FLEXURAL AND POST-FIRE FLEXURAL PROPERTIES OF EGGSHELL HYBRID GLASS FIBRE REINFORCED POLYMER (GFRP) COMPOSITES

by

NITHIKORN SUVANAMPORN

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ENDORSEMENT

I, Nithikorn Suvanamporn hereby declare that all corrections and comments made by the supervisor and examiner have been taken consideration and rectified accordingly.

(Signature of Student)

Date:

(Signature of Supervisor)

Name:

Date:

(Signature of Examiner)

Name:

Date:

DECLARATION

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

(Signature of Student)

Date:

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ABSTRACT

The use of polymer composite materials has increased considerably over the last decade. The unique properties of fibre reinforced composite materials enable their application in various technological areas such as space, aircraft, marine and automotive. Animal fibre of eggshell composites are considered to have potential use as reinforcing agents in polymer composite materials because of their principle benefits such as good strength and stiffness, low cost, and be an environmentally friendly, degradable, and renewable material. Chicken eggshells are crushed, ground and sieved for granules of size 75 µm for reinforcement in the matrix. Different types of composites are fabricated using (0,15,20) wt % of eggshell powder with E-glass fibre and epoxy matrix. Hand lay-up technique is adopted to fabricate epoxy glass composites with eggshell powder. After dispersing the eggshell powder in epoxy, the hardener is added which then will initiate cross-linking process. Then specimens are cured for 24 hours at room temperature. Post-fire and flexural properties of eggshell hybrid GFRP composites as a function of filler content in the particle sizes (75 µm) are investigated. The tests are conducted according to ASTM standards. Post-fire of the composites as a function of filler content examined for 2 minutes showed gradual reduction when the filler content increases because of the chemical composition and nature of egg shell. Experimental result has shown improvements in Flexural Modulus of this newly processed Eggshell Hybrid GFRP

composite. Hence the development of epoxy/eggshell particulate composites material with good mechanical properties and light weight which is relevant to the engineering applications has the potential to be achieved.

SIFAT-SIFAT KELENTURAN DAN PASCA API DALAM KULIT TELUR HIBRID GENTIAN BERTETULANG KACA POLIMER KOMPOSIT

ABSTRAK

Penggunaan bahan komposit polimer telah meningkat dengan ketara sepanjang dekad yang lalu. Sifat unik bahan komposit bertetulang serat membolehkan aplikasi dalam pelbagai bidang teknologi seperti angkasa, pesawat, marin dan automotif. Serat binatang komposit kulit telur dianggap mempunyai potensi penggunaan sebagai agen pengukuhan dalam bahan komposit polimer kerana faedah prinsip mereka seperti kekuatan yang baik dan kekukuhan, kos rendah, dan bahan yang mesra alam, boleh degradasi, dan boleh diperbaharui. Kacang telur ayam dihancurkan, kisar dan disaring untuk granul saiz 75 μm untuk tetulang dalam matriks. Jenis komposit yang berbeza dibuat menggunakan (0,15,20) wt% serbuk kulit telur dengan serat E-kaca dan matriks epoksi. Teknik layang tangan digunakan untuk mengarang komposit kaca epoksi dengan serbuk kulit telur. Selepas menyebarkan serbuk kulit telur dalam epoksi, pengeras akan ditambahkan yang akan memulakan proses menyambung silang. Kemudian spesimen dibiarkan selama 24 jam pada suhu bilik. Sifat mudah terbakar dan lenturan kulit telur hybrid plastic gentian bertulang kaca komposit sebagai fungsi kandungan pengisi dalam saiz zarah (75 μm) dikaji. Ujian dijalankan mengikut piawaian ASTM. Reaksi komposit berkandungan serbuk kulit telur yang tidak mudah terbakar diperiksa, ia menunjukkan bahawa pengurangan secara beransur-ansur apabila kandungan pengisi meningkat kerana komposisi kimia dan sifat kulit telur. Hasil eksperimen telah menunjukkan peningkatan dalam modulus kelenturan kulit telur hybrid plastic gentian bertulang kaca komposit yang baru direka ini. Oleh itu, perkembangan bahan komposit epoksi

berkandungan telur telur dengan sifat mekanik yang baik dan ringan yang berpotensi tinggi ini dapat memberi faedah dan meperluaskan lagi bidang kejuruteraan.

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M_c = Mass of composite specimen, (g)

M_f= Mass of glass fibre, (g)

M_m = Mass Of matrix, (g)

V_c= Volume of composite specimen, (cm^3)

V_m = Volume of the matrix, (cm^3)

v_m = Matrix volume fraction

v_f = Glass fibre volume fraction

ρ_c = Composite density

ρ_m = Matrix density

ρ_f = Fibre density

F = Force or load being applied during the test

σ_f = Flexural stress, MPa

ε_f = Flexural strain

L = Original length, mm

CHAPTER 1

INTRODUCTION

1.1 General Overview

Composite materials can be defined as the combination of more materials to achieve properties that are superior to those of their constituents. The two constituents are reinforcement and matrix. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part (Campbell, 2010). This is the starting point of development for new technology as the advancement of materials can be used to create many new products. The existence of composite materials plays an important role in the evolution of aviation, automotive and medical.

Many fibre-reinforced polymers provide both strength and modulus that are either comparable to or better than many metallic materials. As their low density, the strength–weight ratios and modulus–weight ratios of these composite materials are superior to those of metallic materials (Senthil J, 2015). Therefore, composite materials are either used or being considered for use as substitution for metals in many weight-critical components in aerospace, automotive, and other industries. The characteristics of composite materials which are light weight and high performance in terms of strength and stiffness to weight ratio will take Aerospace Industry to another level (Toozandehjani, 2018). The aerospace market is one of the largest and arguably the most important to the composites industry. Commercial aircraft, military craft, helicopters, business jets, general aviation aircraft and space craft all make substantial use of composites, both inside and outside. Figure 1 shows the evolution composite application at Airbus. Figure 2 shows the materials used in Boeing planes.

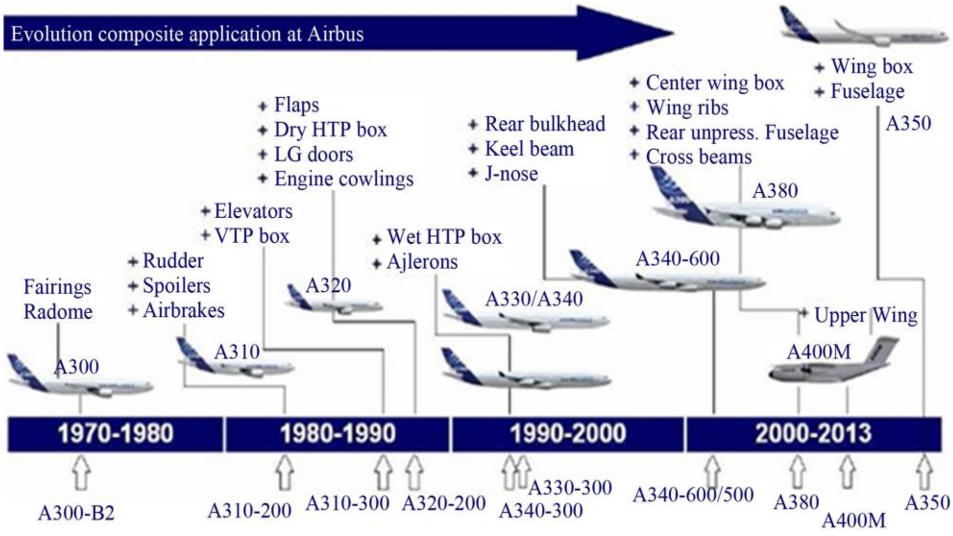

Figure 1: Composite application in commercial transport aircraft (Campbell, 2010)

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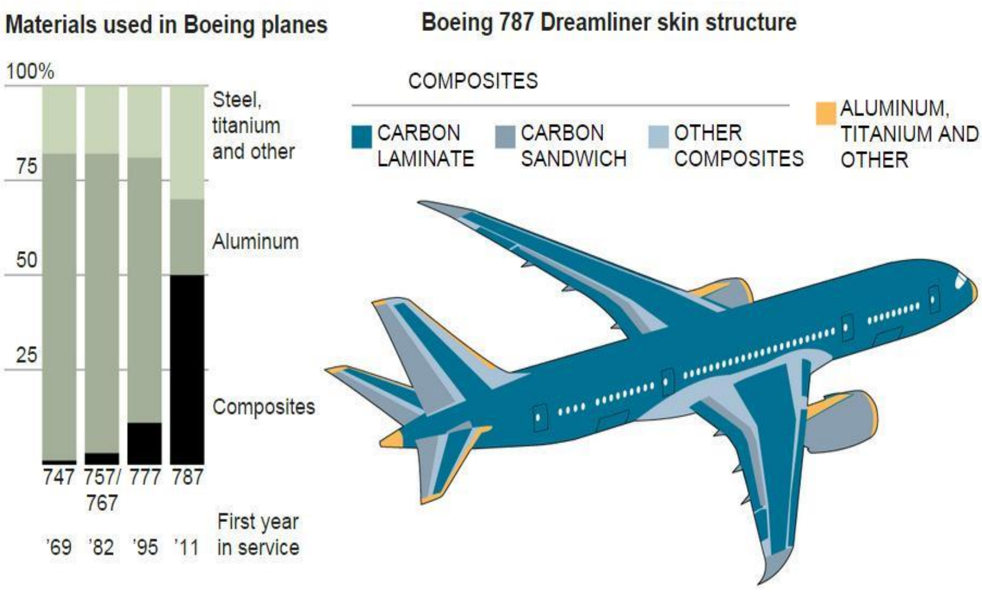

Figure 2: Materials used in Boeing planes (Campbell, 2010)

1.1.1 Post-Fire Composites

With composites usage in demanding applications increasing, knowledge of their fire performance becomes a safety-critical issue. This particularly applies to composites in aircraft, marine and the oil and gas industries. The heat from a fire may weaken the polymer and cause eventual creep, leading to structural failure. Alternatively, the polymer itself may ignite and spread the flame, releasing further heat and potentially toxic smoke, but this can be mitigated by the inclusion of fillers. Moreover, composites, as mentioned, are by their nature inherently fire resistant. The inert fibre-reinforcement displaces polymer resin during fire and thus removes fuel for the fire. When the outermost layers of a composite laminate lose their resin, they act as an insulating layer, slowing heat penetration. The highest performance passive fire protection coatings for steelwork are effectively composite systems and can be used to protect critical systems from even extreme events such as jet-fire (Bar et al., 2015).

1.1.2 Hybrid GFRP

Hybrid composites are more advanced composites as compared to conventional FRP composites. Hybrids can have more than one reinforcing phase and a single matrix phase or single reinforcing phase with multiple matrix phases or multiple reinforcing and multiple matrix phases. They have better flexibility compared to other fibre reinforced composites. Usually they combine a high-modulus fibre with the one on low modulus fibre. The high-modulus fibre provides the stiffness and load bearing qualities, whereas the low-modulus fibre makes the composite more durable and lower in cost (Baba et al., 2015).

1.1.3 Advantage of Composite Materials

Composite products are used in various applications because of their special characteristics. In comparison with most woods and metals, composites are light in weight. The lightness of composites plays an important role in fuel efficiency for automobiles and aircraft (Tornabene, 2017). This is because lesser propellant will be used to lift a lighter aircraft and able to reach its destination in a shorter period. This can be proved when the availability of modern airplanes built with composites more than other material.

The most significant of composite material is that it can be designed to be both strong and light. It has a high strength-to-weight ratio of composites coupled with the capability to idealize strength where required provides engineers with an opportunity to produce lightweight end structures (Yabei and Nesterenko, 2007). Most of the materials that exhibit high strength are heavy, such as steel. This is the reason why composites are used to build airplanes which need a very high strength material at the lowest possible weight (Pandey and M, 2015). A composite can be fabricated to resist bending in one direction, for example. When parts or components are built with metal, higher strength is needed in one direction, which that material usually must be made thicker, results in adding weight. In contrast with composites as it has high strength in minimum weight. Thus, composites are considered to have the highest strength-to-weight ratios in structures today.

Composite has high chemical and damage resistance which are suitable for chemicals to be stored. Thus, composite materials can be used both indoors and outdoors, they stand up to severe weather and wide changes in temperature. It also made to absorb high impacts—the sudden force of a bullet, for instance, or the blast from an explosion.

Indirectly, this categorised composites under high-performance impact absorbing materials where they are used in bulletproof vests and panels, and to protect airplanes, buildings, and military vehicles from explosions (H. V. Rama Krishna and Senthil J, 2005).

Composites exhibit nonconductive property, meaning they do not conduct electricity. It makes them ideal for such items as electrical utility poles and the circuit boards in electronics (Sokolija, 1999). When electrical conductivity is needed, it is possible to make some composites conductive. Since the composition of composites contain have no metals included; hen, they are not magnetic. They can be applied around high sensitivity electronic equipment. MRI (magnetic resonance imaging) equipment able to perform better due to the lack of magnetic interference. Composites are widely used in the house furniture. Moreover, the construction of the room uses composites rebar to reinforce the concrete walls and floors in the hospital. Radar signals able to pass right through composites which makes composites suitable to use in the area where radar is operating, whether on the ground or in the air. Then, composites play a vital role in stealth aircraft, such as the U.S. Air Force's B-2 stealth bomber that makes it nearly invisible to radar.

Lastly, composites are good insulators as they do not easily allow heat or cold to pass through it. They are used in buildings for panels, doors, and windows where extra protection is needed from severe weather. Structures made of composites have a long lifetime and need low maintenance. The determination of composite life is unclear as there is only a few of composites to the end of the life of many original composites. Many composites have been in service for half a century.

1.2 Motivation and Problem Statement

The aim of this study was to investigate the potential of using the eggshell powder as a filler in composite which is derived from poultry waste, in removal of hazardous inorganic as well as organic pollutants, particularly from their aqueous solutions. In this research work, the effects of smaller size of particles on post-fire and flexural properties of Eggshell Hybrid GFRP Composites were studied. Since there is a plan in substitution of aluminium parts on aircraft with composites material, it is crucial to study on the mechanical properties of composites material. This is to ensure it able to withstand during high elevated temperature and high stress where it is important in aircraft safety. The development of new generation composite materials with higher strength and better temperature resistance added with eggshell powder will help in designing high-performance, economical aircrafts.

1.3 Objectives of Research

1. To fabricate the different specimens with uniform distribution of filler all over the surface.
2. To perform the post-fire and flexural tests on Eggshell Hybrid GFRP Composites.
3. To investigate the post-fire and flexural tests on Eggshell Hybrid GFRP Composites.

1.4 Thesis Layout

This thesis comprises 5 chapters. Chapter 1 gives a general overview of the Composites and its advantages toward different field of industry. Then, the general concept in classification of composites and the matrix can be used together to bind together the composites structure. Next, the fire exposure in composites also has been discussed briefly. Some of the incident involving composites and fire also stated besides the important in studying and researching the behaviour and fire resistance of composites material at high temperature. Finally, the problem statement and objectives of the research are defined clearly at the end of the chapter.

Chapter 2 present a critical review of published and recognize research into the fire properties of composites including the behaviour of composites. This chapter is divided into sub-section for clearer explanation and better understanding. The literature review covers all the main aspects that is related to composites material including method of fabrication, testing conducted on composites material and fire-resistant properties of composites which include damage, failure and temperature response.

Methodology presented in chapter 3 focuses more on the all the method involves in completing this project. This chapter include a very detail explanation on how the experiment and testing were conducted on the composites. Equation that been used for analysing the result were also shown in this very chapter.

Chapter 4 provide all the result that were collected during the experimental work. Graph such as stress-strain curve and young modulus were plotted and explained. The trend line of each graph was analyses and discussed.

Chapter 5 summarizes all the analysis done and concludes the project. Suggestions for future works are described to further improvement at the end of this chapter.

CHAPTER 2

LITERATURE REVIEW

In an advanced society like ours, the application of composite materials in various aspects of lives has tremendously increased. As the evolution of technology continues, the quality of materials required needed to be improved to meet the requirements. According to BBC News, last year saw a sharp rise in fatalities from air crashes compared with 2017 but 2018 was still the ninth safest year on record. This has led to many investigations on the case about the materials used in aircraft. Although a significant amount of research has been done studying on the reaction of composite materials toward different of situations that might occur during operation of aircraft. Then, the types of composites and matrix will be discussed in this chapter. The method of fabrication that is taken into consideration for this project will be explained. Finally, the related researches of composites behaviour and performances involving fire resistance and flexural will be reviewed.

2.1 Composite in Aerospace Field

Since the existence of aviation, lift to weight ratios of aircrafts is one of the most important factors that engineers have continuously aimed to improve. The innovation of aerospace industry highly related with composite materials, as these enable engineers to solve the problem occurred by using metal. The first uses of composite materials (boron-reinforced epoxy) was used for the skins of the empennages of the U.S. F14 and F15 fighters. Originally, the percentage by structural weight of composites used in manufacturing was insignificant. However, the usage of composite materials in primary structure such as wings and fuselages has increased as the development of the materials has improved. In the Eurofighter, the composite materials are used in wing skins, forward fuselage, flaperons and rudder. There was a great weight reduction in structural weight as 40 percent of it is carbon-fibre reinforced composite material. Commercial aircraft mainly focused on lower operating costs by reducing the aircraft weight to enable better fuel economy. The significant use of composite material was when the 2,000 parts (excluding fasteners) of the metal fin were reduced to fewer than 100 for the composite fin, decreasing its weight and production cost. Then, a honeycomb core with CFRP faceplates was used for the elevator of the A310. This led to the full application of composite materials for the whole tail structure of the A320, which also featured composite fuselage belly skins, fin/fuselage fairings, fixed leading and trailing-edge bottom access panels and deflectors, trailing-edge flaps and flap-track fairings, spoilers, ailerons, wheel doors, main gear leg fairing doors, and nacelles. Moreover, GFRP is used in floor panels. For A320, 28 percent of airframe weight constituted of composites(Quilter, 2004). The development of space vehicles structure was originated from the concept of composites application in missiles. For example, in local bracketry and antenna reflectors, GFRP is used in applications where thermal insulation is crucial. Carbon-Fibre Reinforced Composite (CFRP) with high-stiffness and good thermal stability over a wide temperature range is applied in fairings, manipulator arms, antennae reflectors, solar array panels and optical platforms and benches (Pan, 2016). Table 1 shows the list of aircraft with composite frame.

Table 1: List of aircraft with composite airframe (Pan, 2016)

Fighter Aircraft	U.S. Europe Russia	AV-8B, F16, F14, F18, YF23, F22, JSF, UCAV Harrier GR7, Gripen JAS39, Mirage 2000, Rafael, Eurofighter, Lavi, EADS Mako MIG29, Su Series
Bomber	U.S.	B2
Transport	U.S. Europe	KC135, C17, 777, 767, MD1 1 A320, A380, Tu204, ATR42, Falcon 900, A300-600
General Aviation		Piaggio, Starship, Premier 1, Boeing 787
Rotary Aircraft		V22, Eurocopter, Comanche, RAH66, BA609, EH101, Super Lynx 300, S92

2.2 Fibre-Reinforced Composite

Fibre-reinforced composites have appeared as structural materials in aerospace and aeronautics due to their high strength, rigidity, and lightweight. The previous study showed that the strength of the fibre-matrix and ability of load transfer from matrix to the reinforcement fibre are the main keys of its ideal performance(A. Godara, 2010). In structural application, most preferable form of composite is laminate; made by stacking a number of laminae (thin layers of fibres) and matrix based on desired thickness. The stacking sequence and its thickness determine physical and mechanical properties of the composite.

2.2.1 Glass Fibres

Glass Fibres exhibit useful bulk properties such as hardness, transparency, inertness and stability as well as desirable fibre properties such as strength, stability, and stiffness (Frederick T. Wallenberger, 2001).They are categorised into two types, low-cost general-purpose fibres and premium special-purpose fibres. According to "Standard Specification for Glass Fibre Strands", over 90% of all glass fibres are general-purpose products. They are known as E-glass and are subject to ASTM specifications. The types of glass fibres are shown in Table 2.

Table 2: Type of Glass Fibres

Letter designation	Property or characteristic
E, electrical	Low electrical conductivity
S, strength	High strength
C, chemical	High chemical durability
M, modulus	High stiffness
A, alkali	High alkali or soda lime glass
D, dielectric	Low dielectric constant

For General-Purpose Glass Fibres, there are two generic types of E-glass. One contains 5 to 6 wt% of boron oxide where environmental regulations need the addition of costly emission abatement systems to eliminate boron from the off-gases of boron containing melts. Therefore, Fiberglas (Owens Corning Corp., Toledo, OH) under the trademark Advantex introduced boron-free E-glass which these melts do not emit boron into environment during processing. They are both usually used in electrical application.

Table 3: Physical and mechanical properties of commercial glass fibres
(Frederick T. Wallenberger, 2001)

Fiber	Log 3 forming temperature(a) °C	Log 3 forming temperature(a) °F	Liquidus temperature °C	Liquidus temperature °F	Softening temperature °C	Softening temperature °F	Annealing temperature °C	Annealing temperature °F	Straining temperature °C	Straining temperature °F	Bulk density, annealed glass, g/cm^3
General-purpose fibers											
Boron-containing E-glass	1160–1196	2120–2185	1065–1077	1950–1970	830–860	1525–1580	657	1215	616	1140	2.54–2.55
Boron-free E-glass	1260	2300	1200	2190	916	1680	736	1355	691	1275	2.62
Special-purpose fibers											
ECR-glass	1213	2215	1159	2120	880	1615	728	1342	691	1275	2.66–2.68
D-glass	...	...	...	...	770	1420	...	...	475	885	2.16
S-glass	1565	2850	1500	2730	1056	1935	...	...	760	1400	2.48–2.49
Silica/quartz	>2300	>4170	1670	3038	...	...	...	...	...	...	2.15

Fiber	Coefficient of linear expansion, 10^{-6}/°C	Specific heat, cal/g/°C	Dielectric constant at room temperature and 1 MHz	Dielectric strength, kV/cm	Volume resistivity at room temperature $\log_{10}$ (Ω cm)	Refractive index (bulk)	Weight loss in 24 h in 10% H_2SO_4, %	Tensile strength at 23 °C (73 °F) MPa	Tensile strength at 23 °C (73 °F) ksi	Young's modulus GPa	Young's modulus 10^6 psi	Filament elongation at break, %
General-purpose fibers												
Boron-containing E-glass	4.9–6.0	0.192	5.86–6.6	103	22.7–28.6	1.547	~41	3100–3800	450–551	76–78	11.0–11.3	4.5–4.9
Boron-free E-glass	6.0	...	7.0	102	28.1	1.560	~6	3100–3800	450–551	80–81	11.6–11.7	4.6
Special-purpose fibers												
ECR-glass	5.9	...	...	...	...	1.576	5	3100–3800	450–551	80–81	11.6–11.7	4.5–4.9
D-glass	3.1	0.175	3.56–3.62	...	...	1.47	...	2410	349	...	...	...
S-glass	2.9	0.176	4.53–4.6	130	...	1.523	...	4380–4590	635–666	88–91	12.8–13.2	5.4–5.8
Silica/quartz	0.54	...	3.78	...	...	1.4585	...	3400	493	69	10.0	5

Special-purpose fibres include ECR-glass, (S-, R-, and Te- glass), D-glass, and pure silica or quartz fibres. The unique properties of ECR-glass are long-term acid resistance and short-term alkali resistance (J.F Dockum, 1987). While S-, R- and Te-glass provide high strength in military applications. Silica or Quartz Fibres are used in application that related with extremely high temperature, commonly used as insulation blankets at temperature up to 1040°C (1900 °F). From Table 3, it shows that D-glass offers special electrical properties which is low in dielectric constant.

2.2.2 Matrix

The matrix is defined as a homogeneous and monolithic material that acts a medium for binding reinforcements together into a solid. It prevents the reinforcement from environmental damage, transfer stresses between fibres and offers durability.

Classification of composite materials in accordance with type of matrix material are categorised into three types.

Ceramic Matrix Composites (CMCs) consists of ceramic fibres which is surrounded by ceramic matrix that will form ceramic fibre reinforced ceramic (CFRC) material. Any type of ceramic materials can be used as matrix and fibres. It was designed specifically to control the fracture toughness, brittleness and thermal shock resistance.

Next, Metal Matrix Composites (MMCs) are consisted of a metal and other material or a different metal. It can be fabricated by using three or more constituents parts which is known as hybrid composite. Magnesium, titanium or aluminium is used as matrix in situation which need lighter weight like structural application (Haghshenas, 2016). While cobalt and cobalt-nickel alloy matrices are applied in high temperature applications. They are specialised in fire resistant, do not absorb moisture and good electrical and thermal conductivity (Mr.Bangarappa.L, 2017).

Lastly, Polymer Matrix Composites (PMCs) can be categorised into two types, namely, thermoset and thermoplastic. Polymer is a molecule consisted of repeating structural units linked by covalent chemical bonds. In this project, thermoset matrix is used as it has greater performance in term of mechanical properties. This is because highly crosslinked structure formed by chemical bonds able to withstand high load pressure when compared to thermoplastic matrix that is connected with weak bonding, Van der Waal bond and hydrogen bond (Gupta and Doddamani, 2018). Thermoset matrix offering heat resistance and structural integrity which make it suitable for the purpose of investigating composite behaviour at high temperature as shown in Figure 3 (W. Peng, 1995).

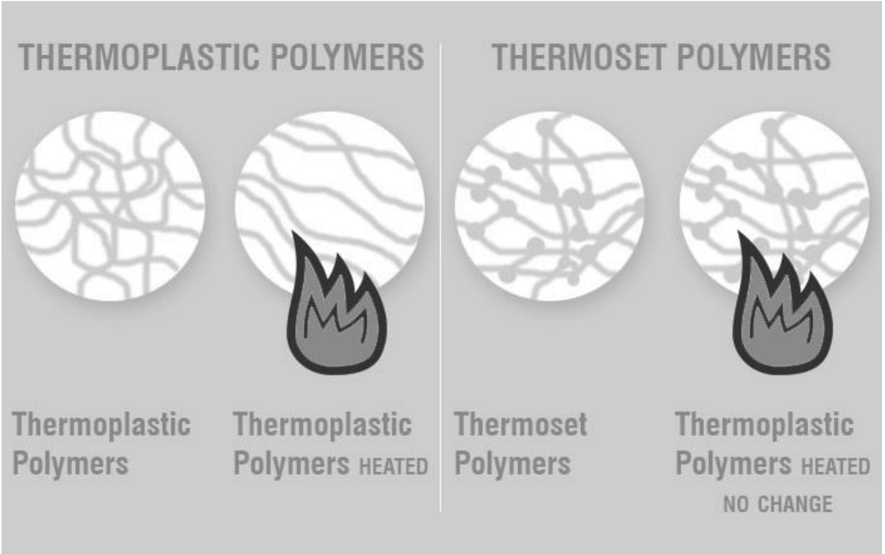

Figure 3: Thermoplastic and Thermoset at elevated temperature

2.2.2.1 Thermosetting Resins

Thermosetting polymers undergo a curing process which is non-reversible chemical reaction and are transformed into infusible material. As stated in "Handbook of Thermoset Resins", thermoset resins are processed from a low molecular weight compound which make them can be moulded at lower temperature and pressure unlike thermoplastics which are processed from high molecular weight macromolecules (Ratna, 2009). There are a few types of thermoset resins available as shown in Table 4. In this section, epoxy resins will be discussed as they are used in manufacturing composites for this project. Epoxy resins are selected due to several reasons: low pressure is required for products fabrication; cure shrinkage is lower and thus lower residual stress in the cured product than that encountered in the vinyl polymerisation is used to cure unsaturated polyester resins and a wide range of temperature by selection of curing agents enables great control over the degree of crosslinking(Manoj Singla, 2010).

Table 4: Important thermosetting resins and their field of application

Resin	Properties	Products
Epoxy	Good electrical insulator, hard, brittle unless reinforced, resists chemicals well	Casting and encapsulation, adhesives, bonding of other materials
Melamine	Stiff, hard, strong, resists some chemicals and stains	Laminates for work surfaces, electrical insulation, tableware
Polyester	Stiff, hard, brittle unless laminated, good electrical insulator, resists chemical well	Casting and encapsulation, bonding of other materials
Urea	Stiff, hard, strong, brittle, good electrical insulator	Electrical fittings, hardles and control knobs, adhesives

2.2.3 Eggshell Fillers Materials

Fillers acts like extenders in composite, influence mechanical and physical strength if filler particles are compatible with polymer matrix or else it might worsen the properties of resin (Vatanpour, 2011).Fillers play an important role as an enhancer in composite which is low in cost if compared to fibres or resins alone. There are a few factors that increases the usage of fillers in composite industry. It can improve fire resistance, reduce resins shrinkage, water resistance, weathering, surface finishing and temperature resistance (Zakaria, 2011). The available filler materials that can be used with composites are calcium carbonate, kaolin, alumina trihydrate and calcium sulphate. In this project will focus mainly on calcium carbonate as an inorganic filler in reinforcement. Calcium carbonate is one of the fillers used in polymer applications, high consumption over ten million tonnes annually. It is nontoxic, soft and easily grinded to a fine size. (Thenepalli et al., 2015). Eggshell comprises calcium carbonate in the form of calcite around 95% and 5% of organic materials like type X collagen, sulphated polysaccharides and proteins (Hussein et al., 2013). The structure of eggshells is different according to its species. The research investigated eggshell as a new bio-filler for composites because it showed that it has lower modulus of elasticity values than talc composites (Toro et al., 2007). It also offers other advantages as it is lightweight, low cost, eco-friendly, available in large quantities and has good thermal stability (M.C. Yewa, 2015). The most significant part of eggshell property is that it has potential as a fire retardant to slow the spread of fire or reduce its intensity.

2.3 Method of Composite Fabrication

There are various methods for fabricating composite parts. Selection of a fabrication method is based on the materials, designs and applications. The suitable fabrication method for thermoset composites is wet or hand layup where the rollers are used to force the resins impregnated in between each ply fibres to form a laminate stack (Nagavally, 2016). The desired thickness of laminate can be obtained by repeating the stacking process. This method has been widely used in numerous applications and low cost in tooling. However, it requires high skills and experiences to avoid the formation of air bubbles and uneven resin over the surface of the fibres. Next is spray method which chopped fibre and resin are sprayed on to a mould, merged and cured. It is a continuous process that can use any type of materials as mould and the error of spraying can be reworked. The main drawback of this method is it consumes more time in preparing, lack of consistency and environmental unfriendly (Mazumdar, 2002). Resin infusion process is a method that applies vacuum pressure to force resin into a laminate. The mixture of resin and catalyst is pumped into the laminate through tubing once a complete vacuum is achieved. It provides a better fibre-to-resin ratio which can reduce the amount of unnecessary resin and unlimited set-up time.

2.4 Flexural Properties

A series of three-point bending test have been performed to investigate the process of damage initiation and propagation in composites. In order to predict the stiffness of anisotropic composite plates in bending, three-point flexural test was one of the mechanical tests used in the research. The results indicate that fibre orientation, laminate stacking, surface waviness and moulding temperature influenced the flexural behaviour (J.P. Nunes 2002). Previous studies of hybridization effects on the flexural properties of fibre-reinforced composites have shown varied results. The replacement of 33% of E glass fibres by S-2 glass fibres produced an increase in flexural strength of 23%, with no significant effects of hybridization to flexural modulus (Sudarisman and Davies, 2008). Then, the flexural strength decreases rapidly as an all-glass reinforcement is progressively replaced by graphite fibre. Slight positive deviations were shown from the theoretical maximum strain failure criteria. A recent study showed that the optimal placement of glass fibres on the compressive side of a test specimen would manifest as an increased flexural performance in CFRP (Sudarisman, 2009).

2.5 Post-Fire Composites

The elevated temperature on the composites has a big effect on mechanical properties of the composites (A. G. Gibson, 2004) .The composite that experienced extremely high temperature environment, initially it will lose its shape or compactness due to the damages occurred internally. The damages caused by ultrahigh temperatures are intra-ply damage, matrix cracking, interlaminar cracks, fibre breakage and subsurface delamination (Benoît Vieille, 2013). This showed that major concern of composites is the poor performance in fire. When the composite is heated at moderate temperature (>100-200ºC), it will soften, creep and distort. While high temperature (300-400ºC), it started to decompose and release smoke, soot and toxic volatiles. Moreover, the soot released can negatively impact air quality as breathing the tiny particles can cause coronary heart disease, asthma, bronchitis and other respiratory illnesses. Research has also shown that many deaths are caused by the air pollution case (Xu-Qin Jiang, 2016).

Various techniques have been developed to improve the fire resistance of composites. Resins with fire-retardant additives such as aluminium trihydrate, antimony trioxide or zinc borate can reduce the flammability of FRP composites when exposed to low-tomedium intensity fires. However, the drawbacks are that fire-retardant resins are expensive, and some additives can decompose into toxic gases when the resin matrix burns (Mouritz, 2002).

2.6 Composite in Fire under Flexural Properties

When composites are exposed to high temperature for a certain period, the composite is thermally degraded which the cause the formation of charring and delamination cracking. Charring is defined as the thermal degradation process in which the resin matrix is combusted and degraded to a carbonaceous residual material. The mechanical properties of the char layer are weaker than the properties of the unburnt composite layer (Mouritz, 2002). Hence, a partially burnt composite can be considered as a two-layer material with one layer having been severely degraded by fire while the second layer has the properties of an unburnt composite (Jun Jiang, 2015). A major simplifying assumption with this analysis is that no damage occurs in the unburnt composite, such as overheating of the resin matrix or heat-induced cracking. It will be described later that some damage does occur, although it does not significantly degrade the flexural properties of the unburnt portion of the composite (Hong-jun FU, 2007).

CHAPTER 3

METHODOLOGY

In this project, there are a few phases involved in preparing the composites. The process and methods can be categorised into four phases as shown in Figure 4. Research and fundamental studies are required at an early stage to provide insights, knowledge and the relationship of each mechanical properties. Then, eggshell preparations which need to be cleaned and ground into the desired size before composites fabrication process. After the fabrication process of composites, the mechanical tests were performed on the specimens according to experimental methods studied during the first phase.

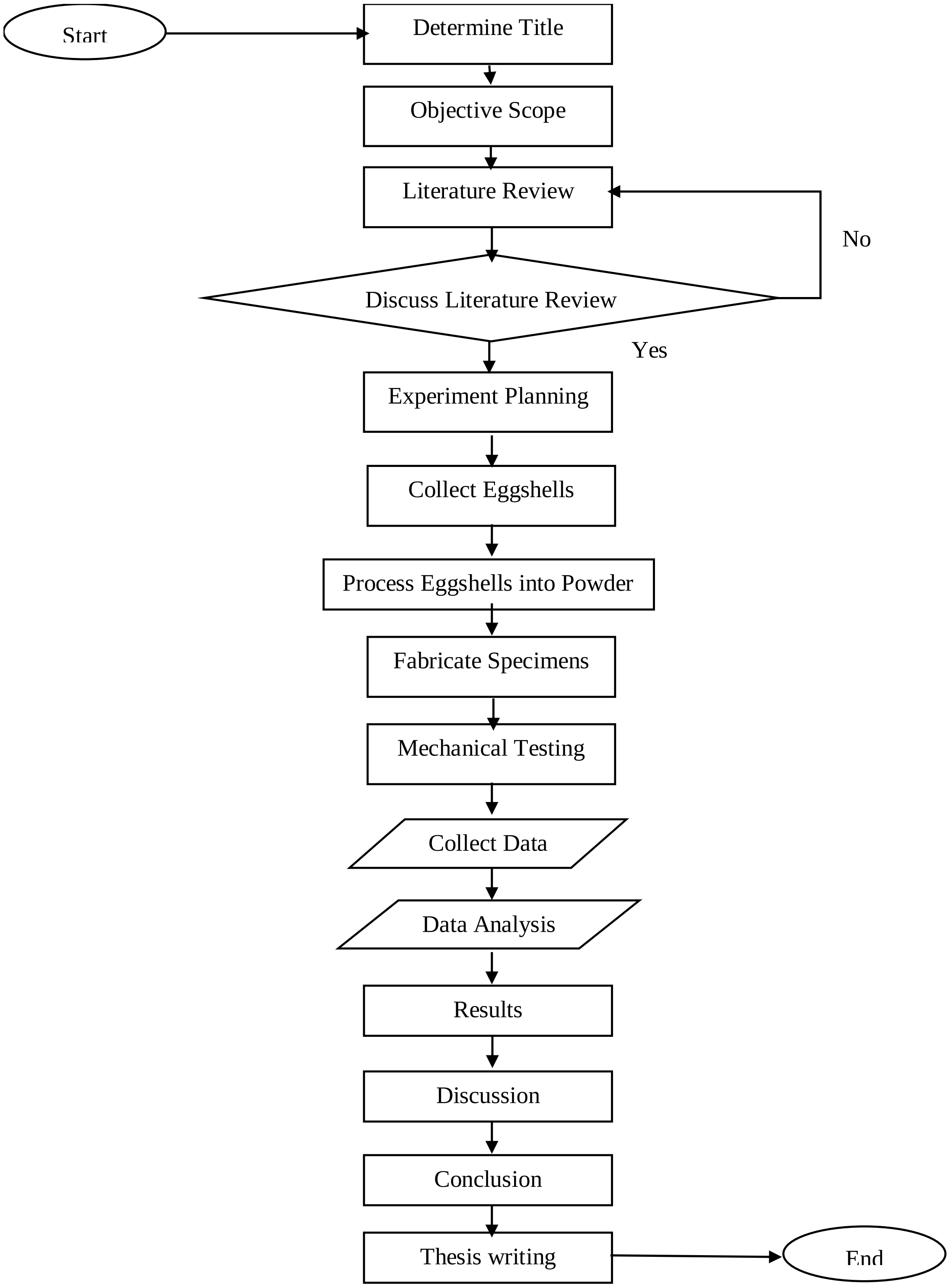

Figure 4: Flow chart for overall process

3.1 Eggshell Preparation

A large number of eggshells were collected from the local seller. To remove impurity and the interference material, the eggshells were washed several times in deionized water. Before the eggshells are exposed to sunlight for drying process, the inner membrane must be removed. Figure 5 and Figure 6 show that membrane removal is achieved by soaking in the water and detached it.

Figure 5: Collected Eggshells

The problems faced during eggshell preparation are the hygiene, smell, and the separation of its membrane. The eggshell must be cleaned right after collected from the local stalls is to ensure its purity is at its best and to prevent from the breeding ground for bacteria, insects and vermin. This indirectly can eliminate the bad odour which might cause air pollution and respiratory diseases. Hence, the eggshell must be washed thoroughly with detergents and followed by water. It was difficult to separate the membrane from eggshell because of the adhesive properties of the membrane resulting in extreme difficulty to purify the fibre. Moreover, wearing gloves during separation process is inefficient as there is no friction between two surfaces which will slower the separation process. Therefore, the eggshells are soaked in a distilled water for 24 hours after they are cleaned which is to ease the process of membrane separation.

Figure 6: Remove eggshells membrane

The actual cylindrical shell of Ball Mill Machine is replaced with Protein Powder Container. Figure 7 shows the actual shell of Ball Mill Machine. This is due to the lighter weight of the container and able to insert and remove grinded eggshell powder out from the container more easily. During eggshell powder preparation process, the modification on the cylindrical shell of Ball Mill Machine is required. This is to ease the process of filling and removing eggshell powder from the cylindrical shell as the actual cylindrical shell is too heavy and rusty which will delay the fabrication process and might affect the purity of eggshell powder. The actual cylindrical shell is replaced with the Protein Powder Container which is lighter in weight as illustrated in Figure 8.

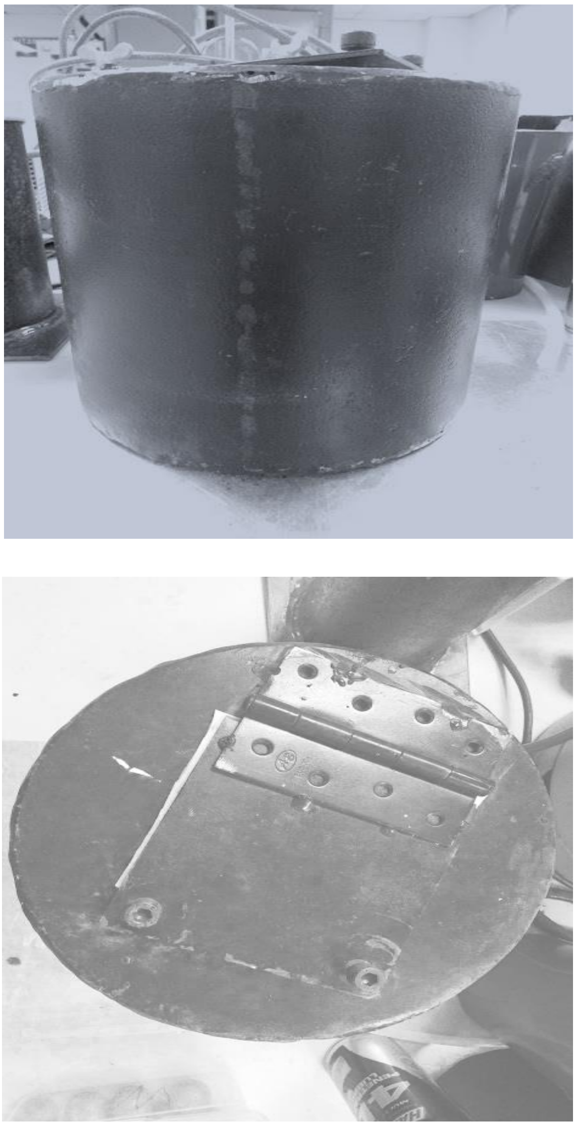

Figure 7: Actual Shell of Ball Mill Machine