STUDY OF MECHANICAL AND WATER ABSORPTION PROPERTIES OF BIO-COMPOSITE THIN FILM FROM WASTE BANANA PEEL

by

CHEE WING TUNG

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UNIVERSITI MALAYSIA KELANTAN

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DECLARATION

I declare that this thesis entitled "Study of Mechanical and Water Absorption Properties of Bio-Composite Thin Film from Waste Banana Peel" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

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Date : ________________________________

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
CMC	Ceramic matrix composite
CMF	Cellulose microfibril
E-glass	Electrical-grade glass
FRP	Fibre reinforced plastic
HAP	Hydroxyapatite
HDPE	High density polypropylene
MMC	Metal matrix composite
Mt %	Water absorption
PEG 400	Polyethylene glycol 400
PMC	Polymer matrix composite
PP	Polypropylene
SEM	Scanning electron microscopy
UK	United Kingdom
UMK	Universiti Malaysia Kelantan

LIST OF SYMBOLS

°C	Degree Celsius
%	Percentage
µm	Micrometre
cm	Centimetre
g	Gram
ml	Millilitre
mm	Millimetre
mm/min	Millimetre per minute
mm^{-1}	Millimetre to the power of negative one
mm^2	Square millimetre
MPa	Megapascal
N	Newton
N/mm	Newton per millimetre
N/mm^2	Newton per square millimetre
w/w	Mass per mass
Wo	Initial mass
Wt	Mass after immersion
wt%	Weight percent

Study of Mechanical and Water Absorption Properties of Bio-Composite Thin Film from Waste Banana Peel

ABSTRACT

The purpose of this study was to fabricate bio-composite from waste banana peel with 0 %, 5 % and 10 % of eggshell filler. Banana peel fibre acts as matrix while eggshell acts as filler. After boiling dry banana peel, it was blended with eggshell filler and glycerol which acts as plasticizer. The mixture was poured on silkscreen and dried in oven. Hand lay-up process was used to laminate the bio-composite with epoxy. The procedures were repeated by using different ratio of banana peel and eggshell. The effect of different ratios of waste banana peel and eggshell filler in bio-composite thin film was determined. The mechanical properties of the bio-composite were determined by using tensile test and tear resistance test. The tensile strength and Young's modulus increased while the percent elongation decreased as the eggshell filler contents increased. Sample with 10 % of eggshell filler showed the highest tensile strength. This proved that eggshell was an effective filler in improving strength of the bio-composite. On the other hand, the tear strength decreased with the incorporation of eggshell filler. The highest tear strength was observed for the sample with 0 % of eggshell. The observation for fracture behaviour of the samples was carried out by using scanning electron microscope. The water absorption properties of the bio-composite were determined by using water absorption test. Sample with 10 % of eggshell filler absorbed the highest amount of water. The percentage of water absorption increased as the filler content increased.

Kajian Sifat Mekanikal dan Penyerapan Air terhadap Bio-komposit Filem Nipis daripada Sisa Kulit Pisang

ABSTRAK

Tujuan kajian ini adalah untuk menghasilkan bio-komposit daripada sisa kulit pisang dengan 0%, 5% dan 10% daripada pengisi kulit telur. Gentian kulit pisang bertindak sebagai matriks manakala kulit telur bertindak sebagai pengisi. Setelah mendidih pisang kulit kering, ia telah dicampur dengan pengisi kulit telur dan gliserol yang bertindak sebagai pemplastik. Campuran telah dicurahkan pada silkscreen dan dikeringkan dalam ketuhar. Proses meletakkan sehingga dengan meggunakan tangan telah digunakan untuk lamina bio-komposit dengan epoksi. Prosedur itu diulang dengan menggunakan nisbah kulit pisang dan kulit telur yang berbeza. Kesan nisbah yang berbeza daripada kulit sisa pisang dan pengisi kulit telur dalam filem nipis bio-komposit ditentukan. Sifat-sifat mekanikal bio-komposit telah ditentukan dengan menggunakan ujian tegangan dan ujian rintangan lusuh. Kekuatan tegangan dan modulus Young meningkat manakala peratus pemanjangan menurun dengan peningkatan kandungan pengisi kulit telur. Sampel dengan 10% kandungan pengisi kulit telur mempunyai kekuatan tegangan yang paling tinggi. Ini membuktikan bahawa kulit telur adalah pengisi yang berkesan dalam meningkatkan kekuatan bio-komposit. Kekuatan lusuh menurun dengan peningkatan kandungan pengisi kulit telur. Sampel tanpa kandungan pengisi kulit telur menunjukkan kekuatan lusuh yang paling tinggi. Pemerhatian bagi kelakuan-patah sampel telah dijalankan dengan menggunakan mikroskop imbasan elektron. Sifat-sifat penyerapan air bio-komposit telah ditentukan dengan menggunakan ujian penyerapan air. Sampel dengan kandungan 10% pengisi kulit telur menyerap jumlah air yang tertinggi. Peratusan penyerapan air meningkati apabila kandungan pengisi meningkat.

CHAPTER 1

INTRODUCTION

1.1 Background of Study

In recent years, researchers concern on their study on using natural fibres in composites. Bio-composites are derived from natural and renewable sources. Researchers found many possible option of combining natural fibres with matrix to produce composite. Examples of natural fibres include kenaf, jute and flax. Their sources can be derived from animals or plants. Nowadays bio-composites are widely used. For example, natural fibre reinforced polymer composites which have beneficial properties are used in commercial application such as automotive industry, buildings, and construction. For building application, natural fibre composites are used in roofing component as alternative for asbestos (Mohammed *et al.*, 2015).

There are many advantages of natural fibres. They are low cost, low density and biodegradable. They are also available in abundance and can be found easily. On the other hand, natural fibres have their weakness and problem. There are some factors that affect the performance of bio-composites. This includes fibre architecture and fibre-matrix interface. Fibre architecture which includes fibre geometry, fibre orientation, packing arrangement and fibre volume fraction influence the properties and behaviours of bio-composites. Furthermore the interface between matrix and fibre in composite leads to adhesion problem. This will affect mechanical properties of bio-composites. Increasing the fibre volume fraction is one of the ways to enhance mechanical properties of composites (Fowler *et al.*, 2006).

In past researches, researchers have focused their study on utilisation of waste banana peel in polymer matrix. Biopolymer made from banana peels was used to fabricate hydroxyapatite (HAP) nanocomposites. They are suitable to be used in the application in the field of biomedicine (Kanimozhi *et al.*, 2014). According to Yuvaraj and Jeyanthi (2015), brake pads were produced using banana peel powder and kenaf powder as fibre or filler material. It was shown that resin has good bonding with banana peels. Besides that, according to Mishra *et al.* (2015), bio-bag as alternative of plastic bag was prepared using banana peels.

Apart from that, polymeric films were synthesized by utilizing of waste banana peel. Different plasticizers such as polyethylene glycol 400 (PEG 400), sorbitol and glycerol were used to produce the polymeric films. The highest tensile strength was observed for the film with sorbitol (Prasad *et al.*, 2014).

It was reported that cellulose microfibril (CMF) which was extracted from banana peels, was used to prepare zein nanocomposite film. When the contents of CMF increased, tensile strength and Young's modulus increased but elongation at break of the films decreased. Higher CMF contents also caused the rigidity of composite films became higher. According to the result of mechanical properties, the amount of cellulose microfibrils in zein film should not more than 4 percent (Phiriyawirut & Maniaw, 2012).

According to the research of Pereira *et al.* (2013), scanning electron microscopy (SEM) micrograph showed that washed banana peel fibre has a rough surface because superficial layer has been removed after washing. This provides a better mechanical anchorage with the polymeric matrix. The result also showed that composites that reinforced with banana peel fibres exhibited higher tensile strength and tensile modulus compared to pure high density polypropylene (HDPE). However the composites with 5 wt% banana peel fibres have higher tensile strength compare with composites with 10 wt% banana peel fibres. A higher amount of fibre reinforcement caused the reduction in their mechanical properties.

Other than that, researchers also have focused on the study of using eggshell powder as filler in composite. For example, bio-polymer thin film was produced from banana peel, eggshell and epoxy. It was used as bio-mulching film and applied in agricultural field. It was biodegradable plastic film which moistened the soil and improved soil ingredient. This helped the plant to grow better. The bio-polymer thin films were degraded in soil burial test according to the result. It was effective and also environmental friendly because waste materials were utilized (Nik Yusuf *et al.*, 2016).

Moreover, polymer composites were synthesized from high density polyethylene and eggshell. The tensile strength and modulus elasticity of the composites reduced but their elongation at break and impact strength increased when the content of eggshell filler increased. The amount of water absorbed also increased when the amount of eggshell filler increased (Hussein *et al.*, 2011).

1.2 Problem Statement

Nowadays people have more concerned on environment pollution and prefer for green and renewable materials as alternative for non-renewable resources. Depletion of petroleum resources also makes people more aware on global environmental issue. Due to environmental problem and consumption of non-renewable resource, researchers have focused their study on the use of environmental friendly materials to produce composite. The development of bio-composites solves the problem and promotes the use of green materials (Chandramohan & Marimuthu, 2011). Researches have focused on the ways of utilizing solid wastes such as industrial and agricultural wastes as a source of raw materials in producing composites. The utilization of wastes is not only economically, but also helps in environmental control (Cheung *et al.*, 2009).

Apart from that, high cost of synthetic fibres is another reason. Natural fibres are available abundantly so they are low cost. They are getting more attention because of their availability and limitless resources. Therefore there is an increase in using natural fibres to fabricate composite compare with synthetic fibres. Due to low cost and low density, natural fibres have high potential to replace synthetic fibres.

The most commonly used natural fibres in bio-composite are from plant. This includes kenaf, hemp, coir and flax. In this research, bio-composite thin film is produced from food wastes. The food wastes used are waste banana peel and eggshell.

Large amount of solid wastes are ended up in dumping and as landfill. The solid wastes not only are plastic, but also contain a lot of food waste and agricultural waste. There are large quantities of food waste produced and thrown away in the world every day. The food wastes include fruit peels, eggshells and tea bags. The wastes are usually are dumped in municipal landfill. This results in environmental problems such as odour problem and water pollution which affect daily life of human. Utilization of food waste reduces the environmental problems. Therefore they are good resources in manufacturing composite by utilization of food waste (Toro *et al.*, 2007).

Environmental issues and depletion of non-renewable resources can became serious problems if no action is taken to solve them and prevent them. Therefore mankind should pay more attention to those issues.

1.3 Objectives

1) To compare the effect of different ratios of waste banana peel and eggshell filler in bio-composite thin film
2) To investigate the mechanical properties of waste banana peel/eggshell filler bio-composite thin film
3) To study the water absorption properties of waste banana peel/eggshell filler bio-composite thin film

1.4 Significance of Study

An effort to find alternative for non-renewable resources has promoted the exploration of environment friendly and renewable resources. Moreover composite materials have become significant option in fabricating product in the industry. Therefore composites are preferred to be produced by bio-based materials which are called bio-composite. This research increases the option for sources of natural fibres used in bio-composite (Fowler *et al.*, 2006).

In this research, bio-composite can be produced by waste banana peel and eggshell. The scope of bio-composite thin film made from natural fibres can be widened by including waste banana peel. Waste banana peel and eggshell can be obtained from solid waste. They are available abundantly and can be found easily. Therefore they can be manufactured at lower cost (Hossain *et al.*, 2012). Utilization of food wastes also reduce environmental problem. In this research, bio-composite is increased in variety type by using different natural fibres and they can be more widely used in different fields of applications.

Major trend nowadays in materials field is fabricating products from green and bio-based materials. However current challenge is improve the properties of bio-composite to compete with composite made from synthetic fibres. The aim of this research is to determine the mechanical and water absorption properties of the bio-composite thin film. Their strength and weakness can be comprehended. This will help in producing the bio-composite with improved and enhanced mechanical properties.

CHAPTER 2

LITERATURE REVIEW

2.1 Composites

Composite consist of two or more types of materials combine together to form a materials with improved properties that cannot be achieved by only individual material. Composite made up of matrix phase and reinforcement phase. The reinforcement phase is typically embedded in the matrix phase. The functions of matrix phase are to transmit externally applied loads and protect the reinforcement phase from mechanical damage. Reinforcement phase provides strength to composite (Fowler *et al.*, 2006).

Composites can be classified into three groups that are polymer matrix composites (PMC), metal matrix composites and ceramic matrix composites (CMC) (MMC). Most commonly used matrix materials are polymeric. It includes a matrix from thermoplastic or thermosetting (Chandramohan & Marimuthu, 2011). Composites have their advantages when compared with metals. They have light weight and can be moulded to complex form easily. However they have disadvantages such as long development times and low ductility (Kispotta). Properties of composites depend on the materials used. Composites which are formed from combination of two or more materials have their distinctive properties (Chandramohan & Marimuthu, 2011).

2.1.1 Bio-composites

Bio-composites are composites that consist of at least one component that is derived from bio-based materials. Natural fibres and polymer matrices which can be either biopolymer or synthetic polymer are the main components. Researchers searched various possibilities of combining natural fibres and with polymer matrices from renewable and non-renewable resources to form composite material. Green composites are bio-composites that fabricated from plant fibres and bio-derived plastics. Green composites are more environment friendly because they are derived from natural fibres and biopolymers (John & Thomas, 2008). Bio-composites with polymer and plant material contents are used in different fields of industries such as automotive industry and construction industry. Application of bio-composites prevents the imbalance of supply and demand of product made from non-renewable resources and promotes recycling process (Barton *et al.*, 2014).

According to the research of Singh *et al.* (2015), palmyra palm petiole fibre reinforced plastic (FRP) composites have good flexural properties and can be used to fabricate for automobile door panels and house hold applications. Bio-composites have potential to replace glass reinforced composite. Materials costs can be reduced by using renewable resources. Moreover market of bio-composite begins to grow in many industries such as automotive and aerospace (Mitra, 2014). Bio-fibres have comparable properties with glass fibres. They can be applied in wide range of industries. The primary idea of bio-composite is to preserve and save the environment (John & Thomas, 2008).

2.1.2 Matrix

The functions of matrix in composite are to bond the fibres together and load is transferred between them. Moreover they provide barrier from the environment. The surface of fibres is protected by matrix from mechanical stress. Polymeric, metallic, ceramic and carbon are major types of matrices. Polymeric matrices are used commonly. They can be divided into thermosetting and thermoplastic.

Other than that, biodegradable composite were fabricated by sisal fibre and cassava starch. Cassava starch which acts as matrix has good adhesion with fibre (Kispotta). Furthermore, biodegradable plastic material was produced from unripe banana which acted as matrix. It exhibited mechanical properties that are suitable for industrial purposes (Martín Martínez *et al.*, 2015).

The fibres or fillers are hold together by matrix in the composite and they are protected from any mechanical damage. Fabrication of bio-composite using matrix from renewable resources is explored although synthetic matrices such as thermoplastic and thermoset polymer are still more commonly used. Bio-based polymers such as starch and vegetable oils can be used as matrices in bio-composite. There is a demand for development on thermoset from renewable resources due to the limitation of thermoplastic (Fowler *et al.*, 2006).

2.1.3 Reinforcement

Fibres act as reinforcement phase in the composites. They are embedded in matrix phase in composites. They provide strength, toughness and stiffness for the composites. Loads are transfer by matrix phase to reinforcement phase. Properties of composites are mainly depended on the fibres used. Fibre can be divided into natural fibres and synthetic fibres (Fowler *et al.*, 2006). Other purposes of reinforcements in composites are as coefficient of thermal transport, thermal extension and conductivity (Kispotta).

2.2 Natural Fibres

Natural fibres are elongated materials from natural sources which act as reinforcement in composites. They are classified according to their sources. Animal fibres, plant fibres and mineral fibres are types of fibres. Plant fibres mainly consist of cellulose and they are applied in the industry of manufacturing paper and cloth. They can be further divided into seed fibre, leaf fibre, bast fibre, fruit fibre and stalk fibre. The most used natural fibres are cotton, flax, hemp, sisal, jute and kenaf (Chandramohan & Marimuthu, 2011).

The animal fibres mainly consist of proteins. Animal hairs are the strands obtained from animals such as goat hair and horse hair. Examples such as silk and wool are used as composite material in biomedical field. Mineral fibres are naturally occurring fibres that are obtained from minerals. They are naturally happening fibre or changed fibre. The most commonly used mineral fibre is asbestos (Kumar & Sujeet, 2014).

The combination of natural fibres and biodegradable polymer produce biodegradable composite which reduces the environmental problem. They should have good strength and stability while can be recycled after being used. They have the potential to be used in biomedical application as they are low cost, biodegradability and reduce the chance of tool wear (Cheung *et al.*, 2009).

2.3 Waste Banana Peel

Figure 2.1: Waste banana peels (Darge & Mane, 2013)

Banana is one of the most commonly consumed fruits in the world. 40 % of world trade in fruits is banana. There are large amount of banana peels being generated and disposed every day. They are dumped to municipal landfill which causes environmental problem. Utilization of banana peel in different fields can reduce the problem (Wachirasiri *et al.*, 2008).

Banana peel consist of rich source of starch (3 %), crude protein (6-9 %), crude fat (3.8-11 %), total dietary fibre (43.2-49.7 %), polyunsaturated fatty acids and micronutrients. Furthermore they are good source of lignin (6-12 %), pectin (10-21 %), cellulose (7.6-9.6 %), hemicellulose (6.4-9.4 %) and galactouroninc acid. Banana peels can be used in wine production and their ash can be used as fertilizer for plants (Mohapatra *et al.*, 2010).

Banana peel is the skin of banana which covers the fruit. Banana peel is a waste material rich in starch. They are 40 % of total weight of the banana. Table 2.1 shows the chemical composition of banana peel. It contains mainly carbohydrates (56.35 %), followed by fibre (15.30 %), ash (12.62 %), moisture content (7.65 %), crude fat (4.34 %), and protein (3.74 %). They can be used to produce valuable product (Singanusong *et al.*, 2014).

In addition, nano-cellulose based bioplastic biomaterials were produced from waste banana peel. It was found that the bioplastic had positive result in tensile test and chemical tests compared to synthetic plastic. Therefore waste banana peel has high potential to be used to produce bioplastic. It can be applied in vehicle bio-bumper (Sharif Hossain *et al.*, 2016).

Table 2.1: Chemical composition of dried banana peel

Chemical composition	Dry basis (%)
Moisture	7.65±0.05
Crude fat	4.34±0.74
Protein	3.74±0.42
Carbohydrate	56.35±0.37
Ash	12.62±0.09
Fibre	15.30±0.85

(Source: Riantong Singanusong, 2014)

A study showed that banana peel had the potential to be used in removal of copper from water. They were grounded into powder form and produce bio-adsorbent through environment friendly process (Hossain *et al.*, 2012). Other than that, banana peels could be used to activate carbon. The banana peel activated carbon was then mixed with 2 % mineral oil. The mixture was used as a precursor for carbon nanotube and nanocarbon (S., 2011).

Furthermore, banana peels were used to prepare nitrogen-doped banana peel derived porous carbon foam and it was used as a binder-free electrode for supercapacitors. They had high potential because they had excellent electrochemical performance. Banana peels provide a high specific surface area because they have high porosity. They also have suitable pore size distribution which lead to efficient contact between the electrolytes and the active material (Liu *et al.*, 2016).

Moreover, banana peel powder was applied as modified binder in four friction composites for manufacturing new brake pad material with new formulation. From the result, it was proved that there was improvement in the coefficient of friction increased at higher temperature. Therefore banana peel powder could be used effectively in producing brake pad to enhance the binding ability of phenolic resin at higher temperature (Bashir *et al.*, 2015).

Apart from that, banana peels were used to produce edible film which is a thin layer that can protect foods from environment and dissolved substances. The edible film which was functioned as food packaging was made from combination of banana peels, glycerol and clove oil. Banana peels had high potential as main component in edible film because they has high amount of starch (Astuti & Erprihana, 2014).

Besides that, banana peels with fish scales were used as adsorbents in removal of heavy metal in waste water. Purification of water using these waste materials was proved to be biodegradable and effective compared to synthetic adsorbent and chemicals. The result proved that the maximum efficiency to remove heavy metal was 60 % and 70 % effectively. It was a low investment and less labour way to purify water (Darge & Mane, 2013). Other than that, banana peels and saw dust ply board was used as non-veneer panel for construction projects. Both sawdust and banana peels ply board and oriented strand board had quite low drying efficiency (U. & Jr., 2013)

The fabrication of banana fibre based epoxy composites with different loading of fibre and different lengths of fibre are possible by hand lay-up process. Mechanical properties such as tensile strength and hardness are affected by fibre loading and length (Kumar & Sujeet, 2014). Composites which are made from banana fibre and natural rubber have higher tensile strength when concentration of fibre increases. This is because close packing of fibres increases the hardness of composite (S.Raghavendra *et al.*, 2013).

Moreover, another research was done on producing banana peel reinforced epoxy composites with different weight fraction of banana peel. From the result, it was found that 20 % reinforced banana peel epoxy composite had excellent mechanical properties. The flexural strength, tensile strength of the composite were found to be maximum for 20 % of banana peel fibre (Naidu *et al.*, 2013).

2.4 Organic Filler

The functions of filler in composite are to give strength and enhance its properties. The purposes of filler are to give support and provide toughness in composite. There are organic and inorganic fillers. Filler can be further classified according to their particle size. Organic fillers are obtained from natural sources such as kenaf and wood.

Bio-composite made from dupion silk fibre reinforced vinylester was added with gelatin as organic filler. The result showed that 30 % filler loading obtained better tensile properties compared to the 0 %, 10 %, 20 % filler content (S *et al.*, 2014).

Bio-composite using wheat straw flour as natural filler and high density polyethylene (HDPE) were manufactured. Flexural and tensile modulus of the composite increased when filler contents increased but flexural strength and elongation at break of bio-composite were reduced (Mengeloglu & Karakus, 2012).

2.4.1 Eggshell Filler

Figure 2.2: Eggshell (S. B. Hassan *et al.*, 2012)

Eggshell powder can be used as organic filler in composites. They showed a higher tensile modulus when added to composite compare to composite with calcium carbonate as synthetic filler (Toro *et al.*, 2007). About 95 % of the dry eggshell is calcium carbonate which has the weight of 5.5 g. Eggshell mainly consists of about

0.3 % phosphorous, 0.3 % magnesium, and traces of sodium, potassium, zinc, manganese, iron and copper. Polymer composite was produced by mixing calcium carbonate with eggshell powder. Addition of eggshell powder caused a decreasing in tensile strength but an increasing in flexural strength. Amount of water absorbed also increased when the content of eggshell increased. Eggshell has the potential to act as filler in composite because it is low cost and environmental friendly (J & Raj.P, 2015).

It was reported that polyester with eggshell particulate composite were produced. The tensile and bending strengths increased with increasing of eggshell particles loading. The hardness values also increased. According to the result of scanning electron microscopy (SEM), eggshell promoted better interfacial bonding between particles and matrix (S. B. Hassan *et al.*, 2012).

Besides that, eggshell was used as filler in E-glass with epoxy composites. Eggshell which had the major component of calcium carbonate had the potential to replace the synthetic calcium carbonate. The tensile modulus and impact strength of composites were improved by adding eggshell filler (Nayak *et al.*, 2015).

Furthermore, composites were synthesized from polypropylene and eggshell. When the content of eggshell filler increased, there were improvement in Young's modulus and hardness of composite. The crystallization properties also increased. This is because of good dispersion of eggshell in composites. However there were reduction in yield strength, impact properties and elongation at break. There was also enhancement in the properties of composites by reducing the size of eggshell particle and modifying the eggshell filler chemically. This result proved that eggshell had high potential to be used as green filler for thermoplastic (Iyer & Torkelson, 2014).

Micro-composites of unsaturated polyester with different percentage of eggshell powder were synthesised using hand- layup method. Mechanical properties such as tensile strength and young's modulus were determined. It was found that the value of mechanical properties reduced as filler loading increased. After eggshell powders were treated using different methods such as stearic acid, sodium hydroxide and silane agent, their mechanical properties are improved. This is because matrix and filler have better adhesion after treatment (Nasif, 2015).

Other than that, polymer nanocomposites were synthesized using polylite and bio-based calcium carbonate. The size reduction of waste eggshells was used to produce bio-based calcium carbonate. The result showed that there was good dispersion of bio-based calcium carbonate nanoparticles in the polymer matrix and the bio-nanoparticles were highly exfoliated in the polymer. Their mechanical properties also had been improved. From the result, polymer nanocomposites with 2 % loading of bio-CaCO3 nanoparticles had superior performance. It was important for the further study on this new class of bio-based materials to the industry such as automotive sector (T. A. Hassan *et al.*, 2011).

Apart from that, composites with polyamide, nylon black and eggshell were synthesised successfully through injection moulding. Polyamide and nylon black were acted as matric phase while eggshell was functioned as reinforcement phase in the composite. As the percentage of eggshell filler increased, mechanical properties such as tensile strength, impact strength and flexural strength of the polyamide/nylon black eggshell composites increased (Asha & Sekhar, 2014).

Low density polyethylene and eggshell powder composites were produced. It was found that there were improvement in tensile strength and water absorption resistance after adding isopthalic acid as a coupling agent. There was better adhesion between modified eggshell powder and matrix. Therefore the formation of agglomerates was reduced. This improves their strength and reduces their percentage of water absorption (Shuhadah & Supri, 2009).

2.5 Epoxy

Epoxy is widely used in the composite. Epoxy functions as structural material. This is because it has high strength and high modulus. The resistance to environmental degradation also can be improved. On the other hand, it is brittle. Therefore it is required to add with fibres and fillers to improve their properties and performance (Nayak *et al.*, 2015).

Epoxy is a chemical group in which there are two carbon atoms bonded to oxygen atom. Epoxy has higher mechanical properties and resistance to environmental degradation among other resins. It is commonly used in aircraft component and boat building. Epoxy which is used as laminating resin has high adhesive properties. It is cured easily and quickly at any temperature. Epoxy has high adhesive strength and high mechanical properties. Therefore it is suitable to be used as paints, adhesives, varnishes and laminating resins in variety of industrial applications (J & Raj.P, 2015).

Moreover, epoxy glass fibre fly ash laminate composite was fabricated using hand layup technique. They are resistance to aqueous environment and they also have high strength to weight ratio. Therefore they are extensively used in aerospace and automobile industries (Bhandakkar *et al.*, 2014).

Apart from that, epoxy was mixed with almond shell and coconut fibre to produce bio-composite. Utilization of renewable agricultural residue for manufacturing bio-composite had the potential to act as alternative of wood (Chaudhary *et al.*, 2014).

Besides that, it was reported that epoxy composites with oil palm press fibre as reinforcement were exploited. Epoxy which is a thermosetting polymer is very important in composite. It functions as structural adhesives materials for fibre-reinforced composite. It also holds the fibres together in the composite to make sure that stress is transferred effectively to the fibres (H.C *et al.*, 2014).

2.6 Plasticizer

A plasticizer is required to increase the flexibility of film. For example, it improved the process ability of chitosan and the mechanical properties of the films. 20 % w/w glycerol concentration was used to improve flexibility of chitosan film (Azeredo *et al.*, 2010).

Plasticizer is needed to fabricate fully biodegradable composite. However, higher percentage of plasticizer causes the fabrication process of bio-composite become more difficult. The plasticizer works better at the amount of 5 % to 20 % (Anuar & Maleque, 2010).

2.6.1 Glycerol

It was reported that glycerol was used in manufacturing of bio-composite with wheat gluten. It improves the flexibility of the bio-composites. However, from the result of SEM, high content of glycerol could lead to a poor interfacial interaction between the matrix phase and sawdust reinforcing particles (Yangsuk *et al.*, 2014).

Biodegradable packaging films were produced using sugar palm starch with different plasticizer such as glycerol and sorbitol. Their elongation at break decreased at a higher plasticizer concentration due to the anti-plasticization effect (Sanyang *et al.*, 2015).

CHAPTER 3

MATERIALS AND METHODS

3.1 Materials

The materials that were used in this study were waste banana peel, eggshell, glycerol 85 % and araldite 506 epoxy resin.

3.2 Methods

3.2.1 Preparation of Banana Peel

Waste banana peels were collected from Universiti Malaysia Kelantan (UMK) Jeli cafeteria. The stems of banana peels were trimmed off. Then they were dried in the oven at 80 °C for 6 hours to remove water present. Banana peels were cut into smaller section. One banana peel was cut into ten parts.

3.2.2 Preparation of Eggshell

Eggshells were collected from UMK Jeli cafeteria. The eggshells were washed with water to remove the membranes. The eggshells were dried under the sun. After that, dried eggshells were blended using blender. A sieve was used to filter the eggshell powder to obtain constant size of 75 μm particles.

Figure 3.1: Dry banana peel

Figure 3.2: Eggshell powder

3.2.3 Production of Bio-composite Thin Film

Banana peels were boiled with water using hot plate magnetic stirrer for 20 minutes to make them soft. The volume of water (ml) and weight of banana peels (g) were in the ratio of 20:1. Then the banana peel solution was blended with eggshell powder and glycerol using blender for 10 minutes. The amount of glycerol used was 15 % w/w of the dried banana peels. The blended paste was boiled at 70 °C for 15 minutes using hot plate magnetic stirrer.

The mesh surface of the silkscreen was moistened with water. Then the blended paste was spread over the silkscreen using ladle. A roller was used to make the surface of paste to be more flat. It was dried in oven at 80 °C for 3 hours. The bio-composite thin film was taken out from the silkscreen. The thickness of the thin film was in the range of 0.55 mm to 0.65 mm. The dimension of the film was 208 mm x 305 mm.

3.2.4 Hand lay-up and Compression Moulding Method

Hand lay-up process was used to fabricate the banana peel based epoxy composite. Epoxy was poured into a container. The bio-composite thin film was taken out from the mould and immersed into the epoxy manually. After laminating for 10 minutes, it was taken out. A roller was used on the thin film to remove excess epoxy and any trapped air. The roller was also used to consolidate the laminate and thoroughly wet the reinforcement. It was then allowed to cure. After drying, the thin film was placed on the mould and compressed. Then it was let to settle down to room temperature for 24 hours.

The procedures were repeated by using different ratio of banana peel and eggshell. Bio-composites with 0 %, 5 % and 10 % eggshell were synthesized. Table 3.1 shows the different types of samples which had different percentage of banana peel and eggshell were used in this study.

Table 3.1: Different types of samples with different percentage of banana peel and eggshell

Types of samples	Percentage of banana peel (%)	Percentage of eggshell (%)
1	100	0
2	95	5
3	90	10

Figure 3.3: Dry banana peel was boiled for 20 minutes.

Figure 3.4: Banana peel was blended with eggshell powder and glycerol for 10 minutes.

Figure 3.5: The blended paste was spread over on silkscreen.

3.2.5 Tensile Test

The mechanical properties of bio-composite thin films produced were tested. For tensile test, bio-composite thin films were cut to obtain the desired dimension of specimen. Six samples from each ratio were used for this testing. Each specimen size was 130 × 30 mm^2 as shown in Figure 3.6. In this test, the material was pulled until it broke to measure tensile strength, Young's modulus, stiffness and strength at break.

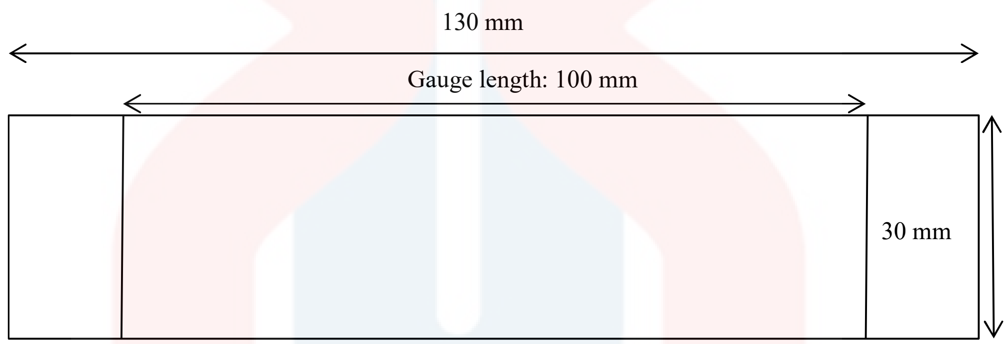


Figure 3.6: Size of sample for tensile test

Tensile test was tested according to standard ASTM D882 using Universal Testing Machine (Instron, model 1011, UK) with load range 20 N, cross head speed 500 mm/min, gauge length 100 mm and efficiency within ± 1%. The films were placed between the two vertical grips of the tester in the test. After that, one of the movable grips was driven to move upward while another was driven to move downward with a speed of 500 mm/min until the rupture of the film. Six samples were tested for each ratio and the average was obtained. Tensile strength and percent elongation at break were calculated using the data from the recorded load-time profiles.

Tensile strength was calculated by dividing the load at break by the original minimum cross-sectional area. The result was expressed in N/mm^2 and reported to three significant figures.

$$\text{Tensile strength} = \frac{\text{(Load at break)}}{\text{(Original width) (Original thickness)}} \qquad \text{Equation 3.1}$$

Percent elongation was calculated by dividing the elongation at the moment of rupture by the initial gauge length and multiplying by 100. The result was expressed in percent and reported to two decimal places.

$$\text{Percent elongation} = \frac{\text{(Elongation at rupture)}\ x\ 100}{\text{(Initial gauge length)}} \qquad \text{Equation 3.2}$$

Young's modulus was calculated by drawing a tangent to the initial linear portion of the stress strain curve, selecting any point on this tangent, and dividing the tensile stress by the corresponding strain. The result was expressed in megapascals (MPa) and reported to three significant figures.

$$\text{Young's modulus} = \frac{\text{(Load at point on tangent) (Original width) (Original thickness)}}{\text{(Elongation at point on tangent) (Initial gauge length)}}$$

Equation 3.3

3.2.6 Tear Resistance Test

For tear resistance test, five samples from each ratio were tested by using the same machine as in tensile test. The standard used was ASTM 1938-08. The specimens were in the size of 90 x 25 mm^2 as shown in Figure 3.7.

Before the test, a pre-made crack was introduced in each sample. The pre-made crack was cut in the middle of the sample with the length of 65 mm. The sample was then mounted in the machine. The two legs which were the pre-made crack were the grip area. During the test, the legs were separated and clamped in the grips to minimize slippage. After that, it was extended when the force with a speed of 250 mm/min was applied, the pre-made crack was continued to grow. The force required to propagate the pre-made crack in a film specimen was measured.

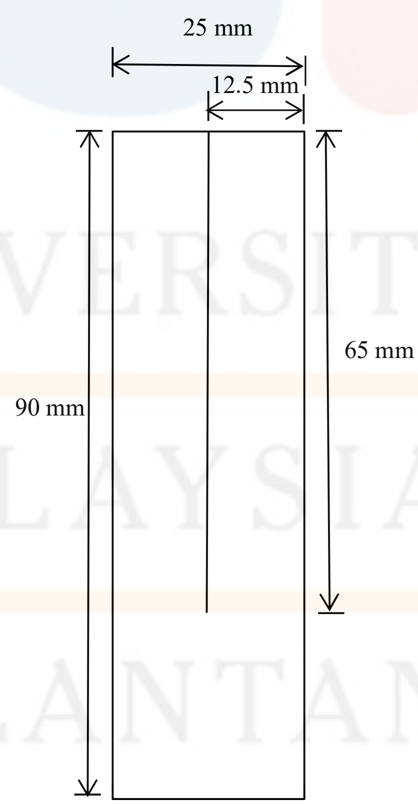


Figure 3.7: Size of sample for tear resistance test

Tear strength was calculated by dividing the maximum force (in Newtons) by the thickness (in millimetres) of the sample. The result was expressed in N/mm and reported in three significant figures.

$$\text{Tear strength} = \frac{\text{Maximum force}}{\text{Thickness}} \qquad \text{Equation 3.4}$$

3.2.7 Scanning Electron Microscopy (SEM)

After the testing of mechanical properties of bio-composite thin film, the samples were observed using SEM (model JSM-6460 LV). Before testing, the samples were coated with a thin conducting layer of palladium. The morphology of tensile fracture surface of the samples was determined.

3.2.8 Water Absorption Test

The standard for water absorption test was ASTM D570-98. The initial weight of the samples were determined and recorded. The size of the sample was 25 x 25 mm^2. Three samples from each ratio were immersed in distilled water. On the first day, the weights of the samples were determined every hour. After that, the samples were weighted regularly at 24, 48, 72, 96 and 120 hours. The percentage of water absorption (Mt %) was calculated by the following equation:

$$Mt\,\% = \frac{Wt - Wo}{Wo}\ x\ 100$$ Equation 3.5

Where W_o is the initial mass and W_t is the mass after immersion. The average readings of three samples were taken in two decimal places.

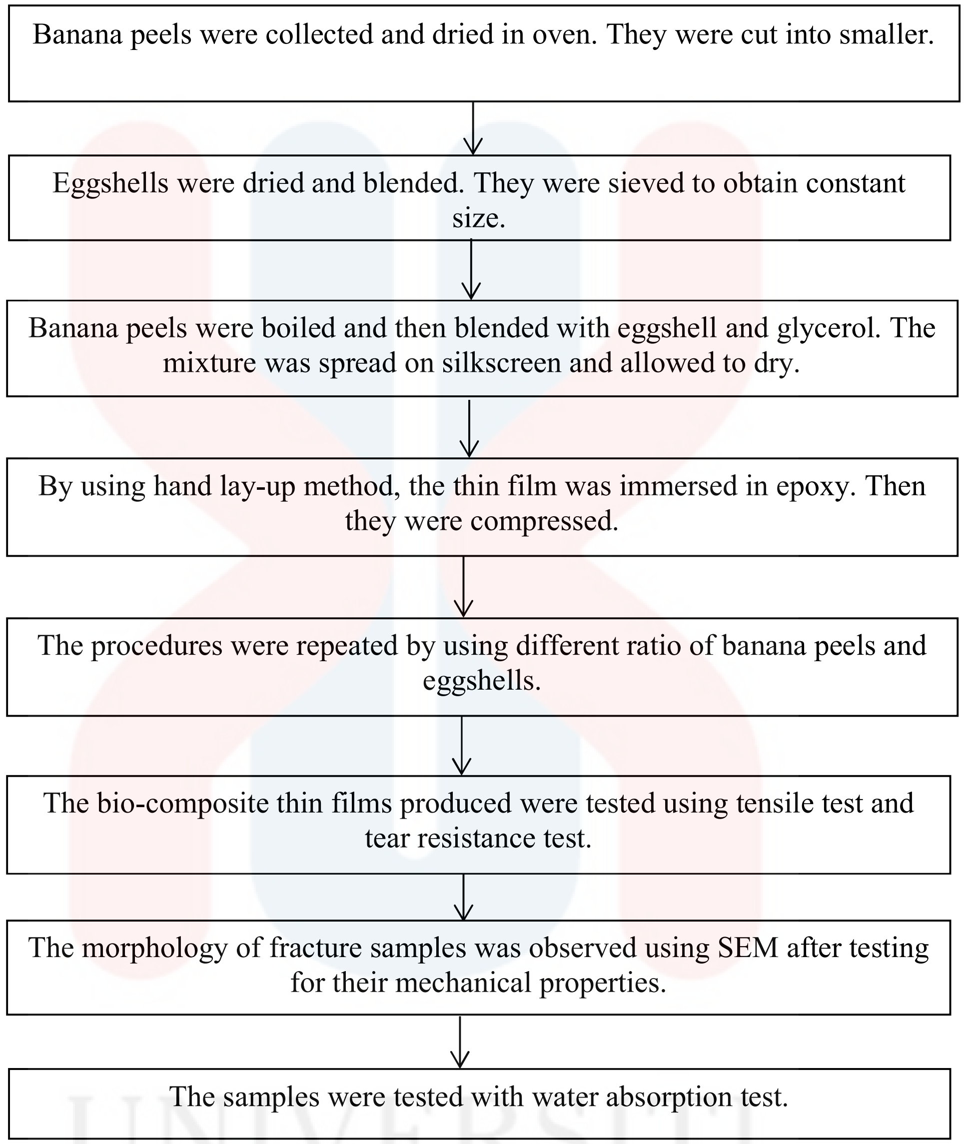


Figure 3.8: Flow chart

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Tensile Test

Mechanical properties of the bio-composite were investigated through tensile test. In this test, tensile strength, percent elongation, Young's modulus and of samples with different percentage of eggshell were determined.

Table 4.1: Tensile strength of samples with different percentage of banana peel and eggshell

Sample	Percentage of banana peel (%)	Percentage of eggshell (%)	Tensile strength (N/mm^2)
1	100	0	0.762
2	95	5	0.927
3	90	10	1.15

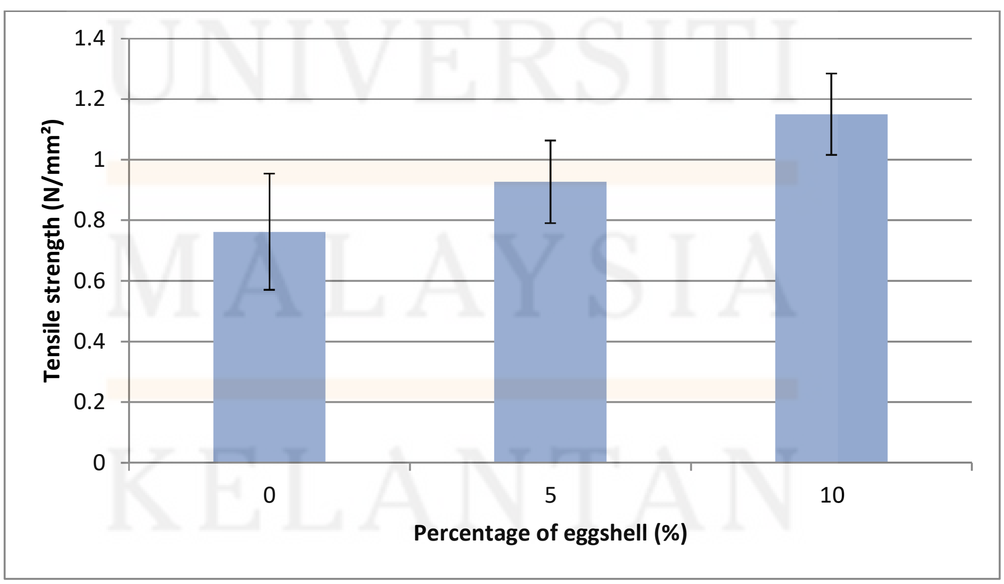


Figure 4.1: Comparison of tensile strength for bio-composite with different percentage of eggshell

Table 4.1 shows the tensile strength of the bio-composite with different percentage of banana peel and eggshell. From Figure 4.1, it can be seen that the tensile strength increased when the percentage of eggshell in bio-composite increased. Bio-composite with 10 % of eggshell exhibited the highest tensile strength that was 1.15 N/mm^2 while bio-composite with 0 % of eggshell obtained the lowest tensile strength that was 0.762 N/mm^2. Compare with sample with only banana peel, the tensile strength had enhanced by 50.92 % after adding 10 % of eggshell. The tensile strength of sample with 5 % of eggshell was 0.927 N/mm^2. The enhancement in tensile strength by adding 5 % of eggshell into was less than that sample with 10 % of eggshell, only improved by 21.65 %.

The improvement in tensile strength with increasing of filler content could be explained by there is stress transfer from the banana peel fibres to eggshell fillers. When the filler particle content increases, more stress can be transferred from the banana peel which acts as matrix to eggshell filler in the composite. This leads to higher tensile strength. As a result there was a sharp increment in tensile strength of sample with 10 % of eggshell. Moreover eggshell filler has good dispersion in the bio-composite. There is higher linkage and interaction between matrix and reinforcement as the eggshell particles loading increases. This strong bonding force and interfacial adhesion help to reduce the slip during tension. Therefore the bio-composite with higher eggshell filler content is able to withstand more load and stress tending to elongate.

On the other hand, sample without eggshell filler exhibited the lowest tensile strength. This is because it has no eggshell filler to assist to withstand the stress that being stretched or pulled during testing before damage. Without eggshell, it only depends on the banana peel which acts as matrix phase in the bio-composite. The load carrying capacity of the bio-composite is limited. It has lower ability to receive stretching force. The addition of filler in molecular chain of matrix phase affects the intermolecular force and chain entanglement of composite because filler has reinforcing ability (Nasif, 2015). Furthermore, there is no reduction in tensile strength of bio-composite even at higher filler content. It is a good indication of compatibility of banana peel and eggshell filler in the bio-composite.

The result shows that tensile strength of the bio-composite increased with the increasing content of eggshell filler. This observation was similar with the result reported by S. B. Hassan *et al.* (2012). Interfacial area between banana peel matrix phase and eggshell particles increases when eggshell particles in bio-composite increase. The probability for the formation of a filler network also increases. This facilitates stress transfer between phase because of increment in interfacial adhesion between matrix and filler.

Table 4.2: Percent elongation of samples with different percentage of banana peel and eggshell

Sample	Percentage of banana peel (%)	Percentage of eggshell (%)	Percent elongation (%)
1	100	0	8.35
2	95	5	7.63
3	90	10	4.98

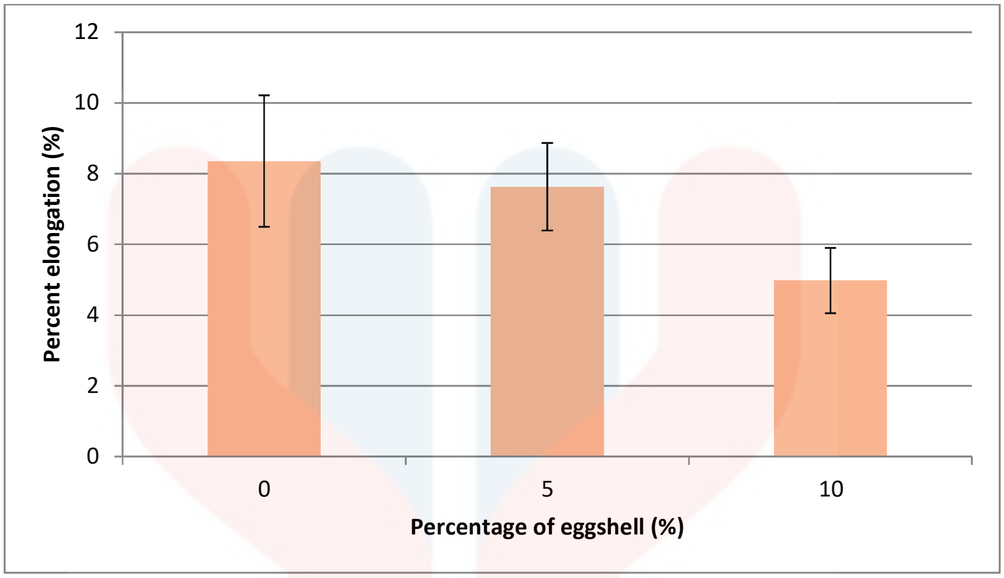


Figure 4.2: Comparison of percent elongation for bio-composite with different percentage of eggshell

Table 4.2 shows the percent elongation of samples with different percentage of banana peel and eggshell. From the result, it can be shown that sample with 0 % of eggshell had 8.35 % elongation while sample with 5 % of eggshell had 7.63 % elongation. The percent elongation of bio-composite had decreased by 8.62 % after adding 5 % eggshell. For sample with 10 % of eggshell, the percent elongation was 4.98 %. Compare with sample which has 0 % of eggshell, percent elongation had decreased by 40.36 % after adding 10 % eggshell in bio-composite.

From Figure 4.2, it can be seen that the percent elongation decreased with the increasing of percentage of eggshell. Sample with 0 % of eggshell showed the highest value for percent elongation while the lowest percent elongation was observed for the sample with 10 % of eggshell. This may due to the amount of eggshell particle plays an important role in banana peel based bio-composite. Percent elongation is the measure of ductility. This means that the ductility of the samples decrease as the eggshell filler content increases. Higher filler content harden the bio-composite. This leads to chain mobility of matrix being restricted and filler particle acting as defect points (Farahana RN *et al.*, 2014). As filler loading increases, there is a higher possibility of filler agglomeration which hinders filler orientation. As a result the stiffness and brittleness of the bio-composite increase. Therefore this results in the deterioration of elongation of composite during tensile test.

For sample which only had banana peel, it demonstrated the highest percent elongation. This means it has the highest ductility among others. This is because it does not have eggshell filler that reduces the chain mobility or deformability of the bio-composite. Therefore, there is retention of ductile behaviour compare to those samples which contain eggshell filler.

It is opposite between strength and elongation at break. By comparing the result of tensile strength and percent elongation of the bio-composite, as percentage of eggshell filler in composite increases, their tensile strength increases while their percent elongation decreases. Improved interface between banana peel and eggshell filler does not contribute to improve ability in elongation. Increasing eggshell filler leads to stiffening and hardening in bio-composite. Their rigidity also increases. This reduces their resilience and toughness which cause the percent elongation of bio-composite to decrease (Shuhadah & Supri, 2009). It has lower ability to resist deformation without formation of crack.

Table 4.3: Young's modulus of samples with different percentage of banana peel and eggshell

Sample	Percentage of banana peel (%)	Percentage of eggshell (%)	Young's modulus (MPa)
1	100	0	42.5
2	95	5	46.9
3	90	10	76.1

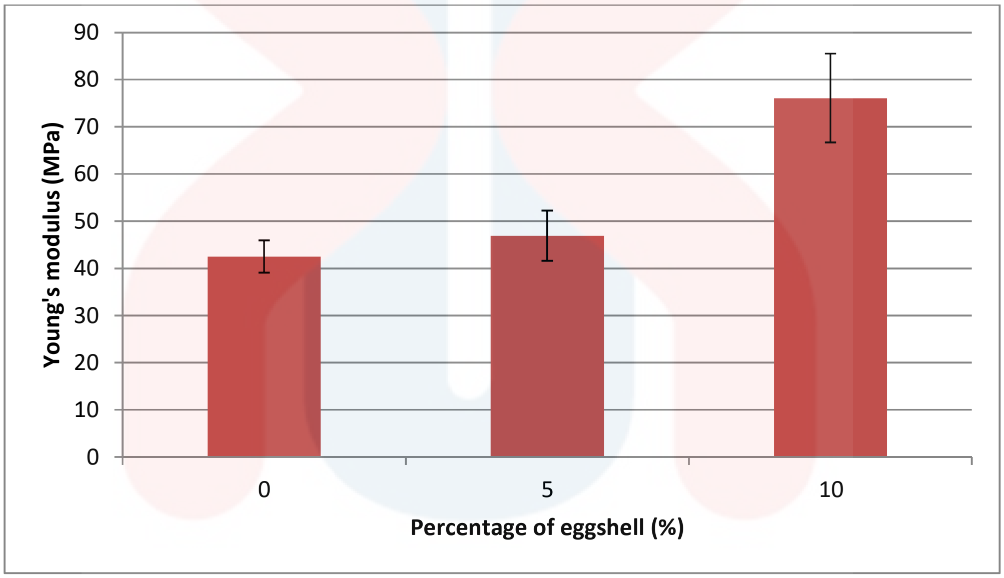


Figure 4.3: Comparison of Young's modulus for bio-composite with different percentage of eggshell

Table 4.3 shows Young's modulus of samples with different percentage of banana peel and eggshell. From Figure 4.3, it can be seen that Young's modulus increased with increasing eggshell filler loading in banana peel based bio-composite. Sample with 10 % of eggshell had the Young's modulus of 76.1 MPa which was the highest among others while sample with 0 % of eggshell demonstrated the lowest Young's modulus that was 42.5 MPa. This means that there was an improvement of 79.06 % in Young's modulus by adding 10 % of eggshell into composite compare with sample with 0 % of eggshell. For sample with 5 % of eggshell, Young's modulus was 46.9 MPa. However its Young's modulus had only increased by 10.35 % compare with sample which only has banana peel.

From the result, it can be showed that bio-composite with 10 % of eggshell filler which demonstrated the highest Young's modulus is the stiffest film among others. Young's modulus and stiffness affect each other because there is a relationship between them. Young's modulus which also can be known as elastic modulus reveal the stiffness of material. It is also the measure of ability of material to resist the elastic deformation under load. The fibre loading and properties of fibre affect Young's modulus of the bio-composite (Phiriyawirut & Maniaw, 2012). Therefore sample with 10 % of eggshell also exhibited the highest stiffness. Sample with 10 % of eggshell filler which showed the highest Young's modulus can be proved that it is the most brittle film compared with others. It changes its shape slightly. It is rigid and requires more force to deform.

As the filler content increases, the mobility and deformability of banana peel matrix phase are restricted. Well dispersion of rigid eggshell particle also leads to uniform stress transfer which prevent stress concentration around eggshell embedded matrix. High Young's modulus of composite with higher filler loading proves that the eggshell filler has its intrinsic properties as a request agent exhibit high stiffness (Shuhadah & Supri, 2009). As a result, eggshell filler increases stiffness of the bio-composite. This interaction between matrix and filler makes them able to withstand more loads and resist the change of shape.

Young's modulus also indicates the stiffness of a material. Hence, the result of Young's modulus also can be proved that the stiffness of the sample increases with increasing of eggshell filler content. It can be proved that eggshell fillers affects Young's modulus of the bio-composite which is also an indication of stiffness of material. This proves that elongation at break of the sample was reduced because the stiffness increases as eggshell filler increases (Iyer & Torkelson, 2014). The rigid interface between banana peel matrix phase and eggshell filler restricts the chain mobility of system. Therefore higher force is required to cause deformation. The adding of eggshell filler into bio-composite gives positive contribution for their enhancement.

On the other hand, sample with 0 % of eggshell obtained the lowest Young's modulus and it can be characterized as the most flexible sample compare to others. It changes its shape considerably. It requires less force to deform. For sample without any eggshell filler, stress cannot be transferred from banana peel which acts as matrix phase to eggshell filler. Bio-composite that without eggshell does not have filler to assist in withstanding more loads. Without eggshell filler, composite with only banana peel does not have enough to restrict the mobility of the system. Therefore it has the lowest rigidity and requires only fewer loads to elastically deform it. Therefore it is easier to be deformed.

4.2 Tear Resistance Test

Table 4.4: Tear strength of samples with different percentage of banana peel and eggshell

Sample	Percentage of banana peel (%)	Percentage of eggshell (%)	Tear strength (N/mm)
1	100	0	2.40
2	95	5	1.63
3	90	10	0.769

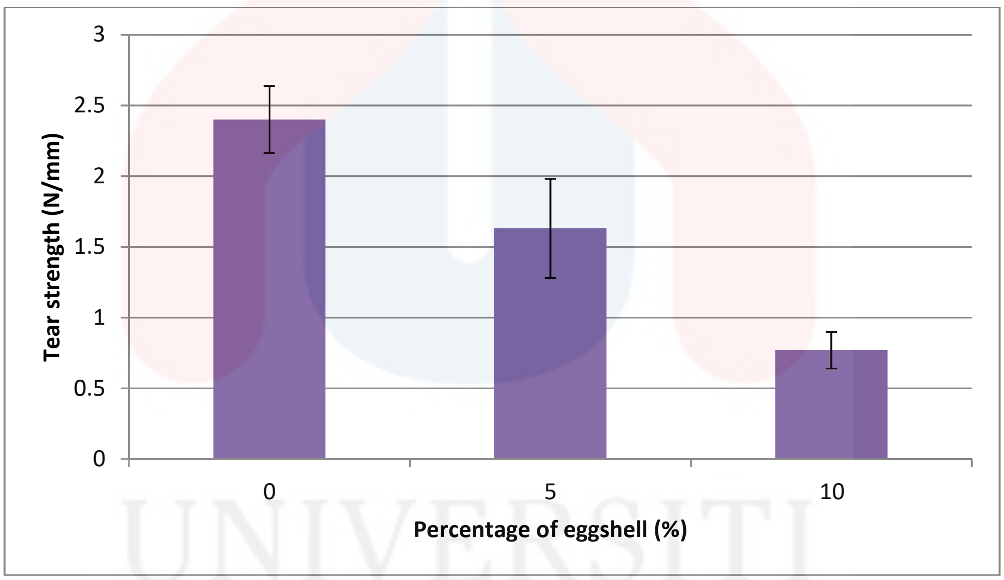


Figure 4.4: Comparison of tear strength for bio-composite with different percentage of eggshell

Table 4.4 shows the tear strength of samples with different percentage of banana peel and eggshell. From the Figure 4.4, it can be observed that the tear strength of the samples decreased with the increasing of eggshell filler loading. The tear strength of sample with 0 % of eggshell demonstrated the highest tear strength that was 2.40 N/mm while the lowest tear strength was observed for the sample with 10 % of eggshell that was 0.769 N/mm. The tear strength of the sample had decreased by 67.96 % after adding 10 % eggshell to the banana peel based bio-composite. For sample with 5 % of eggshell, the tear strength was 1.63 N/mm. Its tear strength had decreased by 32.08 % after adding 5 % of eggshell compare with the sample which has no eggshell.

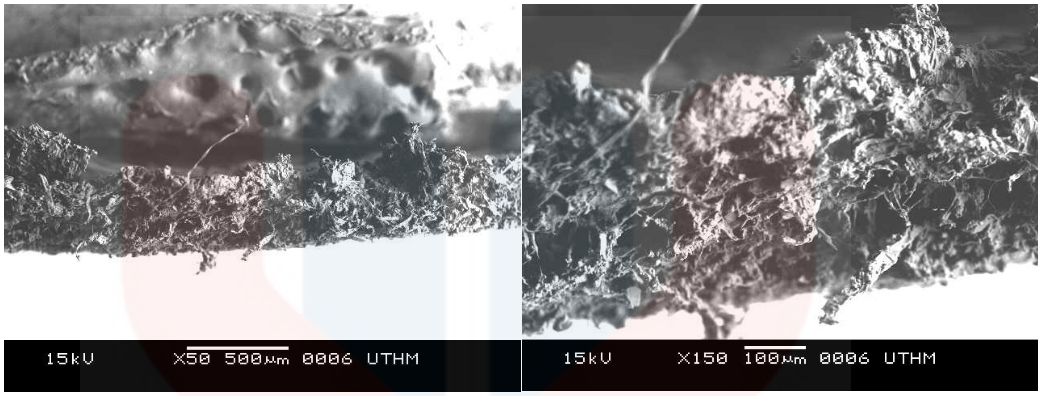
Tear resistance test is used to determine the degree of a material to withstand the tearing effects. Tear strength can be defined as the resistance to crack propagation of a material when under tension. A pre-existing tear is made in the sample before testing. The amount of energy that is able to be absorbed by each material before it fails is determined. The tear strength decreases with the increasing of eggshell filler content. From the result of tensile strength of the samples, the bio-composite exhibited higher tensile strength, higher Young's modulus and lower percent elongation as the percentage of eggshell filler increases. This proves that composite with high eggshell filler content is brittle and low extensible material.

In addition, eggshell filler increases the brittleness of the samples. Hence the sample with higher filler content has higher brittleness and hardness. It is a low extensible material which has low ductility. Therefore it only requires a small force to deform. Moreover high filler content causes the composites to be less extensible and less plastic deformation compare to composite without any filler. As a result, only a small force is required to fracture the low extensible sample. Moreover it is fractured in brittle mode instead of in ductile mode. Besides that, low bonding forces and voids present in the composite may cause crack path follows small voids. This leads to small variation in forces. Energy is used on the adjacent of the crack tip and new crack surfaces are created (Andreasson *et al.*, 2013).

Other than that, sample with highest eggshell filler content showed the lowest tear strength. This is because there is high possibility of agglomeration in composite after adding more filler. The agglomerates act as a barrier to molecular chain movement in the composite which initiate failure under stress. As a result, it has poor resistance to abrasion and fail rapidly when damaged (Gingh *et al.*, 2013).

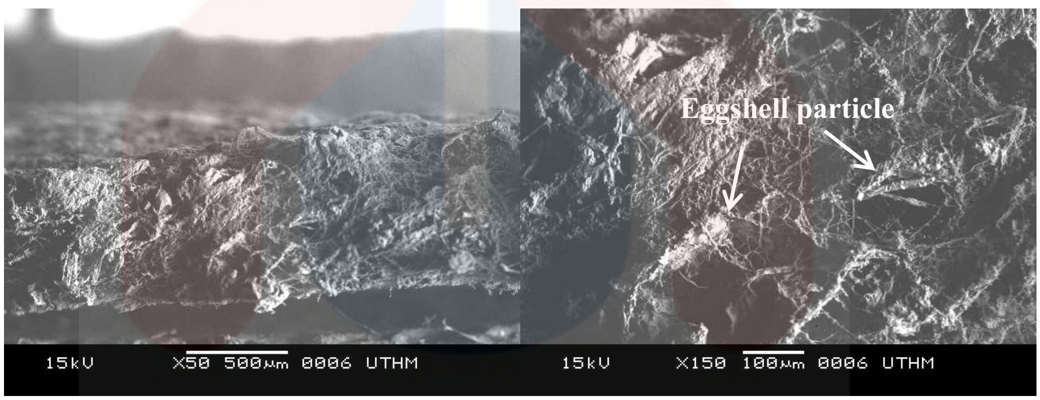
Sample without any eggshell filler exhibited the highest tear strength. Factors that affect the tearing force include types of material, temperature, material anisotropy and loading rate (Andreasson *et al.*, 2013). Due to no eggshell filler, composite with only banana peel is less brittle compare to those with eggshell filler. It shows more plastic deformation and more extensible among others. Therefore it is able to absorbs more force and withstand more tear force before it fails.

4.3 Scanning Electron Microscopy



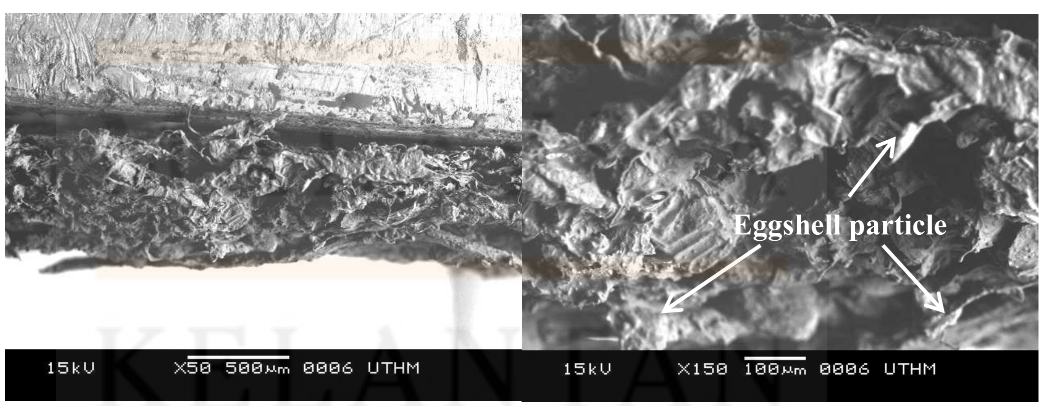
(a) (b)

Figure 4.5: SEM micrographs of tensile fracture surface of sample with 0 % of eggshell (a) and (b)



(a) (b)

Figure 4.6: SEM micrographs of tensile fracture surface of sample with 5 % of eggshell (a) and (b)



(a) (b)

Figure 4.7: SEM micrographs of tensile fracture surface of sample with 10 % of eggshell (a) and (b)

Figure 4.5 shows the tensile fracture micrograph of sample with 0 % of eggshell while Figure 4.6 shows the tensile fracture micrograph of sample with 5 % of eggshell. Figure 4.5 shows rougher surface than in Figure 4.6. There are many voids and it can be seen that the pull out of banana peel fibre during the fracture of composite as in Figure 4.5 (a) (Shuhadah & Supri, 2009). Apparent gaps in banana peel and pull out of banana peel fibre indicate improper and poor adhesion in the composite. This result proves that the composite without eggshell filler as reinforcement phase has weak bonding. Therefore it demonstrated the lowest tensile strength. Sample with 0 % of eggshell shows more plastic deformation of the matrix compare to others but it also fractured in brittle mode.

According to the research of Hossain *et al.* (2012), banana peel fibre has microporous structure. Its surface is heterogeneous and rough with pores. It can be seen that the particles of banana peel are irregular in shape. Therefore the rough texture on the surface of banana peel can facilitate the bonding with filler particle in the composite. Other than that, according to the research of S. B. Hassan *et al.* (2012), morphological study showed that eggshell have smooth spherical surface. Therefore eggshell particle which acts as reinforcement phase have more surface area for interaction with banana peel matrix.

Figure 4.7 shows the tensile fracture micrograph of sample with 10 % of eggshell. Figure 4.7 shows smoother surface than in Figure 4.6. Compare to sample with 0 % of eggshell as in Figure 4.5, sample with 10 % of eggshell has narrower and less apparent gaps. This is because eggshell particle which are added to the composite fill the gaps between the banana peel. The interfacial adhesion between matrix phase and reinforcement phase is determined. The eggshell filler is distributed uniformly. This indicates the good compatibility of eggshell filler with banana peel matrix. There are good adhesion and interaction between banana peel and eggshell filler. Good dispersion of eggshell particle without filler aggregation even in higher filler loading result in the composite leads to better mechanical performance (Iyer & Torkelson, 2014). This is reflected by higher mechanical properties in the composite. As a result, sample with 10 % of eggshell exhibited the highest tensile strength. Higher eggshell filler content in composite leads to more stress can be transferred from matrix phase to reinforcement phase.

It can be seen that the tensile fracture sample has uniform crack propagation as shown in Figure 4.7 (a). This is due to the good distribution of eggshell particles promotes in preventing the crack growth near failure region. However it shows less plastic deformation which indicates brittle failure mode compare to others.

4.4 Water Absorption Test

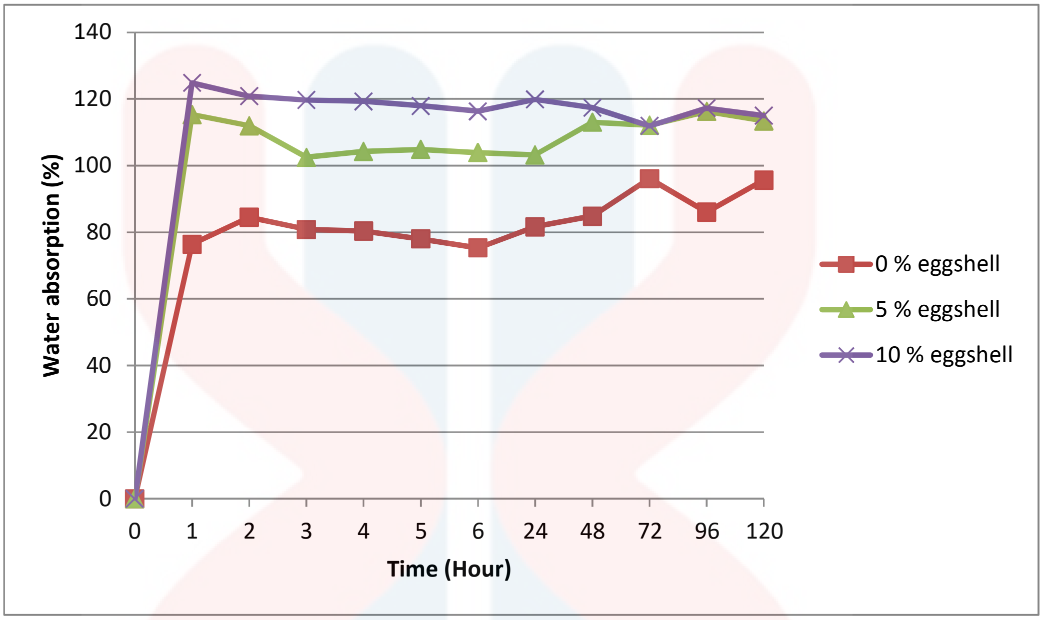


Figure 4.8: Water absorption of samples with different percentage of eggshell

Figure 4.8 shows the water absorption behaviour of samples with different percentage of eggshell. It can be seen that the water absorption of bio-composite increased with increasing eggshell filler content. It also can be observed that the samples absorbed high amount of water in the first hour and after that remained almost constant. The equilibrium inside the composite was rapidly reached after one hour. Sample with 10 % eggshell reached its maximum water absorption of 124.81 % after 1 hour. Then it had its amount of water absorption in the range between 115 % and 120.84 %. For sample with 5 % of eggshell, it reached its maximum water absorption of 116.27 % after 96 hours but it also reached 115.31 % after 1 hour. Then the amount of water absorption was in the range between 102.51 % and 116.27 %. For sample with 0 % of eggshell, it reached its maximum water absorption of 96.09 % after 72 hours but it also reached 76.44 % after 1 hour. Then the amount of water absorption was in the range between 75.30 % and 96.09 %.

Compare with sample with 0 % of eggshell, its maximum water absorption had increased by 29.89 % after adding 10 % eggshell while it had increased by 21.00 % after adding 5 % eggshell. From figure 4.9, sample with 10 % of eggshell demonstrated the highest amount of water absorption among others. Water absorption increased with the increasing of eggshell filler content. This is due to natural fibre are highly hydrophilic in nature. In this bio-composite, banana peel and eggshell are hydrophilic while epoxy is hydrophobic (Shuhadah & Supri, 2009). More eggshell filler which is permeable to water in bio-composite leads to more hydrogen bonds can be formed between components and water molecules. Therefore more water can be diffused into the composite.

Apart from that, as there are more filler contents in the bio-composite, higher level of calcium carbonate is present. This causes them are able to absorb more water (Farahana *et al.*, 2015). Other than that, there is higher possibility for formation of agglomeration of filler in composites when the filler contents increases. This is because difficulties to achieve homogenous dispersion of filler in composite increases at high filler content. Therefore the amount of voids between matrix and fillers also increases. More water molecules can be diffused into gaps and flaws between the interface of matrix and filler (Hussein *et al.*, 2011).

On the other hand, sample without any eggshell filler obtained the lowest amount of water absorption. Composite with only banana peel forms less hydrogen bond with water molecules compare with composite has eggshell filler. Moreover it has less hydrophilic material in the composite without eggshell filler. Therefore less water diffuse into the sample.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this study, bio-composites were successfully fabricated from banana peel, eggshell, glycerol and epoxy. The mechanical and water absorption properties of the bio-composite with different percentage of eggshell filler were determined.

For mechanical properties, sample with 10 % of eggshell demonstrated the highest tensile strength and Young's modulus but showed the lowest percent elongation and tear strength. The tensile strength and Young's modulus of the samples increased as the eggshell filler content increased. This is because more stress can be transferred from banana peel matrix to eggshell filler with increasing of filler loading. On the other hand, percent elongation of the samples decreased as the eggshell filler content increased. This is because eggshell filler increase the strength of the material to withstand more stress but also increase the stiffness of the sample. This result was evidenced by SEM on the tensile fracture surface of the bio-composite.

For tear resistance test, the highest tear strength was observed for the sample with 0 % of eggshell filler. The tear strength of the bio-composite decreased as the eggshell filler content increased. It is less extensible and more brittle with increasing of eggshell filler content. Therefore they require only a small force to fracture.

For water absorption properties, sample without any eggshell filler absorbed the lowest amount of water while sample with 10 % of eggshell absorbed the highest amount of water. The percentage of water absorption of the bio-composite increased as the eggshell filler loading increased. This is because eggshell filler which is hydrophilic cause more hydrogen bond can be formed. Therefore more water can be absorbed.

5.2 Recommendations

In my opinion, other mechanical test can be carried out such as impact test, flexural test and compression test. This is because tensile strength and tear strength were focused mainly in this research. More mechanical properties of the bio-composite can be determined.

Besides that, further research can be done on chemically modifying the banana peel. This may affect their mechanical and water absorption properties. Different chemical treatment on natural fibre can be used to compare the different effect on their properties. Examples of chemical treatment include silane treatment, alkaline treatment and benzoylation treatment.

Apart from that, varying particle size of modified and unmodified eggshell powders can be carried out to study their effect on mechanical and water absorption properties. In this project, bio-composite was fabricated using a constant size of unmodified eggshell filler. By using different size of eggshell powder and modifying them, their interaction with other components in composites can be studied to see whether there is any improvement in their properties.

Moreover, the eggshell filler used in this project is organic filler from natural source of calcium carbonate. Inorganic filler can be used to study the different effect in bio-composite compare with organic filler. One of the examples of inorganic filler is talc.

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APPENDIX A

Tensile strength, percent elongation and Young's modulus of samples

Table A.1: Tensile strength, percent elongation and Young's modulus of sample with 0 % of eggshell

Sample	Gauge length (mm)	Width (mm)	Thickness (mm)	Load at break (N)	Tensile strength (N/mm^2)	Percent elongation (%)	Young's modulus (MPa)
1	100	30	0.62	20.070	1.079	7.1293	45.007
2	100	30	0.62	11.275	0.6062	7.0712	40.061
3	100	30	0.62	10.007	0.5380	6.2712	38.123
4	100	30	0.62	16.622	0.8937	11.667	44.590
5	100	30	0.62	15.692	0.8437	9.8295	47.506
6	100	30	0.62	11.386	0.6122	8.1220	39.434
Mean					**0.762**	**8.35**	**42.5**
Standard deviation					**0.1921**	**1.857**	**3.421**

Table A.2: Tensile strength, percent elongation and Young's modulus of sample with 5 % of eggshell

Sample	Gauge length (mm)	Width (mm)	Thickness (mm)	Load at break (N)	Tensile strength (N/mm^2)	Percent elongation (%)	Young's modulus (MPa)
1	100	30	0.65	23.345	1.197	8.2460	57.494
2	100	30	0.65	15.919	0.8164	6.6040	41.144
3	100	30	0.65	17.658	0.9055	7.6130	47.521
4	100	30	0.65	14.903	0.7643	6.2878	41.854
5	100	30	0.65	18.321	0.9395	9.6627	46.386
6	100	30	0.65	18.300	0.9385	7.3878	47.127
Mean					**0.927**	**7.63**	**46.9**
Standard deviation					**0.1368**	**1.237**	**5.347**

Table A.3: Tensile strength, percent elongation and Young's modulus of sample with 10% of eggshell

Sample	Gauge length (mm)	Width (mm)	Thickness (mm)	Load at break (N)	Tensile strength (N/mm^2)	Percent elongation (%)	Young's modulus (MPa)
1	100	30	0.58	20.892	1.201	3.6124	73.461
2	100	30	0.58	16.381	0.9414	5.5452	69.466
3	100	30	0.58	19.662	1.130	6.1712	67.434
4	100	30	0.58	18.482	1.062	4.8628	83.436
5	100	30	0.58	20.030	1.151	4.0044	69.170
6	100	30	0.58	24.050	1.382	5.7129	93.489
Mean					**1.15**	**4.98**	**76.1**
Standard deviation					**0.1341**	**0.9230**	**9.401**

APPENDIX B

Tear strength of samples

Table B.1: Tear strength of sample with 0 % of eggshell

Sample	Thickness (mm)	Maximum force (N)	Tear strength (N/mm)
1	0.62	1.3197	2.129
2	0.62	1.4345	2.314
3	0.62	1.7478	2.819
4	0.62	1.4025	2.262
5	0.62	1.5312	2.470
Mean			**2.40**
Standard deviation			**0.2368**

Table B.2: Tear strength of sample with 5 % of eggshell

Sample	Thickness (mm)	Maximum force (N)	Tear strength (N/mm)
1	0.64	0.9567	1.495
2	0.64	0.7999	1.250
3	0.64	1.3992	2.186
4	0.64	1.1938	1.865
5	0.64	0.8546	1.335
Mean			**1.63**
Standard deviation			**0.3504**

Table B.3: Tear strength of sample with 10 % of eggshell

Sample	Thickness (mm)	Maximum force (N)	Tear strength (N/mm)
1	0.57	0.36670	0.64333
2	0.57	0.42372	0.74337
3	0.57	0.55149	0.96753
4	0.57	0.48486	0.85063
5	0.57	0.36587	0.64188
Mean			**0.769**
Standard deviation			**0.1254**

APPENDIX C

Water absorption of samples

Table C.1: Water absorption of samples with 0 %, 5 % and 10 % of eggshell

	Time (Hours)	1	2	3	4	5	6	24	48	72	96	120
Water absorption (%)	**Sample with 0 % eggshell**	76.44	84.51	80.86	80.36	78.00	75.30	81.64	84.82	96.09	86.04	95.65
	Sample with 5 % eggshell	115.31	111.97	102.51	104.24	104.89	103.91	103.20	113.03	112.09	116.27	113.42
	Sample with 10 % eggshell	124.81	120.84	119.68	119.28	117.94	116.31	119.87	117.37	111.94	117.26	115.00