INFLUENCE OF AVIATION FUEL ON THE ROOM TEMPERATURE AND POST-FIRE COMPRESSION PROPERTIES OF SANDWICH COMPOSITE MATERIALS

by

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ENDORSEMENT

I, Muhammad Addin Bin Hassan hereby declare that all corrections and comments made by the supervisor and examiner have been taken consideration and rectified accordingly.

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DECLARATION

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

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INFLUENCE OF AVIATION FUEL ON THE ROOM TEMPERATURE AND POST-FIRE COMPRESSION PROPERTIES OF SANDWICH COMPOSITE MATERIALS

ABSTRACT

The main purpose of this final year project is to investigate the influence of aviation fuel on the room temperature and post-fire compression properties of sandwich composite. The materials used to fabricate sandwich composite is E-glass fibre, plastic core and epoxy matrix. The method used to fabricate composite is wet hand lay-up. In order to find the properties of sandwich composite, the specimen undergo immersion test and post-fire compression test. The aviation fuel is used in immersion test to determine how it will influence the properties of sandwich composite. For post-fire compression test, the specimen is heated with fire torch and then compressed using Instron testing machine (UTM). The experimental burn-off testing was conducted in order to calculate the fibre volume fraction of sandwich composite materials. It is found that the fibre volume fraction of sandwich composite is around 48%. Sandwich composite in biofuel has higher moisture absorption percentage compared to kerosene. The compression testing between normal and immersed sandwich composite was conducted and it is found that the compressive properties of immersed composite decrease as the bonding between fibre and matrix become weak. For post-fire compression testing, the compressive strength reduced with different heat exposure time. It was found that there are no significant changes in compressive strength in room temperature and high temperature for all specimen being immersed in aviation fuel.

PENGARUH BAHAN BAKAR TERHADAP SIFAT KEMAMPATAN BAHAN SANDWIC KOMPOSIT DALAM SUHU BILIK DAN PENDEDAHAN API

ABSTRAK

Tujuan utama projek tahun akhir ini adalah untuk menyiasat pengaruh bahan bakar terhadap sifat kemampatan bahan sandwic komposit dalam kondisi suhu bilik dan pendedahan api. Bahan yang digunakan untuk membuat sandwic komposit adalah serat *E-glass,* plastik honeycomb sebagai teras specimen dan epoxy. Kaedah untuk membuat sandwic komposit adalah kaedah tradisional ‘hand lay-up’. Ujian rendaman dan kemampatan pendedahan api terhadap spesimen perlu dijalankan untuk mengetahui tentang sifat-sifate sandwic komposit. Jenis bahan bakar yang digunakan adalah biofuel dan minyak tanah. Bahan bakar ini digunakan untuk menentukan bagaimana pengaruh bahan bakar terhadap sifat sandwic komposit. Bagi ujian kemampatan terhadap pendedahan api, spesimen perlu dipanaskan dengan pencucuh api pada masa yang berbeza dan kemudian dimampatkan dengan menggunakan mesin Instron. Ujian pembakaran komposit dijalankan untuk mencari peratusan kadar serat dalam bahan sandwic komposit. Peratusan kadar serat yang terkandung dalam bahan sandwic komposit adalah di dalam sekitar 48%. Sandwic komposit mempunyai peratusan daya penyerapan yang lebih tinggi dalam biofuel berbanding di dalam minyak tanah.Ujian kemampatan terhadap sandwic komposit yang normal dan direndam telah dijalankan dan didapati sifat kemampatan bagi sandwic komposit berkurangan kerana kekuatan antara serat dan matriks menjadi lemah setelah direndam. Kekuatan sandwic komposit semakin berkurang apabila masa pendedahan api semakin meningkat. Ini didapati bahawa kesemua spesimen yang telah direndam di dalam bahan bakar dalam keadaan suhu bilik dan pendedahan api tidak mempunyai sebarang perubahan dari segi kekuatan dalam kemampatan.

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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 matrix (cm^3)

v_m = Matrix volume fraction

v_f = Fibre volume fraction

ρ_c = Composite density

ρ_m = Matrix density

ρ_f = Fibre density

∂ = Length of the elongation

L = original length

CHAPTER 1

INTRODUCTION

1.1 General overview of composite

Composite is one of the oldest material that have been used since its first time uses where people come out of ideas to create a strong and durable buildings with a mix of mud and straw. The usage of the composite material begin to develop wider as the technology of manufacturing keeps on improving over time. Most of the technology todays are greatly dependent to the material used. Hence, there are hundreds of application can be used with the available materials. Within the circumstances, composite materials are used in wide range application such as in aerospace, automotive and electronics appliances. Composite are known as a material with a combination of two or more constituents material to create a remarkable changes in terms of physical and chemical properties. These combination is most likely to reveal an outstanding properties such as excellent strength to weight ratio, corrosion resistance and able to design and repair easily. Hence, it is assumed that the use of composite material will prolong and grow as the new technology continues to develop in such areas for upcoming years.

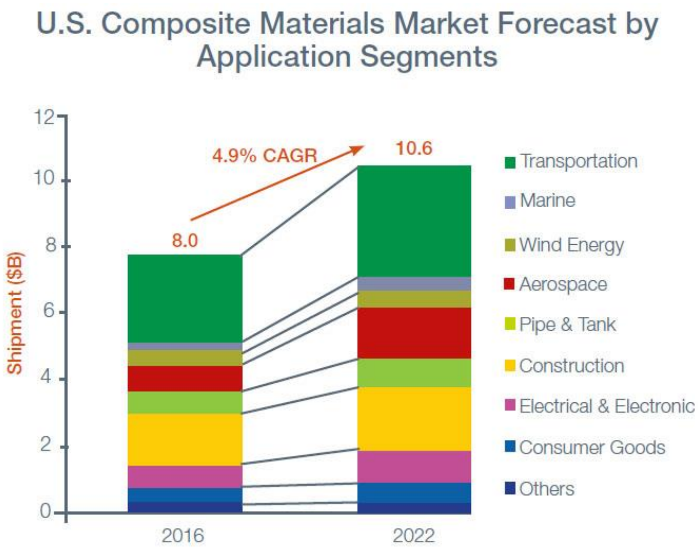

Figure 1.1 : The material market forecast of United States by application segment for upcoming years. Photograph taken from http://www.compositesmanufacturingmagazine.com

1.2 Types of Composite

Composite materials are commonly categorized by two different levels which is the first level is determined by the matrix constituent. For example, this type of level has a major composite classes which include Organic Matrix Composites (OMC), Metal Matrix Composites (MMC) and Ceramic Matrix Composites (CMC). Meanwhile, the second level focus to the reinforcement form such as fibre reinforced composites, laminar composites and particulate composites. Fiber reinforced composites are basically embedded with matrix material. This type of composite are designable and can perform very well in the used of structural design. Besides that, laminar composites and particulate composites are also embedded with matrix. The different between laminar and particulate composites is the composition of materials used. For laminar composites, it is composed by the layers of materials and commonly used to make laminate or sandwich structures. On the other hand, particulate composites are composed by the particles distributed in a flakes or powder form and this type is used for concrete and wood particle boards.

1.3 Application of composite in aerospace industry

From the beginning of the aviation, composite is used and designed to improve a better quality of its materials. A lot of designer continuously focus to improve the lift to weight ratios of aircrafts. This enables them to use composite instead of using metals. Besides that, composite materials are designable and can be produced into various shapes in order to improve the strength or form structures with special properties.

As mentioned above, composite materials are widely used in aerospace component especially in Boeing 787 which uses about fifty percent of advanced composites. For this aircraft, composite materials are used more in its airframe and primary structure compared to previous commercial aircraft. This shows the composite materials are capable to encounter problem such as lift to weight ratios of an aircraft. Instead from that, composite materials are mainly used to build the wing and fuel tank structure. This type of application are important to foresee the ability of the composite materials itself in different condition.

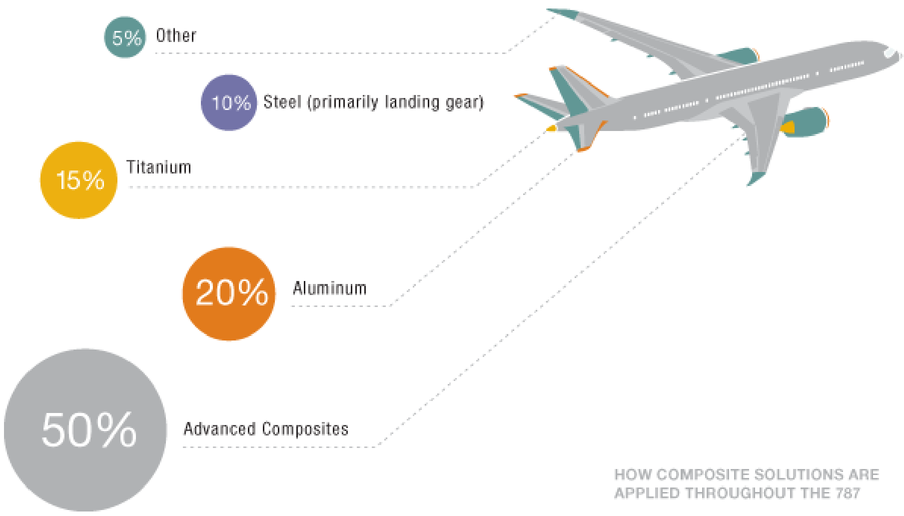

Figure 1.2 : The materials used in the Boeing 787 Dreamliner. Photograph taken from http://www.boeing.com

1.4 Benefits and drawbacks of composite

As mentioned from the previous section, composite are referred as composition materials which have combinations of two or more constituent materials. Composite materials have its own benefits where the material managed to replace metal in manufacturing of an aircraft. The benefits of the composite are stated as below :-

- Has high strength-to-weight ratio which the materials are strong and light. Unlike metals, they are strong and heavy.
- High resistance to corrosion as composite can resist damage from different weather and harsh chemicals.
- Offer a freedom or flexibility in design during manufacturing process
- Have low thermal conductivity and also non magnetic
- Has a smooth finishing and can produce complex parts

Even though composite managed to replace metals, it does not meant that composite are perfect fit to replace the exact properties for metals and other materials. The materials itself has their own drawbacks and limitation. As composite materials has high demand during these days, the cost of materials has skyrocketed compared to the old days. This causes the maintenance and repairing cost to be very expensive as it has high recurring and nonrecurring cost. Besides that, the high temperature application of composite materials are still questionable and still researching in these days.

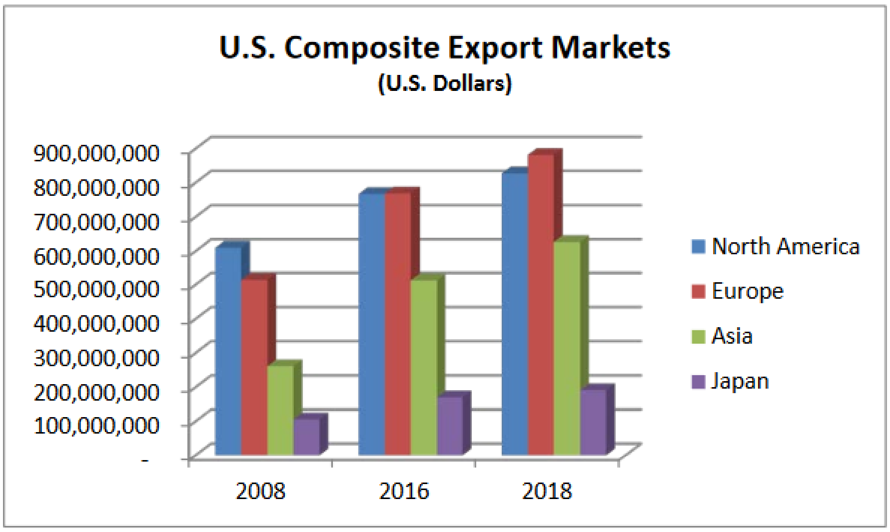

Figure 1.3 : Composite materials market price over time. Photograph taken from https://www.trade.gov

1.5 Composite behaviour to fire

Composite materials usage has grown exceptionally and managed to substitute basic engineering materials such as steels and aluminium alloys[1]. It is used widely in manufacturing aircraft. However, the behaviour of composite in high elevated temperature need to be research in order to help future engineer in designing new aircraft with more fire resistance that may cause damage to the aircraft.

Fire resistance has become one of the most important durability property for composites as the material are used in several applications of industry such as aviation, marine and civil infrastructure. It is important to considerate the use of sandwich composite when it was affect from fire which causes by an accident. Fire from aircraft can give bad effects to the pilots and passengers as such fumes and smokes are produce which can emit toxic from combustion due to excessive heat[1]. As the composite had been exposed to high temperature, the material will degrade and undergo softening effect towards the matrix. This degradation can causes strength of composite to be reduced by 20% 30% and even more[2]. There are few examples about the fire incident that involve the composites material in the aircraft. One of the incidents are when the B-2A bomber crashed and burned during take-off at a US military base due to the combustion in the aircraft fuel tank. Post-fire properties of composite material are also important to analyse in order to seek the residual integrity and safety of the structure. This is the reason why the understanding about the fire resistance and post-fire behaviour of composites material is needed.

Figure 1.4 : B-2 bomber accident in the US military base. Photograph taken from https://gigazine.net/gsc_news

1.6 Motivation and Problem Statement

Composite material had replaced traditional engineering materials such as aluminium and steel due to higher weight reduction and design ability. The usage of composite material has been a significant increase in the making of aircraft fuel tank and wingbox. But, there is an inquisitive that arise on how well the composite performs in the high elevated temperature and fuel attack. The study of the behaviour of the composite in fire and post-fire is important to improve the utmost safety of an aircraft including crews and passengers. There is more research to be done as the study of the behavior of the composite towards different condition is still in the promising stage. This is the main reason in order to complete this project.

1.7 Objectives of the Research

This thesis describe the research work based on the following objectives :-

1) To manufacture sandwich composite with E-glass fiber and plastic core by using wet hand lay-up method.
2) To determine the fuel uptake of sandwich composite due to the immersion in different types of aviation fuel.
3) To investigate the room temperature compression test and post-fire compression test on the sandwich composite.

1.8 Thesis Layout

This thesis consists of 5 chapter. Chapter 1 will explain about general introduction of composite and types of composite used in industry. Besides that, this chapter also discussed about the benefits and drawback of composites in terms of its behaviour and mechanical properties. Plus, it will explain about how good can composite reacts with different environmental condition such as high temperature application. All the problem, motivation and objectives of this research are well defined at the end of this chapter.

Chapter 2 will give a review of published researcher about various condition especially the fire resistance behaviour of the composites. This chapter is divided into subsection for better and clear understanding. The literature review will covers the understanding related to composite materials including the structure of composite, the fuel properties in the aircraft fuel tank and the mechanical and fire resistance properties of composite in terms of the strength.

Chapter 3 will covers about the methodology of this project. This chapter is focus more about the method involves in completing this project. It includes a specific method on how the fabrication of the composite. Plus, it will give a detailed understanding on how the experiment and testing were conducted on the composites. Some equations are used in this project for the purpose to analyse the result in the next chapter.

Chapter 4 provide all the result collected during experimental work. Few graphs such as moisture absorption, stress-strain curve and young modulus were plotted and explained. The trends of the graph was discussed and analysed.

Chapter 5 summarise all the analysis done during this project. This chapter also concludes the project and describes about the suggestions and future works for future improvement for this project.

CHAPTER 2

LITERATURE REVIEW

2.1 The utilization of composite

In the recent years, the development of composite starts to grow and overwhelmed the global market among structural materials. The market potential of composite material has increase throughout the worldwide in recent years due to the advantages of composite. Composite material are been used in many industries such as aviation, automotive, maritime and manufacturing of sports equipment[3]. Use of composite increase as showed clearly from some researcher which stated that the demands of the composite material will be increase due to the ability of composite such as high strength-to-weight ratio material and can improve fuel efficiency of an aircraft[4]. The composite material global market is shown in Figure 2.1.

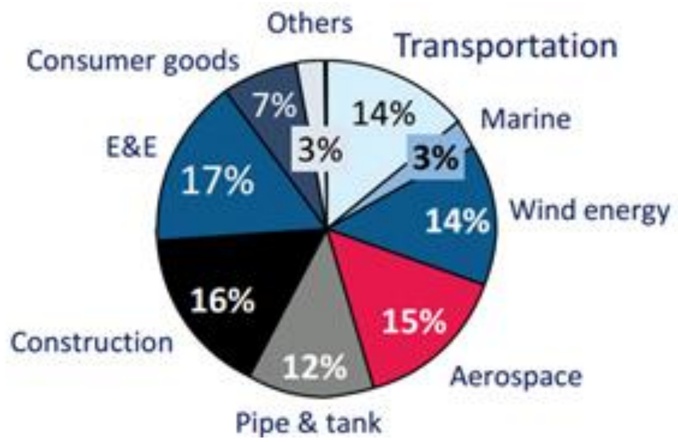

Figure 2.1 : The global composite material distribution by different market segments in 2017 [4]

2.2 Glass fibre

Fibre-reinforced polymer(FRP) composite consists of 2 constituents material which are fibre and matrix. The fibre-reinforced polymer composite is usually made with glass (GFRP), carbon (CFRP) or aramid (AFRP) fibres[3]. E-glass has become the most common types of glass fibre used in fibreglass. There are other types of glass used in fibreglass such as A-glass, S-glass and C-glass. The usage of E-glass is mostly used in electrical application because the alphabet "E" stands for electrical. Glass fibre are possible to be recycled and can be used in future time in order to save cost and enhance certain materials. A. Dehghan et al. investigated the combination of recycled glass fibre reinforced polymer and concrete. It is proven that the addition of recycled glass fibre reinforced polymers to the concrete managed to improve the mechanical properties of the concrete[5]. Glass fibre also possess some advantages such as small density, good toughness, high chemical stability and high temperature resistance[6, 7].

2.3 Thermosets Resin

Matrix is the main support of composite material in order to hold the fibre in solid form. Matrix are divided into two parts which are thermosets and thermoplastic. The relation between thermosets and chemistry are shown in Figure 2.2.

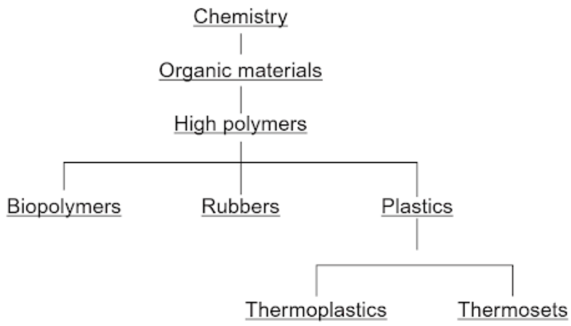

Figure 2.2 : Relationship between thermosets and chemistry [8]

Most of the composite material used thermosets matrix because it has better mechanical properties compare to thermoplastic matrix. In order to form a thermosets resins, two or more chemical substances which is resin and hardener are mixed together. The chemical reaction between resin and hardener form a very strong chemical bond or solid material. There are several types of thermoset resins which is polyester, vinyl ester, phenolic and epoxy[8]. As for this report, type of thermosets resin will fully focused on epoxy resin. Composite with thermoset resin has better strength compared to composite with thermoplastic resin in terms of mechanical properties. V. Arikan discovered the mechanical properties of the epoxy matrix composite and polypropylene matrix composite. It is proven that the mechanical properties such as impact strength and hardness of thermoset composite is better compared to thermoplastic composite[9].

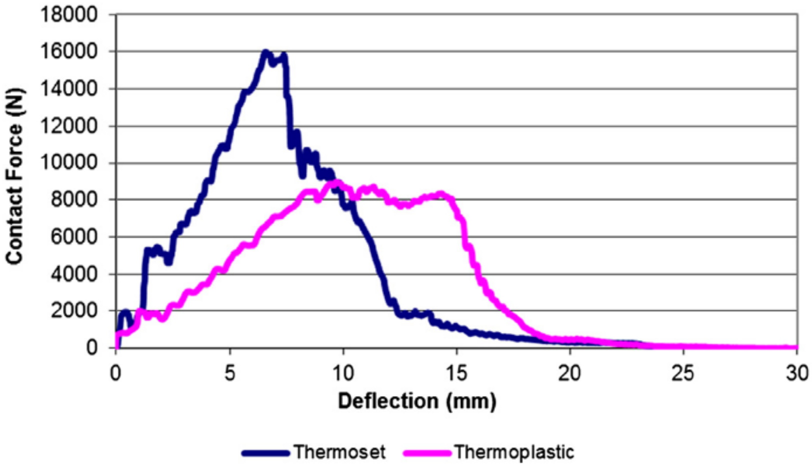

Figure 2.3 : The comparison in impact strength between thermoset and thermoplastic composite [9]

2.4 Sandwich structure composite

Special form of laminated composites is called as a sandwich structure composites. Sandwich structure composite is typically consists of two thin high strength fibre-reinforced polymer composite which is known as skin and bonded together with a light and thick core. The components of sandwich composite structure is shown in Figure 2.4. The skin are usually rigid and core is somehow weak and flexible. But, the combination of both components in a sandwich structure, they produce a very stiff and strong lightweight structure[10].

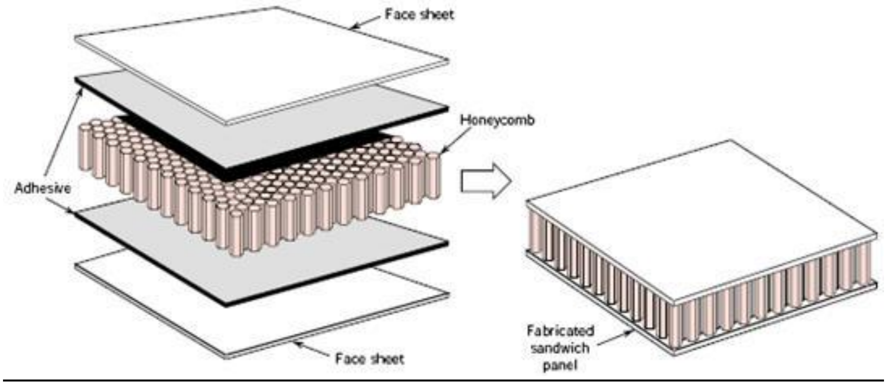

Figure 2.4 : Main components of sandwich structure composite. Photograph taken from http://www.fibre-reinforced-plastic.com

The concept of sandwich structure is the skin will support the bending loads while the core support the shear loads. The comparison between the skin and core is that the skin are much strong in both tension and compression compared to the core which can separate the skin in order to maintain high moment of inertia[11]. Besides that, sandwich structure can be operates in the same way as the traditional I-beam steel. The difference between sandwich structure and I-beam is the material used in sandwich structure which the skin has different material and the core continuously support the skin. As the core support shear loads, it can resists transverse forces and support the skin by stabilizes them against buckling and wrinkling[12].

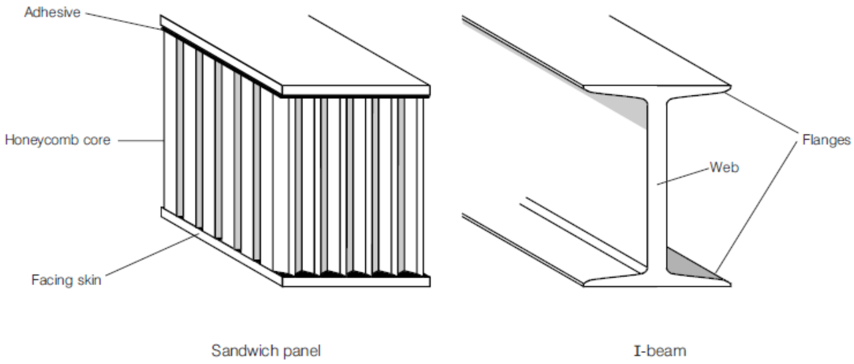

Figure 2.5 : The comparison between sandwich structure and I-beam. Photograph taken from http://www.stressebook.com

2.5 Absorption behaviour of sandwich composite

In the recent research, the absorption behaviour of sandwich composite in the water has been investigated. The purpose of this investigation is to determine how the performance of sandwich composite when fully exposed to water. A. Anjang et al. investigate the absorption behaviour of sandwich composite in the exposure of water. It is proven that the effect of water absorption of sandwich composite can causes the degradation in terms of the mechanical properties of sandwich composite due to the swelling[13-15].

Futhermore, Y. Fang et al. also investigate about the hygrothermal ageing of sandwich structures. It is found that the sandwich structure in hygrothermal environment can cause swelling, plasticization and degradation of the matrix which can reduce the mechanical properties of sandwich structures[16-19].

So, the exposure of sandwich structure in water can give significant changes towards its fibre and matrix properties.

However, the rate of moisture absorption of sandwich composite in water is consider to be slower than other chemical substances. This may due to the different particle of the solution itself.

2.6 Strength of composite in fire and post-fire

In order to study the durability of sandwich composite, the research extends to discover the fire resistance properties. Plus, this investigation also helps to seek information about the mechanical and post-fire mechanical properties. E. Kandare et al. studied the fire reaction properties of epoxy laminates and balsa-core sandwich composite with or without fire protection. It is proven that when the sandwich composite is exposed in elevated temperature, fibre-reinforced polymer composite will lose structural integrity and loss in mechanical properties[20]. Apart from that, C. Luo et al. discover fire resistance properties of sandwich structure composite by develop a thermo-mechanical model using Abaqus software. It is found that the degradation of laminates composite can reduce the mechanical properties as the temperature increase[21]. Figure 2.6 shows the results proven by C. Luo. Furthermore, the study of post-fire sandwich structure is also discovered by A.Anjang et al. It is found that the degradation of the skins causes by blistering and debonding at the skin interface together with voids and cracks[22-24]. A.Anjang et al. also managed to determine the strength of the sandwich composite due to post-fire damage. Figure 2.7 shows the compressive strength of the sandwich composite with different heat exposure time. This shows that the sandwich composite cannot perform well in the high temperature application compared to traditional material such as steel.

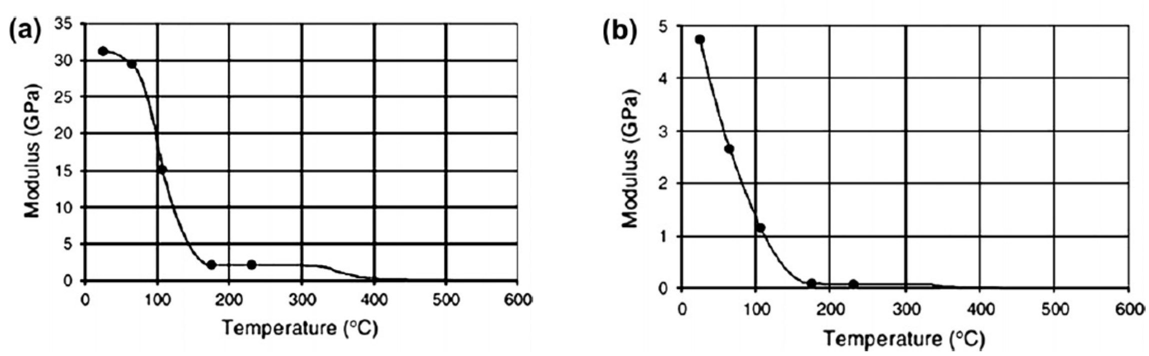

Figure 2.6 : The temperature dependency of (a) longitudinal modulus and (b) shear modulus of glass fibre-reinforced polymer composite[21]

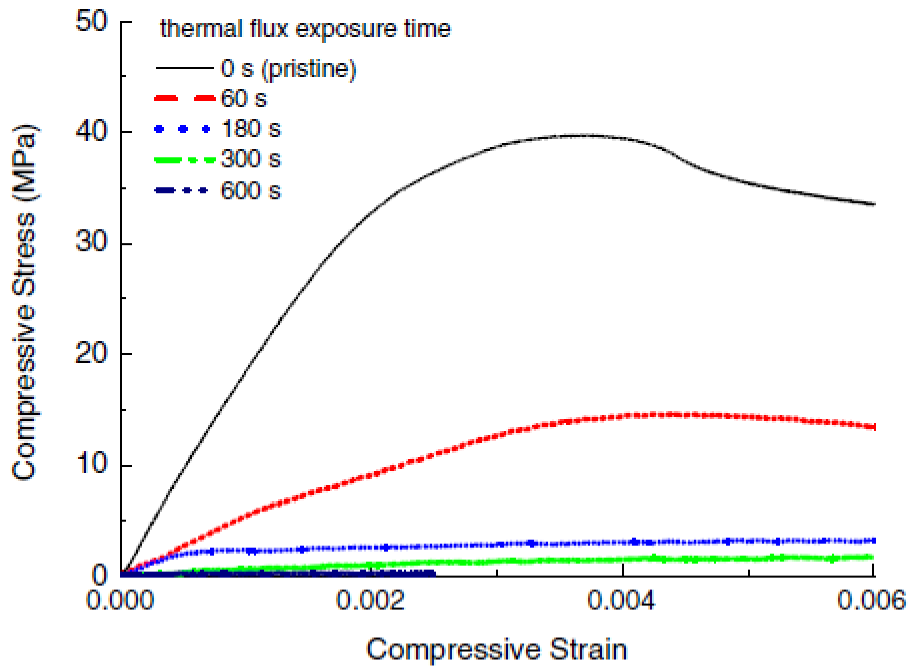

Figure 2.7 : The compressive stress-strain of the sandwich composite with the exposure of different thermal flux[22]

Besides that, there are few experiment was conducted to determine the post-fire properties of composite materials. Yarlagadda et al. discovered that there are four burn zones due to post-fire damage on the composite wing box. Each zone show the change in mechanical properties depending on the severity of fire damage[25]. Figure 2.8 shows the schematic drawing of the typical burn zones due to the fire damage.

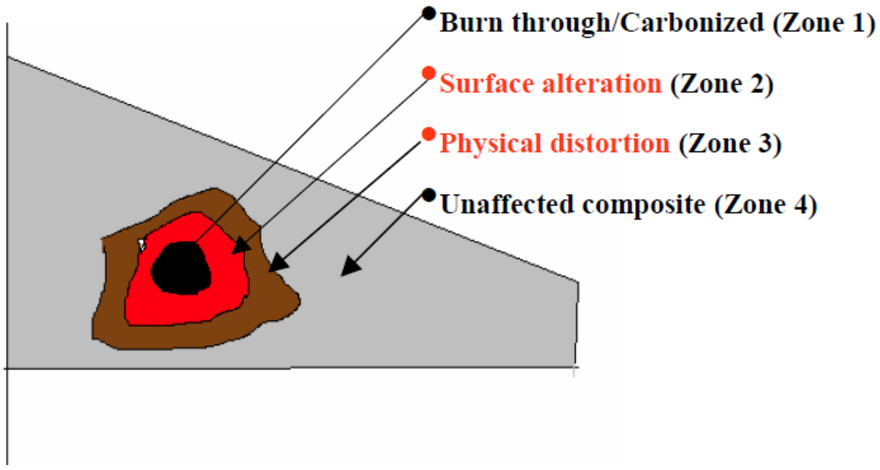

Figure 2.8 : The schematic of typical burn zones due to fire damage

CHAPTER 3

METHODOLOGY

In order to complete this project, there are several stages and process involved. At the beginning of the project, a study of core and skin properties is required to gain knowledge about the sandwich structure composites. Method of manufacturing has to be decided and learn how to perform in order to make a perfect specimen. As the method of manufacturing has been decided, the manufacturing for the specimen will begin. The specimen has to undergo fuel immersion test, room temperature mechanical test and post-fire test. Finally, all the results will be compare with the following circumstances.

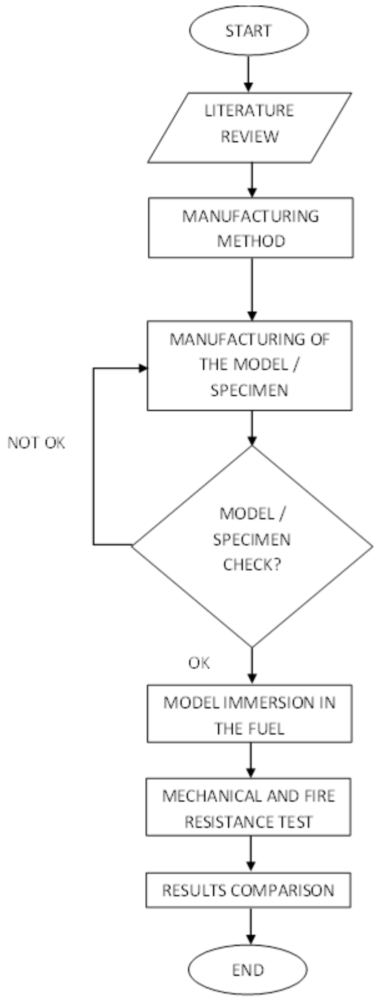

Figure 3.1 : Project flow chart

3.1 Preparation of the specimen

3.1.1 Manufacturing of the sandwich composite

Fabrication of sandwich composite is consider the main process in this project. In order to proceed to experimental stage, the sandwich composite specimen are required to be tested. The sandwich structure composite were manufactured from 2 ply of E-glass fibre woven roving (800 g/m^2) for each skin, a plastic honeycomb core with a thickness of 10 mm and epoxy resin. The hardener used for this fabrication is 103 Slow Hardener which has a heat deflection temperature of 53°C. The resin does not contain any additives and has a glass transition temperature of 137°C. Figure 3.2, Figure 3.3 and Figure 3.4 shows the E-glass fiber, plastic core, hardener and epoxy used for the manufacturing of the sandwich structure composite.

E-glass and plastic core was cut into the size of 350mm x 350mm each.

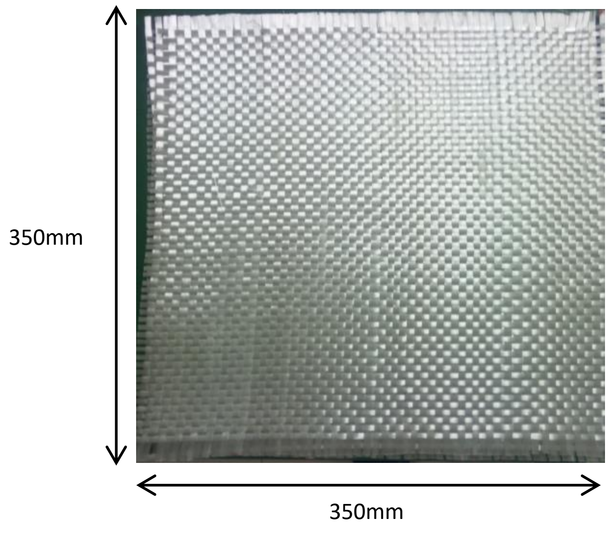

Figure 3.2 : Dimension of E-glass

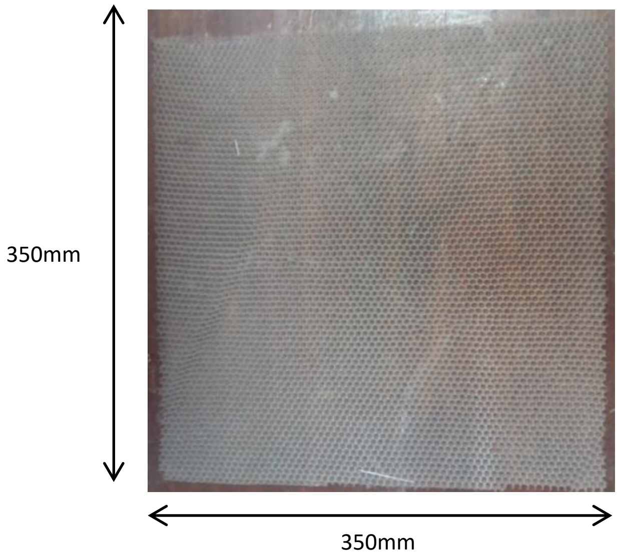

Figure 3.3 : Dimension of plastic honeycomb core

Figure 3.4 : Epoxy and hardener used for fabrication

Throughout this project, there are several stages in manufacturing of sandwich composite using wet-hand layup method. First, the metal plate surface must be clean and smooth from any dust and dirt before waxing the surface. The wax was applied three times in order to prevent the resin stick on the surface and give defects the composite surface (Figure 3.5). Then, the epoxy and hardener were mixed with calculated mass (Figure 3.6). The mass ratio between epoxy and hardener are 1 :1. The ratio between epoxy and hardener are 3.5 : 1. The targeted volume fraction of fibre is around 40% to 45%.

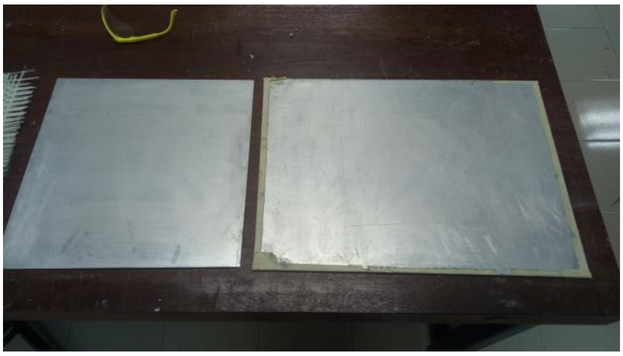

Figure 3.5 : Metal plate with wax surface

Figure 3.6 : Mixing epoxy resin and hardener

After mixing, the resin are ready to be use for fabrication. The resin were poured on top of the metal plate surface. The first layer of E-glass were placed on top of the resin. The previous step was repeated and resin was spread evenly to make sure every area are wetted with resin before proceed with next layer of E-glass (Figure 3.7). Epoxy resin were poured for second layer of E-glass and the steps was repeated for the fabrication of second skin.

Figure 3.7 : Epoxy resin is spread throughout the E-glass

After finish spreading the resin, the skin were left for an hour to make sure resin become gel. The purpose of waiting for resin's gel time is to make sure resin does not enter the core during the process of vacuum bagging. The core were placed on the top of the skin and the second skin were combined together to form a sandwich structure composite (Figure 3.8).

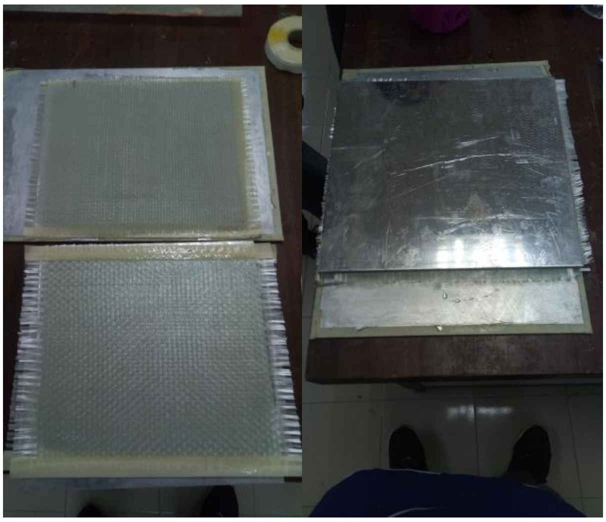

Figure 3.8 : Core placed on top of the skin and combination for both skins and core

Metal plate were placed inside the vacuum bag to continue with the vacuum bagging process. The setup of the process is cover with breather before applying the pressure from vacuum pump (Figure 3.9). The purpose of using a breather is to avoid any air leakage during vacuum bagging process. The pressure from vacuum pump is let for one hour to make sure both skins and core are tightly together. Then, the sandwich composite is let to cure at room temperature for at least one day. The sandwich composite was post-cured in the oven for one hour at 50°C (Figure 3.10). The whole process was repeated to manufacture more specimen for the testing purpose.

Figure 3.9 : Vacuum bagging process

Figure 3.10 : Oven for post-curing process

3.1.2 Cutting and trimming the specimen

For the cutting process, specific dimension of the sandwich composite is required for specimen depending on what type of testing to be performed. The details of each specimen size will be discussed in the testing methodology. The sandwich composite panel was marked based on a specific dimension used for certain type of mechanical testing. The large panel of sandwich composite were cut into a specimen by using a wet diamond cutter as shown in Figure 3.11. Figure 3.12 shows the specimen after cutting process. All specimen were undergo trimming process to follow the specific length. Blade cutter is used to trim the length of the specimen. The equipment was shown in Figure 3.13. All the cut and trim specimen is then measured using ruler and vernier calliper to get the accuracy for further process.

Figure 3.11 : Wet diamond cutter