STRUCTURAL INTEGRITY OF COMPOSITE LAMINATES PANEL USING ULTRASOUND TECHNIQUE

by

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ENDORSEMENT

I, Joshua Boniface Duasing 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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Date:

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ABSTRACT

Advancement of technology made possible the change in utilization of material in the industry especially in aerospace industry. Fiber-reinforced laminated composite are now widely used in aircraft as well as modern vehicle. Comparing to other conventional traditional structural material, composite has high elastic modulus as well as high strength to weight ratio in addition to their wide usage. However, their behavior under impact is still a concern as it may face those event across its entire life span from manufacturing, during service or even in maintenance. This is vital as low-velocity impact can induce internal damage while not noticeable by visual inspection. Ultrasound technique provides a clear answer where a non-destructive test could be carried out to examine the inside of a structure. The test piece are subjected to drop impact test to simulate real world situation. Ultrasound scanning is done before and after the impact test. A good correlation between the impact energy and the maximum peak reading for ultrasound is noticed. This study provides a better understanding about ultrasound technique and why it is important for future structural assessment.

INTEGRITI STRUKTUR PANEL LAMINA KOMPOSIT MENGGUNAKAN TEKNIK ULTRASONIK

ABSTRAK

Kemajuan teknologi membolehkan perubahan dalam penggunaan bahan dalam industri terutamanya dalam industri aeroangkasa. Komposit lamina tetulalng serat kini digunakan secara meluas dalam pesawat serta kenderaan moden. Dibandingkan dengan bahan struktur tradisional dan konvensional yang lain, komposit mempunyai modulus elastik yang tinggi serta nisbah kekuatan kepada berat yg tinggi di samping penggunaannya yang meluas. Walau bagaimanapun, perubahan sifat bahan ini di bawah impak masih menjadi kebimbangan kerana ia mungkin berulalng terjadi sepanjang tempoh hayatnya daripada pembuatan, semasa perkhidmatan atau bahkan dalam penyelenggaraan. Ini penting kerana impak terhadap halaju rendah boleh menyebabkan kerosakan dalaman sementara tidak dapat dilihat melalui pemeriksaan visual. Teknik ultrasonik memberikan jawapan yang jelas di mana ujian tanpa musnah dapat dijalankan untuk pemeriksaan bahagian dalam struktur. Bahan uji kaji ini dikenakan ujian impak bagi meniru keadaan dunia sebenar. Pengimbasan ultrasonik telah dilakukan sebelum dan selepas ujian impak dijalankan. Hubungan yang baik antara tenaga impak dan bacaan puncak maksimum untuk ultrasonik diperhatikan. Rumusan melalui kajian ini telah memberikan pemahaman yang lebih baik mengenai teknik ultrasonik dan kepentingan ia untuk penilaian struktur pada masa hadapan.

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LIST OF ABBREVIATIONS

UT : Ultrasonic Testing

NDT : Non Destructive Test

AR : Augmented Reality

BVID : Barely Visible Impact Damage

CHAPTER 1

INTRODUCTION

1.1 General Understanding of Composite Material

Composite materials are generally a combination of two or more dissimilar materials that are used together which results in better properties than those of the individual materials used alone. It is typically consists of relatively strong, stiff fibers in tough resin matrix. The two materials work side by side to give the composite unique properties. This is in contrast to metallic alloys whereby each material retains its separate chemical, physical, and mechanical properties. Within the composite itself, you can easily differentiate the materials apart as they do not mix or dissolve into each other. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a reduction in weight in the finished product.

1.2 Composite Laminates

Fix two or more plies of material together and we will get a laminate, which is essentially just a material made up of layers. It is also important to know that a laminate is not simply several layers of materials, the materials have to be permanently joined together with something like adhesive, so they will behave as one material and not as several. The adhesive will act as an additional material in a laminate which usually is the matrix resin.

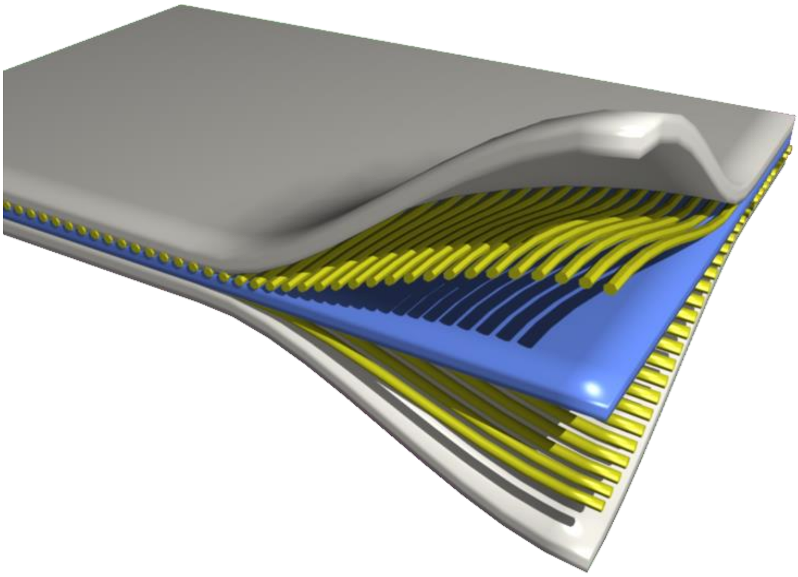

Figure 1.1: Layers in composite laminates. Retrieved from github.com/joaopbernhardt/lamipy

When there is a single ply of composite or a lay-up in which all of the layers or plies are stacked in the same orientation, the lay-up is called a lamina. When the plies are stacked in different angles, the lay-up is called a laminate. Figure 1.1 showing fiber-reinforced composites engineering simulation in Python where different materials of reinforcement stacked and bonded together.

1.3 Structural Integrity

Integrity is a term which refers to the quality of being whole and complete, or the state of being unimpaired or uncorrupted condition. Structural integrity is the ability of an item, either one structural component or a structure which has more than one component, to hold together when subjected to load, including its own weight, without breaking or misshape excessively. Structural integrity will assures that the construction or product will perform to its designed purpose and goal with proper use, for as long as its expected life span. Construction or product without the correct structural integrity can cause catastrophic failure, great damage, severe injuries and even death to the end user.

1.4 Ultrasound Technique

Ultrasonic Testing (UT) uses high frequency sound waves typically in the range between 0.5 and 50 MHz to conduct examination and measurements. UT has a wide application not only in engineering field but in medical field as well. In engineering usage, UT can be used as flaw detection or evaluation, dimensional measurement, material characterization, etc. In medical field, ultrasonic can be used as sonography, therapeutic ultrasound, laparoscopic ultrasound, etc.

Generally, UT is based on the capture and quantification of either the reflected waves (pulse-echo) or the transmitted waves (through-transmission). Figure 1.2 shows the differences between pulse echo method and through transmission method. Pulse-echo inspection uses a transducer to send out a pulse of energy and the same transducer listens for reflected energy, also known as echo. The received ultrasonic pulses are separated by the time it takes the sound to reach the different surface from which it is reflected. Through transmission is performed using two transducer on opposing sides of the product or specimen. One is to act as transmitter and the other as receiver. A defect in the sound path between the two transducers will interrupt the sound transmission. The test result can be determine by evaluating the magnitude of the interruptions.

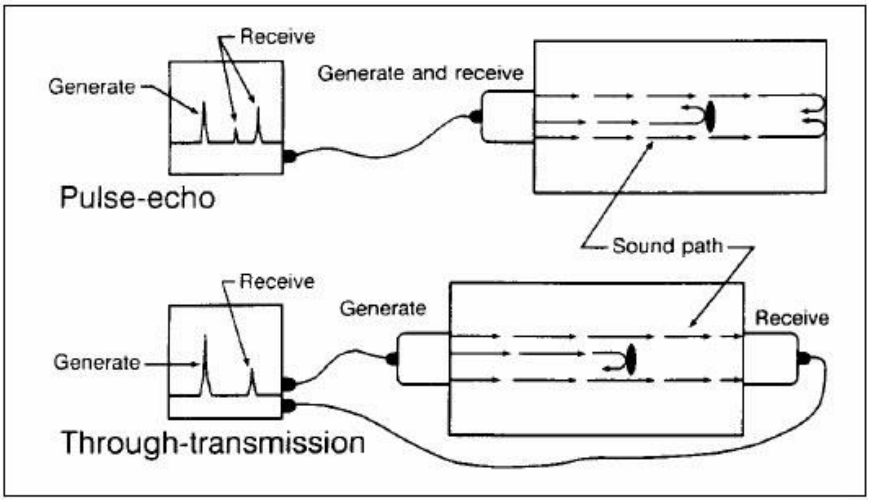

Figure 1.2: Pulse echo vs through transmission system (Bureau, 2010)

Each of the two types is used in certain applications, but generally, pulse echo systems are more useful since they require one-sided access to the object or product being inspected.

1.5 Advantages and Disadvantages of Ultrasonic Inspection

Ultrasonic inspection is a very useful and versatile Non-Destructive Test (NDT) method. Some of the advantages of ultrasonic inspection that are often mentioned include:

- The depth of penetration for flaw detection or measurement is much more superior to other NDT methods.
- Part preparation required for inspection is minimal.
- Instantaneous result could be obtain with the use of electronic equipment.
- Automated systems can produced detailed images of the product.
- It is sensitive to both surface and subsurface discontinuities.

As with every other NDT methods, ultrasonic inspection also has its own limitations, which include:

- Surface must be accessible to transmit ultrasound.
- Coupling medium is usually required to transfer the sound energy into the test specimen.
- Materials that are rough, irregular in shape, very small or thin and not homogeneous are difficult to inspect.
- Cast iron and other coarse grained materials are difficult to inspect due to low sound transmission and high signal noise.

1.6 Research Objectives

The research done that is outline in this thesis is performed based on the following objectives:

1. To fabricate a composite laminate panel using hand lay-up method.
2. To conduct drop impact test on the composite laminate panel.
3. To run ultrasound scanning (pulse echo method) on the composite laminate panels before and after drop impact test.

1.7 Thesis Layout

There are a total of 5 chapter for this thesis starting with chapter 1 which is the introduction. Chapter 1 will give a general understanding about composite material and the meaning of structural integrity for composite. Apart from that, this chapter will also discuss about UT and its usage in measurement and detection of flaw and error in composite material. The advantages and disadvantages of UT compare to other types of NDT will also be mention here.

Furthermore, the problem statement as well as the project's objectives are clearly defined at the end of this chapter.

Chapter 2 is regarding literature review where in this chapter, the summary and findings of past researchers and works will be discuss. This chapter has a purpose to understand clearly past references to set a path for completing this project.

Chapter 3 is this research's methodology. In this chapter, the usage and application of all the method needed will be explain clearly. The step by step procedure to obtain the necessary data in order to achieve the project's objective will be stated in this chapter.

Chapter 4 is the critical chapter where it is about the result and discussion for this project. This chapter will reveal all the result obtain throughout the research. Interpretation and analysation of the findings will be done to explain more about structural integrity of composite with the usage of ultrasound technique.

Chapter 5 is the final chapter to show the conclusion and recommendations for future research. In this chapter, the outcomes are stated and concluded based on the research's objectives. Recommendations for future coming works will be given as well.

CHAPTER 2

LITERATURE REVIEW

2.1 Structure and Mechanics of Woven Fabric

The science and engineering of textiles and clothing have played an important role in one of the major technological transformations known to mankind. Automation and the linking of processes are two ways to reduce labor, improve quality and increase productivity. This trend towards automation and computerization in textile and clothing manufacturing is not only inevitable but also beneficial. However, there are still many problems preventing automation and the integration of process for textile and clothing industries. For example, automation of the handling and transport of apparel fabrics is of important interest to researchers and industrialists, where the cost of labor is a significant portion of the total product cost. However, automated handling of textile materials is a difficult task because of their unique engineering properties and the variability of these properties in diverse product applications. Woven fabrics are the end products of spinning and weaving, but they are also the raw materials for clothing and other industries such as composites and medical textiles. An understanding of the creation mechanisms of fabrics is useful for fabric design and process control.

2.1.1 General Features of woven fabric mechanical behaviour

Textile materials differ considerably from conventional engineering materials in many ways. They are inhomogeneous, lack continuity and are highly anisotropic. They are easily deformed, suffering large strains and displacements even at low stress, under ordinary conditions or in normal use. They are nonlinear and plastic even at low stress and at room temperature. The geometric structure of a fabric is extremely complicated (HU, 2004). Figures 2.1 and 2.2 shows a cross-sectional and surface images of a woven fabric. It is clear that each yarn in the fabric is crimped. The yarn cross-sectional shape is rather irregular. Furthermore, there are also many fibers which protrude from the yarn surfaces.

Figure 2.1 Cross-section image of a woven fabric (HU, 2004)

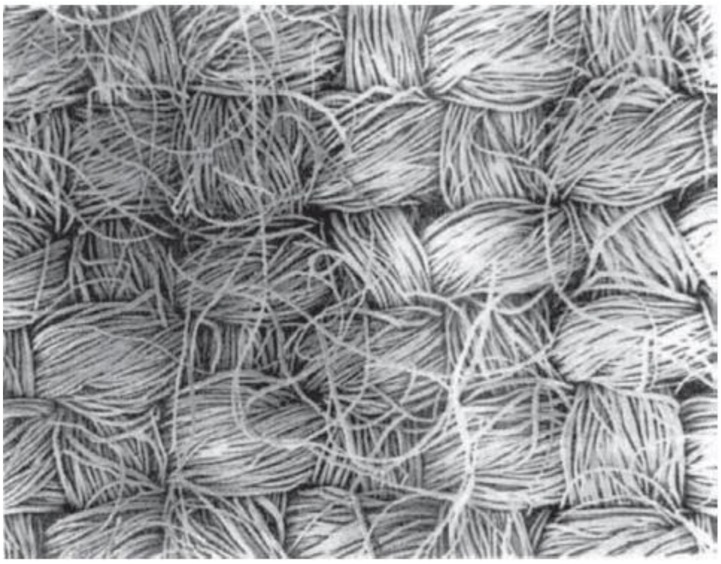

Figure 2.2 Surface image of a woven fabric (HU, 2004)

Every piece of woven fabric is an integration of warp yarns and weft yarns through intersection. The extent of this intersection is dependent on the friction between fibers and yarns together with fiber entanglement, while the distance between two parallel adjacent yarns determines the porosity of a fabric structure. The main difference between textile materials and conventional engineering materials is that the former show very complicated mechanical responses to external loads, even under ordinary conditions of low stress and at room temperature, while this happens to the latter usually under large stress, high temperature or other specific conditions.

2.2 Composite Hand Layup Technique

Hand layup is still the dominant forming process for the fabrication of the extensive range of complex geometry and mixed material composite parts. However, this process is still poorly understood and informed which could limit productivity and creativity. Matthew propose a novel and low cost system enabling a laminator to be guided in real-time, based on a predetermined instruction set, thus improving the standardization of produced components (Such et al., 2014). He compared and critiqued the current methodologies and predicted the future trends prior to introducing the required inputs and outputs, and developing the implemented systems. In hand layup, the desired output form of a ply over a complex surface, is provided to the laminator within a manufacturing instruction sheet. The successful manipulation of a broadgoods carbon or glass prepreg ply presently relies on the skills and experience developed over a number of years, and the chosen process route and results often varies between laminators (Elkington, 2013). There are a number of material properties which contribute to the time and quality of the layup, including flexural rigidity, tack, and shear stiffness (Bloom, 2013); while material variability further introduces a level of complexity to the process.

Manual layup is conducted by highly experienced and qualified crafts-people, which reportedly leads to labor becoming the single biggest contribution to direct cost (M.Kaufmann, 2010). The breakdown of tasks, and understanding of processes, may aid the development of more appropriate automated systems in the longer term. As identified by (Tatlock, 2012), the sources of error that are introduced within a manufacturing process stem from either mistakes made by “the human element”, or a lack of process understanding. Composites manufacture could be argued to be hindered on both sides of the argument, despite many facilities striving for tools such as six-sigma or lean philosophy (D.Winter, 2013). It is envisioned that applying Augmented Reality (AR) through the use of affordable tracking and projection technologies, in order to guide the laminator during hand layup, will lead to improvements in quality and standardization alongside reductions in time and labor costs (Such et al., 2014).

2.3 Ultrasonic Technique on Composite Laminate

By far the most commonly used NDT for composite structures is ultrasonic inspection, often producing a two-dimensional map of the structure. Disbond, delamination in the plane of the material and porosity are the most common defects found in composite structures(R.A.Smith). The reason for favoring ultrasound is that it is very sensitive to these types of defect commonly found in composites. It is one of the few methods available for detecting porosity after manufacturing and it can detect most of the other defects at the same time of scanning(R.A.Smith). Various other method are being developed with potential for rapid or large-area inspection capabilities. However, at present, these have limitations that have prevented them being used extensively. One of the newest method available is the laser ultrasound generation but the cost is currently soaring high. There are other methods such as optical and thermal methods. Although it is not as expensive, it still have limited depth penetration when comparing to the conventional ultrasound methods.

The analysis of damage evolution and monitoring are often complicated by the non-homogeneous and anisotropic nature of composite systems(Papa et al., 2017). A wide variety of damages modes like fiber cracks, delamination, and indentations may occur in composite structures as well established (Timoshenko, Wang and Vu-Khanh, 1995, Liu et al., 1993, Chang et al., 1990). Thus, a valid and simple tool to investigate the internal impact damage could help to understand the damage initiation and propagation as well as the complex interaction between failure modes (Hou et al., 2000, Jaan-Willem et al., 2015, Riccio et al., 2014). In the present contribution, a specific attention is devoted to the preparation of laminated structures based on jute fabric as the reinforcement, even because of the limited availability of the references literature. Internal damages, coming from low-velocity impact events carried out up to penetration, were detected with the help of an ultrasonic NDT technique and by the visual inspection(Papa et al., 2017). The delaminated area is correlated with both the impact energies and the measured indentation depth. The result showed a threshold energy for the beginning of the internal damage.

Moreover, a linear relationship between the delaminated area, the energy and the indentation depth is found (Papa et al., 2017).

2.4 Sound Velocity in Composite Materials

Glass fiber reinforced composites are increasingly used in aerospace, naval and automotive vehicle due to their excellent corrosion and wear resistance. (G.Wrobel and S.Pawlak, 2006) found the relationship between the selected parameter of an ultrasonic wave and the local fiber content in a glass/epoxy composite. The approach to the experiment was divided into two phase. During the first phase, typical glass/epoxy composite materials with different fiber content were examined by means of through-transmission and pulse echo ultrasonic which is the method used for this project. The second phase was done by applying the standard destructive method to determine the actual glass content in the investigated composite materials.

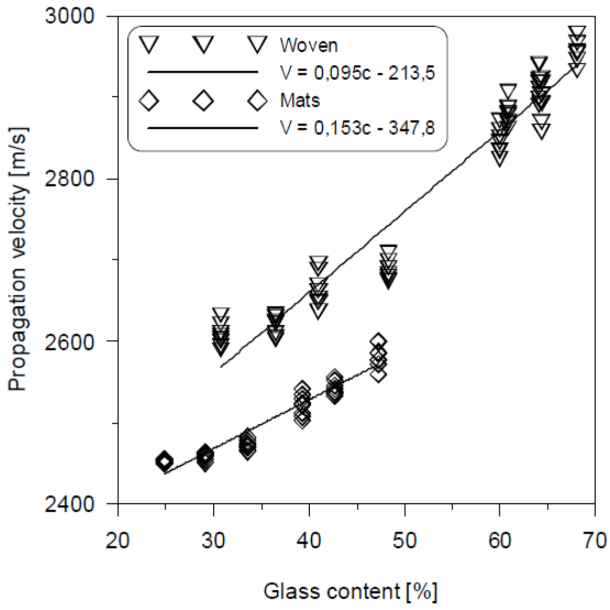

Figure 2.3 Relationship between glass content and propagation velocity (G.Wrobel and S.Pawlak, 2006)

The experimental results showed relationship between ultrasonic wave velocity and the local fiber content in investigated composite materials. This study has also assessed the ability of pulse-echo technique to carry out such testing. The findings also suggested that the evaluation of the composite structures may be improved by using other NDT techniques such as thermography in addition and combination to ultrasonic pulse-echo method.

2.5 Impact Testing

Low-velocity impacts on composite laminates provides major safety problems since they are able to develop prolonged damage within the structure, mostly delamination and matrix cracking, while being hardly detectable in visual inspections (Panettieri et al., 2016). The role of low velocity impact tests at the coupon level is to evaluate quantities that can be useful both in the design process, such as the delamination threshold load, and in dealing with safety issues, that is correlating the internal damage with the indentation depth. Low-velocity impacts represent a serious safety concern since extended damage could be present in the composite structure although rarely detectable by visual inspections. For reference, the threshold of reliable detection is named Barely Visible Impact Damage (BVID). Damage lower than the BVID threshold must not reduce the strength of the structure below its ultimate load capability(European Aviation Safety, 2010). The force-time histories obtained in low-velocity impacts represent global information from which the shape and the extensions of the damage induced in the structure cannot be known. Low-velocity impact cause large-scale delamination and matrix cracking (Davies and Olsson, 2004), where certain delamination can negatively affect the stiffness of the structure in compression (de Freitas and Reis, 1998, Ghelli and Minak, 2011, Remacha et al., 2015). Study by (Panettieri et al., 2016) has built up an extensive dataset of low-velocity impact test on quasi-isotropic carbon/epoxy laminates to serve as a reference for tuning and validation of numerical analyses using advanced damage models.

CHAPTER 3

METHODOLOGY

3.1 Overview

This whole project requires several key stages including starting from understanding the basic principle up to testing the specimen. The technical approach to this project is to study the structural integrity of composite panel by subjecting it to drop impact testing. In aerospace industry, composite material is subjected to different kind of environment such as during service, maintenance and manufacturing. This various situation could impact the composite's structural integrity in numerous ways. This project focused on what drop impact test could affect composite panel and detecting it by using ultrasound technique. An initial scan of ultrasound would be done on the composite panel to establish a baseline reading and followed by post impact scanning to compare it with the initial reading. At the end of the project, we would know the range of reading ultrasound scanning would show if a composite panel has been subjected to drop impact. Ultrasound scanning enables us to see the inside layer of the composite whereby we could not observe it with the naked eye. The overall process flow of this project are as shown below:

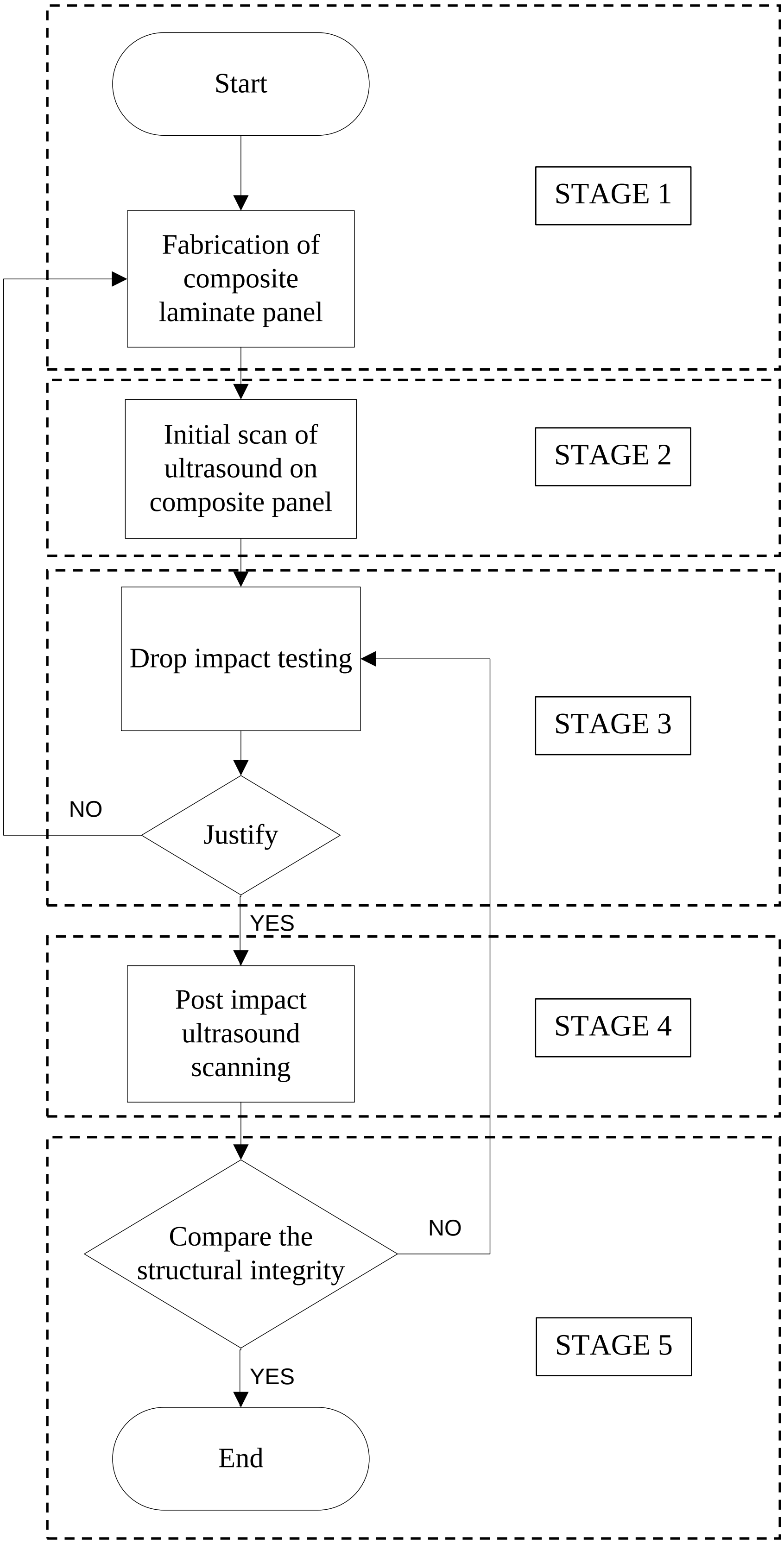

Figure 3.1: Flow chart of overall process

3.2 Specimen Fabrication

The specimen will be fabricate in the form of composite laminate structure which consist of E-glass plain woven roving fabric (600gsm) and epoxy resin. The specimen will be prepared in composite laboratory. This fiber has been chosen due to its extensive used in the industry as well as it is readily available to be used for this project.

Figure 3.2: E-glass plain woven roving fabric (600gsm)

The fibre cloth is cut into a preliminary size of 40cm x 35 cm before later being cut into specific size required for the testing. The composite panel will be fabricated using hand layup technique. This method is chosen for its simplicity in fabricating composite structure without much time consuming and to shift our focus more on to the testing as well as the ultrasonic scanning. With this technique, resins are impregnated by hand into fibres which in this case is in the form of woven fabric. Before starting the process, we need to prepare the surface for our composite to lay on. A glass surface is chosen for this project as glass has smooth surface which allow the composite to have a clean and smooth surface after curing. The glass surface is coated with few layers of mould release wax before the process begins. This is called as surface preparation and the wax prevents the panel from attaching to the surface of the glass.

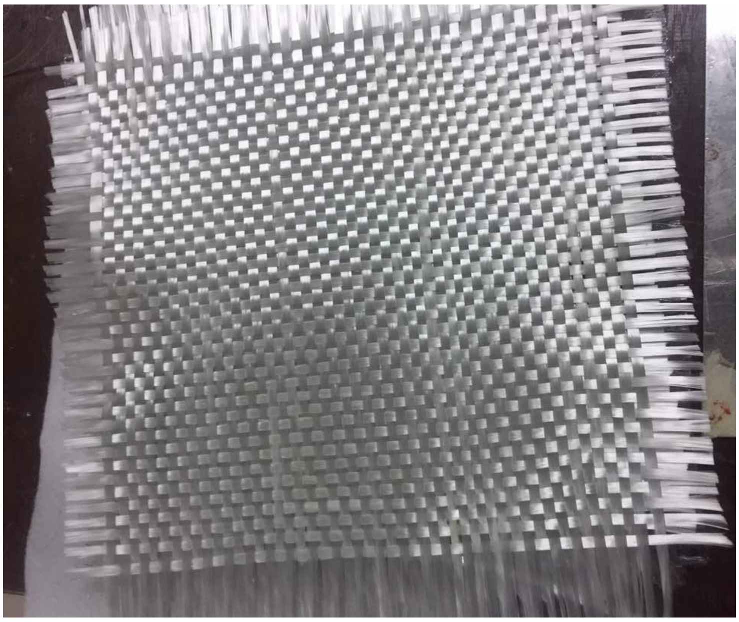

Figure 3.3: Preliminary size of fibre

The resin used for this project is epoxy resin. The total amount of epoxy used will be calculated based on the total weight of the fibre used. The ratio of fibre to epoxy is one to one. The ratio of resin to hardener is three to one based on the type of epoxy used.

Table 3.1: Calculation of epoxy

Mass of fibre	462.7g
Mass of epoxy	462.7g
Mass of hardener	154.2g
Mass of resin	308.5g

Using this calculation, we could estimate and weigh the amount of resin needed based on the weight of fibre without the need to mix a big batch of resin which could lead to wastage of resources. The amount of resin and fibre used for this project is shown in Table 3.1 where a total of 462.7g of fibre used, with fibre to epoxy having ratio one to one, the total weight of epoxy used is the same as well. Using ratio three to one for resin to hardener, the calculated mass of resin is 308.5g with 154.2g of hardener. The type of resin and hardener used is shown is Figure 3.4(a) and Figure 3.4(b). After the resin and epoxy has been mixed, the hand layup process need to be done as quickly as possible as the resin will cure in a limited amount of time.

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Figure 3.4: Resin and hardener used

Next, each layer of the woven fibre is combine with the resin by using a hand roller. The hand roller act as impregnators by forcing resin into the fabrics by means of rotating rollers with a bath of resin. A total of 5 layers of fabric is used for our composite panel structure. The laminates are left to cure under standard atmospheric conditions. After the surface of the panel is no longer tactile, the panel is then put into oven for post cure process at 70 °C for about 1 hour.

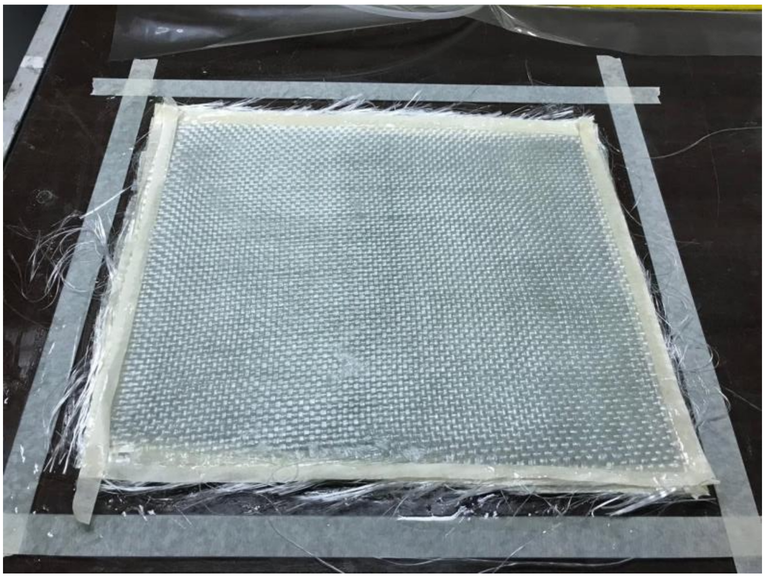

Figure 3.5: Curing under standard atmospheric pressure

After post curing process, the composite panel is then cut into smaller dimension according to ASTM standard used for impact test. The cutting process is done using table saw in the composite laboratory.

Figure 3.6: Cutting test piece into required dimension

There are a total of 6 test piece obtain from the initial composite structure which will be used for the impact testing. The test piece is cut into sizes according to ASTM 7136 standards which is 10cm x 15cm.

3.3 Ultrasound Technique

In this project, immersion ultrasonic inspection is used to scan the test piece. An initial scan which is prior to conduct impact test as well as a post impact scan where the test piece will be scan once again after the impact testing has been done. A common ultrasonic inspection system consist of a pulse-receiver, transducer and a display device which will be a computer.

Figure 3.7: Overall system layout

The pulser will supply electrical voltage to ultrasonic transducer in order to generate pulse. The ultrasonic transducer will convert ultrasonic energy from the electrical energy supplied to propagate through the material in form of waves. Most transducer requires couplant as a medium for the ultrasonic waves to travel from the transducer to the test piece. In this case, water will be used as a medium for the immersion type transducer.

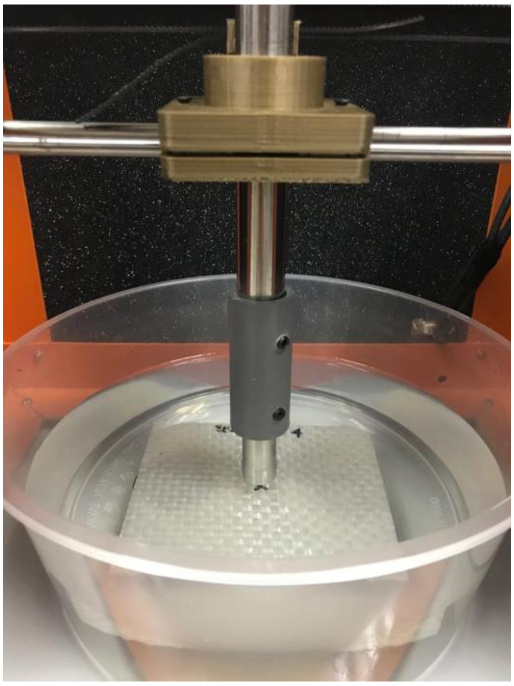

Figure 3.8: Transducer and test piece immerse in water

It is an I3-0206-S model from Harisonic Ultrasonic with 2.25MHz center frequency and a nominal element size of 10mm. USB-UT350 model pulser-receiver from US Ultratex is used with the UT Instrument software provided to display the signal produced and received. As this system is based on pulse-echo technique, signals emitted from the transducer will travel back to the probe and from there we could identify any flaw that present on the test piece. An initial scan will be done on the test piece so that we would have a baseline reading for each test piece. The thickness of the material will be measured with Vernier caliper to obtain the thickness and hence we could first calibrate the system. Calibration is required so that we could ensure the data we obtain after is valid.

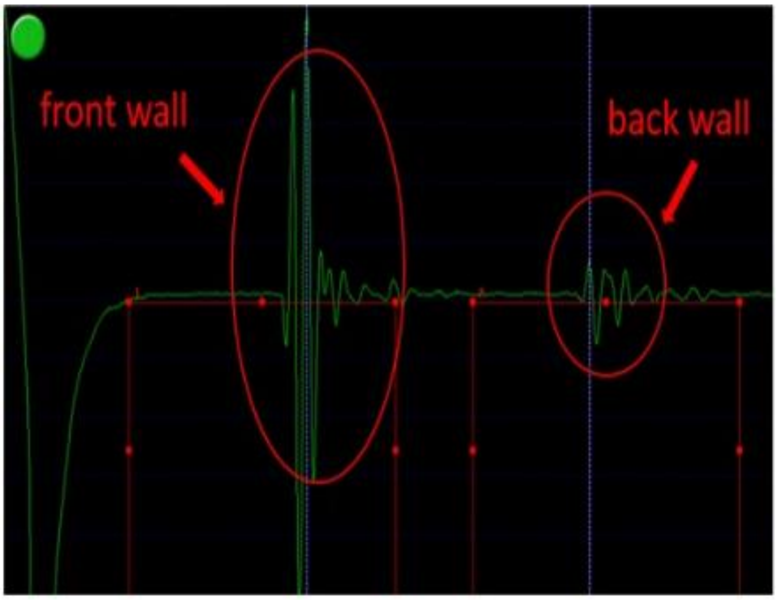

Figure 3.9: Example of initial scanning displayed from UT instrument software

From this initial scanning of Figure 3.9, we could see 2 different peak on the graph where the first peak shows the front wall of the specimen and the second peak shows the back wall of the specimen. From this initial scanning, we could detect any flaw occurs by comparing the amplitude of the peak after impact testing has been done. When there are flaws occurring in the panel, the intensity and amplitude of the reading will increase compare to the initial scanning.

There are few settings that need to be set and keep constant for both of the scanning so that we could compare the result as accurate as possible. The pulse width setting is usually set between 50ns to 500ns in increment of 20ns. Pulse width, w has close relationship with the frequency of the transducer, f_1. The relationship is as follow:

$$w = 500/f_1 \quad (3.1)$$

The transducer used for this project is using 2.25MHz of frequency and hence the pulse width is set to around 230ns. Next the gain needs to be adjust until the signal fits in the display window without any saturation. This setting differs from test piece to test piece and is usually set around 7 to 10dB. The buffer length specifies how many samples the USB-UT350 device will analyse during data acquisition. For this project, a value of 149.9mm was set for all of the scanning process. The trigger delay specifies how many samples should be skip before the device process the response signal. This setting is used to reduce the total data obtained and remove the unnecessary data that are not needed. This project used a trigger delay setting of 0.48mm. Sampling rate is also one of the key setting that needs to be adjust so that we would obtain accurate reading. The sampling rate should be 5 to 8 times greater that the transducer frequency used. USB-UT350 supports few sampling rate which are:

I. 50MHz
II. 25MHz
III. 12.5MHz
IV. 6.25MHz

For this project, the sampling rate is set to 12.5MHz due to the transducer frequency used which is 2.25MHz. Another vital setting used for ultrasonic scanning is the sound velocity. This is determined by the material used where the value is different for steel, composite, glass and other material. In composite material, this is determined by the local fibre content present. The higher the glass content, the higher the sound velocity needed as it has higher density. For this project, the fibre content of the test piece was assume to have value around 40% to 50% and this would require a sound velocity of around 2700m/s.