

AUSTRALIA University of Southern Queensland Faculty of Health, Engineering and Sciences

FRACTURE BEHAVIOUR OF FIBRE/POLYMER COMPOSITES BASED ON SYNTHETIC AND NATURAL FIBRES

In fulfilment of the requirements of

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Abstract

In the current era, there are high demand to find alternative green and renewable, biodegradable products in several industrial and academic sectors. From the literature, natural fibres found to be a good and promising candidate to replace the synthetic fibres for mechanical and civil engineering applications. However, the literature recommends further understanding on the fracture behaviour of such materials since the main issue with the fibre composite is the crack propagation and the fracture weakness. In this work, bamboo fibres reinforced epoxy composites was fabricated. Moreover, glass fibre/epoxy material was fabricated to study the potential of using bamboo fibres. Fracture behaviour of the three materials was investigated and the mico-fracture mechanisms were categorized using scanning electron microscopy.

The current results revealed that bamboo fibres had decent fracture toughness value with 2.21 MPa $m^{\frac{1}{2}}$ for 15 mm fibres length compared to the glass fibres which showed fracture toughness of 2.51 MPa $m^{\frac{1}{2}}$. Increase in the fibre length exhibited significant influence on the polymer composite for both glass and bamboo fibres in the glass or bamboo/epoxy composites, i.e. the longer the fibre is better the fracture toughness. Micro-fracture of the composites showed different features for ach composites. In the glass fibres/epoxy composites, the fractures were predominant by shear (brittle fracture) in both resinous and fibrous regions associated with pull out and detachments of fibres. On the other hand, bamboo/epoxy micrographs showed breakage in the fibres with the matrix. In other words, the bamboo fibres exhibited better interaction with the epoxy compared to the glass fibre

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LIST OF ABBREVIATIONS

FRPC	Fibre reinforce polymers composites
USQ	University of Southern Queensland
SEM	Scanning electron microscope
NaOH	Sodium hydroxide
m	Meter
mm	mile meter
kPa	kilo Pascal
Pa.s Vol	Pascal Seconds Volume
EU-27	
FRP	European Union of 27 member states
	Fibre reinforce polymer
NFRP	
DEDE	Natural fibre reinforce polymer
DIAL	Bamboo fibre reinforce epoxy
GFRE	Glass fibro reinforce opeyy
FREC	
K _{IC}	Fibre reinforce epoxy composite
В	Fracture toughness
W	Specimen Thickness
Р	Specimen Width
c(a)	Load
$f\left(\frac{w}{w}\right)$	Geometry factor

CHAPTER 1

INTRODUCTION

1.1 Introduction

In recent years, engineers are being challenged to 'go green' in many aspects of the engineering areas including environmental friendly processes and innovation of biodegradable or recyclable materials. The usage of the natural fibres brought several issue with regards to their interfacial adhesion with the synthetic matrix such as delamination and decomposition. Fibre reinforce polymer composites (FRPC) are widely used materials among the industry, due to their valuable mechanical properties. The common reinforcement fibres used in the FRPC are carbon and glass as synthetic fibres. However, using synthetic fibres brought several concerns regard their final disposal. Recently researchers are investigating natural fibres ability as a replacement to synthetic fibres (Zakikhani et al., 2014).

The climbing price of synthetic fibres as fibre reinforcement materials, the environmental threat the world facing are the main issues of synthetic fibre, so that natural fibres appear as a great replacement with all the potential, mechanical properties it can provide as reinforcement materials for fabrication of fibre/polymer composites, (Abdul Khalil et al., 2012). However, the usage of the natural fibres brought several issue with regards to their interfacial adhesion with the matrix and their fracture behaviour.

In this project dissertation, the fracture behaviour of a natural fibre (bamboo) was under investigation and comparison with a synthetic fibre (glass) as reinforcement materials to polymer matrix (epoxy), by conducting fracture tests on the developed fibre reinforcing polymer samples, to evaluate the ability

of bamboo fibres to replace glass fibres as reinforcement materials to polymer composites.

1.2 Research Question

The climbing price of synthetic fibres as fibre reinforcement materials, the environmental threat the world facing are the main issues of synthetic fibre, so that natural fibres appear as a great replacement with all the potential, mechanical properties it can provide as reinforcement materials for fabrication of fibre/polymer composites, (Abdul Khalil et al., 2012). However, the usage of the natural fibres brought several issue with regards to their interfacial adhesion with the matrix and their fracture behaviour. In the current study, the research question is focusing on that can bamboo fibres are a possible replacement to glass as a reinforcement material in the fibre reinforce polymer composites, in term of fracture performance?

1.3 Objectives

The main aim of the project is to study the fracture performance of epoxy composites based on glass and bamboo fibres. In details, the objectives are:

- 1. To address the issue with regard of the fracture behaviour of polymer composites based on synthetic fibres from the literature.
- 2. To develop a new composite based on bamboo fibres and synthetic fibres such as glass fibres.
- 3. To evaluate the fracture characteristics of glass and bamboo fibre reinforced epoxy composites.
- To evaluate the fracture behaviour of the composites via scanning electron microscopy.

1.4 Dissertation Organization

The current report contains five chapters as can be seen in Fig. 1.1, mainly chapter 1 covers the introduction and the main objectives of the work, second

chapter summarise the main finding and argument in the literature review. Chapter 3 covers the used methodology to accomplish the work that has been done, in chapter 4 the result are introduces with a dissection and comparison of the work. In the end, chapter 5 summaries the report and list the recommendations.



Fig 1. 1: Layout of the Dissertation

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter introduces the fundamental science of polymers and fibre polymers composites as background information related to the project field. In addition, the chapter reviews literature on natural/synthetic fibres and there issues, fracture behaviour of fibre/polymer composites and the influence of chemical treatment on natural fibre characteristics. At the end of the chapter, a review on bamboo fibre in the recent research studies and the material industry has been written.

2.2 Fundamental of Polymers and Fibre Polymer Composites

2.2.1 Polymers

Every object in this expanding huge universe is composed of atoms, which will form molecules. Molecules can have different or similar properties from each other's and they form the material. Polymers are material category consist of a wide range of materials that we rely on in the modern daily life, formed from many repeated subunits called monomers. The scientific definition of polymers is written by (Young, 2011) is "polymer is a substance composed of molecules which have long sequences of one or more species of atoms or groups of atoms linked to each other by primary, usually covalent, bond" Polymers have existed in natural form since the beginning of life. Since the early mankind naturally occurring polymers has been exploited as a materials to provide shelter, clothes and a lot of other requirements. However, the last decade we have noticed that the polymers have replaced a wide range of traditional materials in their applications. The reason why polymers started to spread among the industry and dominate is the unique attractive advantages that polymers can offer over other materials, for example its productivity, coast effective and the mechanical properties.

The origins of the modern polymers industry started in the nineteen century, when scientists had discover important modifications of certain natural polymers, and Leo Hendrik invented the world first thermoset plastic the Bakelite, through his invention he helped to form the modern plastic industry. Polymers exist in a wide range of marketable forms such as foams, fibres, thin films and sheets and bulks. Polymers materials can be divided into two main types/classes, and they are thermoplastics and thermosetting, (Ku et al., 2011). Within any class there is variety of different polymers.

2.2.1.1 Thermoplastic

Thermoplastics polymers have the simplest molecular structure, with chemically independent macromolecules. Thermoplastic polymers turn to be soft and deformable because of heating, which is a characteristic of linear polymeric molecules. In this sense, thermoplastic and most of the metals share the same characteristic of gaining ductility at a high temperature, (Shackelford, 2009). According to (Biron, 2007) Nowadays Thermoplastic consumption is roughly 80% at least of the total polymers consumption in the industry. To conclude, thermoplastic forming cycle start with subjecting the materials to heat until it turns to liquid state, after that thermoplastic can be shaped into the new manufacture shapes which they will retain when cooled. Multiple cycles of heating and cooling can be repeated without severe damage, allowing reprocessing and recycling. Some of the common thermoplastic polymers nowadays are nylon, polystyrene and polyethylene.

Thermoplastic are a valuable performance material that offers a variety of thermal, chemical, electrical and mechanical properties. The main valuable properties are design flexibility, high strength to stiffness ratio, corrosion resistance, light weight and low coast, (MacDermott, 1997). The great design flexibility for thermoplastics and the ability to be recycled, considered one of the main aspects of the current polymers materials domination over the industry. The injection moulding processes can produce a variety of simple or even the most complex shapes, with a good quality saving a lot of time in manufacturing. In addition it can be remoulded and recycled over again, unlike thermosets. Thermoplastic has been applied instead of metals in many applications due to the considerable weight saving, low coast and the significant corrosion resistance over metals, also the predictable performance when they are subjected to these applications.

Thermoplastic main disadvantages are poor creep and relaxation behaviour compared to thermosets, also thermoplastics can melt fairly easily when exposed to heat sometimes with just the sunlight. In addition, thermoplastic have poor resistance to organic solvents, hydrocarbons and highly polar solvents.

2.2.1.2 Thermosetting

Thermosetting polymers are the opposite of thermoplastic; they have a lot of major differences in the mechanical properties and the characteristics. Thermosetting materials become hard and rigid upon heating, unlike thermoplastic as mentioned previously,(Young, 2011). Thermosetting polymers in general are synthetic materials made from petrochemicals, and they can be manufactured only once to a certain shape at high temperatures. Once it hardened upon cooling it retain the manufactured shape, so that thermosetting polymers unique advantage over other materials is that they can maintain their shape even when exposed to high temperature. Typical types of thermosetting used among the industry nowadays are polyester, polyimide, phenolic and Epoxy, which is going to be applied in the project experiment.

Thermoset materials are generally stronger than thermoplastic with better general creep behaviour. Thermosets are degraded by heat without passing through the liquid state. This improves some aspects of fire behaviour. Due to the significant strength and stiffness thermosetting materials considered as a common metal substitutes. The main thermosetting disadvantage is not being recyclable, and nowadays scientists are encouraged to find "green materials" to substitute traditional materials in many applications, due to the environmental issues.

2.2.1.3 Epoxy resin:

Epoxy resins are a class of thermosetting polymers having epoxide end groups. They can offer a mixture of unique properties over other thermosetting resins, and they are applied in variety of applications from aerospace to sport equipment's industry, where fibres and epoxy resins combine to create composites, (Begum and Islam, 2013). Epoxy resins offer high bending strength, good adhesion, low shrinkage, good electrical insulations and high resistance to deterioration by chemicals and solvents; in addition they are available in wide range of physical forms,(Mallick, 1993). Epoxy resins are used as matrix materials in the fibre reinforcement polymers composites, for example with glass fibre when greater strength is required. Epoxy resins are chemically compatible with other elements so they are great choice for composite applications,(Maureen A. Boyle, 2001). The fracture performance of epoxy composites based on glass and bamboo fibres is going to be evaluated as mentioned in the project aim/objective (Chapter1).

2.2.2 Fibres

Fibres are a wide range of materials that has been used in all cultures for making utilitarian products. Nowadays fibres are playing major role in the materials industry. Fibres are divided into two groups natural and synthetic fibres, depending on their origins, whether they are obtained from nature or man-made materials. Natural fibres can be extracted from the bark (banana, jute, hemp, and ramie), stem (banana, palm, and bamboo), leaf (palm, screw pine, sisal, and agave), husk (coir), seeds (cotton), and grass(Ratna Prasad and Mohana Rao, 2011). In addition, Animal fibres are obtained from a variety of animal coats, and insect fibres from cocoons. On the other hand, synthetic fibres are manufactured.

2.2.2.1 Natural Fibres

Natural Fibres are materials obtained from the nature of plants/animals as mentioned previously. The characteristics and functionalities of natural fibre can vary depending on the chemistry and the fibre structure itself. Natural fibres are applied in the aerospace, fabric, automotive and transportation manufacturing industry due to their valuable properties. They can be used as a component of composite materials to improve the mechanical properties, (Begum and Islam, 2013). Natural fibres cost more to manufacture in general than synthetic fibres, which makes them a second preference in most of the current industry, they are green environmental friendly materials and even if they cost more than synthetic fibres, Natural fibres, Natural fibres still considered cheap compared to other materials, (Wambua et al., 2003). In the past few years a lot of researches have been conducted to determine the ability of natural fibre to replace synthetic fibres in the fibre polymer composites. Examples of natural fibres are hemp, flax, kenaf, sisal and bamboo fibre, (Defoirdt et al., 2010).

2.2.2.2 Synthetic Fibres

Synthetic or chemical fibres were not successful in the materials production industry until the 20 century when they started to replace silk in the United States. In the past 25 years Synthetic fibres became more and more attractive and got high attention simply because they are cheap and provide good mechanical properties. They are durable, effective and less expensive compared to natural fibres. So that, they are applied as reinforcement to materials (Zheng and Feldman, 1995),(Mukhopadhyay, 2014).

2.2.3 Fibres Reinforce Polymer Composites

The use of composite materials dates from centuries ago, and it all started with natural fibres. In ancient Egypt some 3000 years ago, clay was reinforced by straw to build walls. Later other more durable construction materials like metals were introduced. During the sixties, the rise of composite materials began when glass fibres in combination with tough rigid resins could be produced on large scale. Fibre Polymer composite is a composite material made of polymer matrix reinforced with fibres. Composites materials can offer combinations of properties are not available in traditional materials. The mechanical properties of fibres whether they are natural or synthetic is way better than polymers themselves. Therefore, fibres reinforce polymer composites will produce a higher mechanical properties. It is possible to introduce the fibres in the polymer matrix at highly stressed regions in a certain position, direction and volume in order to obtain the maximum efficiency from the reinforcement. In conclusion, fibres reinforce polymer composites consist of natural/synthetic fibre and a polymer matrix, fibres provide the composite with high strength and rigidity while the polymer matrix maintain the fibres alignment, (Begum and Islam, 2013).

2.3 Recent Work on Synthetic and Natural Fibres

2.3.1 Synthetic Fibres and Their Issues

(Zakikhani et al., 2014) reported that the final disposal mode of synthetic fibres still unknown since they are non-degradable materials, and they have a considerable effect on the world environmental issues. In addition, (Begum and Islam, 2013) mentioned that Synthetic fibres are not biodegradable, they consume energy ten times more than natural fibres and their production depends on fossils fuel. So that, synthetic fibres production lead polluted gas emissions. Furthermore, (Abdul Khalil et al., 2012) claiming that the climbing price of synthetic fibres as fibre reinforcement materials and the environmental threat are the main issues of synthetic fibres. So that, natural fibres appear development is progressing among the industry.

2.3.2 Natural Fibres in Recent Era

Researches and scientists are encouraged to work with natural fibres because they are entirely biodegradable and might reduce the cost of the fibre/ polymer composites. So that further research in this composite materials field will bring the benefits in the long run for the industry (Abdul Khalil et al., 2012). Natural fibres as a substitute to synthetic fibres in polymer composites has been reviewed by (Begum and Islam, 2013). In the review, pervious researches result was produced to show and compare between natural and synthetic fibres as reinforcement to polymer composites in many aspects, such as their mechanical properties, economic and environmental impact. Sisal, hemp, kenaf, banana, jute and bamboo and few more natural fibres were compared only with glass as a synthetic fibre in the review. Natural fibres are green materials; they have lower environmental impact compared to synthetic fibres in production. In addition, natural fibres consume ten times less energy to product than synthetic fibres. Natural fibres have great economic impact since their extraction requires large human recourses, so their production will create a lot of jobs. In the review, results of experimental work to determine and evaluate the mechanical properties of natural fibres showed that they have decent values of tensile and flexural strength. Conclusion of the review, natural fibres have proved that it can be applied instead of synthetic fibre to reinforce polymers composites in many applications but not all them and they have a great environmental and economic impact.

Another supporting article has been published by (Reis, 2012a), Natural fibres can be a part of the world solutions towards global environmental issue. They have a wide range of advantages over other inorganic materials, they are cheap, low coast, flexible, biodegradable and available in fibrous form. They got the world industrial attention because of their advantages and they are applied in a variety of applications as reinforcement in the fibre polymers composites. The reason why this study has been conducted is the need of a new natural material in the world right now to replace synthetic fibre due to the world increasing environmental concerns. One of the main widely used natural fibres is sisal fibres. The production of sisal fibres reaches around 4.5 tons a year worldwide. Sisal is applied in carpets, ropes, mattresses and as reinforcement for polymers and cement composites. The conclusion of the experimental article, natural fibres in general and sisal fibres in specific appears as a decent green alternative materials to reinforced polymers composites and can play a major part to reduce the environmental effects issue.

According to (Ku et al., 2011) natural fibres are under a lot of study recently because they have the ability to replace the synthetic fibres as polymers reinforcement. According to the publishes review "A review on the tensile properties of natural fibre reinforced polymer composites" There are reasonable reasons why natural fibre can be the perfect replacement to synthetic such as low coast, low density, recyclable, can reduce energy consumption and comparable tensile strength properties. Another supporting article which mentioned that natural fibre is under a lot of research and seems as a replacement to synthetic fibres reinforcement has been published by (Milanese et al., 2011). In the article "Mechanical behaviour of natural fibre composites" Sisal fibre has been under the microscope to study the mechanical behaviour. There was a comparison between four types of sisal fibre reinforcement composites in the experimental study, humid sisal/polyurethane, humid sisal/phenolic resin, dry sisal/phenolic and dry sisal/polyurethane. The aim of the study was to find out if the sisal fibre could replace glass fibre in terms of its tensile strength value in the technical applications. Similar work was "*Natural fibres: can they replace glass in fibre reinforced plastics*" done by (Wambua et al., 2003), several types of natural fibre were tested and compared between each other's in terms of their mechanical properties, then compared with glass fibre to reinforced polypropylene composites, to determine their ability if they can replace glass fibre. The result of the work showed that coir as a reinforcement material had the lowest value of mechanical properties whereas hemp reinforcement had the greatest value. Natural Fibre composites mechanical properties had a great values compared to glass. Furthermore in some specific properties natural fibre composites were even better. This indicates that natural fibre composites can replace glass in the reinforcement of a lot of applications.

The influence of natural fibres length on the mechanical properties of the fibre polymer composites studied by (Shalwan and Yousif, 2013), the work mentioned that increasing the fibres length or reducing the diameter, will affect the mechanical properties of the fibre/polymer composite positively, this due to the good load transfer between the polymer matrix and the fibres. On the other hand, reducing the fibre length will lead to lower mechanical properties.

Ratna Prasad and Mohana Rao (2011) Published experimental study regards sisal, jowar and bamboo fibres and their mechanical ability as one of the promising natural fibres. The study compared between the three different natural fibres in term of their mechanical ability and as a reinforcement materials to polyester composites. The result of comparison between the three different fibres with the polyester can be seen in Table 2.2 and Table 2.3; both of the tables show an increase in the composites mechanical properties after reinforcement with natural fibres compared to plain polyester. The conclusion of the work stated that jowar fibre had the best properties compared to bamboo and sisal. In the study, jowar fibre had higher mean tensile strength value of sisal and quite the same as bamboo. In addition, Jowar fibre had the highest the mean tensile modulus compared to sisal and bamboo.

	Natural Fibre	Glass Fibre
Density	Low	Twice that of natural
		fibre
Cost	Low	Low, but higher than NF
Renewability	Yes	No
Recyclability	Yes	No
Energy consumption	Low	High
Distribution	Wide	Wide
CO neutral	yes	No
Abrasion to	No	Yes
mechanics		
Health risk when	No	Yes
inhaled		
Disposal	Biodegradable	Not bio-degradable

Table 2. 1: Comparison between Glass/Natural Fibres, (Wambua et al.,2003).

Table 2. 2: Tensile strength of Jowa, sisal and bamboo r fibre asreinforcement fibres to polyester composites, ,(Ratna Prasad and MohanaRao, 2011)

Name of the composite	Volume fraction of fibre	Ultimate tensile strength	Flexural modulus (GPa)
Plain polyester	0.00	31.5	0.63
Jowar	0.40	124	2.75
Sisal	0.40	65.5	1.90
Bamboo	0.402	126.2	2.48

Name of the	Volume	Ultimate	Flexural
composite	fraction of	flexural	modulus
	fibre	strength (MPa)	(GPa)
Plain polyester	0.00	55.08	1.535
Jowar	0.407	134	7.87
Sisal	0.40	99.5	2.49
Bamboo	0.40	128.5	3.70

Table 2. 3: The flexural properties of jowar sisal and bamboo r fibres(Ratna Prasad and Mohana Rao, 2011).

2.3.3 Recent Issues with Natural Fibres

Zakikhani et al. (2014) Specified that high moisture content consider as one of the main issues of natural fibres. Also, Begum and Islam (2013) reported that natural fibres still do not have the ability to replace synthetic fibres as reinforcement for polymer composites in all applications, because they have lower mechanical strength in general. Many researches has been conducted and some still underway to improve the mechanical strength of natural fibres. Another issue regards natural fibres as a reinforcement material is the high moister and low thermal stability for raw natural fibres. This will lead to deterioration of the mechanical properties due to weakness of the fibre and polymer matrix. To overcome this issue a chemical treatment to the fibre surface is required during the preparation to improve the mechanical properties.

2.3.4 Fracture Behaviour of Fibre (Natural/Synthetic) Polymer Composites.

In the current industry one of the main steps of designing a machine component is identification the mode of failure. Fracture simplest definition can be explained as rupture separation of the structural component into two or more pieces due to the propagation of cracks, (Erdogan, 2000). Fracture mechanics is a huge field of materials mechanics that study the influence of

loading and cracks propagation in materials by applying solid mechanics methods to determine the materials mechanical properties such as fracture toughness, (Liu, 2005). This is the main aspect of fracture mechanics that is related to this project.

Reis (2012a) Has published experimental study regards the fracture behaviour of natural fibre reinforced polymer composite. In the study sisal fires were used as raw natural fibres and epoxy resins as the polymer matrix to produce the fibre polymer composite, and study its fracture behaviour. In the experimental study fracture energy and toughness were calculated using the below equations:

$$K_{IC} = \frac{3P_{max}*S}{2W^2*B} \sqrt{\pi aF}(\alpha) \qquad Eq 2.2$$

Where (G_f) is the fracture energy, (A_{lig}) is the fracture area, (δ_0) maximum displacement and (W_0) is the deflection curve vs area under the load. In the second equation (K_{IC}) is the fracture toughness, (S), (W) and (B) are the span depth and width. (P_{max}) is the maximum load that has been measured. The outcome result of fracture testing indicated that the fracture toughness has increased significantly when sisal fibres were used to reinforce epoxy resin compared to plain epoxy as presented in table 2.4.

Table 2. 4 : Fracture test results for sisal fibre reinforce epoxy and plain
epoxy, (Reis, 2012a).

Formulation	$(\boldsymbol{G}_{\mathrm{f}})$	K _{IC}
Plain	383.91 ± 9.56	1.73 ± 0.02
Sisal	1111.07 <u>±</u> 108.62	2.38 ± 0.24

Wong et al. (2010) Placed bamboo fibre reinforced polyester under investigation to have a better understanding of the cracks resistance, toughness and mechanical properties of the short bamboo reinforced polyester. The study used SEM (Scanning Electron Microscopy) to study the fracture surface of the material composite. Several fibres length and volume has been used in the study to determine the best bamboo fibre/polymer composite condition. In the study, hand lay-up technique is used in the composite fabrication, several fracture tests are applied for each composite sample condition (fibre length, volume), and the result indicated by the average. To determine the fracture toughness the below equation is used:

$$K_{IC} = \frac{p}{B\sqrt{W}} f\left(\frac{a}{W}\right)$$
 Eq 2.3

Were (K_{IC}) is the fracture toughness, (p) is the load applied, (B) is the specimens' thickness, (W) indicate the specimens width, and $f\left(\frac{a}{W}\right)$ is the geometry factor. The outcomes of the study indicated that fracture toughness has increased for all the samples tested of bamboo-reinforced polyester composites compared to neat polyester. In specific the best outcome result were when 10mm fibres has been use with 50% volume, fracture toughness increased by 340% in that case. It's also has been noted that fibres with 4mm length showed lower fracture performance behaviour, probably because the polymer matrix was not apple to transfer the load between the fibres very well. To conclude, the fibres were able to increase the resistance in the crack tip which improved the toughness. In addition, the interfacial adhesion of the bamboo with the polyester has been improved with using 6% NaOH treatment.



Fig 2. 1: SEM of Bamboo Fibre, (Wong et al., 2010)

On the other hand, fracture performance of synthetic fibres reinforced polymer has been studied by Reis and Ferreira (2003), an investigation has been conducted on glass fibres ability as a reinforcement to polymer composite in term of fracture behaviour. Conclusion of the work is that glass fibre reinforced polymer would improve both of the material crack resistance and the modulus of elasticity.

2.3.5 Influence of Chemical Treatment on Natural Fibre Characteristics

Gu (2009) Conducted study regards coir fibre tensile behaviour before and after chemical treatment. In the study Noah is the chemical material used to treat coir fibres, different NaOH concentration percentages (2%,4%, 6%, 8%, and 10%) has been under investigation to determine the best treatment percentage situation to improve the mechanical properties of the coir fibres. Scanning electron microscopy has been used in the study to evaluate coir fibres surface condition before and after the chemical treatment. Fig 2.2 (A) shows the surface of coir fibre before conducting the chemical treatment of the fibres, it can be noticed that the surface of coir fibre were its covered with a layer of impurities and is not smooth in Fig 2.2. On the other hand, Fig 2.2 (b) shows coir fibre surface after chemical treatment were the impurities layer has been removed which will improve the fibre/polymers matrix adhesive issue mentioned earlier in (Issues with Natural Fibres) section.



Fig 2. 2: (a) Surface of the Coir Fibre, (b) Coir Fibre Surface after NaOH Treatment, (Gu, 2009)

The result of the study in table 2.5 shows that NaOH with 6% concentration had the highest tensile strength compared to other treatment percentages concentration, which mean the fibre/polymer matrix adhesive issue has been improved with the chemical treatment, from table 2.5 results it also has been noticed that more than 8% of NaOH concentration will start to reduce the tensile strength of the coir fibres.

Fibre	Tensile strength(cN)
Original Fibre	602.8
NAOH 2%	729.3
NAOH 4%	726.1
NAOH 6%	738.9
NAOH 8%	734.4
NAOH 10%	680.0

 Table 2. 5: Chemical treatment percentage vs tensile strength (Gu, 2009)

Mohan and Kanny (2012) Totally agree that NAOH treatments improve the mechanical as well as thermal properties of fibres and reduce water uptake, after studying the influence of chemical treatment on sisal fibres. The results indicate that NAOH treatment improved the fibre matrix interface strength and

tensile properties of composites. In the study the samples were examined by scanning electron microscopy to evidence the result as in Fig 2.3, To conclude the experimental study, sisal fibre that were treated with alkali "NAOH" had better outcome result in terms of mechanical properties, thermal and water absorption resistance over the untreated sisal fibres.



Fig 2. 3: Scanning Electron Microscopy (a) Untreated Sisal Fibre; (b) NaOH Treated Sisal Fibre,(Mohan and Kanny, 2012)

Milanese et al. (2011) Also mentioned that chemical treatment for natural fibres surfaces will reduce the water absorption and improve the strength of the fibre polymer composites. Rokbi et al. (2011) Published a paper regards the the

influence of chemical treatment on natural fibres reinforcing polymer composites. The study focused natural fibre reinforcing polyester composites, In the experiment fibres has been treated with NaOH, Alfa "grass" fibre has been used to determine the chemical influence. The fibre samples were subjected to 1%, 5% and 10% of NAOH for a period of 0-24-48 hours at 28c⁰, to determine the best conditions of the sample treatment. The experiment result indicated that NAOH treatment increases the fibre/matrix interface. Sample treatment with 10% NAOH in 24 hours had the best flexural properties. However after 48 hours the fibre sample will be more brittle and stiffer. Furthermore Mulinari et al. (2011) has published a similar study in the same area which ensure that alkali "NAOH" treatment improves the natural fibre mechanical properties to reinforce polymers. In the experimental study "mechanical properties of coconut fibres reinforced polyester composites" Fatigue and tensile test has been conducted to determine the mechanical properties of the natural fibre samples after the chemical treatment. On the other hand, Reis (2012a) claims that chemical treatment have not affect the fibre fracture behaviour or lead to any significant improvement, after conducting an experimental study on sisal fibre reinforce epoxy. In spite of the fact that fibre surface treatment supposed to improve the fibre polymer composite adhesion however in this case it was not determined.

2.3.6 Bamboo Fibres

2.3.6.1 Introduction to Bamboo Fibres

Bamboo fibres demands has increased tremendously in the last few years as a substitute to synthetic fibres in the fibre/polymer composite, because of the increasing world demands for green sustainable materials. Presently bamboo fibre rise up as one of the natural fibres that has the potential to be applied as reinforcement material to polymer composites, due to its valuable thermal, mechanical properties and chemical modification. Bamboo fibres are extracted from the bamboo tree and can be divided into two types, natural bamboo fibre

which is extracted directly from the tree without any chemical treatment, and bamboo pulp fibre where chemical additive is involve in the process. Bamboo is available in a large scale in Asia and South America. Fig. 2.4 shows the main three continents and the percentage of bamboo fibres in each (Abdul Khalil et al., 2012).



Fig 2. 4: bamboo fibres percentages across the continents,(Abdul Khalil et al., 2012).

2.3.6.2 Bamboo Fibres advantages

Both Defoirdt et al. (2010) and Wong et al. (2010) agreed that bamboo fibres consider as a special natural fibre due to mechanical properties it can provide to the polymer composites industry, and it is one of the strongest natural fibre materials. (Zakikhani et al., 2014) specified that bamboo fibres are low cost materials that grow quickly compared to other natural fibres. In addition, they have low density, high mechanical strength and stiffness. The valuable properties of bamboo place it under comparison with glass fibre as a possible reinforcement alternative for composite materials applications. Comparison between glass and bamboo fibres advantages has been conducted and can be seen in table 2.6, which indicate that bamboo fibres cost less and can be recycled compared to glass fibre.

	Bamboo	Glass	
Density	Low	Higher than bamboo	
Cost	Low	Higher than bamboo	
Disposal	Biodegradable	Non-biodegradable	
CO ₂ absorption	Yes	No	
Recyclability	Yes	No	
Renewability	Yes	No	
Energy from	low	high	
extraction			

Table 2. 6: Comparison between bamboo and glass fibres (Zakikhani et
al., 2014)

2.3.6.2 Economic aspect of bamboo fibres

Bamboo fibre trade is growing enormously worldwide, it was a 45 million trade in 2009; there are mainly two reasons for the market value of bamboo. The main reason is the growth rate of bamboo, it is very fast, where the bamboo tree can reach 18 meters in three months only in some areas, and the second reason is the shortage of wood production in the industry. Farmers are getting the primary benefit out of growing and harvesting bamboo, (Abdul Khalil et al., 2012)

Top Exporters	Top Importers		
Country	US \$ MILLION	Country	US \$ MILLION
Canada	3	Norway	8
South Africa	3	India	9
Mexico	3	Mexico	9
Nigeria	8	South Africa	12
Hong Kong	9	Hong Kong	13
Malaysia	14	Russia	19
Myanmar	15	Switzerland	20
Singapore	18	Rep. of Korea	25
Thailand	18	Australia	26
Philippines	30	Singapore	31
USA	30	China	40
Eu-27	54	Canada	54
Vietnam	84	Japan	194
Indonesia	269	USA	254
China	1034	Eu-27	230

Table 2. 7 : Bamboo export and import trade flow, (Abdul Khalil et al.,2012).

2.3.6.4 Bamboo Reinforce Epoxy

Abdul Khalil et al. (2012) Reported that the wear resistance of bamboo reinforce epoxy showed better result compared to neat epoxy. Furthermore, (Shih, 2007) specified that using bamboo fibre as a reinforcement to epoxy increased the thermal properties compared to neat epoxy as well.

2.4 Summary OF the Chapter

The current chapter addressed several points in the literature and the main point can be drawn as follows:

- 1. Thermoplastic consumption is roughly 80% at least of the total polymers consumption in the industry. Epoxy resins can be used as matrix materials for fibre reinforcement composites to improve mechanical properties.
- 2. Synthetic fibres are non-degradable and there are concerns about their final disposal, Synthetic fibres are getting more and more expensive.
- Natural Fibres reinforcement getting high attention worldwide by scantiest and researchers. Natural fibres cost less than synthetic fibre to manufacture. Production of natural fibres consumes ten times less energy compared to synthetic fibres.
- 4. Natural fibres have lower mechanical strength than synthetic fibres raw natural fibres are high moister and low thermal stability materials. Natural fibre can be applied instead synthetic in the fibre reinforced polymers composites but still not in all applications. The mechanical properties of the fibre reinforce polymer composites depends on the strength of each fibre
- 5. Increasing Fibre content will increase fracture toughness of the composites as mentioned in several studied on both natural and synthetic fibres.
- 6. NAOH treatment is a must to prepare the testing samples for a better tensile strength, 6% concentration of NaOH is the optimum percentage to use in the fibre preparation. Bamboo fibres have great potential and properties to replace synthetic fibres in fibre/polymer composites. There is no much work on the bamboo fibre in term of the fracture behaviour of fibre reinforcement materials to polymer composites.
CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, the details of the materials selection and experimental procedure are introduced in detail. Bamboo fibres, glass fibres and epoxy resin are the materials involved in the experimental study to forum the fibre reinforce polymer composite. All the materials obtained locally from the composite centre at the University Of Southern Queensland (USQ). Two composite samples are developed for fracture testing. The first composite samples are bamboo fibres reinforced epoxy resin (BFRE); epoxy will be reinforced with different fibres lengths (0.5 m, 1 m and 1.5m). During the material preparation bamboo fibres will be treated with NaOH with 6% concentration to overcome the natural fibres issue as mention in the literature review in detail (Chapter 2). The second composite samples consist of glass fibre reinforced epoxy (GFRE), different fibre lengths are also applied in the composite preparation similar to bamboo fibre to compare and discuss the result of fracture testing in the next chapter (Chapter 4). Both of the fibres are randomly distribute in the fibre polymer composite (FPCs) samples. The samples were machined to develop an initial crack, after that fracture test was conducted; analyses of the result to obtain the energy required for the failure and optimize the performance of the material. In the study, Scanning electron microscopy is conducted to evidences the results. Risk assessments also has been conducted for the preparation of the tested samples (Appendix B), standard and formal operating procedure has been followed during the material preparation and samples testing Appendix C and D. All the figures in the chapter are personally taken photos in USQ lap facilities.

3.2 Materials Selection and Preparation

3.2.1 Materials Selection

From the literature (chapter 2), it has been mentioned that there is no much work on the bamboo fibre in term of the fracture behaviour of fibre reinforce polymer composites (FRPC). Based on this fact, bamboo fibre is selected for the current study. For the reasons, there are many available in the; literature and the industries, however, epoxy resin finds its applications in many industrial such as automotive, aerospace and many others (Shih, 2007), therefore it is selected for the current study. Epoxy is used as the polymer resin in the experimental study, Epoxy (R246TX); is supplied by Kinetix composites in a liquid state with specific gravity 1.10 and viscosity 900-1100 MPa.s at room temperature currying, properties of the used epoxy can be found in Appendix F.

3.2.2 Bamboo Fibres Preparation

Bamboo fibres preparation steps are shown in Fig. 3.1, the fibres obtained from USQ in their natural fibrous form without any treatment Fig. 3.1(A), and all the fibres that have been used in the experiment are obtained from the same sack, to ensure consistency in the result. The first stage of the treatment was cleaning the fibres with water to remove the dust, after that, fibres were under chemical treatment with sodium hydroxide (NaOH) which is supplied by ajax finechem company in pellet form, NaOH with 6% concentration (6.1 grams) in Fig. 3.1 (B) is mixed to dissolve in water (94 grams) for the fibre treatment as in Fig. 3.1 (C). The next step in preparing the bamboo fibres, is placing the fibres in the same NaOH/water container for 24 hour due to the reasons mentioned in the literature review (chapter2) as shown in Fig. 3.1 (D). After that, bamboo fibres were placed in the oven for 6 hours at 60c° of temperature to dry at USQ lap facility Fig. 3.1 (E).



Fig 3. 1: Bamboo fibre preparation steps

The last step is cutting the fibres to the desired sample lengths (0.5cm, 1cm, 1.5cm); the entire fibre cutting has been done manually using scissors Fig. 3.1 (F), randomly fibre samples have been picked after the cutting, to determine the chance of error which was ± 1 mm. In the end, bamboo fibres stored in three different plastic boxes based on their length waiting for the composite preparation Fig 3.1 (H).

Scanning electron microscopy (SEM) is conducted to determine the bamboo fibre radius (163 μ m) in Fig. 3.2, also to evaluate and check the fibres situation clearly before and after NaOH treatment. The chemical treatment cleared the surfaced of the fibre as can be seen in Fig. 3.2, so that the epoxy can be fitted between the fibres gabs when manufacturing the fibre polymer composite.



Fig. 3. 2: Scanning Electron Microscopy for Bamboo Fibres

3.2.3 Glass Fibres Preparation

The preparation of glass fibres to develop the FPCs is shown in Fig. 3.3, Glass fibres are obtained in a sheet forum, from the composite center at the USQ Fig. 3.3 (a). Preparation of glass fibre was much quicker compared to bamboo fibre

in the project, the reason behind that is, no chemical treatment has been involved in the fibres preparation, furthermore the cutting process was easier, because glass fibres were in a sheet form. So the main step was cutting the fibres to the desired lengths 0.5cm, 1cm, 1.5cm as shown in Fig. 3.3 (b) to investigate the fracture result with similar length of bamboo fibres samples.



Fig 3. 3 : Glass fibre preparation steps

Similar to bamboo fibre preparation, SEM has been used to determine the glass fibre average diameter, the surface of the fibre has been evaluated and it was clean and relatively free of particles as can be seen in Fig. 3.4.



Fig 3. 4 : Scanning Electron Microscopy of Glass Fibres

3.2.4 Epoxy Composites Preparation

Epoxy resin is the polymers matrix in the experimental study, it will be reinforced with glass and bamboo fibres in the composite preparation to study their fracture behaviour as mentioned in the project aim/objective (chapter1). The epoxy resin samples are prepared in the faculty of engineering & surveying laps at USQ, standard work procedures was followed carefully and risk assessment for the preparation has been done, all the standard procedures for epoxy usage can be found in appendix C and D. The polymer resin consists of epoxy (R246TX) and hardener (H160) Fig. 3.5.



Fig 3. 5: Photo showing the used: (a) epoxy and (b) hardener

Several samples of epoxy / hardener with different ratios have been developed in the lap, to determine the best ratio by show better solidification, in order to use that ratio in the fibre/polymer composite preparation step later on. The first sample had 80% of epoxy (149.6 grams) and 20% of hardener (37.4 grams) as the supplier recommended 4:1 ration between the epoxy and hardener, however the resin has not solidified after 24 hours in room temperature, so that increasing the hardener percentage was the next attempt to determine the best epoxy/hardener ratio. The second sample had 75% of epoxy (100.5 grams) and 25% of hardener (33.5 grams), while the third sample had 70% of epoxy (103.5 grams) and 30% of hardener (44.35 grams), both of the samples did not solidify after 24 hours in room temperature as well, trying to overcome this issue, the three samples placed in the oven to solidify for another 24 hours at 90° of temperature, however the result remain the same and the resin have not solidified. Appendix E has some of the unsuccessful /damaged samples during preparation.



Fig 3. 6: shows the 3 different epoxy resins with different hardener percentage in the oven

After further investigation on why the epoxy resin (polymer) samples haven't solidified, it was found that the materials provided were expired, in specific the hardener. So that, a similar new hardener (H160) as in Fig. 3.5 (b) has been

ordered and used to develop the polymer sample, this time only the recommended ratio from the supplier company (epoxy 80%, hardener 20%) has been applied, positive result were found and the epoxy has solidified after 24 hours in room temperature as recommended.3.2.5 Fibre Reinforce Epoxy Composite Preparation

Fibres reinforce epoxy composite (FRE) Samples preparation for fracture testing has been completed in 3 stages:

- Stage 1 : Designing the mould for FRECs
- Stage 2 : Developing the FRECs
- Stage 3 : Fabrication of FREC specimens dimensions according to ATM D5045

Stage 1: Designing the mould for FRECs

The testing samples have to be similar in term of size and shape to provide accurate results, to study and compare. Therefore, designing the mould was a must for the fabrication process, to study the fracture behaviour of the samples. The first step was determining the mould diminutions and drawing it using CAD software, PTC Creo parametric 2.0 has been used to design the mould, after that the drawing details were sent to the USQ workshop with a request to build it in order to use it for the FRPCs preparation. Unfortunately the mould were built out of wood material which can be seen in Fig. 3.7 (b), so that extracting the FRPC samples out of the mould was very hard and lead to distortion the samples. To overcome the mould sample extraction problem, Wax (NU-CEARAWAX) supplied by huntsman has been used as coating for the mould, to prevent any leakage and provide flexibility when extracting the FRPC samples out of the mould after casting. However, the wax have not solved the samples extraction issue, So purchasing a designed mould with the required diminutions, made out of plastic was the solution to the FREC samples extraction. Some of the damaged samples due to extraction and other reasons can be found in Appendix D.



Fig 3. 7 : Stage 1: Mould making

Stage 2: Developing the FRECs

Fig. 3.8 indicate the second stage of FREC samples preparation step by step, Fig. 3.2 (A) show the different fibres length 5mm, 10mm, and 15mm for both bamboo and glass after the cutting process in the previous materials preparation steps. Fig. 3.8 (B) shows the new experimental plastic square mould (12.5cm \times 12.5cm) which is obtained instead of the wood mould for the reasons mentioned previously, Coating the mould with wax for better extraction of the FREC samples can be seen in Fig. 3.8 (C), after that the fibres are placed inside the mould in randomly distributed way, and the epoxy is prepared as shown in Fig. 3.8 (D) and (E). The next step is casting the epoxy on the fibres in the mould, and then the FREC samples left for 24 hours at room temperature in the mould to solidify. Fig. 3.8 (H) shows extracting the FREC samples out of the mould after solidification. Last stage FREC preparation, is placing the samples in the oven as can be seen in Fig. 3.8 (I) at 110 c^o for 8 hours to cure according to the epoxy supplier company, details and properties of the epoxy in appendix F.



Fig 3.8: Stage 2: FRPC preparation

Stage 3: Fabrication of FREC specimens dimensions according to ATM

D5045

After FRPC preparation is done, cutting the FRPC samples to the desired dimensions was the next stage of preparing the specimens for fracture testing. The dimensions of the specimen are determined according to ASTM D5045 (APPENDIX F), the fracture toughness specimen's diminution are shown in Fig. 3.9.



Fig 3. 9 : Dimensions of a compact tension specimen (ASTM 5045)

Cutting the FREC samples after development in stage 2, to the desired specimens' diminutions according to ASTM D5045 stage 3 has been done manually due to lack of available facilities and time. Therefore, the chance of error was higher compared to other published studies in the same field, due to

lack of cutting/shaping skills using saws, drills and grinding machines accurately, chance of error is ± 0.4 mm by average.

Cutting and shaping FRPC specimens to the desired dimensions started by marking the developed samples into four equal specimens as shown in Fig. 3.10 (A), after that saw has been used to cut the sample based on the marking that has been made equally as in Fig. 3.10 (B). Grinding machine provided by USQ has been used to straight the sides and edges for each specimen, Fig. 3.10 (C) shows the condition of the specimens' surface after using the grinding machine. Two circles have been developed on the specimen's surface using drill press with 7.7 mm diameter in USQ lap facility. The last step was developing the pre-crack 15mm using saw, then the tip of the crack using razor blade with 0.005 thicknesses for 3mm long which can be seen in Fig. 3.11 (C).



Fig 3. 10: Stage 3, cutting/grinding FRPC samples



Fig 3. 11: Stage 3: drilling and developing the crack

3.3 Fracture Testing Machine

MTS universal tensile machine model 810 (Fig. 3.12) has been used in the project to study the fracture behaviour of BRPE and GFRE, the tensile machine located in USQ, Z Block has been used under the supervision of Mr. Mohan Trada Coordinating, Technical Officer of the Faculty of Health, Engineering and Sciences at USQ, Standard working procedures and risk assessment of using the tensile machine has been followed, can be found in appendix J and K



Fig 3. 12 : Tensile Machine at USQ

3.4 Experimental procedure

The fracture toughness test for BFRE and GFRE specimens' has been conducted using the fracture testing machine. The specimens' placed under test at room temperature with a 1.5 mm/m cross wind speed. The diminutions of the specimens were based on ASTM D5045, with 7.7 mm diameter for the two circles, 16 mm thickness, 50mm width and 15 mm pre-crack.

The tested specimens for fracture toughness are:

- 4 samples of GFRE, with 5mm fibres length
- 3 samples of GFRE, with 10mm fibres length
- 3 samples of GFRE, with 15mm fibres length
- 3 samples of BFRE, with 5mm fibres length
- 4 samples of BFRE, with 10mm fibres length
- 4 samples of BFRE, with 15mm fibres length

The fractures toughness can be determined using the below equation:

$$K_{IC} = \frac{p}{B\sqrt{W}} f\left(\frac{a}{W}\right)$$
 Eq 3.1

Were (K_{IC}) is the fracture toughness, (p) is the load applied by the tensile machine, (B) is the specimens' thickness = 16mm, (W) indicate the specimens' width = 50mm, and $f\left(\frac{a}{W}\right)$ is the geometry factor which is given by the below equation:

$$f\left(\frac{a}{W}\right) = \frac{2 + \left(\frac{a}{W}\right)}{\left(1 - \frac{a}{W}\right)^{1.5}} \left[0.866 + 4.64\left(\frac{a}{W}\right) - 13.32\left(\frac{a}{W}\right)^2 + 14.72\left(\frac{a}{W}\right)^3 - 5.6\left(\frac{a}{W}\right)^4\right]$$
 Eq 3.2



Fig 3.13 : Specimens' testing for fracture toughness

3.5 Morphology Study (SEM)

Scanning electron microscopy has been used to examine both BFRE and GFRE specimens' surface conditions after the fracture test. All the specimens has been coated with gold before inspection, the crack propagation on the specimens fracture surface has been studied.



Fig 3. 14: Scanning Electron Microscopy and coating machin

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introductions

In this chapter, comparison has been made between the influence of glass fibres and the bamboo fibres on the fracture behaviour of epoxy composite considering different fibre lengths of 5mm, 10mm and 15mm. Moreover, fracture behaviour of the developed samples has been discussed with the aid of SEM after the test as morphology studies.

4.2 Fracture Behaviour of Glass Fibre

Force vs displacement of different GFRE samples considering different fibres length are given in fig 4.1, each set of data has been conducted at least three times as can be seen in fig 4.1. In general, fig 4.1 (a) to (c) showing fluctuating data and there is no smooth curve for three of them, this indicate that there is breakage in the samples and there is a resistance to the failure during the loading conditions. There could be different explanation about this behaviour; one of them is could be due to the pulling out of the fibre and the resistance of carrying the load during the fracture behaviour. Since the three charts of GFRE showing the same trend in Fig 4.1, this prove that the process of fluctuating is due to the detachment, de-ponding and pull out of the glass fibre from the polymer matrix during the loading conditions, this obviously clear with the 5mm fibre lengths in Fig 4.1 (a) compared to 10mm and then the 15mm in Fig 4.1 (b) and (c), which show smother cure compared to the 5mm length of glass fibres. In the literature review (chapter 2), there are some work has been done on the influence of fibres length on the mechanical behaviour of different composites, in the published work it has been shown that there is a critical

length for the fibre, in which there will be a good transfer of the load during the fracture behaviour.

The critical length of kenaf fibres was 6 mm (Liu et al., 2007), and 15mm for the date palm fibre during the fragmentation test (Shalwan and Yousif, 2014), for the current work it seems also the same, 15mm glass fibres shows a good transfer for the load from the epoxy matrix to the fibres during the loading condition as in Fig 4.1 (c). Further investigation about this point is required and has been given in (chapter 5) in the recommendation.



Fig 4. 1: Load vs Displacement results of GFRE

For comparison purposes the maximum load of the three charts in Fig4.1 has been determined, the average has been taken for the three or four samples depending on the fibres length category associated with the error bar as given in Fig 4.2 for the three different lengths. The Fig. clearly indicates that the longer the length is the better the resistance to the failure during the fracture loading conditions. Since 15 mm shows the maximum loading capacity followed by 10 mm and 5mm in Fig 4.2, similar explanation to the previous finding in Fig 4.1, can be used here in which there is a critical length for the fibre which will be able to transfer the load between the matrix and the fibres.



Fig 4. 2: Average Force vs fibres length of GFRE

For the fracture toughness(K_{IC}), the three different samples are calculated using the average which has been determined using equation 3.1 and equation 3.2 provided and explained in the experimental procedures (chapter 3). The fracture toughness for GFRE samples for different fibre lengths are determined in Table 4.1, Table 4.2 and Table 4.3, and the average also has been given. Basically from the three tables, we can see that the fracture toughness for 15 mm fibres in Table 4.3 is the highest followed by 10 mm fibres in Table 4.2 and 5mm fibres in Table 4.1, again the main reason for the better result of highest fibre length, is the capacity of the fibre to transfer the load between the matrix and the fibre.

 Table 4.1 : Fracture toughness result for GFRE (5 mm fibres length)

5mm fibres length (GFRE)				
Sample number	1	2	3	4
Max (K_{IC}) result (MPa $m^{\frac{1}{2}}$)	1.4509	1.4515	1.8421	1.3521
Average(K _{IC}) samples result (MPa $m^{\frac{1}{2}}$)	1.5242			

 Table 4. 2: Fracture toughness result for GFRE (10 mm fibres length)

10mm fibres length (GFRE)			
Sample number	1	2	3
Max (K_{IC}) result (MPa $m^{\frac{1}{2}}$)	2.4356	1.5840	2.8807
Average(K _{IC}) samples result (MPa $m^{\frac{1}{2}}$)	2.3001		

Table 4. 3: Fracture toughness result for GFRE (15 mm fibres length)

15mm fibres length (GFRE)			
Sample number	1	2	3
Max (K_{IC}) result (MPa $m^{\frac{1}{2}}$)	2.4988	2.6620	2.3879
Average(K _{IC}) samples result (MPa $m^{\frac{1}{2}}$)	2.5162		

Fig. 4.3 shows the final fracture toughness (K_{IC}) results for GFRE based on average testes samples as mention previously. From the figure 15mm fibres had the max fracture toughness result with 2.51 Mpa m^{$\frac{1}{2}$} followed by 10mm with 2.30 Mpa m^{$\frac{1}{2}$} and 5mm with 1.52Mpa m^{$\frac{1}{2}$}, the fracture toughness increased by 51.31% when 10 fibres applied instead of 5 mm and increased again to 65.13% when 15 mm glass fibres length used in the GFRE. This indicates that increasing the synthetic fibres length will increase the polymer composite fracture toughness.



Fig 4. 3: Fracture toughness results for GFRE with different fibres length.

4.3 Fracture Behaviour of Bamboo Fibre

In determining the fracture toughness of bamboo fibres, similar pattern of the previous section for glass fibres has been followed to compare and discuss the two results. Force vs displacement of different BFRE samples considering different fibres length are given in Fig. 4.4, each set of data has been conducted at least three times as can be seen in Fig. 4.4. In general, Fig 4.4 (a) to (c) showing smooth curve of until reaching the peak where the force drop dramatically. This indicate that bamboo fibres did not have the ability to resists the failure during the loading conditions, whereas glass fibre samples resisted as can be seen in Fig. 4.1 (a), (b) and (c). All samples in Fig. 4.4 (a), (b) and (c) showed similar trend pattern until the fracture point in spite of the different bamboo fibres length used to reinforce the epoxy composite.



Fig 4. 4 : Load vs Displacement results of **BFRE**

Fig 4.5 shows the average forces considering different fibres length samples of BFRE. The average has been taken for the three or four samples depending on the fibres length category associated with the error bar as given in Fig 4.4 for the three different lengths. Similar to glass fibres result, it seems the longer length of the bamboo fibres the maximum load can be reached, 15 mm fibres length had the maximum loading capacity with 0.988 KN. On the other hand, 5 mm and 10 mm bamboo fibres had almost similar load capacity value with 0.72 KN and 0.70 KN respectively. Since 15 mm shows the maximum loading capacity followed by 10 mm and 5mm in Fig 4.5, similar explanation to the previous finding in Fig 4.1 and Fig 4.2, can be used here in which there is a critical length for the fibre which will be able to transfer the load between the matrix and the fibres.



Fig 4. 5: Average Force vs fibres length of BFRE

For BFRE fracture toughness(K_{IC}), the three different samples are calculated using the average force which has been determined using equation 3.1 and equation 3.2 similar to the steps used in calculating GFRE fracture toughness values in the previous section. Tables 4.4, 4.5 and 4.6 show the fracture toughness results for different fibre lengths samples. The average fracture toughness also has been given in each table. Based on average (K_{IC}) results, 15 mm fibres length had the highest value with 2.21 MPa $m^{\frac{1}{2}}$ in table 4.6, followed by 10 mm and 5 mm fibres with relatively close (K_{IC}) values of 1.69 MPa $m^{\frac{1}{2}}$ and 1.60 MPa $m^{\frac{1}{2}}$ respectively.

 Table 4. 4 : Fracture toughness result for BFRE (5 mm fibres length)

5mm fibres length (BFRE)			
Sample number	1	2	3
Max (K_{IC}) result(MPa $m^{1\over 2}$)	1.6004	1.4718	1.7564
Average(K _{IC}) samples result (MPa $m^{\frac{1}{2}}$)	1.6095		

 Table 4. 5 : Fracture toughness result for BFRE (5 mm fibres length)

10mm fibres length (BFRE)				
Sample number	1	2	3	4
Max (K_{IC}) result (MPa $m^{1\over 2}$)	1.8956	1.491	1.7318	1.4562
Average(K _{IC}) samples result (MPa $m^{\frac{1}{2}}$)	1.6945			

Table 4. 6 : Fracture toughness result for BFRE (5 mm fibres length)

15mm fibres length (BFRE)				
Sample number	1	2	3	4
Max (K_{IC}) result (MPa $m^{rac{1}{2}}$)	2.0447	2.4653	2.6092	1.7379
$\text{Average}(K_{IC}) \text{ samples result } (\text{MPa } m^{\frac{1}{2}})$	2.2143			

Fracture toughness results for BFRE shown in Fig 4.6 based on the average test results found previously in tables 4.4, 4.5 and 4.6 for different fibres length. In general, 0.5 mm and 10 mm bamboo fibres length had similar influence on the BFRE in terms of fracture behaviour. Starting with the lowest (K_{IC}) result in Fig 4.6, 5 mm fibres (K_{IC}) = 1.6095 MPa m^{$\frac{1}{2}$} followed with a slight increase when 10 mm fibres used with (K_{IC}) = 1.6945 MPa m^{$\frac{1}{2}$}. Fracture behaviour of BFRE increased by 38.12% when 15 mm fibres used compared to 5mm and increased again by 30.76% compared to 10 mm fibres length, again the main reason for the better result of highest fibre length, is the capacity of the fibre to transfer the load between the matrix and the fibre.



Fig 4. 6: Fracture toughness results for GFRE with different fibres length

4.4 Comparison between GFRE & BFRE Fracture

Performance

Based on the previous two section fracture behaviour results for both bamboo and glass fibres reinforcing epoxy composite, a comparison of the two results are introduced in this section. Fig 4.7 shows the fracture behaviour of all the 6 different samples of GFRE and BFRE with different glass and bamboo fibres length ranging from 5 mm, 10 mm and 15 mm. In general, Fig 4.7 show that glass fibres has better fracture behaviour compared to bamboo with the highest (K_{IC}) in the current experimental study 2.51 MPa m^{$\frac{1}{2}$}, however bamboo fibres showed decent results to be considered. It also can be noticed from Fig 4.7 that in spite of the natural or synthetic fibre used, increasing the fibre length had positive effect on the fracture behaviour on the fibre/polymer composite. Summary of fracture toughness results is introduced in table 4.7.



Fig 4. 7 : Fracture toughness results for GFRE & BFRE based on average

Fibres length	Glass (K _{IC}) MPa $m^{\frac{1}{2}}$	Bamboo (K _{IC}) MPa m ¹ / ₂
5mm	1.52	1.60
10mm	2.30	1.69
15 mm	2.51	2.21

 Table 4. 7 : Comparison between glass & Bamboo fibres reinforcing epoxy in term of fracture toughness

4.4 SEM Observation on the Fracture Behaviour of the

Composite

The most significant parameter infusing the fracture behaviour of the composite was the fibre length. To show the influence of the fibre length on the fracture behaviour of the composite, schematic drawing was plotted and presented in Fig 4.8. During the loading process, if the fibre length is short, the possibility of transferring the load form the matric to the fibre is less than the longer length of fibre .In other words, the longer fibres length the better, to transfer the load between fibres and the polymer matrix. However, form the literature their is a critical length In which there is no influence of the fibre length if it is increased. For further understanding, the micrographs of the fractured surfaces are presented in Figs. 4.9-4.15 for different fibre lengths.



Fig 4. 8 schematic drawing showing the influence of the fibre length on the fracture behaviour of the composites

4.4.1 SEM for 5 mm fibres length

The micrographs of both synthetic and natural fibres are given in Fig. 4.9 and Fig. 4.10 for the fibre length of 5 mm. The experimental data showing in the previous section showed that the glass fibre had better fracture performance compared to bamboo fibre. However, the result is very close to each other and bamboo fibres is very promising fibre that could be alternative to glass fibres.

In Fig. 4.9 (a), (b) and (c) one can see that the fracture behaviour of the compote can be pre-dominant by micro fracture, river like, detachment, pull out, fragmentation and breakage in the GFRE. Failure of the composite can be indicated as a brittle failure, due to the present of river like and also micro cracks close to the fibre and the detachment of the glass fibre. Despite of the fact, in the surface of the composite are highly and significantly ditoreited the result of the synthetic composite was slightly better than the natural fibre, the main reason for that is the glass fibres itself has better mechanical properties compared to bamboo fibres, from the literature review (chapter 2) the tensile strength of glass fibre can reach 88.6 MPa (Wambua et al., 2003) ,compared to bamboo which is about 51 MPa (Wong et al., 2010). This could be the main reason of the better performance of the synthetic compared to the natural fibres.

In Fig. 4.10, there are some failures features can be seen for example the detachment of the fibre despite their apart already well adhered, showing the good interfusion adhesion of the fibre with matrix in Fig. 4.10 (a), indicating that there is good transfer of the load from the matrix to the fibre associated with fracture close to the fibre region, and there is river like patter which indicates the brittle failure of the composite as well. Comparing to the glass fibre there is no much differences in terms of brittleness of the composite; however in term of interfacial adhesion of the fibre with the matrix, one can that bamboo fibre had better interaction with the matrix compared to the glass

fibres, which could be the main reason of the comparable fracture behaviour of the bamboo fibre with the glass fibre.

In Fig. 4.10 (b), there is clear indication of breakage in the fibre and there is no pull out and the fibre still adhered well in the bulk of the composite, and there is no clear debonding of the fibre. In addition there are some debris of the epoxy resin inside the core of the fibre, which interlocks the fibre inside the composite, which results very good interfacial adhesion and improvement of the load transfer between the fibre and the resin.

Also in Fig. 4.19 (c), similar behaviour can be seen, despite there is breakage in the fibre, which actually represent the good interfacial adhesion and the good transfer of the load, since the fibre not pulled out from the matrix, similarly can be seen in Fig. 4.10 (d), despite of the fracture behaviour and harsh fracture nature in the resins region associated with sharp lips and river like, but still the fibre adhered well in the bulk of the composite and there is slight breakage in some of the fibres as well, which indicate very good interfacial adhesion of the fibre with the epoxy matrix, so based on these to Figs. one can say that, the bamboo fibre has very good interfacial adhesion with the matrix, which result in good fracture behaviour compared to the glass fibres, which supposed to have much better fracture behaviour than bamboo fibre, however the poor interfacial adhesion of the glass fibres with the epoxy matrix deteriorate performance which made it very comparable and close to the bamboo fibres.



Fig 4. 9 : SEM of fracture surface of GFRE with 5mm fibres length



Fig 4. 10 : SEM of fracture surface of BFRE with 5mm fibres length

4.4.2 SEM for 10 mm fibres length

Scanning electron microscopy of natural/synthetic fibres reinforcing epoxy based on glass and bamboo fibres with 10 mm fibres length is shown in fig 4.10 and Fig 4.11, 10 mm glass fibres showed poor interfacial adhesion with the epoxy composite, which is represented in the fibre detachment and pull out fig 4.11 (a). on the other hand, 10 mm bamboo fibres it can be indicated that there is good adhesion between the fibre and the epoxy matrix due to the appearance of fibre breaking in Fig 4.12 (a) similar to the 5 mm bamboo fibres behaviour in Fig 4.10 (c) and (d).



Fig 4. 11 : SEM of fracture surface of GFRE with 10mm fibres length



Fig 4. 12 : SEM of fracture surface of BFRE with 10mm fibres length

4.4.2 SEM for 15 mm fibres length

Similar results of scanning electron microscopy for the previous two sections, 5 mm and 10 mm glass and bamboo fibres was found when 15 mm fibres are examined. Fig 4.13 shows 15 mm glass fibres in the GFRE, which indicate brittle fracture behaviour due to the presens of rivers or stress lines in Fig 4.13 (a) similar result are shown in Fig 4.9 (a) for 5 mm of glass fibres, 15 mm glass fibres also showed pull behaviour from the epoxy matrix as in Fig 4.9 (c), similarly to 10 mm glass fibres

behaviour in Fig 4.11 (a), again this indicate the poor interfacial adhesion between the synthetic fibre and the polymer matrix. 15 mm Bamboo fibres showed different signs toward the fibre/polymer interfacial adhesion compared to 10 and 5mm, due to the presence of fires pull out as in Fig 4.14 (b), whereas the 10 mm fibres showed breakage sings previously in Fig 4.12 (a) and again in Fig 4.10 (c) and (d) for 5 mm fibres length.



Fig 4. 13 : SEM of fracture surface of GFRE with 15mm fibres length


Fig 4. 14: SEM of fracture surface of BFRE with 15mm fibres length

4.5 Comparison with the Previous Work

The result of the fracture toughness BFRE based on bamboo fibre is compared with similar experimental result done by (Wong et al., 2010) regard the fracture toughness of bamboo fibres as a reinforcement material. In the current work bamboo fibre reinforced epoxy as the polymer matrix with different 0.5 mm, 10mm and 15 mm, however (Wong et al., 2010) used bamboo fibres to reinforce polyester with 0.4 mm, 0.7 mm and 10mm. Wong et al. (2010) Stated that the optimum (K_{IC}) result for 10 mm bamboo fibres reinforcing polyester is 1.73 MPa $m^{\frac{1}{2}}$, which confirm the current study results that has been found with 1.69 MPa $m^{\frac{1}{2}}$ for 10 mm bamboo fibres based on average. Both of the current and (Wong et al., 2010) results showed that increasing the bamboo fibres length increased the fracture performance of the polymer composite.

Comparing bamboo fibre with other natural fibres as a reinforcement material to polymer composites, showed the advantages that bamboo fibres can provide over other natural fibres, however further studied regard other mechanical properties of the bamboo is needed to confirm. The current fracture toughness result has been compared with (Reis, 2012b) where he used 25 mm length of sisal fibres to reinforce epoxy. (Reis (2012b)) Mentioned that, the best fracture toughness of sisal fibres reached 2.27 MPa $m^{\frac{1}{2}}$ for 25 mm fibres length, in the current work fibres with 15 mm had also a high value of fracture toughness 2.21 MPa $m^{\frac{1}{2}}$. So it can be indicated that bamboo fibres are promising natural fibres to consider, further studies regard other aspect need to be studied regards the mechanical performance of bamboo fibres are mentioned in the recommendation and further studied (chapter 5).

4.6 Summary of chapter 4

In this chapter, fracture toughness of glass and bamboo fibres reinforcing epoxy composites has been studied, evaluated and compared with other work from the literature based on different fibres lengths. The fibre/polymers composite tested samples had 0.5 mm, 10 mm and 15 mm fibres length. The result of the study showed decent fracture behaviour of bamboo fibres compared to glass fibres, with maximum fracture toughness value 2.51 MPa $m^{\frac{1}{2}}$ for 15 mm glass fibres, and 2.27 MPa $m^{\frac{1}{2}}$ for bamboo fibres for the same length. From the results it can be indicated that increasing the fibres length in the fibers polymer composite had positive influence on the fracture performance. Fracture toughness increased by 38.12% when 15 mm bamboo fibres used instead of 5mm to reinforce epoxy composite, similar results has been seen when 15 mm glass fibres used to reinforce epoxy composite the fracture toughness increased by 65.13% MPa $m^{\frac{1}{2}}$.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

After conducting the fabrication and experiments on the bamboo and glass fibre reinforced epoxy some of the important points can be drawn as follows:

- 1. Synthetic fibres had several concerns recently by researchers regard their final disposal and their fracture performance. In other words, natural fibres appear as a great replacement to synthetic fibres, in the current study bamboo fibre was investigated to replace glass fibre in term of the fracture behaviour as a reinforcement material to epoxy composites.
- Bamboo fibres had decent fracture toughness value with 2.21 MPa m^{1/2} for 15 mm fibres length, on the other hand glass fibres with similar length had a fracture toughness of 2.51 MPa m^{1/2}. This shows the possibility of replacing the synthetic fibres with the natural ones.
- It has been found that the increase in the fibre length exhibited positive impact on the polymer composite for both glass and bamboo fibres in the glass or bamboo/epoxy composites.
- 4. Micro-fracture of the composites showed different features. In the glass fibres/epoxy composites, the fractures were predominant by shear (brittle fracture) showing river line patents, sharp lips with pull out and detachments of fibres. Meanwhile, bamboo/epoxy micrographs indicated that the fracture mechanisms were breakage in the fibres and brittle nature in the resinous regions associated with good adhesion of the fibres with the

matrix. In other words, the bamboo fibres exhibited better interaction with the epoxy compared to the glass fibres.

5.2 Further Research and Recommendations

Due to the limitation in this study in term of time and facilities, some future works and recommendations can be given as follows:

- Studying the influence of different bamboo fibres diameter and volume on polymer composite could be recoorded since ther are many works in the literater were done in the same area for different natural fibres.
- 2. It is recommended to use plastic polymers instead of thermoset, this may impact on the overall proeprties of the composites.
- 3. X-Ray technique can be used to examine the bulk of the material in case of the presence of inner micro-cracks.

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APPENDIX A

ENG4111/ENG4112 Research Project

Project specification

FRACTURE BEHAVIOUR OF FIBRE/POLYMER COMPOSITES BASED ON SYNTHETIC AND NATURAL FIBRES.

For: RASHED ALTAMAR

Supervisor: Dr. BELAL YOUSIF

Project Aim: the main aim of the project is to study the fracture performance of epoxy composites based on glass and bamboo fibres. In details, the objectives are

- 1. To address the issue with regard of the fracture behaviour of polymer composites based on synthetic fibres from the literature.
- 2. To develop a new composite based on bamboo fibres and synthetic fibres such as glass fibres.
- 3. To evaluate the mechanical properties of the developed composites.
- 4. To evaluate the fracture behaviour of the composites using compact tension technique.

Program:

- Establish the Research the background related to synthetic/natural fibres.
- Developed samples using hand layup technique
- Study the fundamental mechanical properties
- Evaluate the fracture performance of the epoxy composites
- Discuss and analysis the collected data
- Write and submit an academic dissertation on the topic

As time permit:

- Scanning electron microscopy may be conducted for further study and evidences to the results.
- Abacus modelling can be established for verification and further understanding of the fracture behaviour of the composites.

APPENDIX B

University of Southern Queensland

Risk Management Plan http://www.usq.edu.au/hr/healthsafe/safetyproc/whsmanual/whsmanr1. htm

Date:	Faculty/Dept:	Assessment	Contact No:
		completed by:	0416818767 -
22/8/14	Engineering	Rashed	student
	and Surveying	altamar	
What is the task?		Location where tas	k is being
		conducted:	is being
Breparation of resin	sample	conducted.	
Freparation of resin	Sample	7106	
		2106	
Why is the task be	ing conducted?		
under graduate stud	dent project		
	What are the nor	ninal conditions?	
Personnel	Equipment	Environment	Other
Rashed	Hand tools.		
altamar	Resins, mould.	Air condition	
	,		
Briefly explain the	procedure for this task	(incl. Ref to other proceed	lures)
Cleaning and propa	ration of mould Mix racin	and cast into mould	
		and cast into mould.	

		Ris	sk Reg	gister	and	d Analys	is					
Eleme nt / Proces s Step	The Risk: What can happen and what will be the result	EXISTING CONTROLS	with exis cor (See pag	n sting ntrols e nex e)	t	Is it ALA RP? Yes/ No	ADDITIONAL CONTROLS REQUIRED	v ad coi	vith ditic al ntro	n Is	ls it ALA RP? Yes/ No	Risk Deci sion
 Li st major steps or tasks in process 	 Electric shock Eye infection Fire / explosion Physical injury Cut / graze Chemical burn 	List all current controls that are already in place or that will be used to undertake the task eg - List of Personal Protective Equipment (PPE) - Identify types facility, location - Existing safety measurers - Existing emergency procedures	Consequences	Likelihood	Rating		Additional controls may be required to reduce risk rating eg - Greater containment (PC2) - Additional PPE – gloves safety glasses - Specific induction / training	Consequences	Likelihood	Rating		
Cleanin g of mould	Small particles can fly cuts	Wearing eye protection during process. Safe Work Procedures (SWP) have been developed and is readily available. Safe Operating Procedures (SOP) have been developed and are readily available. Risk Management Plan (RMP) has been developed and is readily available. Training and safety induction provided to students Emergency procedures are in place.	2	D		YES	NA	NA	NA	NA	NA	Acce pt
Prepara tion of mould	Pinch Oil spray	Training Safety induction Operating procedure SWP PPE Emergency procedure	1	D	L	YES	NA	N A	N A	N A	NA	Acce pt
Weighi ng of resin	Resin spill Resin smell	Wearing eye protection, hand gloves, Chemical respirator/lab Coat during process. Fume cabinet and eye wash available in room Safe Work Procedures (SWP) have been developed and is readily available. Safe Operating Procedures (SOP) have been developed and are readily available. Risk Management Plan (RMP) has been developed and is readily available. Training and safety induction provided to students Emergency procedures are in place	2	D		YES	N/A	NA	NA	N A	N/A	Acce pt

This Risk Assessment score of Low (L) is only on the co place at the time of the task being conducted. Assessment completed by:	ndition that all existing and additional controls are in
Name: Rashed Altamar	Signature:
Position: Student	Contact No: 0416818767
Date: 25 august 2014	
Supervisor or Designated Officer	
Name: Belal Yousif	Signature: BFY
Position: Senior Lecturer (mechanical engineering)	Contact No:

USQ RISK RATING ADAPTED FROM AS4360:2004

Level	Descriptor	Examples of Description
1	Insignificant	No injuries. Minor delays. Little financial loss. \$0 - \$4,999*
2	Minor	First aid required. Small spill/gas release easily contained within work area. Nil environmental impact. Financial loss \$5,000 - \$49,999*
3	Moderate	Medical treatment required. Large spill/gas release contained on campus with help of emergency services. Nil environmental impact. Financial loss \$50,000 - \$99,999*
4	Major	Extensive or multiple injuries. Hospitalisation required. Permanent severe health effects. Spill/gas release spreads outside campus area. Minimal environmental impact. Financial loss \$100,000 - \$250,000*
5	Catastrophic	Death of one or more people. Toxic substance or toxic gas release spreads outside campus area. Release of genetically modified organism (s) (GMO). Major environmental impact. Financial loss greater than \$250,000*

Table 1 : CONSEQUENCE

* Financial loss includes direct costs eg workers compensation and property damage and indirect costs, eg impact of loss of research data and accident investigation time.

Probability			Consequence		
	Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
A (Almost certain)	М	Н	E	E	E
B (Likely)	М	Н	Н	E	E
C (Possible)	L	М	Н	Н	Н
D (Unlikely)	L	L	М	М	М
E (Rare)	L	L	L	L	L

Table 2– Risk Rating

Table 3: Recommended Action Guide

Abbrev	Action Level	Descriptor
E	Extreme	The proposed task or process activity MUST NOT proceed until the supervisor has reviewed the task or process design and risk controls. They must take steps to firstly eliminate the risk and if this is not possible to introduce measures to control the risk by reducing the level of risk to the lowest level achievable. In the case of an existing hazard that is identified, controls must be put in place immediately.
H	High	Urgent action is required to eliminate or reduce the foreseeable risk arising from the task or process. The supervisor must be made aware of the hazard. However, the supervisor may give special permission for staff to undertake some high risk activities provided that system of work is clearly documented, specific training has been given in the required procedure and an adequate review of the task and risk controls has been undertaken. This includes providing risk controls identified in Legislation, Australian Standards, Codes of Practice etc.* A detailed Standard Operating Procedure is required. * and monitoring of its implementation must occur to check the risk level
М	Moderate	Action to eliminate or reduce the risk is required within a specified period. The supervisor should approve all moderate risk task or process activities. A Standard Operating Procedure or Safe Work Method statement is required
L	Low	Manage by routine procedures.

*Note: These regulatory documents identify specific requirements/controls that must be implemented to reduce the risk of an individual undertaking the task to a level that the regulatory body identifies as being acceptable.

APPENDIX C



<u>PPE Required:</u> Safety Glasses, Chemical Respirator, Hand gloves, covered footwear, laboratory coat

Tools/Equipment Required: mould, hand tools,

Work p	ermit required: yes <u>Training requir</u>	ed prior to task: yes
TASK ST	EPS	KEY POINTS:
1.	Ensure safe/clear working area.	During cleaning mould:
2.	Refer MSDS before using any chemicals	Debris can fly.
3.	Put on PPE.	Cut the fingers
4.	Check fume cabinet is on.	Pouring chemicals from container and mixing
5.	Do not switch on A/C.	Chemical spill
6.	Leave window closed.	Chemical smell
7.	Take right amount of chemicals.	Wear eye protection
8.	Do not spill chemicals.	Use Chemical Respirator Hand gloves
9.	Do not pour any chemical in wash basin.	Covered footwear
		Turn on fume
10.	When operation completed, clean up your work area.	staff.
		Clean up your work area after use.

Issued by :	22/8/2014	Date signed:	
Written by:	Rashed Altamar	Review date:	

Disclaimer

These procedures are for use within the Faculty of Engineering & Surveying, University of Southern Queensland. This information is believed to be reliable and current. The University makes no guarantee and assumes no responsibility as to the absolute correctness of these procedures in all circumstances or for their suitability outside USQ.

APPENDIX D

OPERATING PROCEDURES FOR MAKING COMPOSITES FROM EPOXY RESIN AND NATURAL/SYENTHITIC FIBRES

- 1. Clean and prepare the moulds.
- 2. Weigh the correct amount of fibre in a small plastic container.
- 3. Weigh the correct amount of Kinetix Thixotropic Laminating Epoxy Resin.
- 4. Mix the resin and filler properly and slowly with a plastic spoon.
- 5. Add the weighed Kinetix Medium Hardener, H160.
- 6. Mix the composite properly and slowly with a plastic spoon.
- 7. Pour the mixture into the moulds and put the moulds with composites under the fume cupboard.
- 8. Clean your workplace.

Date: 22/8/2014

APPENDIX E

Damaged samples during preparation:





APPENDIX F

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LAMINATING / R246TX thixotropic

KINETIX R246TX is a solvent free, thixotropic epoxy resin specifically formulated for use with H126, H128, H160, H161 and H162 hardeners to cure at room temperature, or low elevation temperature, and is suitable for fibre composite boat construction.

The thixotropic nature of KINETIX R246TX reduces vertical drainage when high resin contents are employed in heavy laminates. The relatively low activity of KINETIX R246TX offers extended working times* which is another benefit for large laminating projects.

*In comparison with R240 resin, R246TX mixed with associated hardeners, will produce significantly longer working times, typically in the order of 100%.

Cured mechanical properties are excellent. Notably, the cured HDT (heat distortion test) with each hardener is raised some 5-10° C. Toughness is retained.

MIX RATIO

25 parts hardener to 100 parts resin by weight Note: Care should be taken when dispensing and mixing. Do not attempt to control the cure time by altering the hardener ratio. Contact ATL Composites for specific information.

UNCURED PR	OPERTIES					
	R246TX	H126 Super Fast	H128 Fast **	H160 Medium	H161 Slow	H162 Super Slow**
Physical State	Opaque liquid	Clear pale brown liquid	Clear pale yellow liquid	Clear pale brown liquid	Clear pale yellow liquid	Clear pale yellow liquid
Viscosity mPas@25°C	900-1100	160	60	30	25	20
Specific Gravity g/ml@25°C	1.10	0.99	0.95	0.95	0.94	0.93

** Post cure required before handling or removal from mould / framework – H128 exhibits brittle behaviour, while H162 will exhibit plastic like properties prior to post cure. Care should be taken when removing peel-ply or secondary bonding prior to post-cure.

CURE CHARACTERISTICS

	H126 Super Fast	H128 Fast**	H160 Medium	H161 Slow*	H162 Super Slow**
Pot Life -100g @ 25°C	40 mins	55 mins	120 mins	190 mins	300 mins
Thin laminate open time* @ 25°C	4 hrs	4 hrs 20 mins	8 hrs 45 mins	9 hrs 20 mins	10 hrs
Demold time @ 25°C	9hrs 25mins	9 hrs 35 mins	28 hrs	33 hrs 30 mins	28 hrs
Mix viscosity mPas @ 25°C	460	400	300	260	240
Shore D Hardness -1 day	73	68	59	74	68
- 2 weeks	79	83	74	80	77
HDT after 24 hours @ 25°C	47°C	50°C	38°C	42°C	44°C
2 weeks @ 25°C	53°C	53°C	46°C	47°C	48°C
+16hours @ 40°C	65°C	61°C	53°C	57°C	58°C
+16hours @ 50°C	70°C	71°C	57°C	60°C	63°C
+8hours @ 60°C	79°C	80°C	63°C	62°C	65°C
+8hours @ 80°C	96°C	97°C	65°C	68°C	71°C
+4hours @100°C	97°C	97°C	65°C	71°C	73°C
+3hours @120°C	97°C	97°C	67°C	74°C	77°C
Ultimate HDT	97°C	98℃	68°C	75℃	77°C+
* Laminate - 2 layers of 400g biaxial @	25°C/ fibre fractio	on 50%			

к**іпєтіх**.

LAMINATING / R246TX thixotropic

MONITORING OF CURE

A laminator wishing to monitor progress of cure has a number of on-the-spot options open to him. Small test aliquots of mixed resin can be placed in waxed lids during lamination. These should be subjected to the same cure conditions as the actual laminate, and later compared with standard samples which are known to be fully cured.

The samples should be flat on the bottom and approximately 2 to 3 mm thick. Allowance should be made for the possible effect of foam core insulating the curing resin, and reducing the cure of the inner layer.

To meter the development of Heat Distortion Temperature (HDT) immerse the aliquots in a vessel of warming water and noting the temperature at which the resin becomes rubbery. Providing sample thickness is kept constant, this simple technique gives surprisingly reproducible results.

CAUTION

When cured these resins, like all plastics, undergo a transition to a rubbery state when heated above their HDT. Operators should be constantly aware that a partly cured resin will not have developed full HDT, and that components should not be heated above this temperature when they are not supported by vacuum and a mould. Be aware, for example, that heating will cause a considerable build up of pressure in gases in a low density core, and this will always tend to lift a laminate.

Care should also be taken to avoid heating unsupported laminates above the HDT of bonding resins and foam cores.

CALCULATING RESIN/HARDENER FOR A FIBREGLASS LAMINATE

As a rough rule for the amount of resin/hardener required to achieve proper wetting out and consolidation of a laminate, use a 1:1 ratio of fibreglass weight per m^2 to resin/hardener weight, plus wastage.

e.g. $1m^2$ of 600grm biaxial E-fibreglass will require 600grms of mixed resin and hardener + a 10% wastage factor

NOTE Our products are intended for sale to industrial and commercial customers. We request that customers inspect and test our products before use and satisfy themselves as to contents and suitability. Nothing herein shall constitute a warranty, express or implied, including any warranty or merchantability or fitness, nor is protection from law or potent to be inferred. All patent rights are reserved. The exclusive remedy for all proven claims is replacement of our materials and in no event shall we be liable for special or consequential damages. 29 / 01 /13

PACK SIZE	S			
Order Code		Order Code		PACK
Resin		Hardener		
RC 246TX	4 kg	HC 126	1 kg	5 kg
		HC 128	1 kg	
		HC 160	1 kg	
		HC 161*	1 kg	
		HC 162	1 kg	
RD 246TX	18 kg	HD 126	4.5 kg	22.5 kg
		HD 128	4.5 kg	
		HD 160	4.5 kg	
		HD 161*	4.5 kg	
		HD 162	4.5 kg	
RF 246TX	192 kg	HF 126	48 kg	240 kg
		HF 128	48 kg	
		HF 160	48 kg	
		HF 161*	48 kg	
		HF 162	48 kg	

* H161 is a Made to Order product and a minimum purchase quantity is applicable

STORAGE

KINETIX R246TX resin and associated hardeners will keep for 2 years if kept in original containers at room temperature (15° C to 32° C), and out of direct sunlight. Containers should be tightly sealed to prevent moisture absorption.

HEALTH & SAFETY

KINETIX R246TX resin and associated hardeners have moderate sensitising potential, and should be kept out of the eyes and off the skin.

• Use with good ventilation and adequate safety equipment including impervious gloves and safety glasses.

• If skin contact occurs, remove contaminated clothing immediately, and wash the affected area thoroughly with ATL's 845 hand cleaner and water, avoiding the use of solvents except in the case of massive contamination.

• If eye contact occurs, immediately flush with running water for at least 15 (fifteen) minutes and seek medical advice.

If swallowed:

Resins - DO NOT induce vomiting, and contact a doctor or the Poisons Information Centre.

Hardeners - DO NOT induce vomiting, give plenty of milk or water and contact a doctor or the Poisons Information Centre.



ATL composites Pty Ltd Tel (+61) 7 5563 1222 Fax (+61) 7 5563 1585 info@atlcomposites.com www.atlcomposites.com

APPENDIX G

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APPENDIX H

Designation: D 5045 - 99

AMERICAN SOCIETY FOR TESTING AND MATERIALS 100 Barr Harbor Dr., West Conshohocken, PA 19428 need from the Annual Book of ASTM Standards. Copyright ASTM

Standard Test Methods for Plane-Strain Fracture Toughness and Strain Energy Release Rate of Plastic Materials¹

This standard is issued under the fixed designation D 5045; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope *

1.1 These test methods are designed to characterize the toughness of plastics in terms of the critical-stress-intensity factor, K_{lo} and the energy per unit area of crack surface or critical strain energy release rate, G_{le}, at fracture initiation.

1.2 Two testing geometries are covered by these test methods, single-edge-notch bending (SENB) and compact tension (CT)

1.3 The scheme used assumes linear elastic behavior of the cracked specimen, so certain restrictions on linearity of the load-displacement diagram are imposed.

1.4 A state-of-plane strain at the crack tip is required. Specimen thickness must be sufficient to ensure this stress state.

1.5 The crack must be sufficiently sharp to ensure that a minimum value of toughness is obtained.

1.6 The significance of these test methods and many conditions of testing are identical to those of Test Method E 399, and, therefore, in most cases, appear here with many similarities to the metals standard. However, certain conditions and specifications not covered in Test Method E 399, but important for plastics, are included.

1.7 This protocol covers the determination of G_{lc} as well, which is of particular importance for plastics.

1.8 These test methods give general information concerning the requirements for K_{lc} and G_{lc} testing. As with Test Method E 399, two annexes are provided which give the specific requirements for testing of the SENB and CT geometries.

1.9 Test data obtained by these test methods are relevant and appropriate for use in engineering design.

1.10 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

NOTE 1-There is currently no ISO standard that duplicates these test methods. Pending ISO/CD 13586 covers similar testing and references this test method for testing conditions.

2. Referenced Documents

2.1 ASTM Standards

D 638 Test Method for Tensile Properties of Plastics²

D 4000 Classification System for Specifying Plastic Materials³

E 399 Test Method for Plane-Strain Fracture Toughness of Metallic Materials⁴

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method5

3. Terminology

3.1 Definitions:

3.1.1 compact tension, n-specimen geometry consisting of single-edge notched plate loaded in tension. See 3.1.5 for reference to additional definition.

3.1.2 critical strain energy release rate, G10, n-toughness parameter based on energy required to fracture. See 3.1.5 for reference to additional definition.

3.1.3 plane-strain fracture toughness, K_{lc}, n-toughness parameter indicative of the resistance of a material to fracture. See 3.1.5 for reference to additional definition

3.1.4 single-edge notched bend, n-specimen geometry consisting of center-notched beam loaded in three-point bending. See 3.1.5 for reference to additional definition.

3.1.5 Reference is made to Test Method E 399 for additional explanation of definitions.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 yield stress, n-stress at fracture is used. The slope of the stress-strain curve is not required to be zero. See 7.2 for reference to additional definition.

4. Summary of Test Methods

4.1 These test methods involve loading a notched specimen that has been precracked, in either tension or three-point bending. The load corresponding to a 2.5 % apparent increment of crack extension is established by a specified deviation from the linear portion of the record. The K_{lc} value is calculated from this load by equations that have been established on the basis of elastic stress analysis on specimens of the

¹ These test methods are under the jurisdiction of ASTM Committee D-20 on Plastics and is the direct responsibility of Subcommittee D20.10 on Fracture Mechanics.

Current edition approved March 10, 1999. Published June 1999. Originally published as D 5045-90. Last previous edition D 5045-96.

² Annual Book of ASTM Standards, Vol 08.01

Annual Book of ASTM Standards, Vol 08.02. Annual Book of ASTM Standards, Vol 03.01.

⁵ Annual Book of ASTM Standards, Vol 14.02

type described in the test methods. The validity of the determination of the K_{lc} value by these test methods depends upon the establishment of a sharp-crack condition at the tip of the crack, in a specimen of adequate size to give linear elastic behavior.

4.2 A method for the determination of G_{lc} is provided. The method requires determination of the energy derived from integration of the load versus load-point displacement diagram, while making a correction for indentation at the loading points as well as sample compression and system compliance.

5. Significance and Use

5.1 The property K_{lc} (G_{lc}) determined by these test methods characterizes the resistance of a material to fracture in a neutral environment in the presence of a sharp crack under severe tensile constraint, such that the state of stress near the crack front approaches plane strain, and the crack-tip plastic (or non-linear viscoelastic) region is small compared with the crack size and specimen dimensions in the constraint direction. A K_{lc} value is believed to represent a lower limiting value of fracture toughness. This value may be used to estimate the relation between failure stress and defect size for a material in service wherein the conditions of high constraint described above would be expected. Background information concerning the basis for development of these test methods in terms of linear elastic fracture mechanics may be found in Refs (1-5).⁶

5.1.1 The $K_{lc}(G_{lc})$ value of a given material is a function of testing speed and temperature. Furthermore, cyclic loads can cause crack extension at K values less than $K_{lc}(G_{lc})$. Crack extension under cyclic or sustained load will be increased by the presence of an aggressive environment. Therefore, application of $K_{lc}(G_{lc})$ in the design of service components should be made considering differences that may exist between laboratory tests and field conditions.

5.1.2 Plane-strain fracture toughness testing is unusual in that there can be no advance assurance that a valid K_{lc} (G_{lc}) will be determined in a particular test. Therefore it is essential that all of the criteria concerning validity of results be carefully considered as described herein.

5.1.3 Clearly, it will not be possible to determine $K_{lc}(G_{lc})$ if any dimension of the available stock of a material is insufficient to provide a specimen of the required size.

5.2 Inasmuch as the fracture toughness of plastics is often dependent on specimen process history, that is, injection molded, extruded, compression molded, etc., the specimen crack orientation (parallel or perpendicular) relative to any processing direction should be noted on the report form discussed in 10.1.

5.3 For many materials, there may be a specification that requires the use of these test methods, but with some procedural modifications that take precedence when adhering to the specification. Therefore, it is advisable to refer to that material specification before using these test methods. Table 1 of Classification System D 4000 lists the ASTM materials standards that currently exist.

6. Apparatus

6.1 Testing Machine—A constant displacement-rate device shall be used such as an electromechanical, screw-driven machine, or a closed loop, feedback-controlled servohydraulic load frame. For SENB, a rig with either stationary or moving rollers of sufficiently large diameter to avoid excessive plastic indentation is required. A suitable arrangement for loading the SENB specimen is that shown in Fig. 1. A loading clevis suitable for loading compact tension specimens is shown in Fig. 2. Loading is by means of pins in the specimen holes (Fig. 3(b)).

6.2 Displacement Measurement—An accurate displacement measurement must be obtained to assure accuracy of the G_{lc} value.

6.2.1 Internal Displacement Transducer— For either SENB or CT specimen configurations, the displacement measurement can be performed using the machine's stroke (position) transducer. The fracture-test-displacement data must be corrected for system compliance, loading-pin penetration (brinelling) and sample compression by performing a calibration of the testing system as described in 9.2.

6.2.2 External Displacement Transducer— If an internal displacement transducer is not available, or has insufficient precision, then an externally applied displacement-measuring device may be used as illustrated in Fig. 1 for the SENB configuration. For CT specimens, a clip gage can be mounted across the loading pins. For both the SENB and CT specimens, the displacement should be taken at the load point.

7. Specimen Size, Configurations, and Preparation

7.1 Specimen Size:

7.1.1 SENB and CT geometries are recommended over other configurations because these have predominantly bending stress states which allow smaller specimen sizes to achieve plane strain. Specimen dimensions are shown in Fig. 3 (a, b). If the material is supplied in the form of a sheet, the specimen thickness, *B*, should be identical with the sheet thickness, in order to maximize this dimension. The sample width, *W*, is *W* = 2*B*. In both geometries the crack length, *a*, should be selected such that $0.45 \le a/W \le 0.55$.

7.1.2 In order for a result to be considered valid according



⁶ The boldface numbers in parentheses refer to the list of references at the end of these test methods.



to these test methods, the following size criteria must be satisfied:

$$B, a, (W - a) > 2.5 (K_Q/\sigma_y)^2$$

where:

 K_Q = the conditional or trial K_{lc} value (see Section 9), and σ_y = the yield stress of the material for the temperature and loading rate of the test.

The criteria require that B must be sufficient to ensure plane strain and that (W - a) be sufficient to avoid excessive plasticity in the ligament. If (W - a) is too small and non-linearity in loading occurs, then increasing the W/B ratio to a maximum of 4 can be attempted for SENB specimens.

7.2 Yield Stress:

7.2.1 The yield stress, σ_{y_p} is to be taken from the maximum load in a uniaxial tensile test. The yield-stress test can be performed in a constant stroke-rate uniaxial tensile test where the loading time to yield is within ± 20 % of the actual loading time observed in the fracture test. The definition of yield stress is not identical to that found in Test Method D 638 which requires a zero slope to the stress-strain curve. If it is established that 2.5 $(K_Q/\sigma_y)^2$ is substantially less than the specimen thickness employed, then a correspondingly smaller specimen can be used.

7.2.2 Yielding in tensile tests in most polymers can be achieved by carefully polishing the specimen sides. If yielding does not occur and brittle fracture is observed, the stress at fracture may be used in the criteria to give a conservative size value.

7.2.3 If a tensile test cannot be performed, then an alternative method is to use 0.7 times the compressive yield stress.

7.2.4 If the form of the available material is such that it is not possible to obtain a specimen with both crack length and thickness greater than 2.5 $(K_{lc}/\sigma_y)^2$, it is not possible to make a valid $K_{lc}(G_{lc})$ measurement according to these test methods.

7.2.5 The test method employed for determining yield stress, as mentioned in 7.2.1-7.2.4, must be reported.

7.3 Specimen Configurations:

7.3.1 Standard Specimens—The configurations of the two geometries are shown in Fig. 3(a) (SENB) and Fig. 3(b) (CT), which are taken from Annexes A3 and A4, respectively, of Test Method E 399. The crack length, a (crack prenotch plus razor notch), is nominally equal to the thickness, B, and is between 0.45 and 0.55 times the width, W. The ratio W/B is nominally equal to two.

7.3.2 Alternative Specimens—In certain cases it may be desirable to use specimens having W/B ratios other than two. Alternative proportions for bend specimens are $2 \le W/B \le 4$. This alternative shall have the same a/W and S/W ratios as the standard specimens (S = support span).

7.3.3 Displacement Correction Specimens— Separately prepared unnotched specimen configurations for the determination of the displacement correction mentioned in 9.2 are shown in Fig. 4(a) for SENB and in Fig. 4(b) for CT configurations, respectively.

7.4 Specimen Preparation:

7.4.1 Initially, prepare a sharp notch by machining. Subsequently, initiate a natural crack by inserting a fresh razor blade and tapping. If a natural crack cannot be successfully initiated by tapping, a sufficiently sharp crack can alternatively be generated by sliding or sawing a new razor blade across the notch root. The procedure is given in 7.4.1.1-7.4.1.5.

7.4.1.1 Machine or saw a sharp notch in the specimen and generate a natural crack by tapping on a fresh razor blade placed in the notch.

7.4.1.2 The depth of the natural crack generated by tapping must be at least two times longer than the width of the sawed-in slot or the machined notch tip radius (notch diagram in Fig. 3 is not to scale).

7.4.1.3 If a natural crack cannot be successfully generated, either because the specimen fractures during tapping, as in

(1)

a) Single edge notch bend



b) Compact Tension



FIG. 4 Arrangements for Finding Indentation Displacement

some brittle materials, or because a crack cannot be seen, as in some tough materials, then a fresh razor blade can be slid in one motion, or with a sawing motion across the machined notch.

7.4.1.4 The depth of the razor notch generated by sliding the razor blade must be two times longer than the width of the sawed-in slot or of the pre-notch tip radius (the notch diagram in Fig. 3 is not to scale).

Note 2—Pressing the blade into the notch is not recommended for more ductile resins because it may induce residual stresses at the crack tip which can give an artificially high value of K_{tc} .

7.4.1.5 The total depth of the notch obtained by machining and generation of the natural crack is the crack length, a.

8. General Procedure

8.1 Number of Tests—It is recommended that at least three replicate tests be made for each material condition.

8.2 Specimen Measurement—Specimen dimensions shall conform to those shown in Fig. 3(a, b). Three fundamental measurements are necessary for the calculation of K_{Ic} and G_{Ic} namely, the thickness, B, the crack length, a, and the width W.

8.2.1 Measure the thickness, B, to 0.1 % accuracy at not less than three positions. The average of these three measurements should be recorded as B.

8.2.2 Measure the crack length a, after fracture to the nearest 0.5 % accuracy at the following three positions: at the center of the crack front, and the end of the crack front on each surface of the specimen. Use the average of these three measurements as the crack length, a.

8.2.3 Measure the width, W, to within 0.1 % as described in the annex appropriate to the specimen type being tested. 8.3 Loading Rate:

8.3.1 Since plastics are viscoelastic materials, it is necessary to specify both the temperature and time scale under which the result was obtained. As a basic test condition it is recommended that a temperature of 23°C, and a crosshead rate of 1.67 × 10⁻⁴ m/s (10 mm/min) be used. Both loading rate and loading time should be noted on the report form.

Note 3—If it is not possible to obtain valid results at 23°C, it is often possible to do so by decreasing the temperature which usually does not change K_{lc} greatly but increases the yield stress, rendering the fracture more brittle.

8.3.2 It is recommended that speeds greater than 1 m/s or loading times less than 1 ms should be avoided because of the risk of dynamic effects causing errors.

8.4 Loading—The test is performed and the load versus loading-point displacement curve obtained. In the ideal case this is a linear diagram with an abrupt drop of load to zero at the instant of crack growth initiation. In some cases this occurs and K_{O} can be found from the maximum load.

8.5 Load-Displacement Area—A procedure for determining G_{lc} is included in 9.3. This requires an accurate integration of the load versus loading point displacement curve, which necessitates an accurate displacement determination using a displacement transducer. A cross check on the accuracy of G_{lc} is provided through a corrected compliance.

9. Calculation and Interpretation of Results

9.1 Interpretation of Test Record and Calculation of K_Q —In order to establish that a valid K_{lc} has been determined, it is first necessary to calculate a conditional result, K_Q , which involves a construction on the test record, and to then determine whether this result is consistent with the size of the specimen in accordance with 9.1.3. The procedure is given in 9.1.1-9.1.5.

9.1.1 Load the specimen and obtain a diagram as shown in Fig. 5. Draw a best straight line (AB) to determine the initial compliance, C. C is given by the reciprocal of the slope of line (AB). Draw a second line (AB') with a compliance 5 % greater than that of line (AB). If the maximum load that the specimen was able to sustain, $P_{\rm max}$, falls within lines (AB) and (AB'), use $P_{\rm max}$ to calculate K_Q . If $P_{\rm max}$ falls outside line (AB) and line (AB'), then use the intersection of line (AB') and the load curve as P_Q . Furthermore, if $P_{\rm max}/P_Q < 1.1$, use P_Q in the calculation of K_Q . However, if $P_{\rm max}/P_Q > 1.1$, the test is invalid.

9.1.2 Calculate K_Q in accordance with the procedure given in A1.4 for SENB and A2.5 for CT. For this calculation, a value of a, which is the total crack length after both notching and pre-cracking, but before fracture, is best determined from the fracture surface after testing. An average value is used, but the difference between the shortest and longest length should not exceed 10 %. Take care that it is the original crack which is



a) LOAD - DEFLECTION IN FRACTURE TEST



b) LOAD - DEFLECTION IN INDENTATION FIG. 6 Method of Correcting for Indentation

TABLE 1 Calibration Factors SENB⁴ S/W - 4

a/W	1 (X)	φ́	Ψ	ηø
0.450	9.14	0.274	45.8	2.00
0.455	9.27	0.272	46.7	2.00
0.460	9.41	0.269	47.6	2.01
0.465	9.55	0.266	48.5	2.01
0.470	9.70	0.263	49.5	2.02
0.475	9.85	0.260	50.4	2.02
0.480	10.00	0.257	51.4	2.03
0.485	10.16	0.254	52.5	2.03
0.490	10.32	0.252	53.5	2.03
0.495	10.48	0.249	54.7	2.03
0.500	10.65	0.246	55.8	2.03
0.505	10.82	0.243	57.0	2.03
0.510	10.99	0.241	58.2	2.04
0.515	11.17	0.238	59.4	2.04
0.520	11.36	0.236	60.7	2.04
0.525	11.54	0.233	62.1	2.04
0.530	11.74	0.230	63.5	2.04
0.535	11.94	0.228	64.9	2.04
0.540	12.14	0.225	66.4	2.04
0.545	12.35	0.223	67.9	2.04
0.550	12.56	0.220	69.5	2.05

^A Values calculated using A. Bakker, Compatibility Compliance and Stress Intensity Expressions for the Standard Three-Point Bend Specimens. Paper submitted for publication in International Journal of Fatigue and Fracture of Engineering Materials and Structures (March 1989).

10. Report

10.1 List the information required to perform the test and the results obtained in the form of a table. The form to use is provided in Table 3.

TAB	LE 2 Calibrat	tion Factors C	Compact Tens	sion ⁴
a/W	1(X)	φ	Ψ	η.
0.450	8.34	0.208	28.9	2.64
0.455	8.45	0.207	29.6	2.63
0.460	8.57	0.207	30.4	2.61
0.465	8.70	0.206	31.1	2.60
0.470	8.83	0.205	31.9	2.58
0.475	8.96	0.204	32.7	2.57
0.480	9.09	0.203	33.5	2.56
0.485	9.23	0.202	34.4	2.54
0.490	9.36	0.201	35.3	2.53
0.495	9.51	0.200	35.3	2.53
0.500	9.65	0.199	37.1	2.51
0.505	9.81	0.198	38.0	2.50
0.510	9.96	0.197	39.0	2.49
0.515	10.12	0.196	40.0	2.48
0.520	10.28	0.194	41.1	2.47
0.525	10.45	0.193	42.1	2.46
0.530	10.62	0.192	43.3	2.45
0.535	10.80	0.190	44.4	2.44
0.540	10.98	0.189	45.6	2.43
0.545	11.17	0.188	46.8	2.42
0.550	11.36	0.186	48.1	2.41

^A Values calculated using J. A. Knapp, G. S. Leger and B. Gross, Fracture Mechanics Sixteenth Symposium, ASTM, STP 868, 19, pp. 27–44.

TABLE 3 Testing Summary

Fracture Test Parameters				
Tracture Test Parameters Testing laboratory Materials/orientation Specimen geometry Test temperature, *C Loading rate, m/s Notching method Specimen number Witch (W), mn Crack length from 7.2.2, mm P_max N P_not adding rate, s P_0, N P_0 loading time, s Stable or unstable growth K_0, MPa : m^{12} Hearmant the ensure L				
Corrected energy, J				
G _{lo} KJ/m [*]				
Tensile Test Parameters				
σ_{y} MPa σ_{y} loading time, s				
Validity Checks				
P_{max}/P_{O} 2.5 $((K_{0}/\sigma_{x})^{2})$ $E(1 - v^{2})$ via C, MPa $E(1 - v^{2})$ via K_{O}^{2}/G_{O} MPa				

11. Precision and Bias

11.1 Table 4 is based on a round robin conducted in 1988 in

TABLE 4 Precision Statistics from Round-Robin Study in Accordance with Practice E 691

Material ^A	Average	S _x	S,	S _R	1	R
Α	4.34	0.652	0.235	0.679	0.658	1.90
в	5.70	1.420	0.618	1.510	1.730	4.23
с	3.60	0.692	0.343	0.747	0.960	2.09
D	5.90	1.950	0.944	2.100	2.640	7.39

^A Material A is values of K_{le} for nylon. Material B is values of G_{le} for nylon. Material C is values of K_{le} for polycarbonate. Material D is values of G_{le} for polycarbonate. Unlits for all columns are as follows: K_{le} in units of MPa · m^{1/2}. G_{le} in units of kJ/m². accordance with Practice E 691, involving four materials tested by nine laboratories. For each material, all the samples were prepared at one source, but the individual specimens were prepared at the laboratories which tested them. Each test result was the average of three individual determinations. Each laboratory obtained one test result for each material.

Note 5—The following explanations of r and R (11.2-11.2.3) are only intended to present a meaningful way of considering the approximate precision of this test method. The data in Table 4 should not be rigorously applied to acceptance or rejection of material, as those data are specific to the round robin and may not be representative of other lots, conditions, materials, or laboratories. Users of this test method should apply the principles outlined in Practice E 691 to generate the data specific to their laboratory and materials, or between specific laboratories. The principles of 11.2-11.2.3 would then be valid for such data.

11.2 Concept of r and R—If S_r and S_R have been calculated from a large enough body of data, and for test results that were averages from testing three specimens, the information in 11.2.1-11.2.3 applies. 11.2.1 Repeatability, r (comparing two test results for the same material, obtained by the same operator using the same equipment on the same day)—The two test results should be judged not equivalent if they differ by more than the r value for that material.

11.2.2 Reproducibility, R (comparing two test results for the same material, obtained by different operators using different equipment on the same day)—The two test results should be judged not equivalent if they differ by more than the R value for that material.

11.2.3 Any judgement in accordance with 11.2.1 or 11.2.2 would have an approximate 95 % (0.95) probability of being correct.

11.3 Bias—There are no recognized standards by which to estimate bias of these test methods.

12. Keywords

12.1 critical-strain energy release rate; energy-to-break; fracture toughness; plane-strain fracture toughness

ANNEXES

(Mandatory Information)

A1. SPECIAL REQUIREMENTS FOR THE TESTING OF SINGLE-EDGE NOTCH-BEND SPECIMENS

A1.1 Specimen

A1.1.1 The standard bend specimen is a single edgenotched beam loaded in three-point bending with a support span, S, nominally equal to four times the width, W. The general proportions of this specimen configuration are shown in Fig. 3(a).

A1.1.2 Alternative specimens may have $2 \le W/B \le 4$. These specimens shall also have a nominal support span S, equal to S = 4W.

A1.1.3 Specimen Preparation—For generally applicable specifications concerning specimen size and preparation see 7.1.

A1.2 Apparatus

A1.2.1 Bend-Test Fixture—The general principles of the bend-test fixture are illustrated in Fig. 1. This fixture is designed to minimize frictional effects by allowing the support rollers to rotate and move apart slightly as the specimen is loaded, thus permitting rolling contact. Thus, the support rollers are allowed limited motion along the plane surfaces parallel to the notched side of the specimen, but are initially positively positioned against stops that set the span length and are held in place by low-tension springs (such as rubber bands).

A1.2.2 Displacement Gage—For generally applicable details concerning the displacement gage, see 6.2. For the bend specimen the displacements will be essentially independent of the gage length up to a gage length of W/2.

A1.3 Procedure

A1.3.1 Measurement— For a bend specimen measure the width, W, and the crack length, a, from the notched side of the

specimen to the opposite side and to the crack front, respectively.

A1.3.1.1 For general requirements concerning specimen preparation see 7.4.

A1.3.2 Bend Specimen Testing—Set up the test fixture so that the line of action of the applied load shall pass midway between the support roll centers within 1 % of the distance between these centers. Measure the span, S, to within 0.5 % of nominal length. Locate the specimen with the crack tip midway between the rolls within 1 % of the span, and square to the roll axes within 2°.

A1.3.2.1 Load the specimen at a rate of 10 mm/min, as suggested in 8.3.1.

Note A1.1—A loading rate of 12.5 mm/min (0.5 in/min) may be used if this is the only rate available.

A1.4 Calculation

A1.4.1 Interpretation of Test Record—For general requirements and procedures in interpretation of the test record, see 9.1.

A1.4.2 Validity Requirements—For a description of the validity requirements in terms of limitations on P_{max}/P_Q and the specimen size requirements, see 9.1.1.

A1.4.3 Calculations of K_Q —The general formula for K_Q calculation of bend specimens is given in (3). For bend specimens with S/W = 4 (Note A1.2), K_Q in units of MPa · m^{1/2} is as follows:

$$K_Q = \left(\frac{P_Q}{BW^{1/2}}\right) f(x)$$

where $(0 \le x \le 1)$:

$$f(x) = 6x^{1/2} \frac{[1.99 - x(1 - x)(2.15 - 3.93x + 2.7x^2)]}{(1 + 2x)(1 - x)^{3/2}}$$
 (A1.1)

and

- P_Q = load as determined in 9.1.1, kN, B = specimen thickness as determined
- specimen thickness as determined in 8.2.1, cm,
- W = specimen depth (width) as determined in 8.2.3, cm, and
- = crack length as determined in 8.2.2, cm. a

$$x = a/W$$

Tabulated values of $f(x)$ are given in Table 1.

Note A1.2-The expression in A1.4.3 is considered to be accurate within ± 0.5 % over the entire range of x from 0 to 1 for an S/W = 4 (6).

A1.4.4 Calculation of G_Q —For the bend specimens calculate G_Q in units of kJ/m² from the corrected energy, U, as follows

$$G_Q = U/(BW\phi)$$
 or $G_Q = \eta_e U/[B(W-a)]$ (A1.2)

Values of ne are given in Table 1. The energy calibration factor, d, is defined as:

$$\phi = C/[dC/d(A/W)] \qquad (A1.3)$$

and may be computed from the following:

$$\phi = \frac{A + 18.64}{dA/dx} \quad (A1.4)$$

$$\begin{array}{l} A &= [16x^2/(1-x)^2][8.9-33.717x + 79.616x^2 \\ &- 112.952x^3 + 84.815x^4 - 25.672x^5], \text{ and} \\ dA/dx &= [16x^2/(1-x)^2][-33.717 + 159.232 x \\ &- 338.856 x^2 + 339.26 x^3 - 128.36x^4] \\ &+ 16[8.9-33.717x + 79.616x^2 \\ &- 112.952x^3 + 84.815x^4 - 25.672x^5] \\ &\{[2x(1-x)+2x^2]/(1-x)^3\} \end{array}$$

Values of ϕ are given in Table 1.

A2. SPECIAL REQUIREMENTS FOR THE TESTING OF COMPACT-TENSION SPECIMENS

where

A2.1 Specimen

A2.1.1 The standard compact-tension specimen is a single edge-notched plate loaded in tension. The general proportions of this specimen configuration are shown in Fig. 3(b).

A2.1.2 Alternative specimens may have $2 \le W/B \le 4$ but with no change in other proportions.

A2.2 Specimen Preparation

A2.2.1 For generally applicable specifications concerning specimen size and preparation, see 7.1.

A2.3 Apparatus

A2.3.1 Tension-Testing Clevis-A loading clevis suitable for testing compact tension specimens is shown in Fig. 2. Both ends of the specimen are held in such a clevis and loaded through pins in order to permit rotation of the specimen during testing. In order to provide rolling contact between the loading pins and the clevis holes, these holes are provided with small flats on the loading surfaces. Other clevis designs may be used if it can be demonstrated that they will accomplish the same result as the design shown.

A2.3.1.1 The critical tolerances and suggested proportions of the clevis and pins are given in Fig. 2. These proportions are based on specimens having W/B = 2 for B > 12.7 mm and W/B $= 4 \text{ for } \vec{B} < 12.7 \text{ mm.}$

A2.3.1.2 Careful attention should be given to achieving as good alignment as possible through careful machining of all auxiliary gripping fixtures.

A2.4 Procedure

A2.4.1 Measurement- For a compact-tension specimen measure the width, W, and the crack length, a, from the plane of the centerline of the loading holes (the notched edge is a convenient reference line, but the distance from the centerline of the holes to the notched edge must be subtracted to determine W and a). Measure the width, W, to the nearest 0.025

mm, at not less than three positions near the notch location, and record the average value.

A2.4.1.1 For general requirements concerning specimen preparation see 7.4.

A2.4.2 Compact-Tension-Specimen Testing-When assembling the loading train (clevises and their attachments to the tensile machine) care should be taken to minimize eccentricity of loading due to misalignments external to the clevises. To obtain satisfactory alignment keep the centerline of the upper and lower loading rods coincident within 0.76 mm during the test and center the specimen with respect to the clevis opening within 0.76 mm

A2.4.2.1 Load the compact-tension-specimen at a rate as specified in 8.3.1.

A2.5 Calculation

A2.5.1 For general requirements and procedures in interpretation of the test record see 9.1.

A2.5.2 For a description of the validity requirements in terms of limitations on P_{max}/P_O and the specimen-size requirements see 9.1.

A2.5.3 Calculations of Ko-For the compact-tension specimen calculate K_Q in units of MPa m¹/₂ from the following expression (see Note A2.1).

$$K_Q = (P_Q/BW^{1/2})f(x)$$
 (A2.1)
where $(0.2 \le x \le 0.8)$:

$$f(x) = \frac{(2+x)(0.886+4.64x-13.32x^2+14.72x^3-5.6x^4)}{(1-x)^2}$$

where:

 P_Q = load as determined in 9.1.1, kN, B = specimen thickness as determine W = specimen width as determined in

specimen thickness as determined in 8.2.1, cm,

$$W =$$
 specimen width as determined in A2.4.1, cm,
 $a =$ crack length as determined in 8.2.2 cm and

x = a/W.

Values of f(x) are given in Table 2.

Note A2.1—The expression in A2.5.3 is considered to be accurate within ± 0.65 % over the range of a/W from 0.2 to 1 (6).

A2.6 Calculation of G_Q —For the compact tension specimen calculate G_Q in units of kJ/m² from the corrected energy, U, as follows:

REFERENCES

φ =

- (1) Brown, W. F., Jr., and Srawley, J. E., "Plane Strain Crack Toughness Testing of High Strength Metallic Materials," *ASTM STP 410*, ASTM, 1966, p. 1.
- (2) "Fracture Toughness Testing and Its Applications," ASTM STP 381, ASTM, April 1965, p. 30.
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(4) Newman, J. C., "Stress Analysis of Compact Specimens Including the Effects of Pin Loading," ASTM STP 560, ASTM, 1974, p. 105.

- (5) Williams, J. G., "Fracture Mechanics of Polymers," Ellis Horwood/ Wiley, 1985.
- (6) Towers, O. L., "Stress Intensity Factors, Compliances and Elastic n_e Factors for Six Test Geometries," *The Welding Institute*, March 1981.

SUMMARY OF CHANGES

This section identifies the location of selected changes to these test methods. For the convenience of the user, Committee D-20 has highlighted those changes that may impact the use of these test methods. This section may also include descriptions of the changes or reasons for the changes, or both.

D 5045-99: (1) Revised A1.4.3.

(2) Added Summary of Changes.

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 $G_Q = U/(BW_{\Phi})$ or $G_Q = \eta_e U/[B(W - a)]$ (A2.2)

The energy-calibration factor, ϕ , may be computed from

 $(19.118 - 5.0244x - 69.678x^2 + 82.16x^3)(1 - x) + 2(1.9118)$

+ 19.118x -2.5122 x^2 - 23.226 x^3 + 20.54 x^4)

$(1.9118 + 19.118x - 2.5122x^2 - 23.226x^3 + 20.54x^4)(1 - x)$

Values of ϕ and η_{\bullet} are given in Table 2.

Appendix I



PROTECTIVE EQUIPMENT:

1 Safety goggles/shield if testing a brittle material (fibre composite materials)

GENERAL PROCEDURE:

Writte Date:	n By:	Issued By: 5/07/2010
Materia must re	al Safet ad thes	y Data Sheets are available in the laboratory for all hazardous materials. You e for more specific information on the chemicals used in this process.
	13	Keep the surround area and machine clean after use.
	12	The operator should not leave the control panel during the test.
	11	Specimen under compression must be located centrally before applying any load.
	10	Do not allow anyone to stand in front of a specimen being tested under compression.
	9	Always keep hands away from the specimen while a load is being applied.
	8	Clamp the top and bottom end of the specimen in the grips.
	7	Checking that the crosshead is clear, adjust the crosshead. Never adjust the crosshead while anyone else clamps the specimens in the machine.
	6	Select the right pressure for the jaws.
	5	Raise the crosshead to adequate height and raise the ram to adequate height (Normally 120 to 140 mm).
	4	Check for the possibility of clash of jaws/grips (ram has total 160mm travel).
	3	Select the correct jaws and grips for the type of specimen.
	2	Personal protective equipment as designated must be worn.
	1	A work Permit (SWP 001) is required if the test is not being supervised by the Lecturer or laboratory staff.

ASTM Standard D5054, 2003, "Specification for Concrete Aggregates," ASTM International, West Conshohocken, PA, 2003, DOI: 10.1520/C0033-03,

Appendix J

Operating Procedure for MTS Testing Machine Part 1

A. Start-up Procedure for MTS Testing Machine

Check pump room for water supply, hydraulic pipe damage Switch on machine controller Open station manager Select file i.e. Flex test 40 Select Parameters: i.e. Default Open From station manager Station Control **Open Signals Auto Offset Open Manual Command** Check Enable manual command Control mode to Displacement Auto off set displacement Reset interlock if required Start HPS Start HSM **B.** Test Set Up Adjust cross head position refer raising or lowering of cross head Change jaws/plates as per requirements

Open TWE Open custom template Select appropriate template (FOES tensile template) Check the variables from define if required Raise the ram (Refer section C manual raising an lowering of hydraulic actuator) and or cross head to testing position (Refer **D** raising & lowering of cross head) Adjust grips pressure if required

Uncheck Enable manual command

C. Manual Raising & Lowering of Hydraulic actuator (If required) From Manual Command Check Enable manual command Control mode: Displacement -ve for raising actuator and +ve for lowering actuator Auto offset axial Force if required Auto offset displacement Uncheck Enable manual command

D. Raising or lowering of cross head

Unlock cross head Raise or lower cross head Lock cross head

Reset interlock on station manager Operating Procedure for MTS Testing Machine Testing of Materials Tension and Compression Part 2 E. Specimen Testing Procedure Test works 4 Run test

Enter required edit variable value (Dimension of specimen) Place the test piece in grips Lock hydraulic grips Adjust grips pressure if required Close the safety screen Ok

Test will stops when test piece fails or reaches the limits

To stop the test click

stop button (if required)

Actuator is about to return Remove test piece yes Save sample file- export- raw data Format- coma Repeat the procedure <u>*E*</u> **After finishing one group(Sample)** Generate report if required Generate report for all sample if required Repeat the procedure <u>*E*</u>

G. To Stop Machine

Station Manager Off all TWE Yes Save change to file <u>No</u> Close station manager window Yes Save change to file NO Switch off control panel Clean workplace

In emergency hit emergency buttom

Appendix K

University of Southern Queensland Risk Management Plan

Date: 15/10/2014	Faculty/Department: Engineering and Surveying	Assessment completed by: Rashed Altamar	Contact number:0416818767					
What is the task? Potesting for GFRE and	erforming Tensile I BFRE	Location where task is being conducted: Z108						
Why is the task beir Testing for final year	Why is the task being conducted?							
What are the nominal conditions?								
Personnel Trained personnel	Equipment Tensile Testing Machine,	Environment Air-condition- Room	Other					
Briefly explain the p Studying tensile prop	procedure for this task erties of GFRE and BFR	(including referenc E	e to other procedures)					

Element or Process Step	The Risk:	R	Risk atin	g	Is it ALARP ?	ADDITIONA L CONTROLS REQUIRED	Ris ad co	k Ratii with ditiona ntrols	ng al ?	Is it ALA RP? Yes/ No	Risk Deci sso n
		Consequences	Likelihood	Rating			Consequences	Likelihood	Rating		
Measuri ng dimensio ns of sample	NA	N A	N A	N A	NA	NA	NA	NA	N A	NA	NA
Turn on the tensile machine	Electric al shock	3	E	L	YES	NA	NA	NA	N A	NA	Acc ept
Placing the sample on the machine	Pinchin g crushin g	2	D	L	YES	NA	NA	NA	N A	NA	Acc ept
Breaking the sample	Debris could fly from the fracture	2	E	L	YES	NA	NA	NA	N A	NA	Acc ept
Remove the sample	NA	N A	N A	N A	NA	NA	NA	NA	N A	NA	NA
Turing off the machine	Electric al shock	3	Е	L	YES	NA	NA	NA	N A	NA	Acc ept

Risk register and Analysis [ALARP = As Low As Reasonably Practicable]

The task should not proceed if the risk rating after the controls are implemented is still either HIGH or EXTREME or if any risk is not As Low As Reasonably Practicable (ALARP).

This Risk Assessment score of Low (L) is only on the condition that all existing and additional controls are in place at the time of the task being conducted.

Assessment completed by:	
Name: Rashed Altamar	Signature:
Position: Student	Contact No: 0416818767
Supervisor	
Jupervisor	
<u>Belal Yousef</u>	Signature: BYF