POST-FIRE COMPRESSION PROPERTIES OF SANDWICH COMPOSITE MATERIAL

by

ABDUL RAHMAN BIN ZAINUL

(Matrix no: 120551)

Supervisor

DR. ASLINA ANJANG AB RAHMAN

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POST-FIRE COMPRESSION PROPERTIES OF SANDWICH COMPOSITE MATERIAL

ABSTRACT

The primary objective of this final year project is to investigate the post-fire, mechanical properties of sandwich composite which is a structure that is widely used in aircraft and spacecraft. In this project, E-glass reinforced epoxy laminate has been used as the composite skin and a plastic honeycomb for the core of the composite specimen. By applying fire, structural experiment method, this project investigates the behavior of sandwich composite after exposure to fire (post-fire). The experiment conduct of this project is to simulate the post-fire effect of on the sandwich composites. The effects of increasing exposure times on the residual compressive properties of the sandwich composite are experimentally determined. To investigate the mechanical properties, the compression test method was used to measure the stress, strain and young modulus of the sandwich composite. Compression test was performed for specimen at room condition first to select the suitable length. Next, specimen with suitable length was exposed to fire at different times and compression test was performed to find out the mechanical properties. Moreover, burn-off test also was conducted in this project to identify the fiber volume fraction of laminate layers of sandwich composite. It was found that the stress, strain and young modulus of sandwich composite decrease when exposed to fire at increasing the time. While for the burn-off test, the fiber volume fraction is obtaining around 40% to 46%.

UJIAN MAMPATAN SANDWICH KOMPOSIT SETELAH TERDEDAH KEPADA API

ABSTRAK

Tujuan utama dalam projek tahun akhir ini adalah untuk menyiasat sifat-sifat mekanik komposit sandwich selepas terbakar yang mana sandwic komposit ini banyak telah digunakan secara meluas dalam struktur pesawat dan kapal angkasa. Dalam projek ini, E-glass epoksida telah digunakan sebagai polimer berpenguatan serat dan plastic honeycomb sebagai teras spesimen. Dengan menggunakan kaedah eksperimen, projek ini menyiasat kelakuan sandwic komposit selepas terdedah kepada api. Ujian dalam projek ini untuk mensimulasikan kes terbakar terhadap sandwic komposit. Untuk mengkaji sifat-sifat mekanikal, kaedah ujian mampatan telah digunakan untuk mengukur tekanan, ketegangan dan modulus muda komposit sandwic. Bagi memperolehi pengetahuan terhadap terdedahnya sandwic komposit kepada api, projek ini menentukan mekanisme kegagalan pada masa yang berbeza dan pembakaran lapisan lamina juga telah dijalankan dalam projek ini untuk mengira pecahan isipadu gentian lapisan lamina sandwic komposit. Hasil daripada ujikaji bahawa fiber volume friction telah diperolehi kira-kira 40% kepada 46%.

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Last but not the least, I would like to thank my family, my parents Zainul Bin Taha and Saerah binti Saari, for giving birth to me at the first place and supporting me spiritually throughout my life.

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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STATEMENT 1

This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

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NOMENCLATURE

M_c = Mass of composite specimen, (g)

M_f = Mass of glass fiber, (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 fiber volume fraction

$\rho_c = Composite\ density$

$\rho_m = Matrix\ density$

$\rho_f = Fiber\ density$

CHAPTER 1

INTRODUCTION

1.1 General overview

The historical backdrop of composites goes back to antiquated circumstances for development applications; straw was blended with mud to frame a building material known as adobe. The straw gave the structure and quality, while the maid gone about as a folio, holding the straw together in place. Since the times of adobe, the utilization of composites has developed to generally consolidate an auxiliary fiber and a plastic, this is known as Fiber Reinforced Plastics or FRP. Like straw, the fiber gives the structure and quality of the composite, while a plastic polymer holds the fiber together. Regular sorts of filaments utilized as a part of FRP composites include fiberglass, Carbon Fiber, Aramid Fiber, Boron Fiber, Basalt Fiber and natural Fiber (Wood, Flax, Hemp, and so on.). On account of fiberglass, a huge number of minor glass strands are arranged together and held inflexibly set up by a plastic polymer gum. The common plastic resin used as a part of composites includes Epoxy, Vinyl Ester, Polyester, Polyurethane and Polypropylene.

1.2 Advantages of using composite

The composite material most ordinarily connected with the expression "composite" is Fiber Reinforced Plastics. This kind of composite is utilized widely all through our everyday lives. Normal regular employments of fiber reinforced plastic composites such as aircraft, boat, car segments, wind turbine cutting edges, body armor, building materials, water channels and stepping stool rails. In contrast with basic materials utilized today, for example, metal and wood, composites can give a particularly preferred standpoint. The essential driver and preferred standpoint in the reception of composites are the lightweight properties. In transportation, less weight compares to more fuel investment funds and enhanced increasing speed. In wearing gear, lightweight composites take into consideration longer drives in golf, speedier swings in tennis, and straighter shots in arrow based weaponry. While in wind vitality, the less a sharp edge measures, the more power the turbine can create. Other than weight reserve funds, the most critical advantages of composites include non-corrosive, non-conductive, flexible, low maintenance, long life and design flexibility.

1.3 Composite when exposure to fire

Such flames can warm the surface of the composites to more than 100 degrees Celsius in a brief timeframe and to more than 400 degrees Celsius. Campsites that had been presented to high raised temperature, it will make the polymer lattice mellow and cause genuine contrition, clasping and disappointment of load-bearing structures. There is likewise other occurrence, including fire and composites that had taken hundredths on lives. Consequently, there is a need to comprehend the imperiousness to fire and the conduct of composite materials under raised high temperature. To investigation of the conduct of various sort composites including its fire properties under elevated temperature are still in its incipient stage. There is space for a great deal of exploring that should be possible for better understanding. Having a complete understanding on how well the composites carry on in high temperature will unquestionably help toward the better planning of the airplane. This is the fundamental reason for finishing this venture[1].

1.4 Motivation and Problem Statements

Composite is one of the advance technology that has been used widely around the world because its properties have the light in term of weight and good in term of strength. Sandwich composite is one of the example advance material that has been used widely. Study about mechanical properties of sandwich composite is also important to improve the structure of the aircraft or spacecraft and to make sure the safety of the passenger. To understand about how well composite can withstand when expose to the fire, thus will improve the safety and reliability of an aircraft or spacecraft.

1.5 Objectives of Research

The research work described in this thesis is performed based on the following objectives:

i. To fabricate clamp and perform compression test by using sandwich composite specimen.

ii. To fabricate sandwich composite E-glass for laminate layer and plastic honeycomb for core by using method wet hand lay up

iii. To study compression mechanical properties effect of sandwich composite when expose to the fire.

iv. To compare compression properties of sandwich composite with different thickness of core.

v. To investigate the effect of length on compression mechanical properties of sandwich composite.

1.6 Thesis Layout

This thesis comprises 6 chapters. Chapter 1 gives a general overview of the composites and the advantages of composite. Next, the general concept of composite which is include the classification of composite, the matrix and the core used in this project.

Chapter 2 reviews all literatures related to this work. The focus is on the post-fire, mechanical properties. The literature review covers all the aspect that related to the project such as material used, method of fabrication and test that will be conducted.

Chapter 3 will focus more on the methodology of the project. All the procedure of fabrication, conducting the test and material used was discussed in detail in this chapter. All the equation used to obtain the result also was discussed in this part.

Chapter 4 was discussed about all the result that has been obtained during the testing process. Graph, figure and collected date will be discussed and analyzed.

Chapter 5 conclusion about all the obtained result and analysis that has been done. Suggestion for the future fork also was discussed for future improvement.

CHAPTER 2

LITERATURE REVIEW

Revolution in term of politic, education, economy and technology globally cause of demand on advance material such as composite, polymer and alloy becomes increase. The demand on the advance material increase because it gives better material properties compare than raw material. Lately, demand of composite in aerospace field has become encouraging because it is light and tough compared than other material. In the other hand, to meet the requirement and demand of the market, a lot of research and experiment has been conducted to improve the mechanical properties of the composite. Composite are a combination of two or more materials to form new advance material. Usually material used in the fabrication of composite such as E-glass, carbon fiber, wood, fiberglass, honeycomb and resin.

2.1 Reinforcement composite

Composites allude to a material comprising of at least two individual constituents. The strengthening constituent is inserted in a lattice to form the composite. Composite structures are very normal in nature where fiber and grids are joined. There is a wide range of sorts, of fibers that can be utilized to fortify polymer framework composites. The most widely recognized are carbon fibers is AS4 and IM7. On the other hand, the most widely recognized of fiberglass are S-glass, E-glass, A-glass and C-glass. Similarly, as with the lattice, the fiber picked will be controlled by the end application.

2.2 Glass Fiber

Glass fiber, likewise called fiberglass. It is material produced using amazingly fine filaments of glass Fiberglass are a lightweight, greatly solid, and powerful material. Although quality properties are to some degree lower than carbon fiber and it is less stiff, the material is ordinarily far less fragile, and the crude materials are considerably less costly. Its mass quality and weight properties are likewise exceptionally great when contrasted with metals, and it can be effortlessly framed utilizing shaping procedures. With regards to the crude material, glass used to make glass strands or Nonwovens of glass filaments, the accompanying grouping is known, A-glass as to its creation, it is near a window glass. C-glass, this sort of glass shows better imperviousness to synthetic effect and good resistance to chemical. E-glass are joins the attributes of C-glass with great protection for electricity. Lastly, for AE-glass the advantage of this material is its resistance to alkali [2]. Glass fiber additionally can be reused to be utilized as a part of future undertakings keeping in mind the end goal to upgrade certain material. M. Mastali et al. examined the mechanical properties of the reused fiber glass which is strengthened with cement. It is demonstrated that the including of reused glass fiber fortified polymers brings about enhancing the effective resistance and mechanical properties of the self-compacting concrete [3].

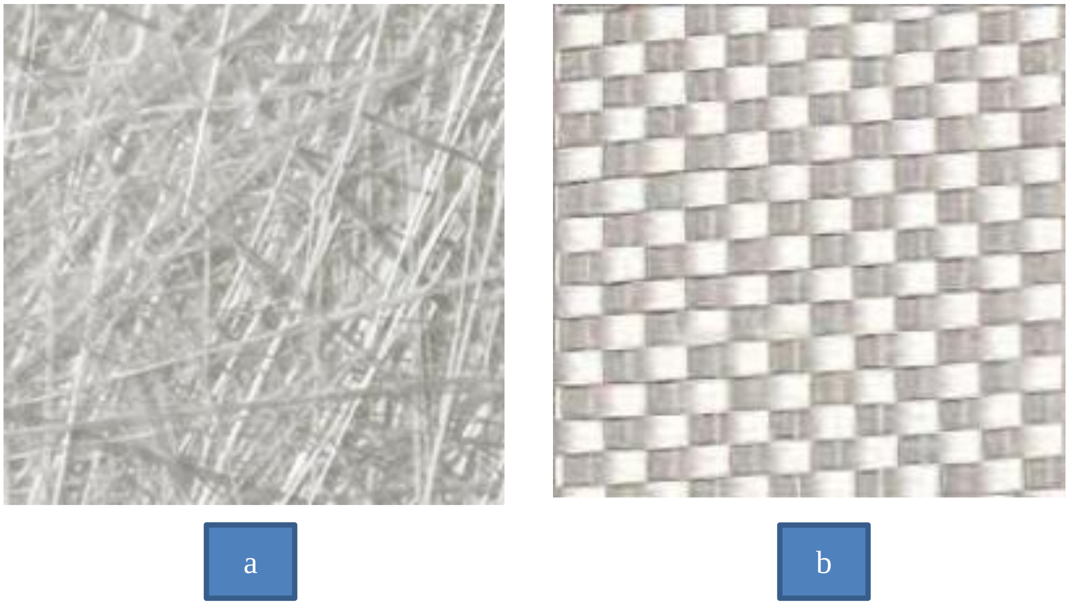

Figure 1: (a) Chopped strand mat glass fiber[4], (b) woven glass fiber[2]

2.3 Matrix

Matrix-resin is a holding material or bonding in composites. They are varied as the reinforcements such as plastic resin, metals and ceramics. Epoxy plastic resin is the most essential composite matrix for airframe and aviation application. A matrix can be classified into few types which is thermosetting polymeric resin, thermoplastic resin, elastomers, metal matrix and ceramic matrix. Composite material has the properties of being a thermoplastic and thermoset. A thermoplastic, dissimilar to a thermostat, can be melted and remolded. This implies once the composite is can't be changed. Thermostats for example, like steel, once made can be warmed to its liquefying temperature and adjusted into an alternate coveted shape. When we relate these properties to composites, it is as a rule in the metal network that is thermoset, the matrix, for example, epoxy, phenol, vinlyester, and polyester are thermoset once the chemical reaction take place and the substance solidifies, the filler is stuck in that position. Thermoplastic matrix materials such as, PPS, PEEK, and PEI. Notwithstanding thermoset and thermoplastic materials, there is a characterization called natural and inorganic materials [5].

2.4 Core

Core can be defined as centers of structure sandwich composite. The core of a sandwich structure can be use of any material or design. Usually, the core can be classified into four sorts which is foam or solid core, honeycomb core, truss core and web core [6]. The two most honeycomb sorts are the hexagonally-formed cell structure known as hazel and the square cell or egg-carton. Web core development is comparable to a gathering of I-beam with their flanges welded together. While, truss or triangulated core usually used in bridge development. In most, foam core and honeycomb core are used for sandwich developments. In addition, it can be assumed for all practical purposes that the in plane and lateral bending loads on foam and honeycomb core are carried by the faces only. However, in truss core and web core developments, a segment of these heaps is conveyed by the center [7].

2.5 Laminate layer

Laminate configuration can be divided into three classes which is unidirectional lamina, laminate and bulk composite. Unidirectional lamina is a single lamina likewise called layer or ply, or a few laminae (plural) with a similar material and orientation in all laminae. While laminate can be said that a few laminae stacked and reinforced together, where in any event some laminae have diverse orientation or material. Lastly, bulk composites, for which laminae can't be distinguished, including bulk molding compound composites, particle-reinforced composites, and so on [8], [1].

2.6 Sandwich composite

Normally the face of the sandwich composite is same, however, it can vary or can be different. within sandwich can incorporate nearly anything such as in density, thickness, and strength. periodically, one can experience a two-layer sandwich as well. frequently there are two faces, indistinguishable in material and thickness, which primary resist the in-plane and lateral load. In unique cases, the faces may vary in either thickness or material or both, because perhaps one face is the essential load conveying, low-temperature portion while the other face must withstand a raised temperature, destructive condition and so on[9],[10].

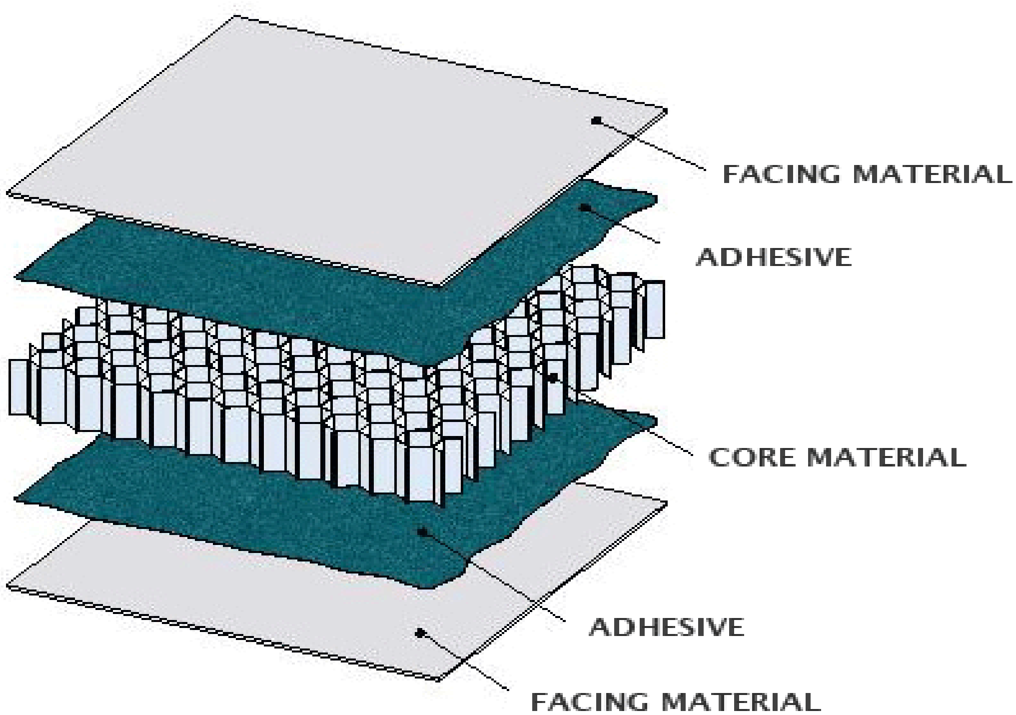

Figure 2: Sandwich composite lay-up[11]

2.7 Hand Lay-up

The hand lay-up is the least difficult and most established strategy for the composite manufacture forms. It is a work requesting technique suited especially for expansive parts, for example, airplane fuselages and pontoon structures. Glass or other fortifying sheets or woven material is situated by submitting in open mold, resin is poured or showered over and into the glass utilizes. Air is expelled physically by machine or rollers to finish the covers structure. Room temperature curing polyesters and epoxies is the most ordinarily utilized lattice saps as talked about above. The manufacturing of fiber-reinforced composite by using method wet hand lay-up technique can be classified as traditional technique or early manufacturing technique. A wet lay-up method using a low-viscosity and low temperature-curing base epoxy resin [12]. For curing process, woven roving, E-glass fabrics were stacked, vacuum bagged, and cured under a pressure of 1 bar [13]. Fabrication of hand lay-up was performed by placing a reinforcement layer by layer impregnated with epoxy resin [14].

2.8 Compression test

To perform compression tests on sandwich composite, the test should be carried out according to the C364 ASTM standard. All tests were performed with a head speed of 0.5 mm/min. To make sure proper alignment and to reduce sample buckling, a specific fixture was designed according to the standard to lateral support both ends of the sample [2]. The ends of sandwich composite were clamped, and the relatively high unsupported length-to-thickness ratio (approximately 50-to-1) caused the sample of deform and fail by buckling [15].

2.9 Post-fire testing of composite materials

Composite behavior under post-fire is clearly an issue due to their various modification possibility matrix and fiber degradation, oxidization and delamination. Fire downgrade the material mechanical properties and the structural resistance. At the point when exposed to fire, polymer matrix softens and loses its properties in term of strength and stiffness. The radiant heater of a cone calorimeter was utilized here to simulate post-fire to composite specimen. By using this technique, the heat flux and the heating conditions are controlled and repeatable [16]. The heat flux that produce by using a radiant heater was used to apply flux on one side of specimen [17]. In other cases, to study the post-fire, mechanical properties, a liquefied petroleum gas (LPG) burner was used as a medium to generate fire. The specimen was exposed to fire LPG gas directly [18]. Only one side of the specimen was exposed to fire and the location is in the middle of the specimen while another region was thermally insulated to avoid softening and heat damage [19]. Tests were performed at different heat fluxes of 10, 25, and 50 kW/m2, which heated the laminate surface of the structure to maximum temperatures of about 270,480, and 650C, respectively. The temperatures were measured using thermocouples located at the heated and unheated sides of the laminate specimen together with a thermocouple located in the center of the laminate [17]. The distance between the butane gas torch and the specimen is set to be 120 mm. For each heating time, total of three specimens were exposed to butane gas torch [1].

CHAPTER 3

METHODOLOGY

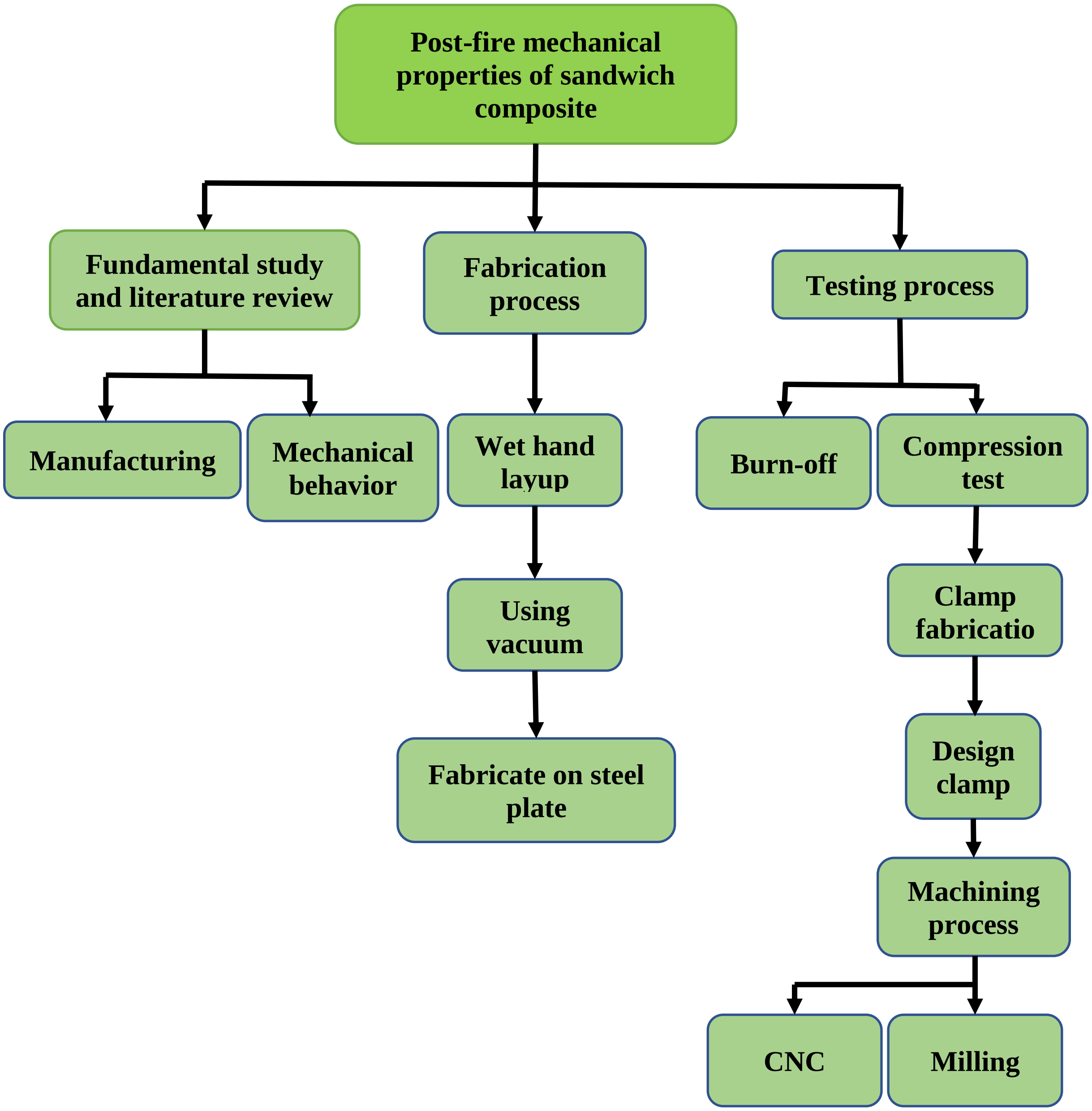

Figure 3: Work breakdown structure of project

This chapter presents all the method used to fabricate the spacemen and analysis the result after performing the test. Furthermore, all tests and procedure also will be explained further in this chapter. In addition, to perform test followed the ASTM standard, a jig or clamp has been fabricated. All the design, material and fabrication process of the clamp will be discussed. All the process involve in this project can be divided into three stages and all the process involves showing in break down structure below.

3.1 Material Used in Fabrication

Preparation of composite specimen required combination of the material to perform the fabrication process. Sandwich composite can be classified into three sections. First section (upper surface) and third sections (lower surface) is laminate surface. Upper and lower surface were fabricated by using two layers of woven E-glass (800g/m2) with dimension 500mm x 500mm and epoxy as resin during the lay-up. The ratio of epoxy resin used during fabrication process is 100 (resin): 29 (hardener). The second section (middle) is the core of the sandwich composite and used plastic honeycomb with dimension 500mm x 500mm. During the fabrication process, two steel plates with dimension (500mm x 500mm) were used for the curing process.

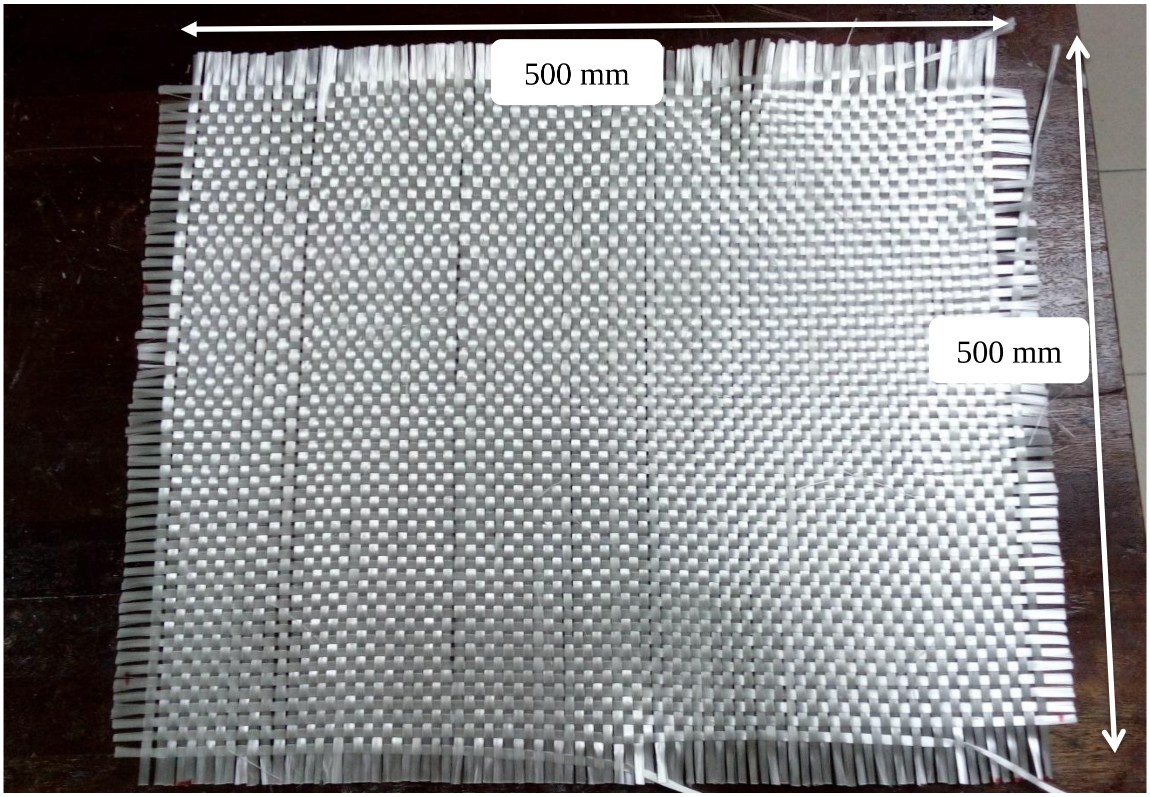

Figure 4: Dimension of woven E-glass

3.2 Hand Lay-up

In the first place, the surface of two steel plates where the fabrication will be conducted was cleaned with acetone. After that the surface was waxed three times to make sure the resin will not stick to the surface and damage the laminate surface of sandwich composite. The main purpose of using steel plate is used to create a smooth surface and to make sure the composite easily can be moved to another place during the fabrication process.

Figure 5: Waxed steel plate

Epoxy resin was poured on the surface of the steel plate and spread evenly. After that, the first layer of E-glass was placed and fewer amounts of resin were poured in the E-glass. Roller and cardboard were used to eliminate air bubbles traps before the second layer of E-glass were placed on the first layer of the E-glass. The lay-up process was checked several time and epoxy resin was added if there are area of E-glass not covered with resin. The steps were repeated for the second laminate surface of sandwich composite by performing fabrication process on a second steel plate. The volume friction for both sides of the surface was controlled and make it balance for both surfaces. Next, plastic honeycomb was placed on the one of the laminate surface and other E-glass laminate surface was placed on top of honeycomb surface. The sandwich composite with two steel plates on top and bottom were placed in the vacuum bag and the vacuum bag was vacuumed for the curing process. The main purpose of using vacuum bag is to make sure both surfaces of sandwich composite ware applied the same amount of force during the curing process. The sandwich composite was let be cured at room temperature for one day.

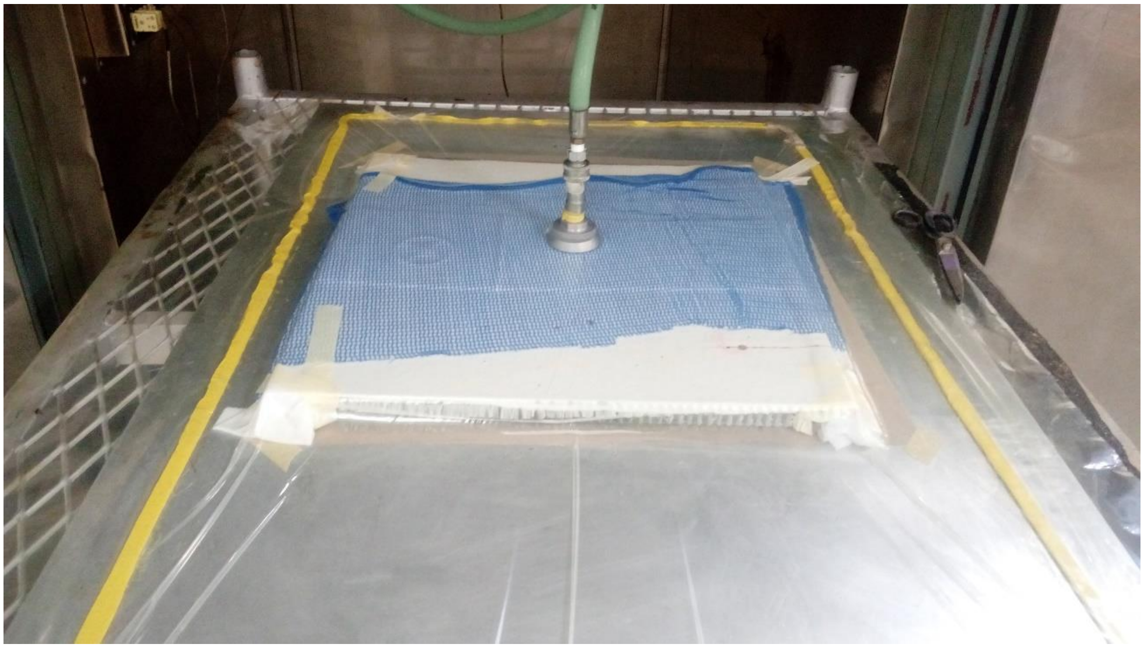

Figure 6: sandwich composite was placed in vacuum bag

3.3 Cutting process and preparation size of specimen.

The dimension of the specimens used is depend on the type of the testing and machine that will be used. The detail of the cutting process of specimen due to the testing process will be discussed in each of the testing methodology. For compression test, cutting process method was performed by using a disc cutting machine. The specimens were cut from large panel to become a small dimension by using a disc cutting machine. Before performing cutting process, sandwich composite panel was marked by using a marker pen. After cutting process, all the cut specimen was measured back their dimension in term of length, width and thickness by using Vernier calipers to achieve accuracy in the testing process. For the burn off test, the cutting process was performed same as compression test where the specimen was marked to desired dimension and cut by using shear cutter machine.

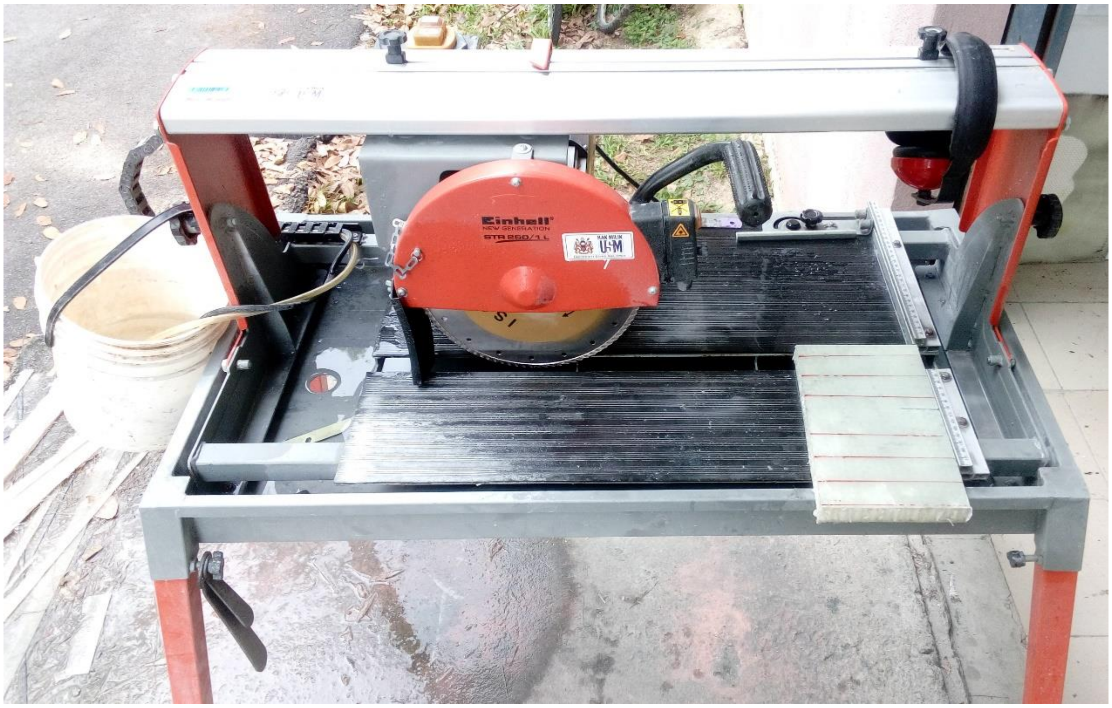

Figure 7: Cutting machine

3.4 Compression Test

Compression test was performed by using the Instron compression machine. The purpose of conducting compression test is to measure mechanical properties of the specimen and to plot failure map of sandwich composite. After fabrication process, specimen was cut to small size, which is 30mm wide and have different length, which is 50mm, 100mm, 150mm, 200mm and 250mm. there are three types of failure mode that are concerned here, which are pure compression, mix failure mode (Buckling and compression) and pure buckling.

Figure 8: Setup for compression test

3.5 Clamp design and manufacturing process.

To perform a compression test for sandwich composite, suitable clamp or the jig is needed to make sure the test follows the ASTM standard. Since the available clamp at laboratory cannot clamp the sandwich composite because the maximum clamp thickness is below 15mm. Therefore, new clamp has been designed to make sure the compression test can be performed to the sandwich composite. The idea and concept operational of sandwich composite clamp was obtained from ASTM standard paper and from the web site. Next, the design and selecting material of the clamp was performed by using SolidWork software. After finalizing the design of the clamp, material of the clamp was ordered and fabrication process will be proceeded. Ordered material from the supplier was undergoing the facing process by using a milling machine to make sure the surface is flat enough and square before proceeding to computer numerical control (CNC) process. Next, the material was preceded to shaping process at CNC machine. Before performing shaping process by using CNC machines, drawing of the clamp was observed and investigate about their shape and dimension. In addition, the suitable cutting tool was chosen and simulation of the cutting process was set by using a computer. Simulation of the cutting process was observed, if the simulation cannot perform well, adjustment of the cutting process should be done to get the smooth simulation of the cutting process. Lastly, the complete fabricated clamp was tested on an Instron machine to make sure it works and can be used for compression test sandwich composite.

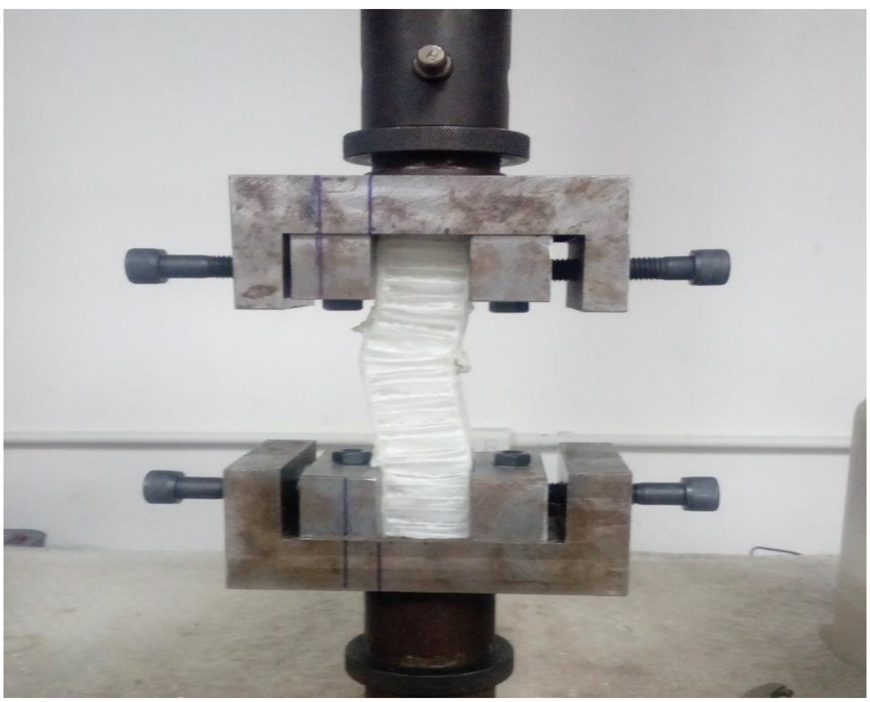

Figure 9: Clamp after fabrication process

3.6 Post-Fire compression test

In post-fire, compression test, the material used to fabricate sandwich composite are same as before which is woven E-glass 800g/m2, plastic honeycomb for the core and epoxy as resin. The procedure of fabrication sandwich composite for post-fire is same as mentioned in section 3.2. To perform post-fire, compression test, the specimen was cut to dimension 30mm width and 120mm length (including clamp area). Nine specimens with four core thickness 30mm and 20mm each was prepared. A 50mm long section of the specimen was exposed directly to butane gas torch that can produce around 980˚C as its maximum temperature. The specimen was exposed to the fire for differing time range from 10 second to 30 seconds with increment of 10 second. The temperature of the surface that expose to the heat was measured and observed by using thermocouple type-K. In the clamp area at 35mm at the top and bottom of the specimen was covered by a steel plate to avoid the clamp area from exposing to the fire. The distance butane gas torch and specimen was set to be 120 mm. For each post-fire time, three specimens were prepared to expose to butane gas fire. The end of the specimen which is at clamp area were covered to prevent from expose to butane gas fire. The end of the specimen which is at clamp area were covered to prevent from expose to fire [15].

Figure 10: Set up for post-fire

3.7 Burn-off method

Burn off experiment was conducted to obtain the fiber volume fraction of the specimen. The specimen was prepared with dimension 25mm x 25 mm approximately. From sandwich composite, the laminate layer was separated with their honeycomb core. The only laminate layer has been used for the burn-off test.

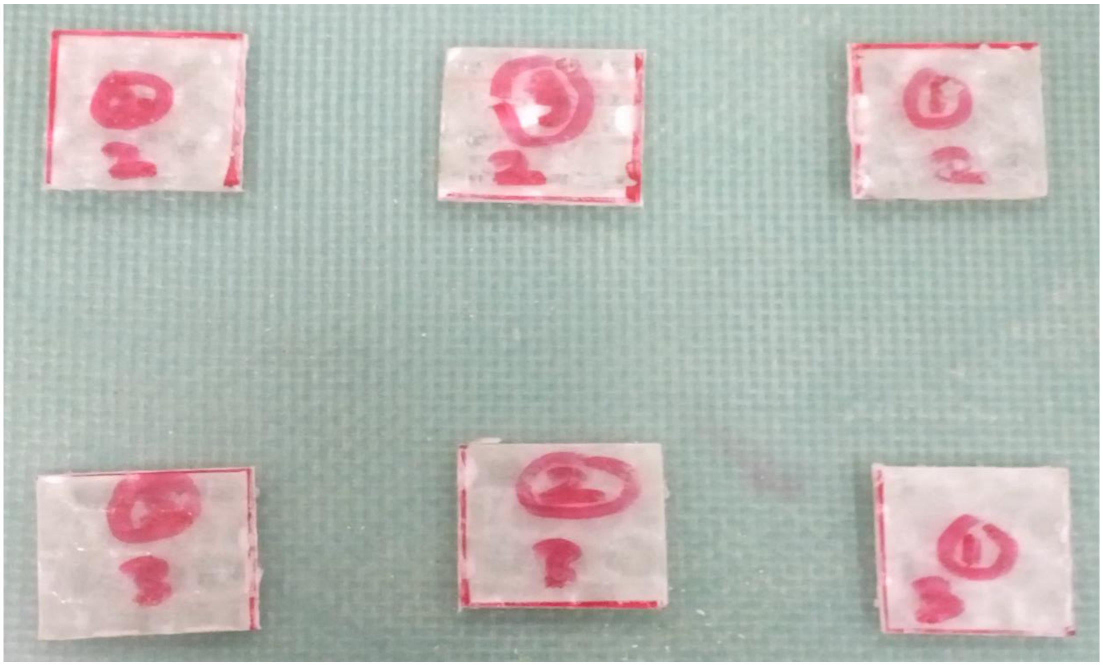

Figure 11: Specimen for burn-off test

The crucible is used as container to place the specimen. The furnace was heated first to temperature 525˚C and after that empty crucible was placed in the furnace for 10 minutes. After 10 minutes, the crucible let be cool at room temperature and the weight of the crucible was recorded by using laboratory analytical balance digital scale. Next, the specimen was placed in the crucible and waited again. All specimens are placed in the furnace with temperature 565˚C for two hours. Lastly, the specimen was weighted again after placing in furnace for two hours. All the data were recorded.

Figure 12: Crucible used to place specimen

3.8 Fiber volume fraction calculation

After performed burn-off testing, all the recorded data was used to calculate the volume fraction of the specimen. The formulae used to calculate volume fraction of laminate layer of E-glass are as follows:

$$M_c = M_f + M_m \quad (1)$$

$$V_f = \frac{M_f}{\rho_m} \quad (2)$$

$$V_m = \frac{M_m}{\rho_m} \quad (3)$$

$$V_c = V_f + V_m \quad (4)$$

$$v_f = \frac{V_f}{V_c} \quad (5)$$

$$v_m = \frac{V_m}{V_c} \quad (6)$$

3.9 Density method to calculate volume fraction of laminate layer of E-glass

Density method is one of another method to find out the volume fraction of fabricated specimen. But the difference is in this method only used an equation to calculate the fiber volume fraction compare than burn-off method. The volume fraction of laminate, E-glass was calculated by using the rule of mixtures:

$$v_f = \frac{\rho_c - \rho_m}{\rho_f - \rho_m} \tag{7}$$

3.10 Calculation Stress Strain curve and Young Modulus.

Graph of stress strain curve was obtained for each specimen after performing compression test. The following equation was used to calculate the stress and strain of specimen.

$$Stress = \frac{F}{A} \tag{8}$$

$$Strain = \frac{\Delta L}{L} \tag{9}$$

Young modulus of specimen was calculated by using stress strain curve. The equation bellow was used in calculating young modulus.

$$Young\ modulus = \frac{\Delta\, Stress}{\Delta\, Strain} \tag{10}$$