when exposed to fire for a short duration only, the composite retains most of its tensile properties with slight burn on the surface. But after exposing it to fire for a longer period, the resin is completely burnt, and the fibre is exposed to fire. This further decreases the mechanical properties of the composites. From the study, it can be stated E-glass fibre has better fire performance than jute fibre polyester composite.

SIFAT MEKANIKAL PASCA KEBAKARAN KOMPOSIT GENTIAN SEMULA JADI DAN SINTETIK

ABSTRAK

Kemampanan merupakan aspek penting dalam reka bentuk kejuruteraan. Kilang pembuatan sedang mencari bahan yang lebih mampan sebagai alternatif kepada gentian sintetik dalam komposit. Gentian semula jadi berkemungkinan mampu menjadi alternatif yang bagus kepada gentian sintetik dalam aplikasi bahan komposit. Walau bagaimanapun, sifat mekanikal bahan komposit selepas pendedahan kepada api perlu dipertimbangkan dalam proses reka bentuk. Kajian ini mengisi jurang penyelidikan di mana sifat mekanikal pasca kebakaran komposit poliester bergentian semula jadi dan sintetik boleh dibandingkan dan dianalisis. Dalam kajian ini, komposit poliester bergentian kaca dan komposit poliester berserat jute dihasilkan dengan menggunakan kaedah lapisan tangan atau basah. Kemudian, penampilan fizikal kedua-dua komposit selepas didedahkan kepada api untuk tempoh tertentu dikaji dan akhir sekali, sifat mekanikal komposit pada suhu bilik dan pasca kebakaran dibandingkan dengan menjalankan ujian tegangan. Hasil kajian menunjukkan bahawa secara umum, apabila didedahkan kepada api untuk tempoh yang singkat sahaja, bahan komposit mengekalkan kebanyakan sifat tegangannya dengan sedikit kesan terbakar pada permukaannya. Selepas mendedahkannya kepada api untuk tempoh yang lebih lama, resin pada bahan komposit mula terbakar dan gentian dalam komposit akan terdedah kepada api. Ini seterusnya akan mengurangkan tegasan tegangan dan modulus tegangan. Kajian ini menyatakan komposit poliester bergentian kaca mempunyai prestasi api yang lebih baik dari komposit poliester berserat jut.

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
gsm	gram per square meter
PF	Post-fire

LIST OF SYMBOLS

%	Percentage
V_f	Fibre volume fraction
V_m	Matrix volume fraction
V_v	Void volume fraction
V_p	Filler volume fraction
W_f	Fibre weight fraction
W_m	Matrix weight fraction
W_p	Filler weight fraction
µm	micrometer
mm	millimeter
cm	centimeter
g	gram
σ	Tensile stress
F_{axial}	Axial tensile load
$A_{cross\text{-}sectional}$	Cross-sectional area
ϵ	Strain

δ	Elongation
L_g	Gauge length
E	Tensile modulus
$\Delta\sigma$	Change of tensile stress
$\Delta\epsilon$	Change of strain
°C	Degree Celcius
s	Second
MPa	Megapascal
GPa	Gigapascal
CaO	Calcium oxide
$CaCO_3$	Calcium carbonate
CO_2	Carbon dioxide
(g)	Gas state
(s)	Solid state

CHAPTER 1

INTRODUCTION

This chapter is divided into three parts. First part discusses the general overview and basic concept of this research. The second and third part of this chapter are describing the problem statement and objectives of this study, respectively.

1.1 General Overview

Composite material is a combination of two or more distinct materials with different properties to form a material that is engineered according to needs such as enhanced strength, lighter or resistance to electricity. Composite materials consist of two components, matrix and fibre. Some examples of phases of reinforcement are fibre, sheets, or particles. Meanwhile, metals, ceramics, non-metal, and polymer are examples of material that can be used as a matrix depending on the end use of the composite (Mathur & Bairwa, 2017).

A lot of traditional materials are replaced with composite materials because of superior properties such as high strength and stiffness, low density, and compared to bulk materials, there are room for weight reduction in the finished part (Campbell, 2010). Another advantage of using composites is that the properties can be easily tailored according to needs. The aerospace industry specifically uses composite a lot due to the characteristics of high strength to weight ratio of composite material (Shivi Kesarwani, 2017).

In general, the fibre for the composite can be natural or synthetic. Natural fibre is used for bio-composite, while synthetic fibre is used as reinforcing material for synthetic fibre composite. Natural fibres are non-homogenous as in their properties are not the same for all because it grows naturally but synthetic fibres are homogenous and have uniform properties. Concern regarding protection of the environment has been on the rise which has brought more research about using natural fibre as alternative to synthetic fibre.

Despite composite materials having many advantages, their fire performance is still a major drawback. Fire has been known as one of the major hazards that causes significant damage to the structure. This problem is very serious especially in applications that involves operating at elevated temperatures or exposed to potential fires such as aircrafts and structure of buildings. Therefore, post-fire mechanical properties of composite materials are often being looked into to ensure the safety of the structure (W. Zhang et al., 2019).

1.2 Problem Statement

In a lot of applications such as aviation, land and marine transports, civil engineering and chemical industry, the integrity of composite materials after exposure to fire is an important aspect that needs to be considered in the design. Composite materials, when exposed to large heat flux from fire will cause thermal decomposition on the resin of the composite. This reaction yields volatile gases, char, and soot particles. In general, the post-fire mechanical properties of reinforced polymer composites reduces due to formation of char (Mouritz & Mathys, 2000).

Sustainability is an important aspect in engineering design. Manufacturers are looking to find more sustainable materials as an alternative to synthetic fibre in composites. Natural fibres have a lot of advantages in terms of availability, abundancy, production cost and their effect on the environment. Therefore, natural fibre seems to be a great alternative to replace synthetic fibres in composite materials applications. However, the mechanical properties of the composite materials after exposure to fire needs to be considered in the design process. This study could lead to further development of natural fibre in future applications for better impact on the environment.

1.3 Objectives

Objectives that are to be achieved in this project, include:

1. To fabricate two types of reinforced polyester composites which are natural fibre (jute) and synthetic fibre (E-glass).
2. To perform investigation on the physical appearance of the burnt jute fibre and glass fibre reinforced polyester composite after exposed to fire for multiple durations.
3. To compare the room temperature and post-fire tensile properties of jute fibre and glass fibre reinforced polyester composites.

1.4 Thesis Outline

This thesis is subdivided into five chapters and structured as stated below:

Chapter 1 gives an overall outline of the study done for this project. It addresses the current problem in composite manufacturing industry to find a more sustainable material as alternative to synthetic fibre. A concise introduction to composite materials, its application and the objectives of the project are also provided in this chapter.

The related literature is reviewed in Chapter 2, to present previous studies regarding post-fire mechanical properties of composite materials. The review also covers the required theory for the research and published literature of comparison between natural and synthetic fibre.

Next, Chapter 3 discusses the implemented methodology and technique involved throughout the research. It covers from the manufacturing process of the specimens to the post-fire experiment and the mechanical testing. The method used and testing process were based on ASTM standards and made sure to fulfil the project objectives.

Chapter 4 is where the results are presented with discussion based on the findings from the tests. The results between jute fibre polyester composite and glass fibre polyester composite are compared. The correlation between various manipulated variables is studied based on the results.

Finally, Chapter 5 summarizes the research findings, and a conclusion is to be drawn based on the parameter correlation in the experiments. It also provides some recommendations on ways to improve future research regarding the topic.

CHAPTER 2

LITERATURE REVIEW

In this chapter, the concepts and literature related to this research are discussed. The focus will be on types of fibre reinforcements, method of fabrication and post-fire performances of composites.

2.1 Fibre Reinforcement

This research focuses on comparison between types of fibre reinforcements in composite. The fibre is an important component in fibre reinforced polymer (FRP) composites. A lot of research has been done to encourage the development of more environmentally friendly and sustainable composite material. Synthetic fibre composites are known to have greater tensile properties than natural fibres but natural fibres reinforced composites showed better performance and lower cost of production while having a better impact on the environment (Shahinur & Hasan, 2020). Hence, this section will be discussing on glass fibre and jute fibre.

2.1.1 Glass Fibre

Glass fibre is the most commonly used reinforcement material because of its high stiffness, strength, and stability. It is the oldest high-performance fibre that has been used since 1930 (Park & Seo, 2011). It is a versatile material in industrial and domestic applications. To name a few, it is used a lot in aerospace, automotive, oil and gas, and civil construction industries. Some other advantages of glass fibre are it can be manufactured at low cost and obtained easily.

There are various forms of glass fibres such as woven mat, chopped fibre, unidirectional fibre, and glass tissue. Woven fabric has a bidirectional arrangement. The difference between bidirectional and unidirectional fibre is bidirectional has strength in two directions while the unidirectional is only in one direction. Figure 2.1 shows both the schematic diagram and its photograph of bidirectional woven fabric.

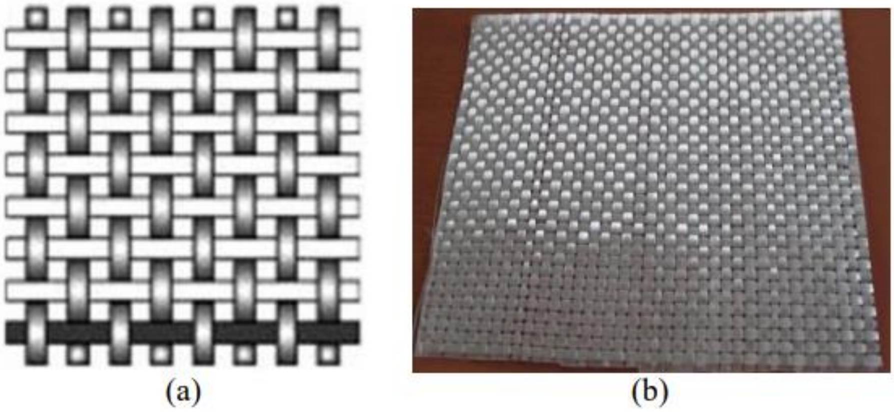

Figure 2.1: View of bidirectional woven glass fibres: (a) schematic, (b) photograph

2.1.2 Jute Fibre

Jute, the Golden Fibre of Bangladesh, is the second most important natural fibres behind cotton. Bangladesh was once the second largest producer of jute fibre but has fallen behind because of the fluctuating trend of production of jute around the world. (Hossain & Abdulla, 2015). Jute fibre has high tensile strength, low extension ability, adequate heat and fire resistance while being more environmentally friendly than synthetic fibres. It is biodegradable and its products can be easily disposed without causing potential harm to the environment. Table 2-1 shows the comparison between natural and glass fibres (Wambua et al., 2003).

Table 2-1: Comparison between natural and glass fibres

	Natural fibres	Glass fibres
Density	Low	Twice that of natural fibres
Cost	Low	Low, but higher than NF
Renewability	Yes	No
Recyclability	Yes	No
Energy consumption	Low	High
Distribution	Wide	wide
CO_2 neutral	Yes	No
Abrasion to machines	No	Yes
Health risk when inhaled	No	Yes
Disposal	Biodegradable	Not biodegradable

Jute fibre are mainly used in the textile industry but has made its way into the automotive industry as well. Many companies in the USA started using them to make different parts for both interior and exterior of vehicles (Ashraf et al., 2019). Their lightweight properties definitely help reduce weight of the car and improve mileage. Jute fibre are also used in the packaging industries, cosmetics, and medical sector for various applications. Table 2-2 shows the mechanical properties of jute fibre compared to other natural fibre.

Table 2-2: Mechanical properties of jute fibre compared to other natural fibres (Thyavihalli Girijappa et al., 2019).

Fibre	**Density (g/cm^3)**	**Tensile strength (MPa)**	**Young's modulus (GPa)**	**Elongation at break (%)**
Jute	1.23	325-770	37.5-55	2.5
Flax	1.38	700-1000	60-70	2.3
Hemp	1.35	530-1100	45	3
Ramie	1.44	915	23	3.7
Banana	1.35	721.5-910	29	2

2.2 Polyester Matrix

Polyester is a thermoset resin that is widely used in composites. It is produced by reaction of dibasic organic acids and polyhydric alcohols. They are used a lot in manufacturing due to its advantages such as room temperature cure capability, decent mechanical properties, and transparency. Polyester is very versatile because it does not form any by-product during curing reaction, so it can be moulded, laminated, and casted.

2.3 Volume Fraction and Weight Fraction

Volume fraction is derived from fibre-to-resin weight ratio. Volume fraction plays a significant role is determining the mechanical properties of composite materials. The volume fraction of fibre and matrix in a composite can be calculated using the equation as shown in Equation 2.1 and Equation 2.2, respectively.

$$V_f = \frac{volume\ of\ fibre}{total\ volume} \tag{2.1}$$

$$V_m = \frac{volume\ of\ matrix}{total\ volume} \tag{2.2}$$

To calculate the total volume fraction, the equation is as Equation 2.3 where the volume of fibre, matrix and void content are added together.

$$V_f + V_m + V_c = 1 \tag{2.3}$$

Equation 2.4, 2.5, and 2.6 are used for calculations of weight fraction of fibre, matrix, and total weight fraction, respectively.

$$W_f = \frac{weight\ of\ fibre}{total\ weight} \tag{2.4}$$

$$W_m = \frac{weight\ of\ matrix}{total\ weight} \tag{2.5}$$

$$W_f + W_m = 1 \tag{2.6}$$

From the calculation of weight fraction and volume fraction, we can calculate the void content of the composite. The study of void content is important as it affects the mechanical property of composite designed in which when void content of the fabricated composite increases, the mechanical performance of the composite decreases (Mehdikhani et al., 2019).

2.4 Mechanical Performance

As with every mechanical part, a composite material has to be able withstand loadings. Therefore, its mechanical properties need to be one of the main considerations when designing the composite material. Examples of mechanical properties of a composite material are tensile, flexural, compression, shear, and impact. Common concepts such as stress, strain, elasticity, and deformation are involved when determining the mechanical properties of composite materials.

Definition of tensile stress is the elongation of material when a stretching force is applied axially under tension loading. To calculate tensile stress, Equation 2.7 is used where the tension load is divided by the cross-sectional area of the body. Doing tensile tests will yield information such as yield stress and tensile modulus of the composite material. For tensile test, the equations involved are as shown:

$$\sigma = \frac{F_{axial}}{A_{cross-sectional}} \tag{2.7}$$

$$\epsilon = \frac{\delta}{L_g} \tag{2.8}$$

$$E = \frac{\Delta\sigma}{\Delta\epsilon} \tag{2.9}$$

2.5 Tensile Standard

For this study, the tensile test standard that will be used for reference is ASTM D-3039 standard with the title "Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials" since the material that are involved are polymeric composite materials. This standard provides a full guidance and details needed for the tensile test such as sampling size, size of specimen, speed rate of test, and gripping to provide a standardized method and procedure of tensile testing for polymer matrix composite (ASTM, 2014).

ASTM D-3039 is used in various research as standard to design and determine the performance of the material (Irawan & Sukania, 2015; Mouritz & Mathys, 2000; Shivanand N Pujar, 2019).

2.6 Post-Fire Composite

A study was carried out by Ellis et al., (2018) on the residual tensile strength of glass fibre reinforced polymer after exposure to elevated temperatures. Two types of tests were conducted in the study. The first one addresses the residual strength of glass fibre reinforced polymer bars after exposure to high temperature. The second one focuses on bond pull-out strength of the bars in concrete after exposure to high temperature.

The specimens were heated by wrapping a heating tape around the specimen with thermocouples attached under it to record the temperatures. The result of the first type of the test shows that after the bars were exposed to 400°C heat and cooled to ambient temperature, it retained 83% of the original tensile strength. This result raises major concern on the fire performance of composite. In addition to this matter, the comparison of mechanical properties between the natural fibre and synthetic fibre is an area of study that is under-explored with only few research papers discussing on the topic such as those by Rozyanty & Firdaus, (2019) and Begum et al., (2020). Therefore, this study plays a vital role in filling that gap and developing better fire-resistant composite that will benefit the composite industry.

2.7 Significance of the Study

Although there is ample research available on behaviour of fibre reinforced polymers after being exposed to fire, there is little published information on the difference of post-fire mechanical properties between natural fibre and synthetic fibre. This study will fill that gap specifically between two of the most commonly used fibre which is jute fibre and glass fibre. The main idea of this study is to examine whether jute fibre is a potential replacement for natural fibre in fibre reinforced polymer composite.

This study is also important in the development of composite material and trying to find a more sustainable alternative that can reduce waste material which will be more beneficial to the environment.

CHAPTER 3

METHODOLOGY

This section will cover the method to fabricate jute fibre polyester composite and glass fibre polyester composite, specimen cutting and measurement, the post-fire test setup and tensile test on the specimen. All process and setup considerations are explained and justified. A detailed flowchart of this project is shown in Figure 3.1.

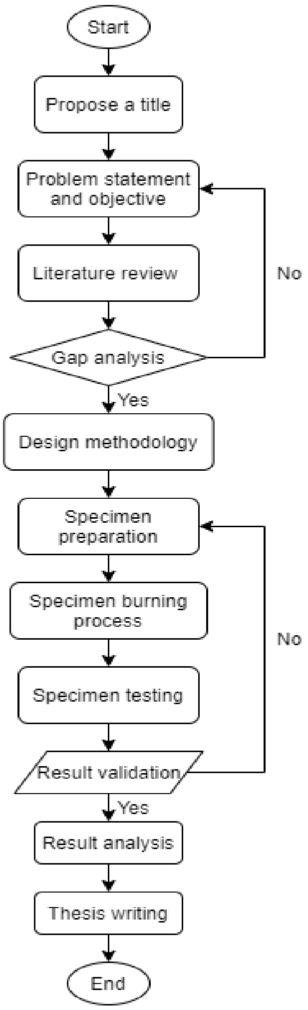

Figure 3.1: Flowchart of this project

3.1 Fabrication

The fibre fabric used to make the composite specimen are 200gsm E-glass woven mat for synthetic fibre composite and jute fabric for natural fibre composite. The target thickness of the specimen is 3.0 mm. The specimen is conditioned to be 40% fibre volume fraction. Therefore, to achieve the targeted fibre volume fraction, the thickness and volume of fibre mat are calculated and estimated. For 200gsm E-glass, 5 layers is needed to achieve the target thickness and for jute fibre, only 3 layers are needed because it is thicker compared to 200gsm E-glass. The fabric of both 200gsm E-glass and jute are cut into the size of 300×300 mm to make a panel to be cut into 9 specimens with gaps and clearance in consideration.

For the matrix, polyester resin is used. The fabrics are weighted, and the mass is used to calculate the mass of polyester resin and hardener needed for each panel. The ratio of fibre to resin for 200gsm E-glass is 100:80. For jute fibre, the ratio of fibre to resin is 100:200 because the fibre absorbs more resin than E-glass. The mass of hardener used is 4% of the mass of the resin. Figure 3.2 shows the polyester resin used in this fabrication.

Figure 3.2: Polyester resin used.

After mixing the resin and hardener, the fabrication was done using the wet hand layup technique. The resin mixture is spread around the fabric before laying up another fabric. A roller is used to ensure the resin mixture is well spread and equally distributed on each layer. Using the roller also prevent air bubbles from being trapped inside the laminate. Air bubbles are not preferred because it can cause void content in the specimen. After wet hand layup, the composite panel was left to cure completely for approximately 24 hours. Figure 3.3 and 3.4 shows the jute fibre composite panel and glass fibre composite panel respectively.

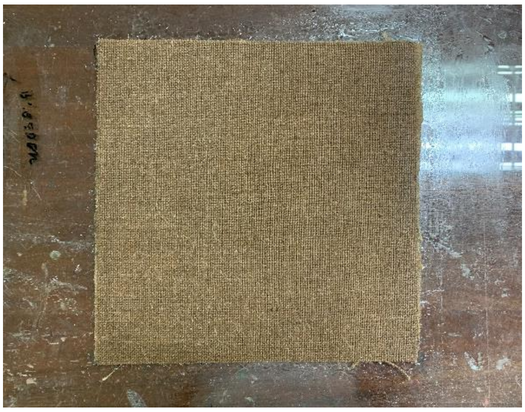

Figure 3.3: Jute fibre composite panel

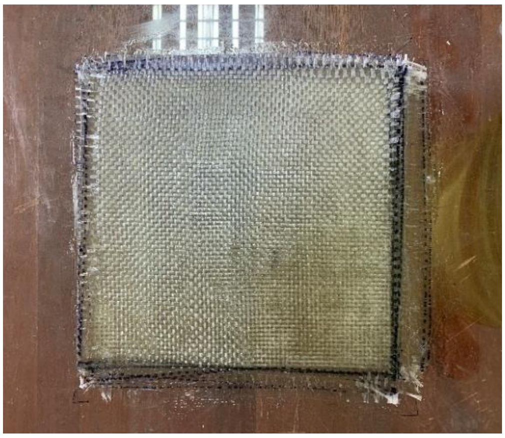

Figure 3.4: Glass fibre composite panel

3.2 Specimen Cutting

For this project, the dimensions of specimens are based on ASTM D3039 Standard Test Method. The specimen size recommended by ASTM D3039 standard is 25×250 mm. Each panel was marked the size of specimen with a 5 mm gap between each specimen to give clearance for the blade used for cutting. The panels were cut using EINHELL STR 250-1 L-3 Tile Cutting Machine as shown in Figure 3.5.

Figure 3.5: EINHELL STR 250-1 L-3 Tile Cutting Machine

After cutting process, each specimen was labelled into different group for the post-fire test. The length, thickness, width, and weight of each specimen was measured and recorded to make sure the specimens are within the designated specifications. Figure 3.6 shows the jute fibre composite specimens after they are cut and labelled.

Figure 3.6: Finished jute composite specimens with labelling

3.3 Post-Fire Experimental Setup

The setup for the burning process of the specimens is based on the setup of a previous study carried out by Suvanamporn (2019), with some adjustments to the equipment used. The previous setup is as shown in Figure 3.7.

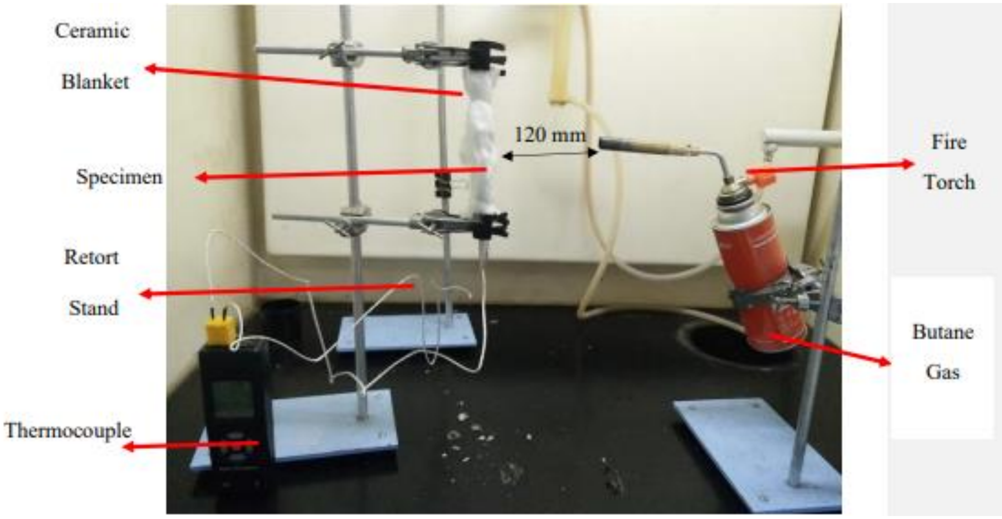

Figure 3.7: Post-fire setup in the previous study (Suvanamporn, 2019)

Each specimen was insulated before the burning process was carried out to ensure the fire is focused on the middle of the specimen and not burn the whole thing. The material used to insulate the specimen is Starlite material. Starlite is a material that can withstand extreme heat and swells when exposed to heat, also known as intumescent. The Daily Telegraph wrote an article about a demonstration conducted by Maurice Ward, the inventor of the Starlite material (George, 2009). Maurice Ward pointed blowtorches at a pair of eggs, one coated with the Starlite material and one without. The one without shattered within seconds while the coated egg was warm and had not even begun to cook. The Starlite material when heated, charred and expanded into a low-density foam of carbon which is thermally resistant. It is made by mixing corn starch and baking soda with a ratio of 10:1 and adding PVA glue until the mixture has a putty like consistency. The wrapping of Starlite on the specimen is as shown in Figure 3.8.

Figure 3.8: Starlite insulation on the specimen

The burning test was set up inside a fume chamber to prevent spreading of harmful fume produced during the burning process. The specimen and blow torch were held by two retort stands with the nozzle aligned to the centre of the specimen as shown in Figure 3.9. Only the middle front face of the specimen was exposed to heating to simulate a fire exposed scenario. The opening of the gauge of the blow torch was marked beforehand to make sure the burning rate of each specimen is approximately the same. For the burning test, the specimens are group into 5 different burning time which are 0s (room temperature), 10s, 15s, 20s, 25s. The groups labelling and their respective time of exposure to fire are as in Table 3-1. Each group has 3 specimens to obtain the average result for more accuracy.

Figure 3.9: Post-fire test setup

Table 3-1: Groups of specimens by exposure time

Group	Type of fibre	Exposure time (seconds)
1A-1C	Jute	0
2A-2C	Jute	10
3A-3C	Jute	15
4A-4C	Jute	20
5A-5C	Jute	25
6A-6C	E-glass	0
7A-7C	E-glass	10
8A-8C	E-glass	15
9A-9C	E-glass	20
10A-10C	E-glass	25

3.4 Tensile Test

After the post-fire test, tensile test was done on the specimens to study its mechanical properties after being exposed to fire. The tensile test was done using the Instron 3367 Tensile Test Machine as shown in Figure 3.10 Each specimen was attached with tabs at both ends to provide extra grip to the specimen and avoid it from slipping during the testing. All the data and result from the test are stored in a computer which the machine was connected to.

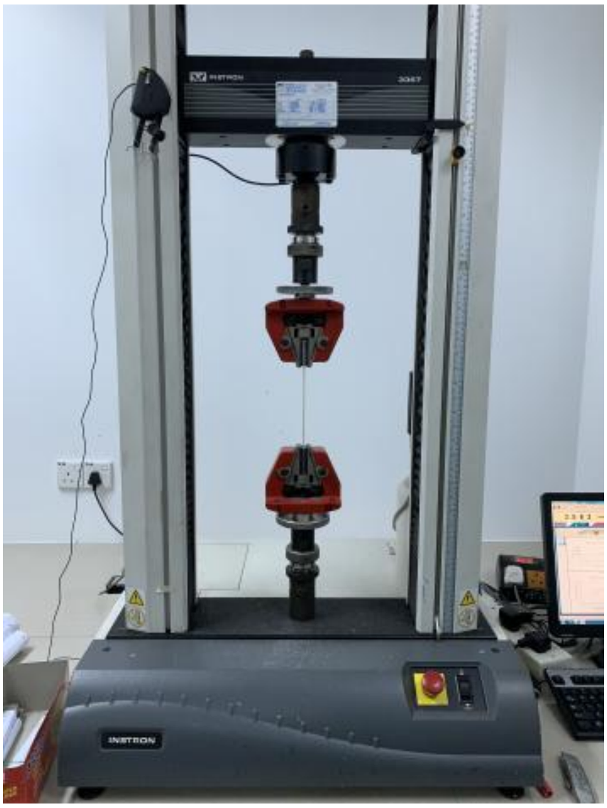

Figure 3.10: Instron 3367 Tensile Test Machine

3.5 Result Analysis

The result of load versus extension for every specimen are collected and analysed. Using the data, stress against strain graph, average yield stress, and average tensile modulus are plotted. From the data and graphs, the trend for strength and modulus relating to exposure time are observed. The performance of specimens in initial condition and post-fire condition for both glass and jute fibre composite are compared and discussed.

CHAPTER 4

RESULT AND DISCUSSION

The result of this study is performed in 2 major parts, which is the burning test and tensile test. For the burning test, the discussion is done from the aspect of burn mark appearance. Whereas for the tensile test, the results are discussed from the stress-strain diagram by specimen groups and comparison between maximum tensile stress and tensile modulus by specimen groups of different exposure time and fibre. The failure mode is also compared and discussed.

4.1 Fire Performance

To determine the difference of fire performance between jute fibre and glass fibre polyester composite, 3 specimens are burnt from each respective specimen group. After the specimen were burnt, tensile test were performed to analyse their post-fire mechanical properties. The comparison of the fire performance will be done among the specimen groups from aspects of appearances.

4.1.1 Post-Fire Appearance

Images of the specimen after conducting the burning test was taken and their physical appearances were compared. The comparison was done by their intensity and size of burn mark. The images taken for post-fire specimens are shown by groups in Figure 4.1 to Figure 4.10. Group 1 to 5 specimens are made from jute fibre and group 6 to 10 specimens are made from E-glass.

Group 1 and group 6 are room temperature specimens which means there are no burn marks and are in as received condition. This can be seen in Figure 4.1 and 4.2. For group 2 and group 7, they are burnt for 10 seconds. From Figure 4.3 which is group 2 jute fibre, there are small burn marks in the middle of the specimens. Meanwhile in Figure 4.4 which is group 7 glass fibre, there are very minimal burn marks compared to group 2.

For specimens that are burnt for 15 seconds which are group 3 and 8, they are shown in Figure 4.5 and 4.6. They appear to have bigger burn marks and some fibre exposed. In Figure 4.7 and 4.8 which are group 4 and 9 that were burnt for 20 seconds, their physical appearance seems to have more intense burn mark with a lot of the fibre exposed to air directly. It is more obvious for the glass fibre than the jute fibre.

And last for Figure 4.9 and 4.10, they are burnt the longest which is for 25 seconds. Both group of specimens shows the darkest burnt area with the jute fibre having more intense burn mark but glass fibre having bigger burn mark. For group 10 in Figure 4.10, it is obvious that the polyester is completely burnt off and the fibre is fully exposed. In summary, the longer the burning time, the bigger and darker the burn mark gets. Although there was some inconsistency with the burn marks, but the increasing trend can be seen clearly. There were some deformations in structure of some of the jute fibre composites after exposure to fire. For glass fibre composite, there are little changes in structure with only the surface layer of polyester burnt off.