University of Southern Queensland

Faculty of Health, Engineering and Sciences

The influence of NaOH and fibre length on the load transfer in sugarcane bagasse fibre/ polymer composites

Dissertation submitted by

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[redacted]

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University of Southern Queensland

Faculty of Health, Engineering and Sciences

ENG4111/ENG4112 Research Project

LIMITATIONS OF USE

CERTIFICATION

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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ABSTRACT

Sugarcane bagasse fibre has many applications in the industrial sector. However, its application is limited to non-load bearing materials. Making composite of bagasse with polymers have been tested by scientists to improve strength and quality. Fibres' physical properties like length, the diameter can have significant influence on the load transfer and load bearing capacity of the fibre as observed for other natural fibres. Although physical and mechanical properties of various composites of bagasse/ polymers have been studied, very few have been revealed about load transfer mechanism in bagasse fibre/ polymer composites. This study aims to explore the influence of fibre length on the load transfer in bagasse polyester polymer composite. Sugarcane fibres will be prepared locally. The fibres will be chemically treated with different concentrations of NaOH. The findings of the work was that addition of the fibres at optimum NaOH treatment of 6% significantly improve the tensile strength of the polyester composites. Low percent of NaOH (below 4%) is not good option since there is pull out of the fibres during the test and the fibres did not really support the matrix. Fibre length effected the strength of the composites and 15 mm fibre length found to be the critical value. Scanning Electron Microscopy observation (SEM) showed different damages in the fibres. Pull out of fibres took place at low percent of NaOH and breakage occurred in the fibres with high NaOH concentration treatment.

CHAPTER 1 INTRODUCTION TO THE PROJECT

1.2 INTRODUCTION

With the increasing demand for environment-friendly and cost-effective products, various types of natural fibre reinforced composites are emerging to replace the synthetic fibre reinforced composites. Considering low cost and suitability in climatic condition, the natural fibres locally available from renewable sources have got attention to the researchers. Because of low strength and durability of natural fibres, making composites of natural fibres with other materials are common. Recently, a wide range of research has been done on natural fibre based composites. For example, hemp, jute, cotton, flax, and bamboo fibres are used to make a composite with polymers like polyolefins, polystyrene, and epoxy resins. Some of these composites are employed in many products and applications.

Sugarcane bagasse, a commonly available natural fibre, has a high potential for using in making composite materials. Usually, sugarcane bagasse is used for cellulose, fermentation products, cane wax, paper and pulps, insulating material, particleboard, filter material, etc. However, a large quantity of bagasse is used as fuel in the sugar industries. Value-added products based on bagasse fibre polymer composites have been emerging since the 1990s. The potential application of bagasse fibre polymer composites has been tested for many products such as geotextile, automobile parts, and other industrial appliances (Lu et al. 2006). Considering the increasing production of sugarcane globally including Australia, there is an enormous potential of using the bagasse fibre for making composite materials.

The mechanical and physical properties of natural fibres are crucial for making composites. Several studies on mechanical and physical properties of sugarcane bagasse have been carried out, but little has focused on the load transfer characteristics of bagasse fibre depending on the length of the fibres. Understanding the load transfer through the bagasse fibre will open up new opportunities to produce composites for various applications. Accordingly, this study is directed to investigate the influence of fibre length on the load transfer in sugarcane bagasse fibre/ polymer composites. In particular, this study will help to understand the specific aspects of composite materials and their performance evaluation process, which is very much relevant to my field of study.

1.2 PROBLEM DEFINITION

Most of the natural fibres are proved to be effective reinforcement in the thermoset and thermoplastic matrices. Although there is greater interest to eco-friendly natural fibres, utilisation of those fibres has been restricted to the non-bearing applications because of their poor strength and stiffness than that of synthetic fibre reinforced polymer composites. The mechanical properties (stiffness and strength) of natural fibre composites can be improved through changing structural configurations and arrangement of fibres in the composite for achieving higher performance (El-Tayeb 2008). Then, the natural fibre composites can be applied to many industrial processes.

Recently, several studies have been carried out on the physical and mechanical properties of bagasse fibre based composites (EL-Tayeb 2008; Ghazali et al. 2008; Trada et al. 2012). The physical properties of bagasse fibres (e.g. diameter, length) are found to have a significant influence on the overall mechanical performance (e.g. strength) of the bagasse fibre based composites (Lu et al. 2006). However, very few information has been explored about the influence of fibre properties on the load transfer mechanism in the bagasse fibre based composites. Several studies on other natural fibre based composites, like banana, glass with polymers, revealed the influence of fibre length on stress transfer in the composites. Most of these studies determined the critical fibre length for highest performance of different composites (Thomason 2009; Sumaila, Amber & Bawa 2013). So, understanding the load transfer in bagasse fibre based composite relating to fibre length will show the level of performance that can be achieved with varying lengths of fibres. This could provide alternative application opportunities of these bagasse fibre base composites where load bearing/ strong products are required.

1.3 AIM AND OBJECTIVES

The overall aim of the study is to determine the influence of fibre length on load transfer in sugarcane bagasse fibre/polymer composites.

The specific objectives are:

- To understand the physical and biochemical properties of sugarcane bagasse fibre
- To understand the mechanical properties of bagasse fibre based composites that are essential for improving performance of the composites
- To determine the influence of fibre length on load transfer in bagasse fibre/ polymer composites

1.4 EXPECTED OUTCOME

The results of this project will contribute to the knowledge of understanding the influence of fibre length on load transfer in bagasse fibre/ polymer composite. This will show the pathway of how to increase the strength of bagasse fibre based composites, which is necessary for producing commercially viable products for large-scale industrial use.

1.5 JUSTIFICATION OF THE STUDY

As the demand for natural fibre based composite materials is increasing around the world, possible options of using largely produced fibres like sugarcane bagasse are being explored by the scientists. The output of this study will help to improve the strength and performance of bagasse fibre/ polymer composite products used in automotive and other industries. It will provide information to the industrial and commercial entrepreneurs of how the bagasse fibre/polymer composites can be used according to load transfer characteristics. On the other hand, the producers of sugarcane bagasse fibres (e.g. sugarcane mills and farmers in Australia) will be benefited if the application of bagasse fibre increases in the industrial sector. Further, increasing use of bagasse fibre will help to reduce waste generation and disposal at the sugar mills.

1.6 SCOPE OF THE STUDY

The scope of the study is described in figure 1.1 showing the stages of the work. The detail of the timeline of the work is given in table 1.1.

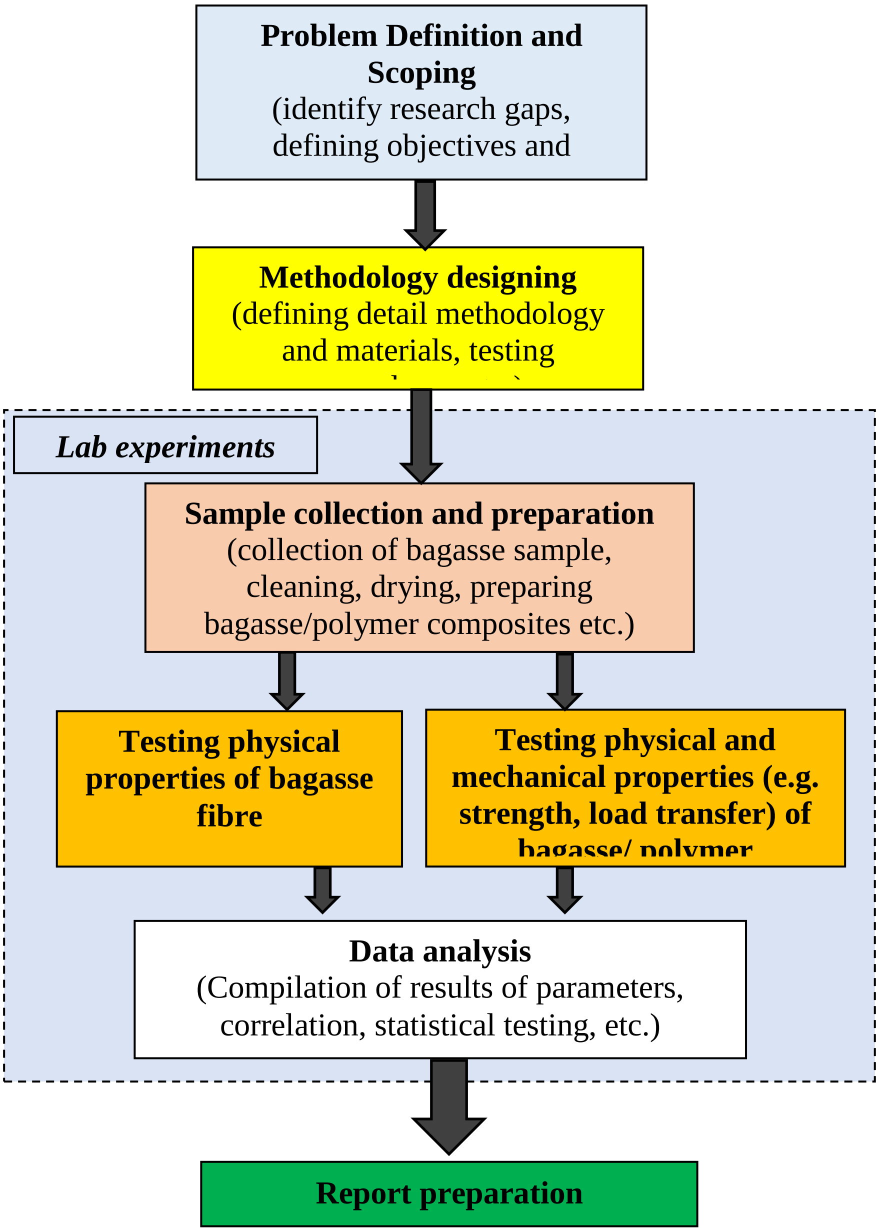

Figure 1. 1 Scope of the study.

Table 1.1: Work schedule of the research

SL. No	Major activities	Semester One																				Semester Two														
		W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28	W29	W30	W31	W32	W33	W34	W35
1	Problem Definition and Scoping																																			
2	Methodology designing																																			
3	Review and approval of research including method by supervisor																																			
4	Sample collection and preparation																																			
5	Testing physical properties of bagasse fibre																																			
6	Testing physical and mechanical properties of bagasse/ polymer composites																																			
7	Data analysis																																			
8	Draft report preparation																																			
9	Review by supervisor																																			
10	Presentation in seminar																																			
11	Final report submission																																			

Continuous   Intermittently

CHAPTER TWO: LITERATURE REVIEW

2.1 INTRODUCTION TO COMPOSITES

Composite materials can be defined as a martial with more than one ingredient. Composites can be divided into three general types as metals, polymer, and ceramics. Polymer composites are developed to substitute the expensive metals and metal composites. Polymer composites have good properties over the metal ones with regards to their strength to weight ratio, low cost of manufacturing, (Chawla, 2012). In the current years, polymeric composites have numerous industrial applications and their products are involving billions of dollars. Industrial and academic sectors are paying attention in the development of the composites and there are investments going on in different areas.

One of the most common polymeric composites is the ones based on fibre reinforcements, (Hull & Clyne, 1996). In such composites, the arrangements of the fibres and the fibre properties are the essential parameters for the composites performance, (Thomason, 2002). There are different fibres arrangements in the polymeric composites which has been introduced by Campbell (2010) as given in figure 2.1. Basically, the fibres arrangement can be divided into two classification as continuous or discontinues. Both types are commercialised and have their own industrial applications. However, the fibres are produced first and can be reproduced to form the given classifications. Therefore, the properties of the fibre itself is the key in the composites, (Rong, Zhang, Liu, Yang, & Zeng, 2001). If the fibres are able to adhered well into the matrix, they should be able to resist the deformation of the overall composites.

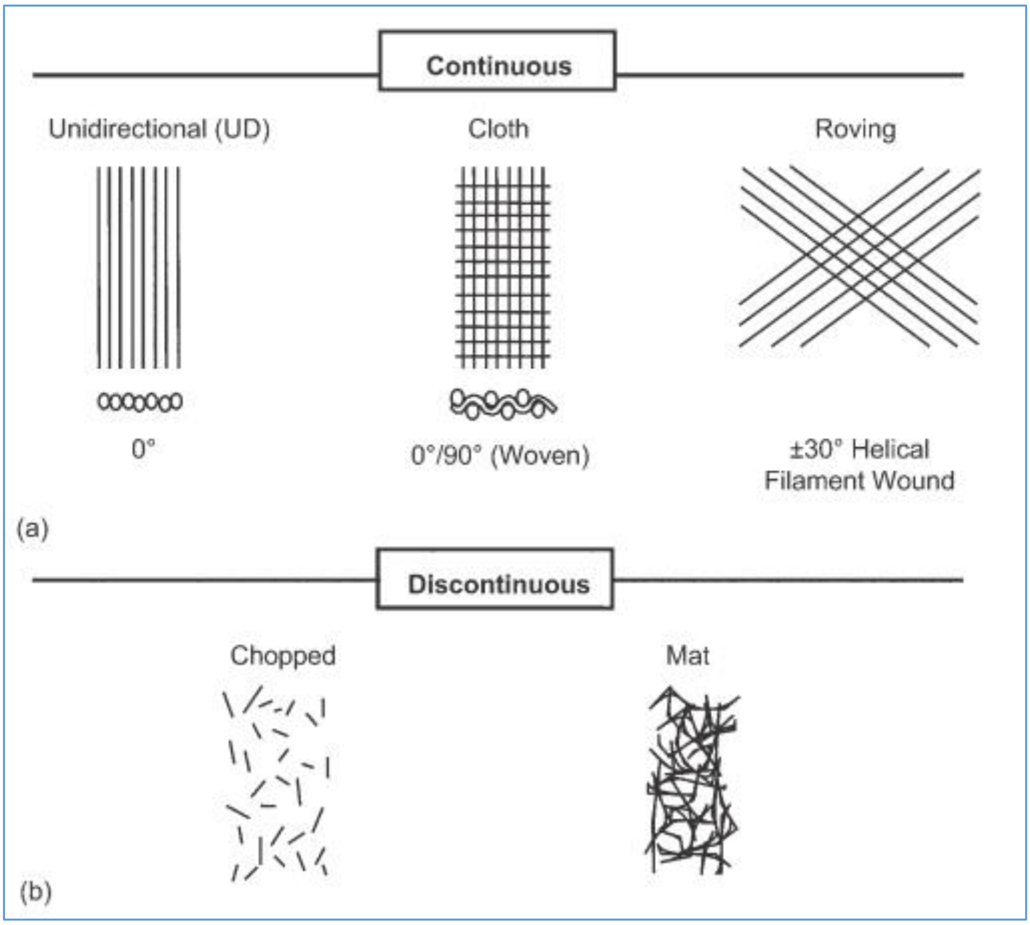

Figure 2. 1 Fibres arrangement in polymer composites according to Campbell (2010).

On the other hand, the fibre properties, such as the tensile, are an important element as well. It is known that the synthetic fibres such as glass or carbon have very high ultimate tensile strength which can reach up to 4000 MPa as reported by Steinmann and Saelhoff (2016) and represented in figure 2.2. on the other hand, some of the thermoplastic materials does not exceed 50 MPa tensile strength such as High Density Polyethylene (HDPE), which is about 23 MPa as reported by Dikobe & Luyt,(2017). Thermosets would have better tensile strength with poor ductility, e.g. epoxy tensile strength can be more than 100 MPa with 0.8% elongation, (L. Liu, Barber, Nuriel, & Wagner, 2005). Therefore, the addition of the fibres into such polymers would have remarkable improvements to the properties of the composites ensuring that the fibres have good properties.

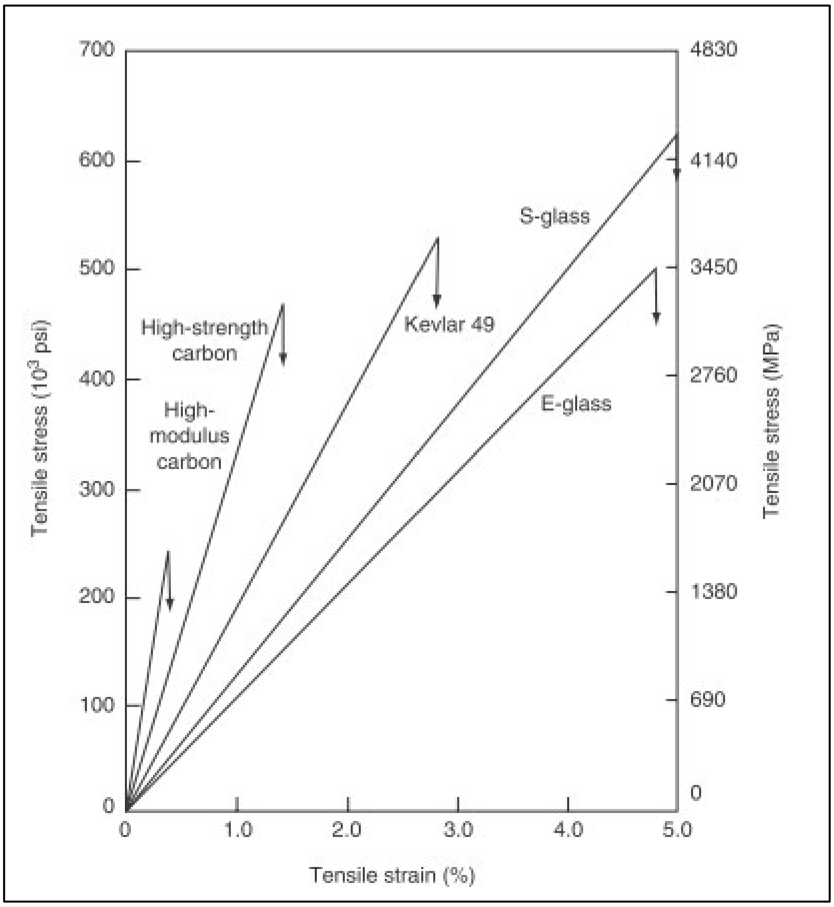

Figure 2. 2 Common synthetic fibre tensile behaviour introduced by Steinmann and Saelhoff (2016).

With regards to the manufacturing process of fibre/polymer composites, the selection of the process is controlled by the type of the polymer and the form of the fibres. Campbell (2010) classified the fibre composites according to the fibre form and manufacturing process as shown in figure 3.2.In the manufacturing process of fibre/thermoplastic, there are many two types as injection moulding or lay-up thermoforming. In both process, the polymer will be heat up and then pressed to form the composites. With regards to the fibres, there are two forms as short or continues. Moulding process accept only the short fibres since they cannot produce them in long due to the limitation of the machine and also the high friction of the fibres with the wall of the injectors, (Bright, Crowson, & Folkes, 1978). In the current study, lay-up method will be used to produce the composites since it is available at the University of Southern Queensland.

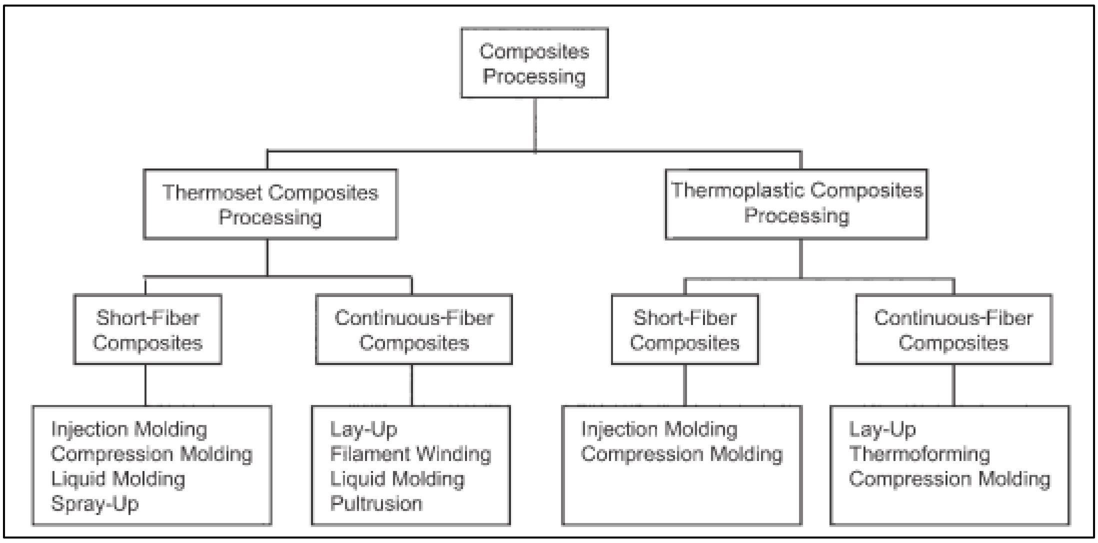

Figure 2. 3 Manufacturing process of different fibre/polymer composites, (Campbell, 2010).

2.2 NATURAL FIBRE COMPOSITES

The production of the synthetic fibres and plastic has significant impact on the environments since there is large pollution production associated with the production of such materials. According to Vuure et al. (2013), the energy required to produce glass fibres is about 30-50 MJ/Kg and this significantly increased when the fibres are formed in a mat geometry. Carbon fibres have high energy consumption in their production. On the other hand, it has been found natural fibres can be produced with less energy compared to the synthetic fibres, Table 2.1. In addition, natural fibres are biodegradable, have low weight, and high ductility compared to the syntactic fibres. These properties of natural fibres over the synthetic increases the production of the natural fibres in the work owing to be utilized by industries. Van Dam (2008) stated that (Table 2.2), the production of jute fibres can reach up to 2.5 million tonnes in India and Bangladesh alone. The availability of the natural fibres and low cost attracted the industries to use the natural fibres in polymer composites to replace the synthetic fibres for several applications such as aerospace, automotive, house goods…etc. However, there are limitations should be mentioned here about the usage of natural fibres. These limitations are; the variation in the fibre properties at each seasons and country;

consisting of large amount of wax at the surface of the fibres which required chemical treatment; and structure of the fibres are not consistencies. These disadvantages are currently the challenge for the researchers. In the following section, the issue of the interfacial adhesion of the fibre with the matrix will be addressed.

Table 2. 1 Energy required for synthetic and natural fibre production by (Vuure et al., 2013).

Some data on energy utilisation for fibre production:	
Lignocellulosic fibres:	4-15 MJ/kg
Natural Fibre Mat:	9.7 MJ/kg
Glass Fibre:	30-50 MJ/kg
Glass Fibre Mat:	55 MJ/kg
Carbon Fibre:	130 MJ/kg
Hemp can store about 0.75 kg of CO_2 per kg of fibres during growth	
Hemp releases 10 MJ/kg upon incineration (with energy recovery)	

Table 2. 2 Production of natural fibres according to (van Dam, 2008).

	Mill. tonnes	Main producer countries
Cotton	25	China, USA, India, Pakistan
Kapok	0.03	Indonesia
Jute	2.5	India, Bangladesh
Kenaf	0.45	China, India, Thailand
Flax	0.50	China, France, Belgium, Belarus, Ukraine
Hemp	0.10	China [1]
Ramie	0.15	China
Abaca	0.10	Philippines, Equador
Sisal	0.30	Brazil, China, Tanzania, Kenya
Henequen	0.03	Mexico
Coir	0.45	India, Sri Lanka

2.2.1 Interfacial adhesion of the natural fibres with the matrix

As mentioned in the previous section, natural fibres have some issues such as the poor characteristics of the fibres surface. Due to the importance of the natural fibres in composites science, there are several works have been recently conducted to improve the surface interfacial adhesion of the fibres. Some of the works, methods and findings are given in Table 2.3.

Table 2. 3 Some of the recent methods used in treating the natural fibre surfaces

Reference	Method	Findings
(George & Bressler, 2017)	sulfonic acid methodologies	Improve the surface of the fibres without any damage to the structure of the fibres. But it need to invest some money.
(Szolnoki et al., 2015)	immersion of preheated fabric into cold phosphoric acid solution aminosilane-type coupling agent, sol–gel surface coating	poorer mechanical performance
(M. Liu et al., 2017)	laccase treatment	Significant increase in the strength and stiffness of the composites
(Ridzuan et al., 2016)	5, 7, 10, 12, and 15% sodium hydroxide	5% NaOH gives maximum tensile stress
(Preet Singh, Dhawan, Singh, & Jangid, 2017)	aminopropyltriethoxysilane	Good improvement to the tensile properties of the composites
(A Shalwan & Yousif, 2014)	NAOH with different concentrations	4-6% is the optimum concertation

Most of the works done on the fibre treatments are owing to improve the surface of the fibres to results in good fibre polymer composites. Treatment of the fibres would remove all the undesirable soft materials on the surface especially the wax layers, (Alsaeed, Yousif, & Ku, 2013). For instance, the date palm fibres were treated with different NaOH concentrations of 0-9% as reported by Alsaeed et al. (2013). In that work, as can be seen in the extracted figure 2.4 the surface of the date palm fibres significantly improved by removing all the waxy layers on the surface and expose the inner bundle of the fibres. In addition, there are some holes appear on the surface of the fibres which can assist to interlock the fibre in the matrix during the manufacturing process.

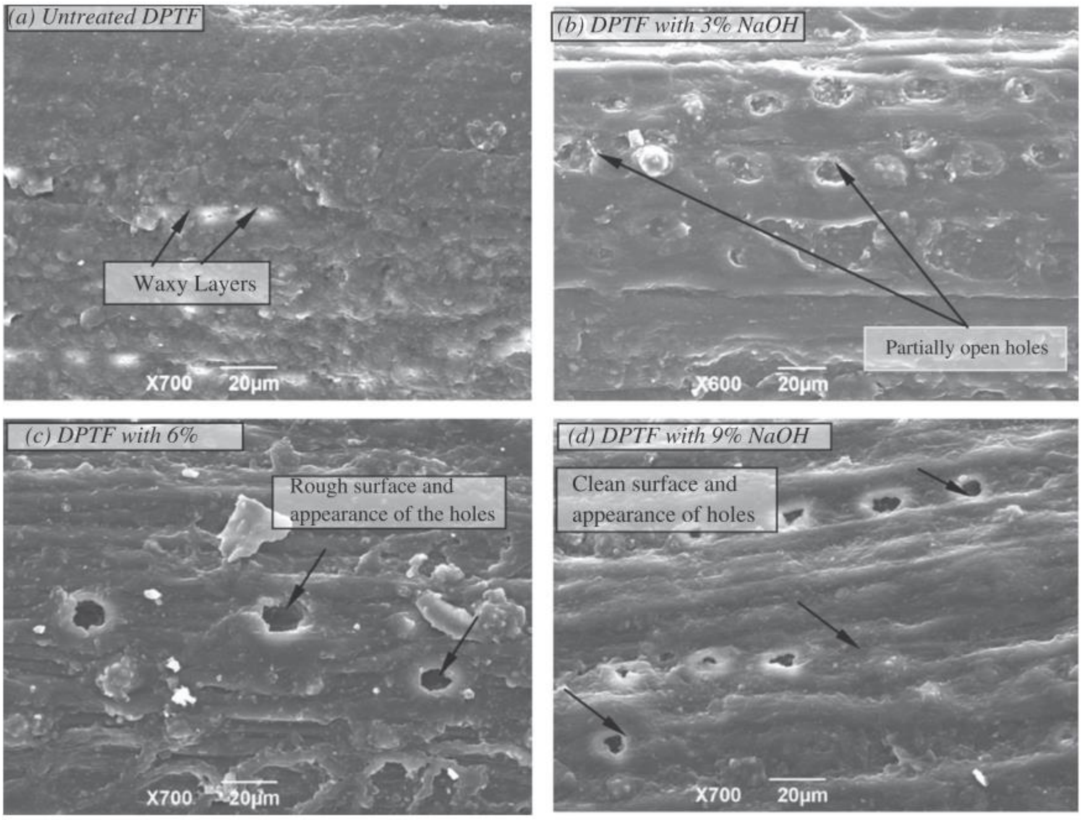

Figure 2. 4 Influence of the fibre treatment on the date palm fibre surface with different NaOH concentrations by Alsaeed et al. (2013).

2.3 SUGARCANE FIBRES

Sugarcane is a common agricultural crop grown around the world including Australia. According to Australian Sugar Milling Council (2016), 34.8 million tonnes of sugarcane was crushed in 2015. The sugar mills produce sugar and other related products from sugarcanes. The sugarcane stems have various parts such as nodes, inter-nodes, lateral buds, leaf blades and sheaths. The outer part of each stem contains rind or cortex, and the inner part contains a huge amount of storage tissues that store sucrose. Sugarcane bagasse is usually extracted as the residual material of the sugarcane stems produced in the crushing and extraction process from the sugar factory. Bagasse constitutes rind, vascular bundles, and the parenchyma (pith). The biochemical components of bagasse are cellulose (46%), hemicellulose (24.5%), lignin (19.95%), fat and waxes (3.5%), ash (2.4%), silica (2%), and other elements (1.7%). The rind part contains cellulose fibre (50%), lignin (18%) and hemicellulose (30%) (Paturau 1989; Rowell 1998; Lu et al. 2006).

2.3.1 Recent works on Sugarcane

Bagasse fibres are traditionally being used as single raw material in many industrial products such as cane wax, fermentation products, plastics, insulating board, pulps and paper, particle board, fertilizer (filter mud or cake), cellulose, sucrose and sucrose-based goods. Nevertheless, a large amount of sugarcane bagasse is used as a fuel in the sugar mills to reduce the wastes and negative environmental effects. The last few decades, value-added bagasse fibre based composite products have been developed for several industrial applications. In the 1990s, the United Stated Department of Agriculture (USDA) Forest Products Laboratory (FPL) has investigated the potential composites of wood and non-wood plant fibres like jute, hemp, bagasse with thermo-plastic fibres to make natural fibre/ polymer composites (Krzysik & Youngquist 1991; Youngquist et al. 1992). In that period, a number of studies have been published on the bagasse fibre based composites. Rowell and Keany (1991) have determined how bagasse board can be the fabricated using acetylated bagasse fibre. Collier et al. (1995, 1997) revealed the potential use of sugarcane bagasse fibre as geotextile material. A nonwoven process is developed by Chen et al. (2004) to prepare bagasse fibre / polymer composites for various applications in the automobile industry. Further, Han and Wu (2004) have examined the mechanical and physical features of sugarcane rind flakes (e.g. moisture sorption, thermal properties, tensile strength) and compared with those properties of wood flakes. The study found that the strand composites made of sugarcane rind flakes had better strength as well as dimensional stability compare to those of wood flakes based composites.

In recent years, various types of bagasse fibre based composites used. EL-Tayeb (2008) has examined the potential of using sugarcane fibre/ polyester composite as a substitute of conventional synthetic glass fibre. The characteristics of bagasse fibre/ cement composites were examined by Ghazali et al. (2008) for Malaysian sugarcane using electron beam radiation techniques. Lu et al. (2006) studied sugarcane fibre/ High Density Polyethylene (HDPE) composites and found that the HDPE resins with a low MFI exhibit high tensile and impact strengths for the composites. They also revealed that the fibres with a large aspect ratio and low sucrose content increase the strength of the composites. Moreover, examining the bagasse fibre/epoxy resin composites, Trada et al. (2012) found that the values of tensile strength and Young modulus of the composites decreased with increasing fibre content. Also, the study observed that the fractured surfaces were correlated with the tensile strengths, and suggested that, in terms of tensile properties of the composite, bagasse was not found as a suitable filler. These studies helped to develop a greater understanding of the behaviour of bagasse fibre.

Feasibility of any fibres for reinforcement purposes depends on the characteristics of the fibres and the matrices. Several studies have been carried out on characterising the bagasse fibre in different composite materials. The influence of bagasse fibre properties (e.g. type, diameter, length, morphology, biochemical composition) on the mechanical behaviour (e.g. tensile strength, impact strength) of the composite materials have been examined by several researchers. Trada et al. (2012) revealed that tensile strength and Young modulus of bagasse/epoxy composite decreases with the increase of bagasse fibre content, which suggests non-suitability of bagasse as good filler in that composite. Whereas, while examining with the polymer matrix, Lu et al. (2006) observed that sugarcane fibre/HDPE polymer composites had high tensile and impact strengths, and the fibres with a large aspect ratio and low sucrose content increased the strength of the composites. Adhesion between fibre and matrix is found to determine the mechanical properties of bagasse fibres reinforced polypropylene composites, in which fibre insertion could improve the flexural modulus and the rigidity of the composite (Luz et al. 2007). Gilfillan et al. (2012) explored that composites of soluble potato starch or hydroxypropylated maize starch with bagasse fibre have high tensile strength and Young's modulus. Reflecting on the size of the bagasse fibres, Gilfillan et al. (2014) explored that adding bagasse nanofibers to starch-based films can significantly increase the tensile strength and Young's modulus of the film. Further, tribological application of bagasse fibre/polyester composite (SCRP) and glass/polyester composite (GRP), studied by EL-Tayeb (2008), suggests that SCRP composite exhibits good performance in friction and wear properties compare to GRP composite. The study also suggests that increasing fibre length to 10 mm increases wear rate drastically. The above-discussed studies suggest the varying level of suitability of bagasse fibres in different composites depending on the fibre properties and how it behaves as combined with various matrices.

Although most of the recent researches focused on the features of the bagasse fibre and the mechanical properties of composites, how the fibre dimensions (e.g. length, diameter) impacts the strength of the bagasse fibre based composites and the load transfer in the composites are not well understood. Scientists have observed the effect of fibre length on strength and stress transfer in some other fibre based composites. For instance, Thomason (2009) has examined how the fibre characteristics affect the performance of long glass-fibre reinforced polyamide 6:6. The results showed that fibre diameter, fibre concentration, residual fibre length, hydrothermal conditioning and testing temperature have a significant influence on impact performance of the composite. Amuthakkannan et al. (2013) have studied the influence of fibre length and fibre content of basalt fibre on the mechanical characteristics of fabricated composites. They tested tensile strength, flexural strength, impact strength, and failure of composites made of short basalt and polyester resin. Another study conducted by Sumaila, Amber & Bawa (2013) investigated the physical and mechanical characteristics of banana fibre/epoxy composite and how the performance varies with the fibre length of banana. The study revealed that some properties of the composite such as the moisture absorption, void content, and the compressive strength increased with the increase of fibre length, whereas density was decreased with the increase of fibre length. The 15 mm fibre length with highest tensile strength, tensile modulus was found as critical fibre length for effective and maximum stress transfer. On the other hand, impact energy failure decreased with the increase of fibre length. However, few studies have found negligible or no impact of fibre length on the mechanical properties of composites. As for example, while studying the polystyrene reinforced with short sisal fibre and benzoylated sisal fibre, Nair, et al. (1996) have found that the properties were almost independent of fibre length. Although the ultimate tensile strength was marginally improved at 10 mm fibre length. Overall, it is commonly observed that the increase in fibre length or decrease in diameter of the natural fibres has a positive impact on the mechanical behaviour of the polymer composites.

The stress transfer mechanism in the natural fibre based composites relating to fibre length and other properties is also observed by the scientists. In the late 1980s, the theoretical process of stress transfer in single fibre reinforced composites has been explained by Termonia (1987) using finite difference approach. The study revealed that the ratio between the Young elastic moduli of fibre and matrix was one of the key determinants of the critical fibre length for efficient stress transfer to the fibre. Also, the mechanism of stress transfer from the fibre to the matrix through an imperfect surface was illustrated by Nairn et al. (1996). This study suggested that the theoretical predictions of stress transfer well agree with experimental Raman spectroscopy results, and the predictions could be used to determine the interface properties. Yu et al. (2015) has analysed stress transfer of unidirectional composites with randomly distributed fibres and found that the stress released from the broken fibre is shared by the nearest fibres and the second nearest fibres share. The stress transfer coefficient and the ineffective stress transfer length of the nearest fibres has a direct relation with the distance to the broken fibre and the stiffness ratio, whereas there is an inverse relation to the fibre volume fraction. Blassiau, Thionnet & Bunsell (2009) has developed a three-dimensional model of load transfer around fibre breaks in a composite, which showed that the initial impacts of a fibre break were local in the composite, and the stress level remained unchanged up to a distance of several fibres from the break. The impact of increasing the debonding and damage state facilitated the change from the limited effect of the break to the level that affected the entire composite. Further, Fu & Lauke (1996) developed an analytical method for predicting the tensile strength of short-fiber-reinforced polymers with respect to the impact of fibre length and fibre orientation. This model can provide the information to decide what fibre length distribution, what fibre orientation distribution and what interfacial adhesion are necessary to attain an expected composite strength. Shalwan & Yousif (2013) argued that the stress transfer efficiency between the matrix and the fibre reduces if the fibre length decreases more than the critical length of the fibre.

Similar to the studies on other natural fibre based composites, load transfer mechanism in bagasse/polymer composites can be studied which is not clearly known yet. The advanced methodologies already applied by different researchers can be followed. For example, Doherty et al. (2007) have used contemporary methods to reveal the overall mechanical properties of bagasse lignin and fibre/polymer composites such as peak stress, peak strain. Similarly, Kilian (2011) has examined the characteristics of bagasse fibre and mechanical performance of the composite material with varying content of bagasse fibre to determine the suitability of sugarcane bagasse as a fibre additive in LDPE and LLDPE polymers composites. The study was conducted in the University of Southern Queensland, which indicates that the proposed research would be suitably done in the university. The load transfer in the composite can be examined by Single Fibre Fragmentation Test (SFFT) which is applied by Awal et al. (2001). The study analysed the fragmentation pattern in two natural fibres (flax and ramie fibre) /Polypropylene (PP) composites using SFFT.

Detail understanding of the impact of fibre length on load transfer in bagasse fibre/polymer composite could reveal the possibilities of strengthening the composites based on bagasse fibre.

High Density Polyethylene (HDPE) is one of the very common commercialised thermoplastic polymer. HDPE have many applications which can be in plastic bottles to corrosion resistance big pipes. It is a petroleum product and recyclable materials. The recyclability, low cost and easy in manufacturing, low melting point of the HDPE made the material very popular among engineering applications. Some of the properties of the HDPE among another polymer is given in Table 2.4.

Table 2. 4 general properties of HDPE with other polymers represented by Klein (2012).

Resin	Temperature of use [°C]	Crystallization grade [%]	Specific weight [g/cm^3]	Tensile strength [N/mm^2]
PA 6	−40–100	20–45	1.12–1.15	38–70
HDPE	−50–90	65–80	0.95–0.97	19–39
PETP	−40–110	0–40	1.33–1.38	37–80
PP	−5–100	55–70	0.90–0.91	21–37
PPS	<230	30–60	1.35	65–85
PVDF	−30–150	−52	1.77	30–50

In the recent literature, there are few works have been reported on the HDPE. For instance HDPE reinforced with wood powder were investigated by (Dikobe & Luyt, 2017). In that work, the addition of the wood powder significantly improves the module of the HDPE and gave promising results in improving its tensile strength as well. The micrographs of the fracture surface showed some of pull out particles which is due to the poor interfacial adhesion of the particle with the HDPE matrix. This encourages the current study to consider the treatment of the fibres. In interesting work by Yang, Bai, and Wang (2016), HDPE were reinforced with waste electrical particles and the tensile strength increase when the content of the particle increased, however, the ductility reduce proportionally with the increase of the article content.

This is due to the brittleness properties of the electrical waste materials since they are mainly made of thermoset composites. Similar work have been reported by Muniyandi, Sohaili, & Hassan (2013) with non-metallic waste particles. However, the tensile strength reduced with the addition of the particles. This was due to the pull out of the particles which have not been seen in the work done by Yang et al. (2016). There is no explanation can be provided at this stage.

With regards of the usage of natural fibres as reinforcement for HDPE composites, Singh, Deepak, Aggarwal, and Gupta (2014) manged to use recycled HDPE and reinforced with different content of hemp fibres (10-30%). The results showed no much effect of the hemp fibres on the tensile behaviour of the HDPE composites. Despite the fibres were treated with 5% NaOH, pull out of the fibre is evidence at the micrographs of the composites, figure 2.5. Salleh, et.al (2014) exhibited similar poor performance of HDPE when it was reinforced with kenaf fibres and the reason was the poor interfacial adhesion of the fibre with the HDPE.

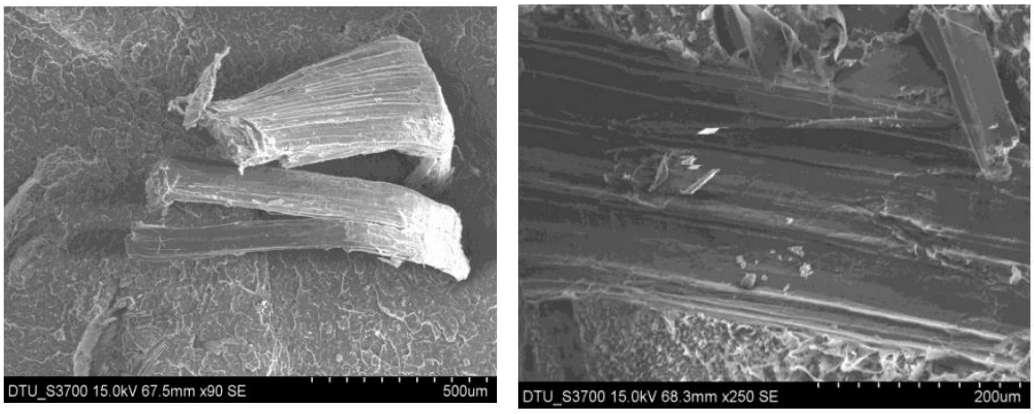

Figure 2. 5 Micrographs of the HDPE composites reinforced with hemp fibre by Deepak, Aggarwal, and Gupta (2014).

2.5 SUMMARY OF THE LITERATURE

From this chapter, there are many points can be addressed and mainly the disadvantages of natural fibres due to their poor interfacial bonding with the synthetic matrix. Moreover, HDPE is very attractive polymer which needs some improvement to its properties. The addition of natural fibres into HDPE composites could be the promising way for the HDPE.

CHAPTER THREE: METHODOLOGY

3.1 SAMPLE COLLECTION AND PREPARATION

3.1.1 Sugarcane bagasse sample collection

Sugarcane bagasse fibre material one of most common sugarcane species will be collected from a sugar mill in Queensland, Australia. About 3-5 kg of bagasse will be collected. Appropriate communication will be made with the Sugar mill authority to collect the sample.

3.1.2 Preparation of bagasse fibre

Cleaning/ washing: The raw sugarcane bagasse fibre will be cleaned by washing with water to remove the dust, sand and other materials. At first, the raw bagasse will be soaked in water for 30mins to 1 hour depending on the amount of bagasse. While soaking, all the dust materials will be settled down and the bagasse fibre will float on the top. This cleaned bagasse fibre will be transferred to another water filled pot. And wash it again to clean the dust. The same process will be followed 3-4 times to remove all the dust from bagasse. Then the wet fibre will be washed with hot water including bleaching powder to remove any fungus from the raw bagasse material. Then, finally, the cleaned bagasse fibre will be washed with cold water.

Drying: The wet clean bagasse fibre will be dried in the oven at 40-50 degree Celsius temperature to remove the moisture out of it. This process may take 10-20 hours depending on amount of fibre (Mandava 2011).

Cutting: The dried bagasse fibre will be cut into the desired length (possibly 3 specific lengths – 3 mm, 5 mm, 8 mm size, to see the effect of fibre length) using cutting devices. Large and dense fibres will be removed to maintain a homogeneous mix of the fibres.

Figure 3. 1 Sugar can fibre.

<u>Sifting:</u> The processed bagasse fibre will be sifted using a sieve to separate the fibres of desired lengths. An appropriate amount of bagasse fibre sample with different length will be collected in separate pots for testing.

3.1.3 NaOH Treatment

Figure 3.2 showing the treatment of the fibres with different NaOH concentrations. The fibres were soaked for 24 hours and then cleaned with tap water. After that the fibres were dried for the composites preparations.

Figure 3. 2 NaOH treatment of the fibre at different concentrations.

3.1.4 Polyester Resin

For this experiment, polyester resins will be used as a matrix to prepare bagasse fibre/polymer composite material. 6% of the hardness is used for chemical curing to the polyester as recommended by the manufacturer. Figure 3.3 showing the polyester when it was mixed with the hardness before the fabrication.

Figure 3. 3 Polyester mixing.

3.2 PREPARATION OF BAGASSE/ POLYMER COMPOSITES

The sugarcane bagasse fibre sample of various lengths will be mixed with polyester resins. The weight percentage of the fibre and resin will be recorded. A fixed amount of fibre and resin will be mixed. The mixing process will be done in high temperature (around 165°C) for about 10-15 minutes (Lu et al. 2006). After mixing, the blend will be removed from the mixer and cooled down to room temperature. The mixer of resin and fibre (with specific length) will be placed in stainless steel mold set and the specimen of composite with various thickness (1mm – 5 mm) will be made. These composite specimens will be used for testing properties of the composite.

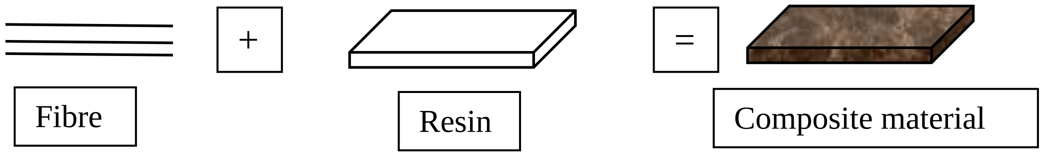

Figure 3. 4 Composite material production.

3.2.1 Composite specimen preparation for single fibre fragmentation test

Single fibre bundle of bagasse will be separated manually. Then fibre will be placed between two thin sheets of POLYESTER resin. The fibre with resin will be pressed by pressure machine at high temperature (around 185^0C) for short time (around 1 -2 minutes) (Awal et al. 2011). Then the specimen will be cooled down to room temperature (Fig. 7.3). Several specimens will be prepared with desired fibre length. Only the specimen with straight fibres will be considered for testing. Some specimen will be prepared with only resin sheets not putting any fibre so that the strength of the resin only can be tested.

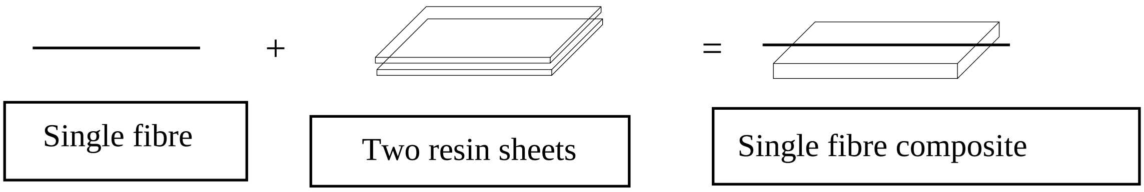

Figure 3. 5 Single fibre composite production.

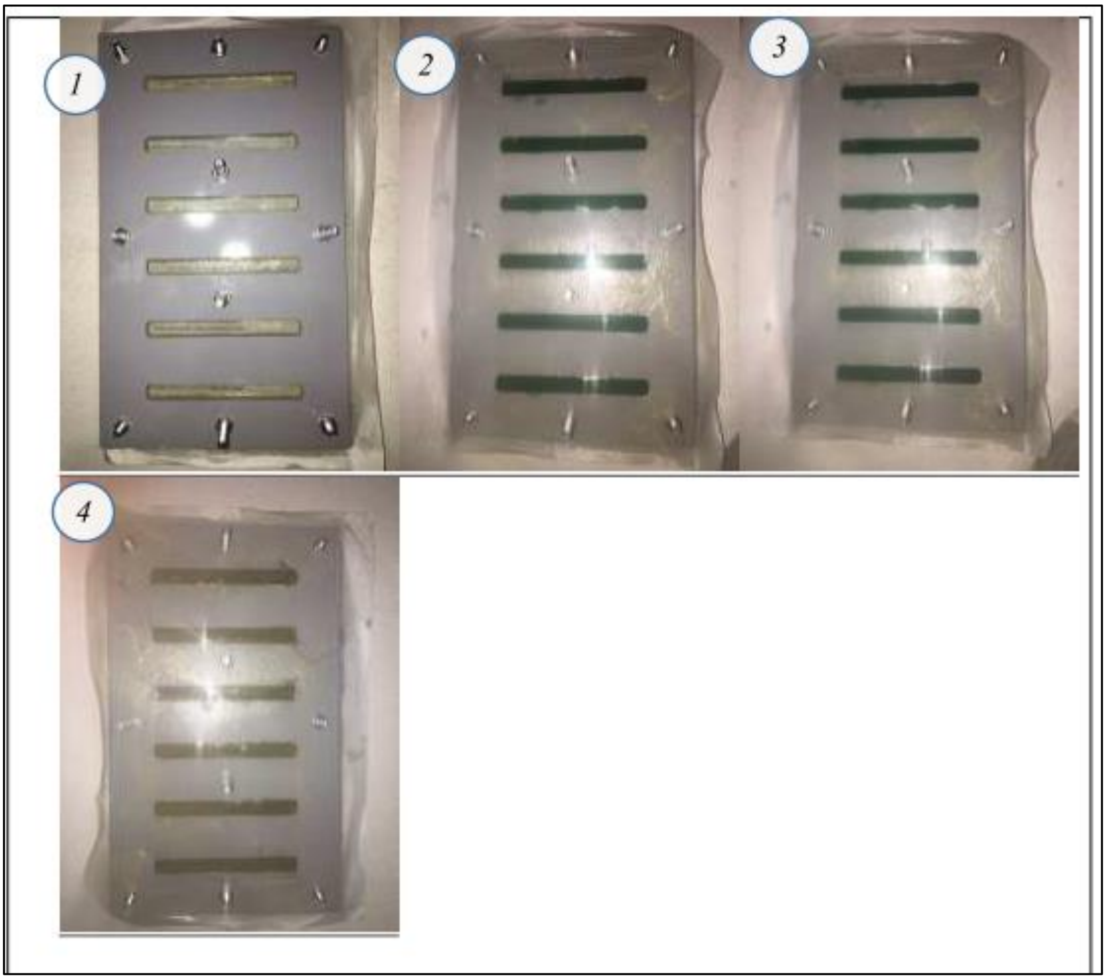

Figure 3. 6 Preparation of the samples.

3.2.2 Testing physical properties of bagasse fibre

Before making the composites, the physical dimension of bagasse fibres (such as length, diameter, weight-volume, etc.) will be measured using standard measurement procedures. Also, the biochemical composition (e.g. sugar content) will be determined from the available literature to define which fibres will be used in the experiment. The physical dimension of fibres will be important to define the type of fibre and making specific relation to the mechanical parameters.

- Testing physical and mechanical properties of bagasse/ polymer composites

General physical and mechanical properties of the composite such as tensile strength, flexural strength, impact strength will be done using Universal Testing Machine

(UTM) according to ASTM standards (Doherty et al. 2007; Kilian 2011). A brief of the mechanical tests procedures is given below.

Flexural strength test

Flexural strength of the bagasse fibre/ polyester composite will be tested suing Universal Testing Machine (UTM) following the ASTM standards. The UTM will be set with three-point testing apparatus and appropriate computer program (ISO14125 laminate flexural testing procedures). Each specimen of composite with specific width and thickness will be placed in the machine. The test will be started with the computer that will move the top cross-head downwards at a specific velocity while recording the load applied to the composite to maintain the movement. When any failure of the composite will be detected, the machine will be stopped manually. Peak load and deflection at peak will be recorded. And then flexural stress, strain at peak, flexural modulus, and flexural strength will be calculated.

Tensile strength test

Tensile strength test provides the properties of the composite material such as strength and ductility under uniaxial stress. When any load is applied to the composite material, the material may be expanded and it may be deformed when the load is removed and material return to original state. The test will be started with placing the specimen in the machine and running the computer. The hydraulic system will apply a load to the specimen at a constant crosshead movement in the direction of separation. When the failure occurs, the machine will be stopped. Then, the peak load, peak stress and change in crosshead position will be recorded. And, stress, strain, tensile strength, and Young's modulus (elastic limit) will be calculated using following formulas.

Stress (σ) = Force (F)/Area (A)

Strain (ε) = Change in length (ΔL)/ Original Length (L)

Tensile Strength= Maximum load (F)/ Original Cross sectional area (A)

Young's Modulus (E) = Stress (σ)/ Strain (ε)

Yield Strength = Yield load (F) / Original cross sectional area (A)

Load transfer test using single fibre fragmentation method

For testing the load transfer in the composite, single fibre fragmentation test will be carried out (Awal et al. 2011). Stress/ load Transfer Coefficient (STC) and ineffective load transfer length (Lc) will be determined to analyse the effect of fibre length on the composite (Blassiau, Thionnet & Bunsell 2009; Yu et al. 2015). The composite specimen with single fibre will be placed in the UTM machine and tensile testing procedure will be followed. Various tensile loads will be applied until the fibres breaking point. The fibre fragmentation will be closely observed using optical imaging polarisers at different test speed and strain rates (Awal et al. 2011). The fragmentation length will be calculated by counting the number of fibre breaks. The optical images will also be used to measure fragment length. Then, the following key parameters for load transfer evaluation will be determined (Awal et al. 2011; Yu et al. 2015).

Probability of failure ($F(\sigma)$): Probability of failure of the fibre can be calculated by

$$F(\sigma) = 1 - \exp\left[\left(-\frac{L}{L_0}\right)\left(\frac{\sigma}{\sigma_0}\right)^m\right]$$

Where, L = fibre gauge length L_0 = reference length

σ = applied stress σ_0 = constant (scale parameter)

m = Weibull modulus or shape parameter

Critical length of fibres (L_c): The critical fibre length is the shortest fragment length which is broken by application of a stress/ load. This is also called ‘ineffective load transfer length’. It can be calculated by

$$L_c = \frac{4}{3} \times \overline{L}$$

Where,

$\bar{L}$ = Average fragment length.

Interfacial shear strength (τ): Interfacial shear strength of fibres can be calculated by

$$\tau = \sigma_f \left(\frac{L}{L_c}\right)^{\frac{1}{m}} \frac{d}{2L_c}$$

Where, σ_f = tensile strength at gauge length d = fibre diameter

L = fibre gauge length L_c = critical fragment length of fibre

m = Weibull modulus

Stress/ load transfer coefficient (STC): STC reflects "the stress increasing along the nearest fibre owing to the fibre break. It is defined as the ratio of the average fibre stress in the failure section and that in the section far away from the failure location" (Yu et al. 2015).

$$STC = \frac{\overline{\sigma_N}(z = z^*)}{\overline{\sigma_N}(z = 0)}$$

Where,

$\overline{\sigma_N}(z = z^*)$ = average fibre stress in the failure plane z = z*

$\overline{\sigma_N}(z = 0)$ = average fibre stress in the plane z = 0.

3.3 DATA ANALYSIS

Scanning electron microscopy will be used to examine the morphology of the samples after the testing. All the data of the parameters will be analysed following statistical procedures and presented in graphs and tables. Correlation among the parameters will be established and necessary statistical tests will be done to verify the significance of the outputs. Also, the results will be compared with other relevant studies.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 INTRODUCTION

In this chapter, the experimental results will be presented. Basically, the experiments were conducted on the samples given in chapter 3, figure 3.6. The collected data are presented in different form to represent the fragmentation results, tensile properties and then the interfacial bonding between the fibre and the matrix. The determination of those parameters has been calculated as described in chapter 3 section 3.2.2. The following sections will address those results in detail and the last section of the chapter will cover the scanning electron microscopy observations.

4.2 FRAGMENTATION RESULTS

The fragmentation results of sugare cane fibre reinforced polyester composites are presented in figure 4.1 considering different NaOH percent chemical treatments to the fibres. The general view of the figure indicates that the values are scattered. However, the general trend suggests that there is increase in the force with the increase of the displacements. This is the nature behaviour of the materials. the scattered data could be due to the presence of the fibres in the polyester. There must be some detachments of decomposition is taking place during the tests. This has been shown in the literature as well when different natural fibres used such as flax reported by Baley, et al (2006) and sisal reported by Sreekumar et al. (2009). To give clear picture on the influence of the treatment on the fragmentation results, the maximum values of the stress (strength) and the maximum value of the strain (ductility) are extracted from this figure and represented in figure 4.2. Figure 4.2 proposes that the ductility of the composites are in increasing when the NaOH concertation increase. On the other hand, the strength of the composites increases when NaOH increase to a maximum value of 6% and then start decreasing. This can be due to the deterioration of the fibre strength with the high concertation of the NaOH since it has been reported that the high concertation of the NaOH can destroy the structure of the fibres, (Manikandan et al., 2017; Misra, Misra, Tripathy, Nayak, & Mohanty, 2002).

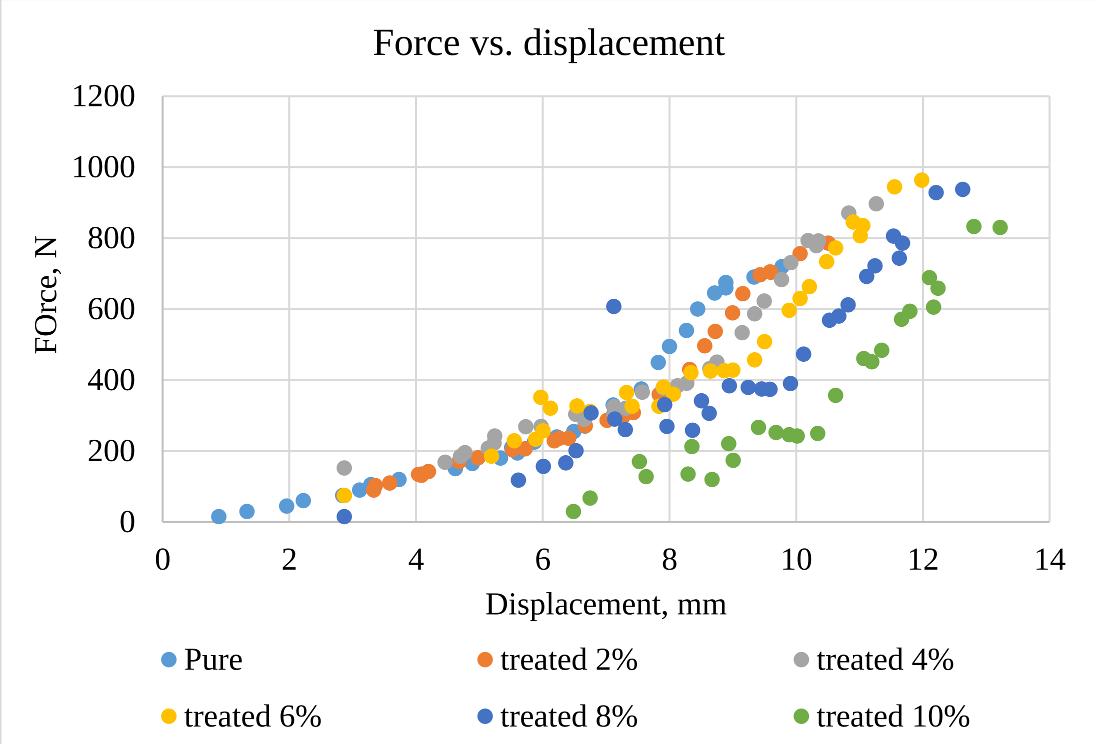

Figure 4. 1 Fragmentation results showing the force vs. displacement of different treated fibre reinforced polyester composites.

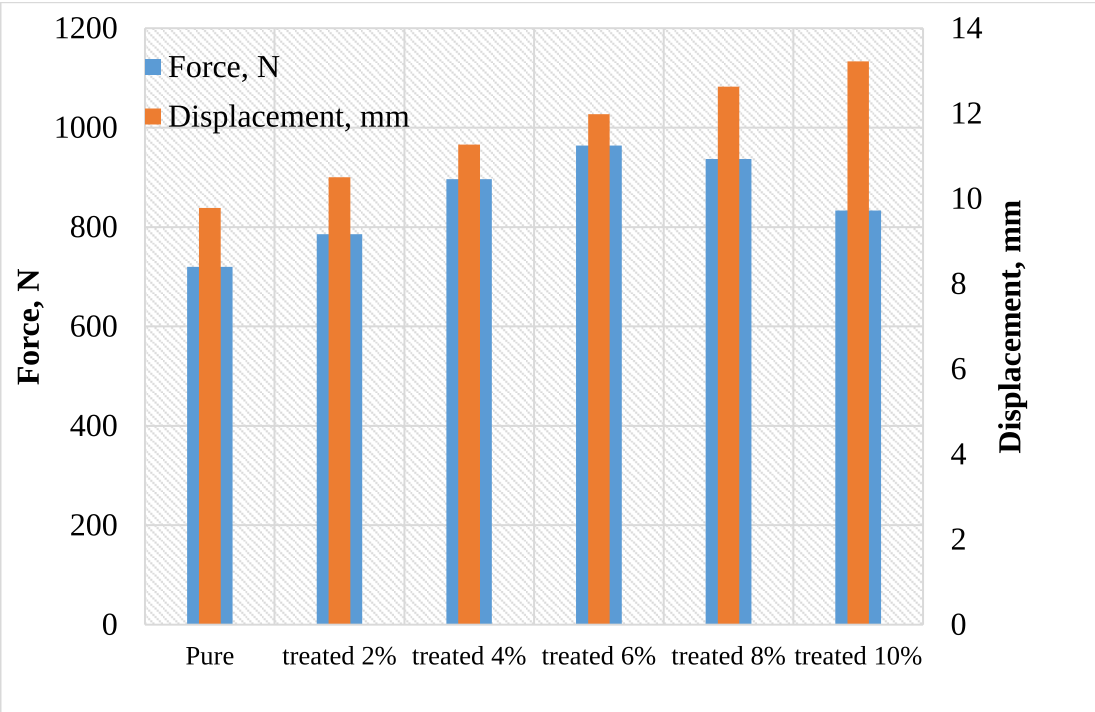

Figure 4. 2 Maximum force and displacement of fragmentation results of different treated fibre reinforced polyester composites.

4.3 TENSILE RESULTS

The stress vs. strain of the prepared polyester composites with different treated sugare cane fibres are presented in figure 4.3. The results are similar to the one presented in the previous sections, there is scattered values but the main trend showing there is elastic region with the absence of the plastic deformation. Polyester is one of the thermoset materials which has the nature of the brittle behaviour which in line with the current data. With the addition of the fibres, there is a region clear elastic which is a linear relation followed by a bit of could be plastic deformation. This indicates that the addition of the fibres improve the ductility of the composites. This is an important point since the main issue limiting the usage thermoset in the industrial is the high brittleness of the composites. He et al. (2017) addressed this issue and attempted to improve the toughness of the polyester by using Graphene oxide.

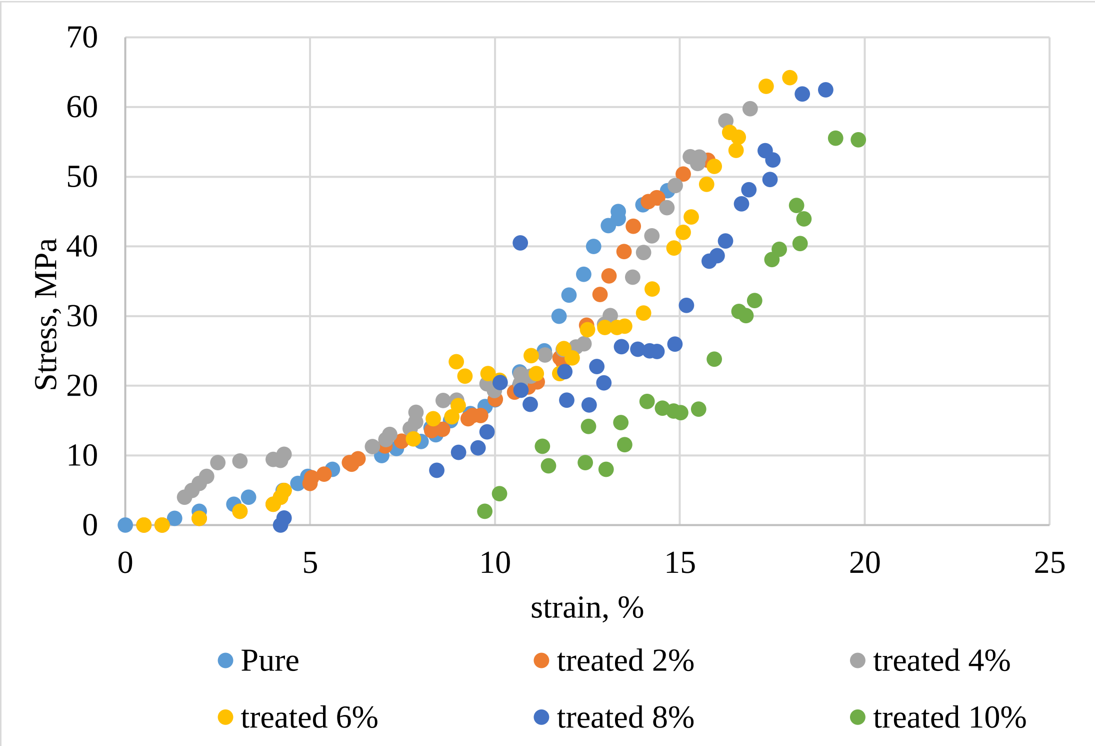

Figure 4. 3 Tensile results showing the force vs. displacement of different treated fibre reinforced polyester composites.

The improvement to the polyester achieved by He et al. (2017) is similar to the one presented in this work. This is clear when the maximum values of the stress and the strain extracted from figure 4.3 and represented in figure 4.4. the ductility increased by about 6% with the addition of the fibres. But, one should notice that there is deterioration in the strength of the composites as well with the high concertation of the NaOH. Naguib, et al (2015) reported similar findings for the same material but with respect to the chemical resistance and flexural results. But, in that work, the concentrations of the NaOH was too high (15%) which significantly reduces the strength of the sugarcane fibres.

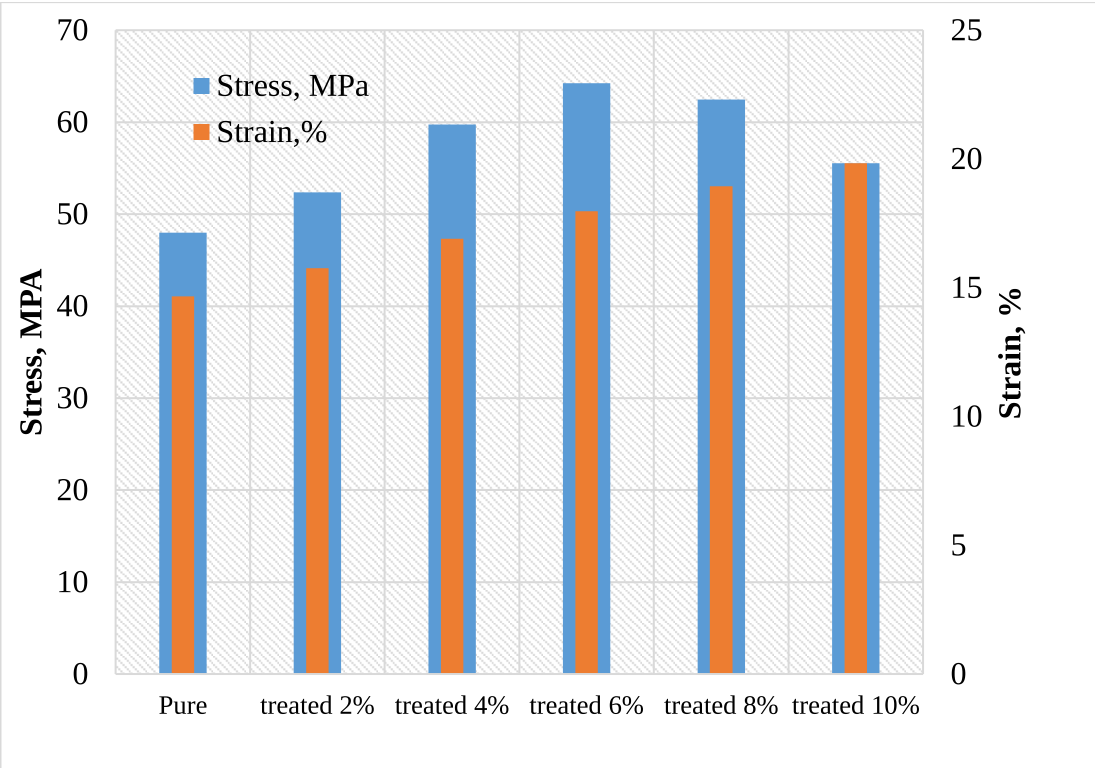

Figure 4. 4 Maximum stress (strength) and strain (Ductility) of tensile results of different treated fibre reinforced polyester composites.

4.4 LOAD TRANSFER

The shear between the sugarcane and the polyester for different NaOH concentrations is displayed in figure 4.5. The shear resistance increases with the increase of the load applied and the displacements as well. There could be deboning, detachment of fibres or breakage in the fibres. This is mainly depending on the bonding region of the fibres and the matrix. To clarify this, figure 4.6 extracted from figure 4.5 to show the maximum shear in the composites. Basically, it can be seen that there is reduction in the shear with the high percent of the NaOH more than 6%. 6% of the NaOH chemical treatment to the sugarcane seems to be the optimum value of treatment. In the literature, there are many works suggested that either 4% or 6% is the optimum. Naguib et al. (2015) tested the flexural strength of 5%, 10% and 15% NaOH of sugarcane fibre/polyester composites. In that work, it is found that the 5% is the optimum value since there is deterioration in the bonding of the fibres with the matrix due to the distortion of the fibres at high strength of the NaOH. Shalwan and Yousif (2013) proposed 6% NaOH is the optimum treatments for different natural fibres in high review article.

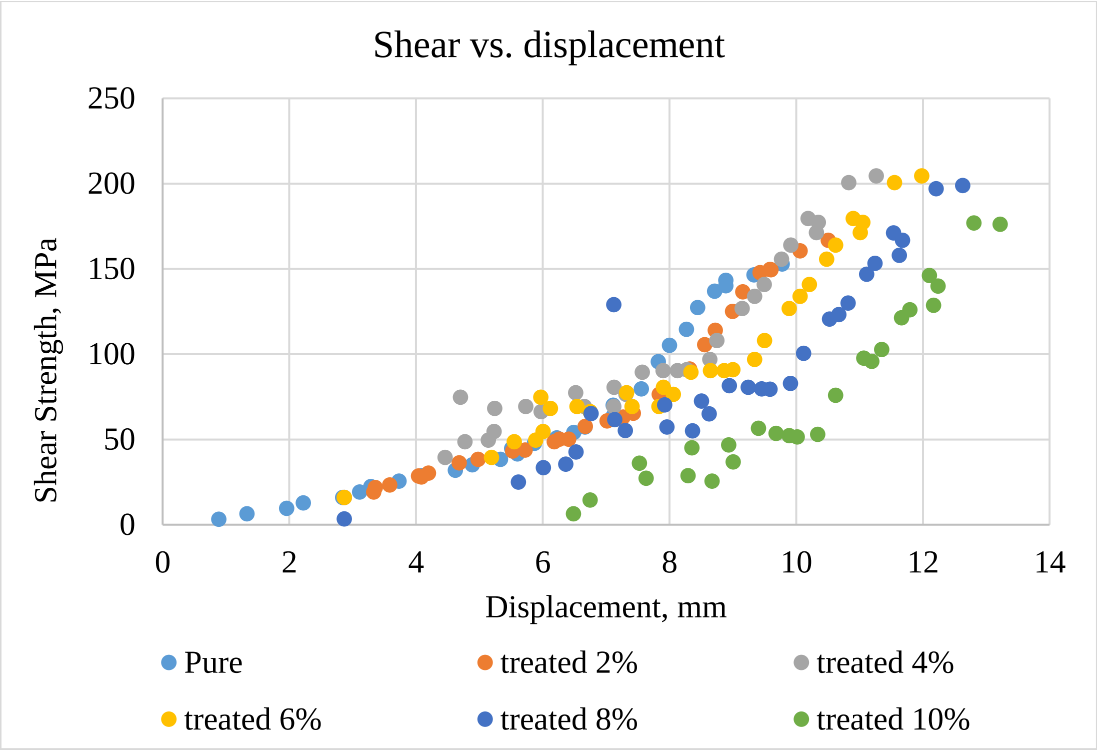

Figure 4. 5 Shear results showing the force vs. displacement of different treated fibre reinforced polyester composites.

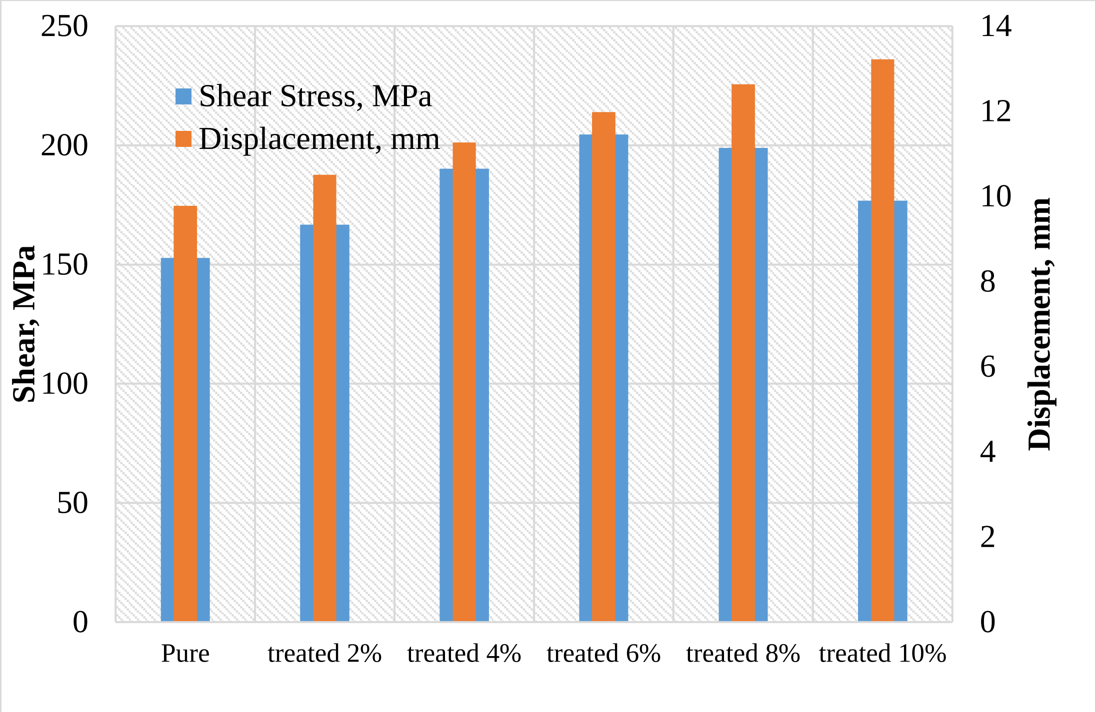

Figure 4. 6 Maximum shear stress and displacement of different treated fibre reinforced polyester composites.

4.5 HARDNESS

The hardness of the polyester composites with different sugarcane treated fibres are presented in figure 4.7. The figure shows that the hardness of the composites reduces with the addition of the fibres. The lowest value of the hardness seems to be at the 6% NaOH treated fibres. In the literature, the hardness of similar composites has not been reported. It can be suggested that the reduction in the hardness due to the presence of the fibres which can have some voids in the fibres themselves. The presence of air in the composites will defiantly reduce the hardness of the composites.

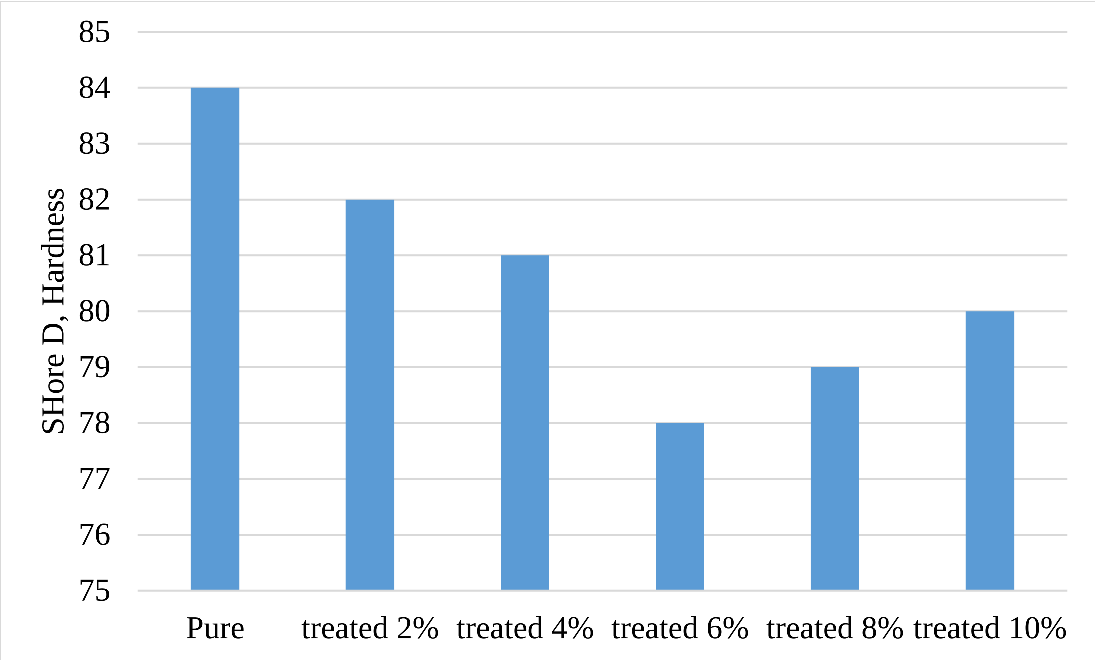

Figure 4. 7 Sore D hardness values of different materials based on different treatment of fibres.

4.6 SCANNING ELECTRON MICROSCOPY OBSERVATIONS

The observation on the fractured area of the composites are displayed in the following figures (figures 4.8-4.12). in Figure 4.8, the 2% NaOH treated fibres seems to be pulled out of the composites which can be explained by the poor support of the fibre to the matrix during the fragmentation tests. Also, the low shear in the 2% NaOH treated fibre seem to be due to the pulled out of the fibre from the matrix.

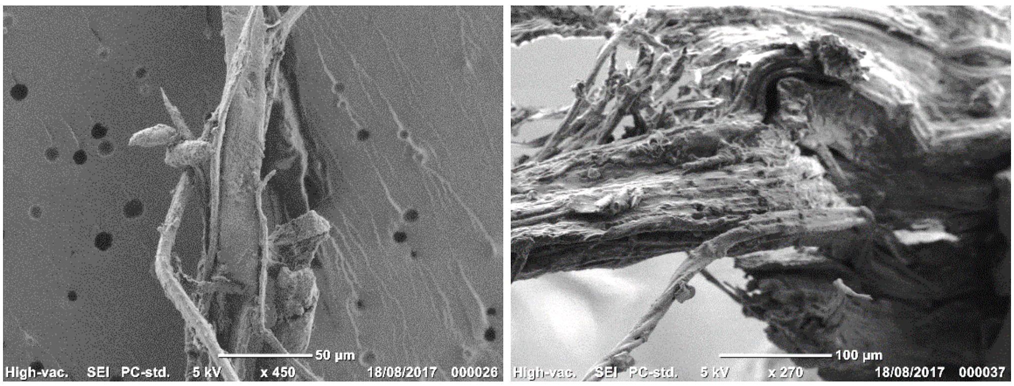

Figure 4. 8 SEM of 2% treated fibre/polyester composite.

At the 4% NaOH treated fibres, figure 4.9 shows that there is a slight pulled out of fibres followed by breakage of the fibres. This indicates that the 4% NaOH successfully improved the interaction of the fibres with the matrix. But, with high concentration of 6%, figure 4.10 shows the bonding of the fibres with the matrix is quite strong since the break in the fibres tool place without any pull out of fibres. This is the best behaviour can be seen since it indicates that the fibres are able to carry the load during the tensile and managed to assist the resin to carry some of the load.

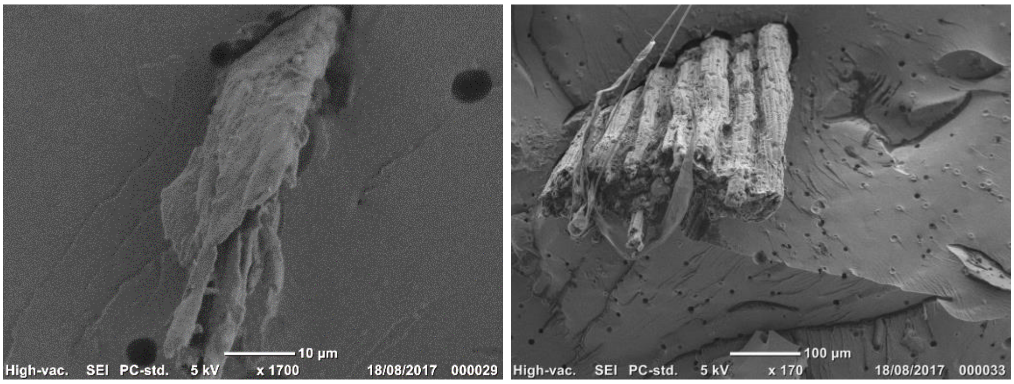

Figure 4. 9 SEM of 4% treated fibre/polyester composite.

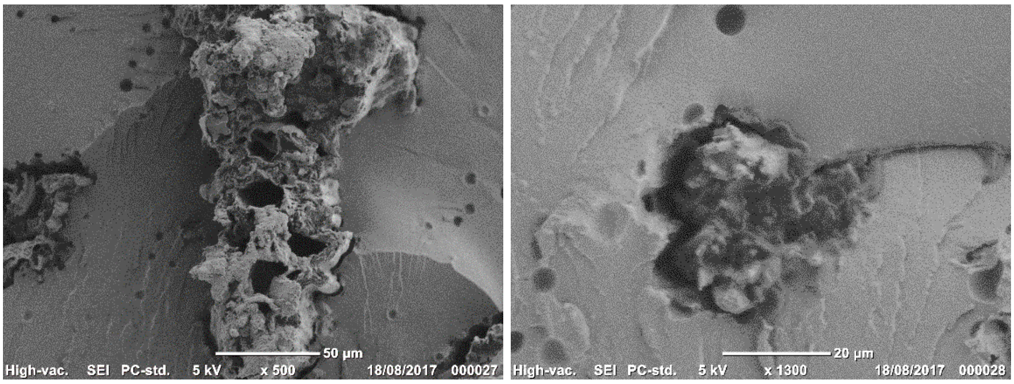

Figure 4. 10 SEM of 6% treated fibre/polyester composite.

At high percent of NaOH treatment (8% and 10%), figure 4.11 and figure 4.12 displayed distortion of the fibres with the breakage in the bundle of the fibres. This is not a good option since the fibres are not strong enough to carry the load due to the distraction in the structure of the fibres. This explains the low strength of the composites at these high concentrations of NaOH.

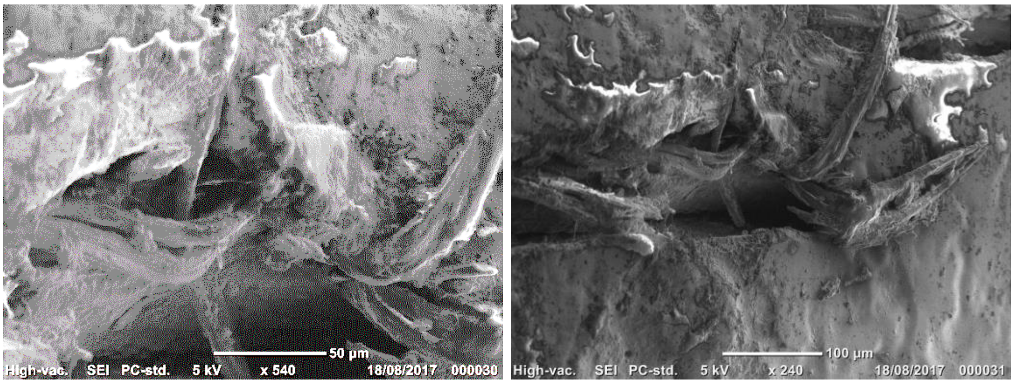

Figure 4. 11 SEM of 8% treated fibre/polyester composite.

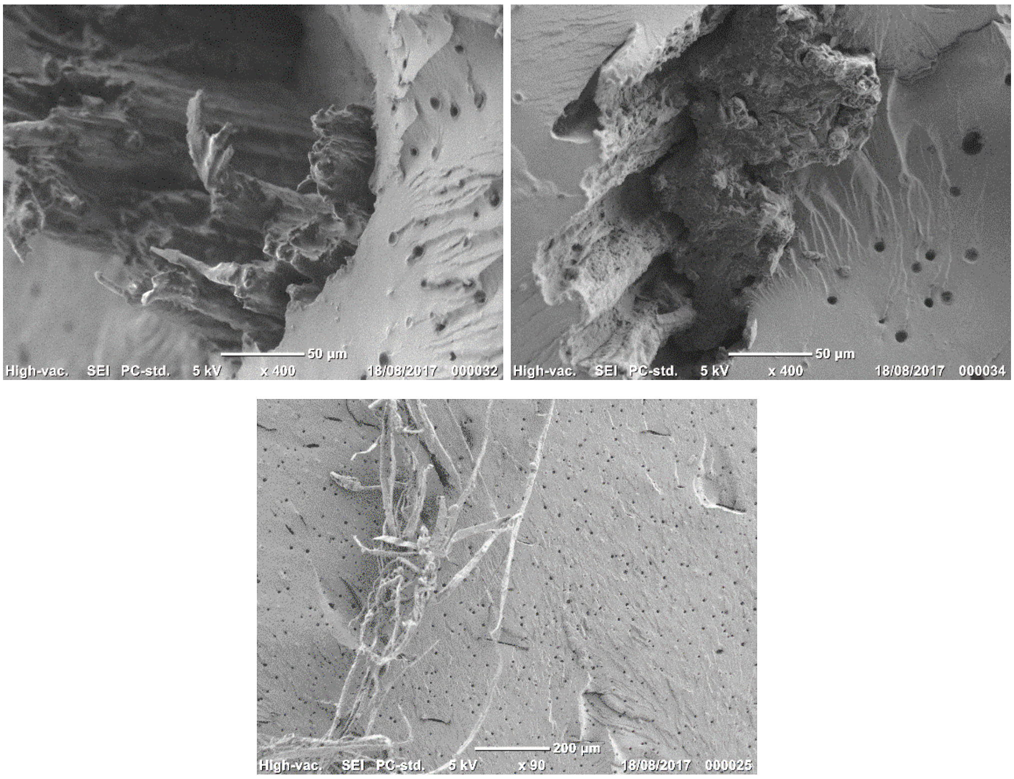

Figure 4. 12 SEM of 10% treated fibre/polyester composite.

4.7 EFFECT OF FIBRE LENGTH

The effect of the fibre length on the strength of the composites and the hardness is given in figure 4.13. The figure shows that increase the fibre length increases the tensile strength of the composites. However, increase the fibre length more than 15 mm does not show that much effect on the strength of the composites. In other words, 15 mm is the critical length which can provide high support to the matrix. Similar findings have been reported previously by Shalwan (2014) when date palm fibres used in epoxy composites. With regards to the hardness, there is proportional drop in the hardness of the composites since the fibres is much less hardness than the resin. It should be mentioned here that the hardness represented in the figure is the average since there is too much variation in the hardness value due to the vibration in the surface of the composites. When the test conducted in the fibrous regions, low hardness measure. Meanwhile, in the resinous region the hardness was higher for the same composites.

Figure 4.13 Effect of fibre length on tensile strength and hardness of the composites.

CHAPER 5 CONCLUSION AND RECOMMEDNATIONS

5.1 CONCLUSIONS

The current work is on the sugarcane fibres in polyester composites. The work is aimed to study the influence of different NaOH concentrations on the interfacial adhesion of the fibre with the polyester.

The main conclusions of the current work can be given in the following points

- The addition of the fibres at optimum NaOH treatment of 6% significantly improve the tensile strength of the polyester composites. In addition, the fibres at this concentration is able to carry most of the load and showing the high shear resistance in the bonding regions of the fibres with the matrix.
- Low percent of NaOH (below 4%) is not good option since there is pull out of the fibres during the test and the fibres did not really support the matrix.
- At high percent of NaOH above 6% destruction in the fibre structure occurred and the fibres broken before carry the load.
- Fibre length effected the strength of the composites and 15 mm fibre length found to be the critical value. With regards to the effect of the fibre length on the hardness of the composites, there is no confirm findings can be given since there was variation in the hardness of the same composites at different spot on the surface.

These are the main points can be concluded. The usage of the sugarcane in polyester composites is a possible industrial material for different applications. There is good knowledge in this project which be used for other students to teach them how to treat the fibres and how to conduct the tests.

5.2 RECOMMENDATIONS

There are many possible improvement or future work to be considered. First, the fabrication process should be conducted under vacuum process to avoid any bubble in the structure of the composites. Secondly, each test should be repeated more than 5 times. In this project, three times is repeated and the variation is still large.

It is recommended to conduct other tests such as thermal, degradation and water absorption to get a clear picture on the application of the composites.

Work plan and resource requirements

Work schedule

The research will take around 35 weeks in 2017 starting from week 1 of semester one and will end on week 15 of semester two. The detailed schedule of the major activities of the research is shown in the following Table 8.1.

Resource requirements and budget

The major resources required for this research includes:

- Materials (sugarcane bagasse fibre, Polyester resin, water, bleaching, etc.)
- Equipment (UTM machine, measuring apparatus, oven, bucket, plates/ tray, Poleriser, etc.)
- Human resources (student researcher, lab technical/ instructor, Supervisor, admin officer, etc.)
- Office/ laboratory set up (at the university lab)
- Computer for data analysis and reporting

The total budget of about AUD$6000 - $8,000 will be required to complete the research. The budget will be further detailed out during finalisation of the proposal. The fund will be sought from the department/ university.

Risk management plan

A risk is a potential event that might occur either internal or external factor related to the research, which may cause negative effects such as delay of the completion, economic loss, injury and failure of the research. In every project, there is always a risk and not every risk can be avoided, but by completing a risk management plan, the impact of the risks can be reduced. It has been recognised that there should be a risk management plan in order to achieve research output on time ensuring safety, and quality. In this section, the potential risk associated with this research has been identified and evaluated their significance. At the end, risk management plan is provided for the research.

Risk identification

In this experimental study, there are many risks involved as listed below.

Internal Risks

- Experimental set up in the lab
    - Timely availability of the machines and apparatuses
    - Accidents (electricity lines)
    - Defective machine
    - Delayed deliveries of chemicals
    - Wrong selection of materials
    - Health & safety concern related to chemical and machine use
    - Fund availability

External Risks

- Delayed delivery of Bagasse sample from sugar mills

Parties involved to the risks and their management

In this research, there are several parties involved such as the student (myself), supervisor, administrative officer of the department/ lab, lab technician/ instructor, health & safety department of the university, and the sugar mill manager. Each of them has their in risk management as described in section 9.4.

Risk evaluation

Risk evaluation involves assessing the risks identified in terms of the possibility of occurrence or likelihood of the risks and the impact of these risks on the research. Likelihood and impact can be determined with qualitative descriptions which translate into a quantitative rating as outlined in the following table, which has been used to define the rating level of the identified risks.

Likelihood / Impact	Very Unlikely	Unlikely	Likely	Very Likely
Low	1	1	2	3
Moderate	1	2	3	4
Extreme	2	3	4	4

Note: 1 = low risk; 2 = medium risk; 3 = high risk; 4 = very high risk

The rating level of the identified risk is outlined in the following table.

Potential risks	Rating level	Reasons
Internal Risks		
• Experimental set up in the lab		
○ Timely availability of the machines and apparatuses	2	Many students are working in the lab. So it may be difficult to make available all the required apparatus on time.
○ Accidents (electricity lines)	2	Accidents may happen with the machine and chemicals
○ Defective machine	3	There is only one UTM machine. If this one fails, then it will take the time to repair or replace.

○ Delayed deliveries of chemicals	2	Due to administrative procedure
○ Wrong selection of materials	3	Wrong selection of sample and chemical will give wrong results
• Health & safety concern related to chemical and machine use	2	Careless use of chemicals and machinery may cause health injury.
• Fund availability	2	Fund for purchasing chemicals and samples may be delayed.
External Risks		
• Delayed delivery of Bagasse sample from sugar mills	2	Sample collection from sugar mill may be delayed due to administrative procedures.

Risk management plan

A risk management plan for the identified risks is given below with risk management strategies, and responsible parties.

Potential risks	Risk management strategies	Responsible parties
Internal Risks		
• Experimental set up in the lab		
○ Timely availability of the machines and apparatuses	Schedule the works early ahead and contact to the department/ lab.	Supervisor, administrative officer of the department/ lab

○ Accidents (electricity lines)	Follow safety instructions, check safety regularly.	student (myself), lab technician/ instructor
○ Defective machine	Check the machines early before starting the testing, arrange alternative option before the experiment begins, Laboratories of another department or university may be contacted.	lab technician/ instructor
○ Delayed deliveries of chemicals	Check the requirement of chemicals well ahead of time.	lab technician/ instructor
○ Wrong selection of materials	Check the materials two-three time before using them.	student (myself), lab technician/ instructor
• Health & safety concern related to chemical and machine use	Use appropriate dresses, gloves and safety instruments while doing experiments.	student (myself), lab technician/ instructor, health & safety department
• Fund availability	Allocate required fund for the research including some reserves for uncertain reasons.	supervisor
External Risks		
• Delayed delivery of Bagasse sample from sugar mills	Contact to sugar mill manager well ahead of time through administrative procedures. Two three alternative sugar mills may be contacted.	student (myself), supervisor, sugar mill manager

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