A Study of the Effect of Patch Bonded Surface Area and Shape on Flexural Strength of Glass/Polyester Composite using External Bonded Repair Technique

By

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CERTIFICATE OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this report, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not taken or done by unspecified sources or persons.

MUHAMAD FAIZAL ABU BAKAR

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ABSTRACT

The objective of this project is to investigate the effectiveness of patch surface area and shape on flexural strength of the composite material. The material under study is glass/polyester composite and it is prepared by using hand lay-up technique. The patch shapes under investigation are square and octagonal. Five different patch surface areas were prepared varying from 2mm until 8mm. The parent laminates were damaged by drilling a standard 8.42mm diameter hole in the middle of it as artificial damage. A piece of composite material is then attached to the original primary composite structure using an adhesive to restore the original performance of the composite. The flexural test is conducted under ASTM Standard D790 by using three point loading system. However, from the results obtained from the test, it was found that the flexural yield strength value is more relevant to be calculated rather than flexural strength due to the constraints of the test specimen. The results show that by increasing the surface area of the patch, the flexural yield strength of the test specimen is also increased. Besides, octagonal patch shows a higher value of efficiency of flexural strength compared to the square patch. For square patch, the highest value of flexural yield strength is 355.33Mpa while the highest value of efficiency is 183%. Meanwhile, for octagon patch, the highest value of flexural yield strength is 366.57Mpa while the highest value of efficiency is 188%. Yet, the results obtain depend on other criteria such as sample preparation and joint design of the composite structure.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION TO COMPOSITE REPAIR

In general, composite is any multiphase materials that exhibit a significant proportion of each phase to produce better properties and performance from the combination. In engineering aspect, composites can be defined as a result of embedding high-strength and high stiffness fibers of materials in a surrounding matrix of another material.

Nowadays, the increased usage of composite materials for various engineering areas has initiated researchers around the world to develop new techniques on repairing the composite structures. This is because parts of composite material have higher repair capability compared to other types of material. Existing technology applicable to the repair of composite has emphasized the utilization of sophisticated materials and processes to restore damaged components to a fully functional state. Thus, many of repair techniques for structural composites were developed to meet requirement of various engineering aspects, especially in aerospace industry in maintaining the composites component performance.

The majority of the repair techniques usually address to skin repairs. Skin repairs technique is attachment of piece of composite material to the original primary structure to restore the original mechanical performance of the material. In line with that, researches on effects of the types of adhesive, thickness of adhesive and laminates have been conducted.

The strength of skin repair technique usually depends on the type of fiber and matrix used and types of adhesive applied to it. Types of resins, whether thermoplastic or thermoset also affect the strength of the composite structures.

However, the shape of the patch can also affect the strength of the repair structure. Besides, by introducing different values of surface area of the patches, it also can affect the strength of the composite materials. Thus, it is the aim of the writer to find how these two parameters affect the strength of the repaired polymer matrix composite. The shapes of patch under study are octagonal and square.

1.2 COMPOSITES THEORY

The major constituents of a fiber-reinforced composite material are the reinforcing fibers and a matrix that acts as a binder for the fibers. Other constituents that may also be found are coupling agents, coatings and fillers. Coupling agents and coatings are applied on the fibers to improve their wetting with the matrix as well as to promote bonding across the fiber-matrix interface.

Fibers are principal constituents in a fiber-reinforced composite material. They occupy the largest volume fraction in a composite laminate and share the major portion of the load acting on a composite structure. Thus, it influences composite materials characteristics such as tensile strength, compressive strength, fatigue strength and cost.

The role of the matrix or resin in composite material is to transfer stresses between the fibers, to provide a barrier against an adverse environment and to protect the surface of the fibers from mechanical abrasion. The matrix also plays a minor role in the tensile load-carrying capacity of a composite structure.

1.3 REPAIR THEORY

There are several basic principle of repair theory that must be understood before begins the repair process of composite material structure [1]. The first basic principle is that all repairs are secondary bonds, so they rely on the adhesive quality of the resin for their strength. Structural repair theory begins by recognizing the difference between a repair and the original piece. When a part is first fabricated, all the resin in it cures chemically as a single unit regardless of the number or orientation of the reinforcement plies. This is called the primary structure or bond, and it is the strongest form in which a part can exist. Once the part is damaged, all repairs become secondary bonds attached to the original primary structure. This means that the repair is only as strong as the adhesive used to make it.

Second principle is by increasing the surface area will increase the strength and the durability of the repair. Since repairs depend upon adhesion to the primary structure, increasing the surface area of the bond line will increase the strength and longevity of the bond. This is usually done by taper or scarf sanding the area next to the damage so the void can be filled gradually. The size of the taper is expressed as a ratio comparing the depth of the repair to the width of the taper. Generally, the stronger or more critical the repair needs to be, the larger the taper ratio.

Third principle is striving to duplicate the thickness, density and ply orientation of the original laminate will increases the strength of the repair structure. Many people go overboard on repairs thinking that if a little bit is good, then more is even better. This is dangerous thinking with reinforced composites, because as a part becomes thicker, it automatically becomes stiffer, regardless of the material in use. The proper approach is to carefully replace every ply that has been removed while preparing the damaged area with an identical material in the same orientation. This ply-for-ply replacement approach will guarantee the structure can withstand the same loads as the original.

1.3.1 Criteria for Implementation of External Patch Repair

Basically, there are four criteria that must be considered before the implementation of external patch repair technique. The criteria are:

1.3.1.1 Adhesive Bonding

The adhesive bonding is a term to describe the joining of the parent material to the repair patch by the used adhesive. Whenever bonding is planned, adhesive selection is a primary selection. Usually, the two-part, medium viscosity, nonslumping, room temperature curing adhesive are the most successful because of their user-friendly properties (i.e. epoxy).

The most desired properties of adhesive can be classified into two [2]. First is a 1:1 mix ratio of the two different-color components that combine to give a third distinct color, signify a complete mix. Second, a rapid curing time must be achieved for rapid handling strength.

The adhesive also must posses a pot life sufficient enough to allow time to complete the application without rushing [2]. Usually, there is typical tradeoff between rapid cure and a long pot life.

Ultimately, the choice of adhesive depends on the required performance characteristics necessary to make an effective attachment. Characteristics such as installation environment, cure time, pot life, application equipment, desired strength level, optimal failure mode and cost are the factors when identifying proper adhesive.

1.3.1.2 Surface Preparation

When adhesive bonding is used, surface preparation replaces hole preparation as the major concern for making a successful joint. The amount of surface preparation required for reliable adhesive bonds depends on the material being bonded and the adhesive used.

There are standard steps done by researcher during preparation of sample that will always enhance bonding regardless of adhesive selection [2]. First is a good solvent wipe of the substrate and the fastener base is considered to be the minimum surface preparation required. Second is abrasion of the surfaces by means of scuff pad, sandpaper or grit blasting. This process is implemented prior to the solvent wiping which will provides a surface condition that is generally accepted as excellent for successful adhesive bonding.

A general relationship exists between the viscosity of an adhesive and the optimum bondline range for the adhesive. The relationship follows that a low viscosity adhesive will have a thin optimum bondline thickness. Furthermore, higher viscosity adhesive will require a thicker bondline to achieve optimum performance characteristics such as bond strength and long term bond reliability.

1.3.1.3 Taper Degree

The composite patches that will be prepared by the writer will have a taper. Basically, the taper is slope fabricate at the both end of the patch to increase its surface area. The taper must have a certain degree, typically 5^0C, to minimize sudden changes in stiffness and they also may have a curved platform [3].

1.3.1.4 Joint Geometry

Basically, the strength of the bonded joints is related to the geometry of the joints and adherend thickness [3]. By referring to below Figure 1, it was found that the weakest bonded joints are those which is limited by interlaminar failure of adherend and type of joint geometry. The next strongest joint are those in which the load is limited by the shear strength of the adhesive while the strongest joint will fail outside the joint area at a load equivalent to the strength of the adherend.

Adhesive layer is at their most efficient in the thickness range 0.1-0.25mm. Thicker bonds are not practicable because of the imposibility of making them without unacceptable levels of flaws or porosity.

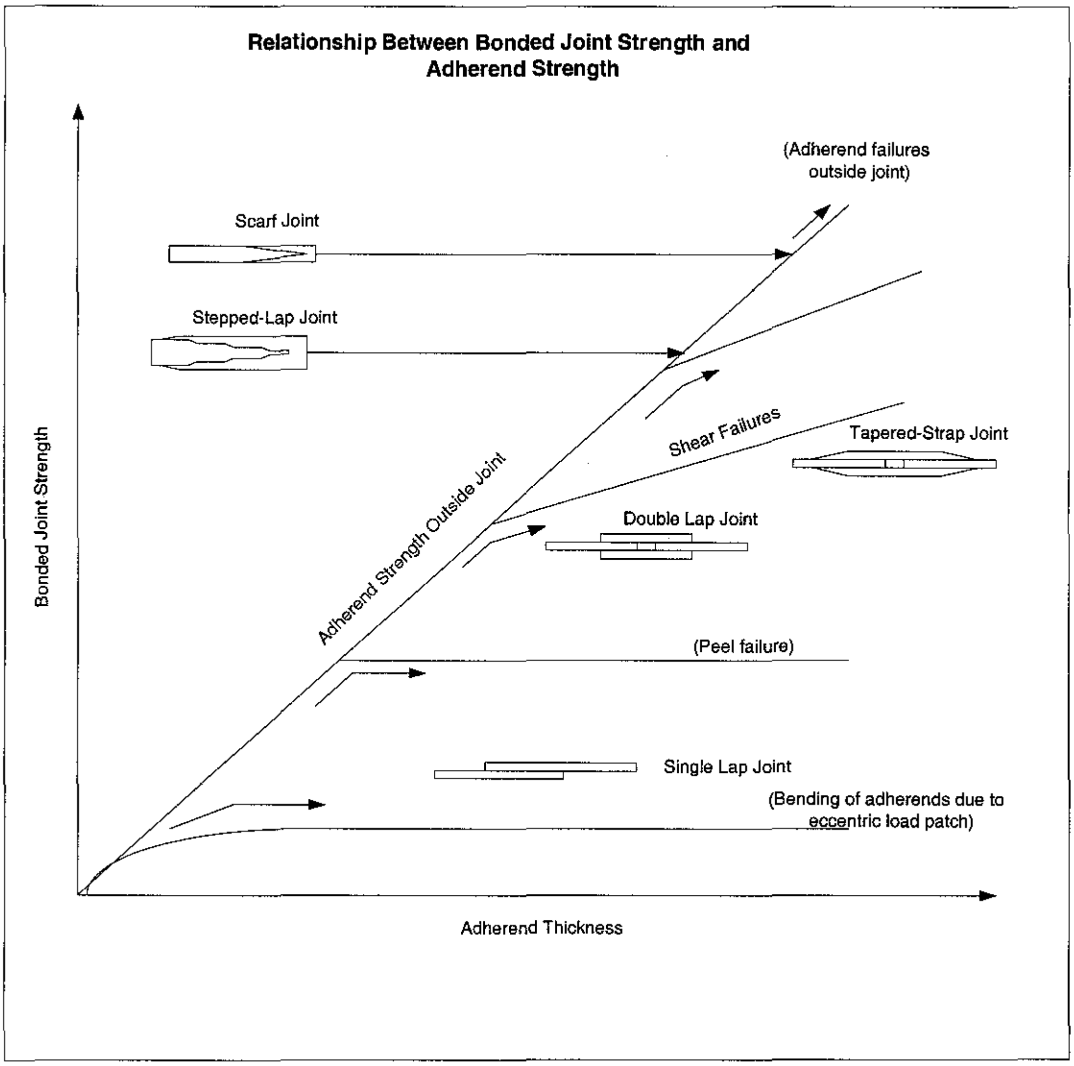


Figure 1.1: Relationship between Bonded Joint Strength and Adherend Strength (source: Handbook of Polymer Composite for Engineering, Leonard Hollaway, Woodhead Publishing Ltd, Cambridge England

1.4 LITERATURE REVIEW

Before the introduction of patch bonded repair technique for composite structures i.e. aircraft, researchers and aircraft manufacturers around the world depends on the traditional repairs procedures that have been based on mechanically fastened metallic patches.

However, according to A.A. Baker [4], the old method changed when the Aeronautical Research Laboratory of the Australian Defence Science and Technology pioneered the use of adhesively bonded advanced fibre reinforced plastic patches to repair crack in aircraft components in mid 70's. Apart from that, A.A. Baker [4] also stated that a few considerations that have to be taken into account in designing an external patch bonded repair technique. By this technique, the load that exerted to the repair structure can be transfered effectively by minimizing the shear stress inside the bonded laminate. By using this technique also, it is easier to produce the test specimen and find the perfect configuration of bonded joint which yield the highest value of strength.

According to Goering and Griffiths [5], the majority of the repair techniques for composite structure reported in the literature usually address to the skin repair. Skin repairs are generally reduced to metal or composite patch bolted or bonded to the outer mold line (OML) of the composite structure. Composite patches have higher stiffness value and suit to more complex surfaces than metal patches, but their application is more complicated than the metal patches.

A study by R.L Evans and M. Heller [6] stated that the patch shape also affects the strength of repair structure. Three difference shapes have been tested which were circular, oval and eliptical and they conclude that the eliptical give the best result because of the significant reduction in the plate stress concentration. This is because the ellipse is more slender than other shapes analyzed during this experiment. However, since the eliptical shape is difficult to machine, the practical and economic value of this shape is restricted.

Lastly, according to Jacky C. Prucz, Constantine C. Spyrakos and Bruce Henderson [7], adhesive bonded joints of rhombic (diamond) configuration shown higher efficiency of strength, stiffness, damping and weight characteristics than conventional double lap configurations. Strength properties which is higher for the rhombic joint indicates the possibility of enhancing load transfer efficiencies by employment of such joints.

1.5 PROBLEM STATEMENT

In composite repair technique, the shape and surface area of the patch can affect the strength of repair structure of composite material. Therefore, the study of the effect of patch bonded surface area and shape on flexural strength of glass/polyester composite can be further developed as a new technique of improving the strength of the damage composite structure in the future. This is because, the composite material that has been damaged usually will be changed with the new complete parts. This operation will increase the repair cost, time and raw materials used of the project undergone certain maintenance process.

1.6 OBJECTIVE AND SCOPE OF STUDY

1.6.1 Objective

The main objective of this study is to study the effectiveness of various patches bonded surface area and shape on the flexural strength of the glass/polyester composite. The patch shapes under study are square and octagonal. All repairs are implemented using external patch bonded repair technique where an epoxy adhesive will be used to join the patch to the damage test specimen.

1.6.2 Scope of Study

Basically, scope of study for this project is mainly on sample preparation of the composite material and also the experimental work. All samples were prepared by using typical hand lay-up technique and the experiment was completed by using Instron Universal Testing Machine.

Mechanical property of the samples that wanted to be observed by the writer is the flexural strength. Therefore, only flexural test will be implemented for this project and the test was governed under ASTM Standard D790. Besides, no microscopic observation was done on the test specimens for failure mode investigation except visual naked eye examination of the test specimens.

From this experiment, the writer wants to seek the relationship of various surface areas and shape of the patch with the flexural strength of the repaired specimen. Only square and octagonal shapes were studied for this project. This is due to the cutting tool constraints that limit the writer in producing other patch shape such as circle. Apart from that, the writer also assumed that no other effect such as type of resin used, type of lap configuration and thickness of adhesive is accounted during the test.

1.7 SIGNIFICANT OF STUDY

Nowadays, the current application of composite materials is varied from aerospace industry to the sporting goods. Usually, the composite material that has been damaged will be change with the new complete parts. This will increase the repair cost, time and raw materials used. Thus, introduction of new kind of composite repair technique will reduce the cost, reduce time consumption and save a lot of raw materials used for fabrication of the new parts.

CHAPTER 2

EXPERIMENTAL METHODS AND PROCEDURES

2.1 RAW MATERIALS

For this research, the author will use glass polyester composite as the main material. This composite consists of 3 main materials, which are glass (fibre), polyester (matrix/resin), epoxy adhesive and catalyst.

2.1.1 Glass

Glass fibers are the most common of all reinforcing fibers for Polymer Matrix Composite (PMC). They may have high strength to weight ratios, dimensional stability and resistance to heat, cold, moisture and corrosion. They also have high tensile strength combine with low extensibility which give exceptional tensile, compression and impact properties, with a relatively high modulus and good bend strength.

Glass fibers also exhibits elastic behaviour when it stretches uniformly under stress to its breaking point without yielding. This lack of hysteresis and high mechanical strength makes it possible for glass fiber to store and release large amounts of energy without loss.

There are many types of glass fibers available in the market. The most common is E-glass. This glass has good electrical characteristics. It has a tensile strength of about 1380 MPa to 2070 MPa with a relative density of 2.55gcm^{-3}. For stronger application, S-glass (high-strength glass) is used, having tensile strength of about 4480 MPa and a density 2.48gcm^{-3}. This glass is about 20% stronger than E-glass and five times more costly [8]. Most applications are for structural composite in the aerospace industry.

E-glass is available as continuous filament, chopped strand, and random fiber mats suitable for most methods of resin impregnation and composite fabrication. For S-glass, it is available as rovings and yarn, and with a limited range of surface treatment.

For this project, the writer had used glass fiber in form of woven roving mat manufactured by Central Glass Co. Ltd. in Taiwan.

2.1.2 Unsaturated Polyesters

The majority of glass fiber parts are constructed using unsaturated polyester resins. Polyester resins are easy to use, fast curing, tolerant to temperature and catalyst, and less expensive than epoxy system.

Since a polyester resin is a thermoset, the properties of it depend strongly on the cross-link density. The modulus, glass transition temperature and thermal stability of cured polyester resins are improved by increasing the cross-link density, but the strain to failure and impact energy are reduced.

Polyester resins are cured by organic peroxides which initiate a free radical copolymerisation reaction. The catalyst system comprises organic peroxides, which are activated by accelerators or promoters. The speed of the reaction depends on temperature, resin and catalyst reactivity.

The main disadvantages of polyester resin over other expensive resin such as epoxy is it high volumetric shrinkage. The difference in shrinkage between the resin and the fibers will results in uneven depressions during molding process. Usually, this defect can be reduced using low-shrinkage polyester resins that contain a thermoplastic component.

For this project, the writer used common unsaturated polyester resin which is cured which methyl ethyl ketone peroxide catalyst. However, the writer was unable to trace the manufacturer of the polyester resin except that it was imported from Taiwan.

2.1.3 Epoxy Adhesive

The function of the adhesive is basically to transfer load from the parent material to the patch. In order to achieve a high durability of mechanical properties and thermal properties, temperature and pressure cure are required during preparing the specimen.

Therefore, the adhesive cure temperature must be limited to certain temperature in order to minimize thermal strain (residual) due to mismatch of coefficients of thermal expansion and prevent changes in the heat treatment in the surrounding specimen structure. The typical thicknesses are from 0.1mm to 0.2mm. The thicker bonds are not practicable because the imposibility of making them without unacceptable levels of flaws or porosity.

For the writer final year project, the adhesive that plan to be used is epoxy. Epoxy gives advantages to the author since it has high strength, rapid curing time, and low shrinkage during cure and easy to used. The epoxy used is known as Epicote 1006

System which using amine as it hardener.

2.1.4 Catalyst

Catalyst (initiator) will be used as curing agent to cause the ends of monomers in resin to polymerize and cross-link. The most common ambient initiator for polyester resin is methyl ethyl ketone peroxide (MEKP). It reacts with the accelerator and attains full cure within a short period of time.

For the project, the writer has estimated that 1gram of MEKP catalyst is sufficient to cure about 100grams of polyester resin. The MEKP catalyst is manufactured by Wee Tee Tong Chemicals Ltd. in Singapore with a batch number of UN No. 3105.

2.2 SAMPLE PREPARATION

2.2.1 Preparing the Sample Using Hand Lay-Up Technique

The hand lay-up technique is one of the oldest, simplest and most commonly used methods for manufacture of composite or fiber-reinforced products. This technique is best used where production volume is low and other forms of production would prove too expensive.

Hand lay-up is descriptive of several procedures in which a single mold, either male (plug) or female (cavity) type is used. Molds may be made of wood, plaster, polymer or metal. All molds are properly prepared to prevent the composite from sticking to the mold surface. Wood and plaster molds are commonly sealed with epoxy or polyester to cover any pores. A mold-releasing agent is then applied to form a release layer between the composite and the mold surface. For this project, the writer had used glass sheet as a mold.

2.2.2 Process of Hand Lay-Up Technique

Basically, the first step of hand lay-up technique is mold preparation. A mold is actually a flat surface where the glass/polyester composite to be made is created. The mold is made of glass sheet with a dimension of 100 cm x 100 cm with thickness of 4 mm. Before applying the glass fibers and the polyester resin into the surface of the mold, a release wax (mold-releasing agent) is applied to the mold surface.

Then, fiberglass sheet in form of woven roving with dimension of 50cm x 40cm is applied to the glass mold. Polyester resin and methyl ethyl ketone peroxide catalyst is then thoroughly mixed together. For one layer of fiberglass sheet, it needs about 100grams of polyester resin plus 1gram of MEKP catalyst. To ensure complete air removal and consolidation of the excess resin, serrated rollers are used to press the material evenly against the mold. After that, the next layer of fiberglass sheet is applied until the desired thickness is reach. The writer had used about 6 layers of fiberglass sheet that gave a thickness about 2.5-2.6mm. Lastly, another glass sheet is placed on top of the fiberglass layers and it pressed with a large object to make sure that the resin is uniformly distributed on the whole area of the mold.

After that, the glass/polyester composite is allowed to completely harden for one day before machining can be performed. The example of hand lay-up technique that can be used is shown in Figure 2.1.

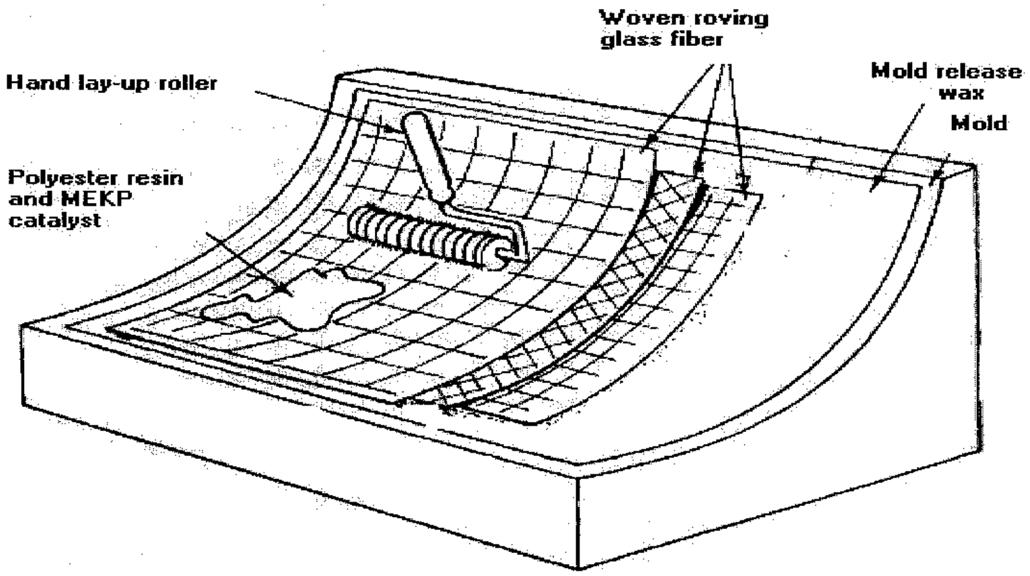


Figure 2.1: Hand Lay-Up Technique (source: Composites Design Guide, Terry Richardson, Industrial Press Inc)

2.2.3 Procedures for Test Specimen Preparation

Firstly, the glass/polyester composite patch is prepared by cutting the composite into the desire shapes which are octagon and square using handsaw. The characteristic of each patch shape and dimension is given in the Figure 2.2 (square) and Figure 2.3 (octagon).

Then, a parent material by dimension of 150mmx26mm is cut from the original sample. After that, 8.42mm diameter hole is created on the parent material using electric drilling machine. The characteristic of the parent laminate and dimension is given in Figure 2.4.

All the patches and parent laminate is then surface treated by using sand paper. After that, each patch is bond into the parent material by using epoxy adhesive. After the adhesive is cured, the hole of the parent material is covered by using the same mixture of epoxy resin. All procedures are repeated for a different value of surface area (increase the width of the taper every 2mm until 8mm, as shown in Figure 2.2 and 2.3).

Another important thing that has to be clarified for this project is the introduction of the taper to the patch. As mention in previous section, the author plan to make patch with taper at the edge of it. However, this task cannot be implemented since there is no suitable equipment or machine that can be used to make the taper. Thus, all the patch for this experiment is produced without the taper.

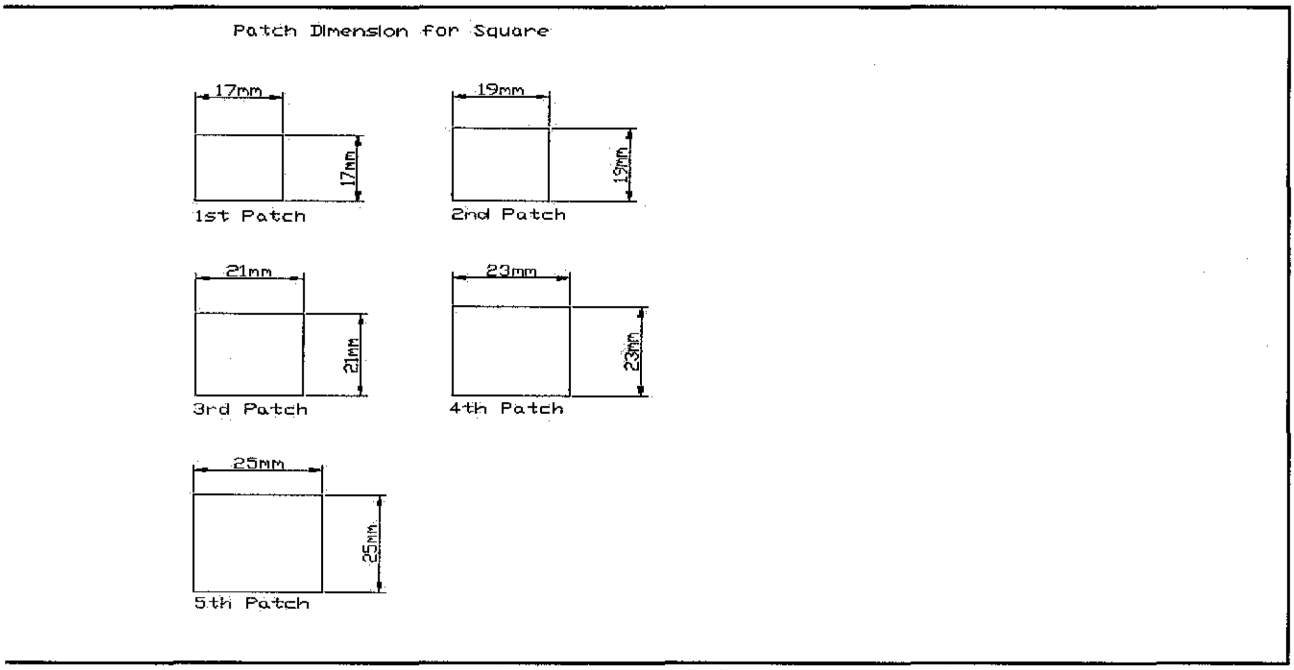


Figure 2.2: Characteristic of Square Patch

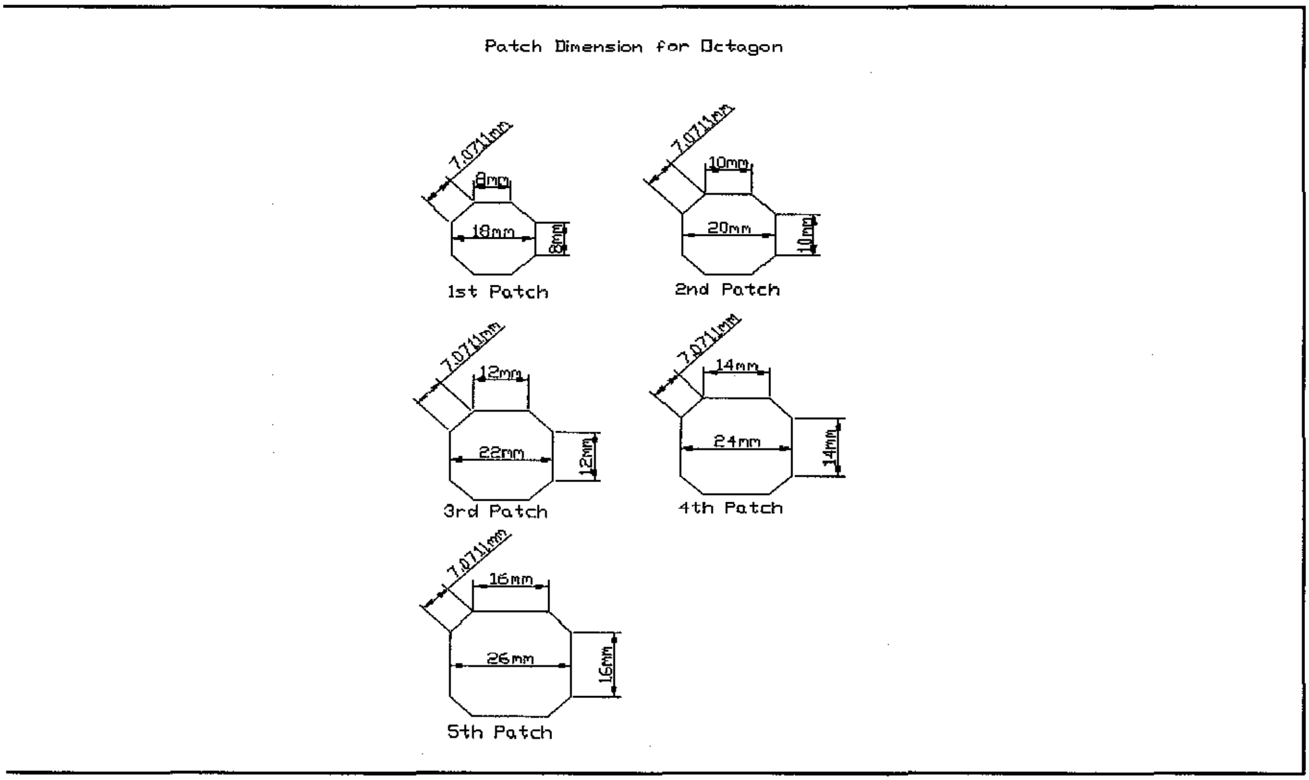


Figure 2.3: Characteristic of Octagon Patch

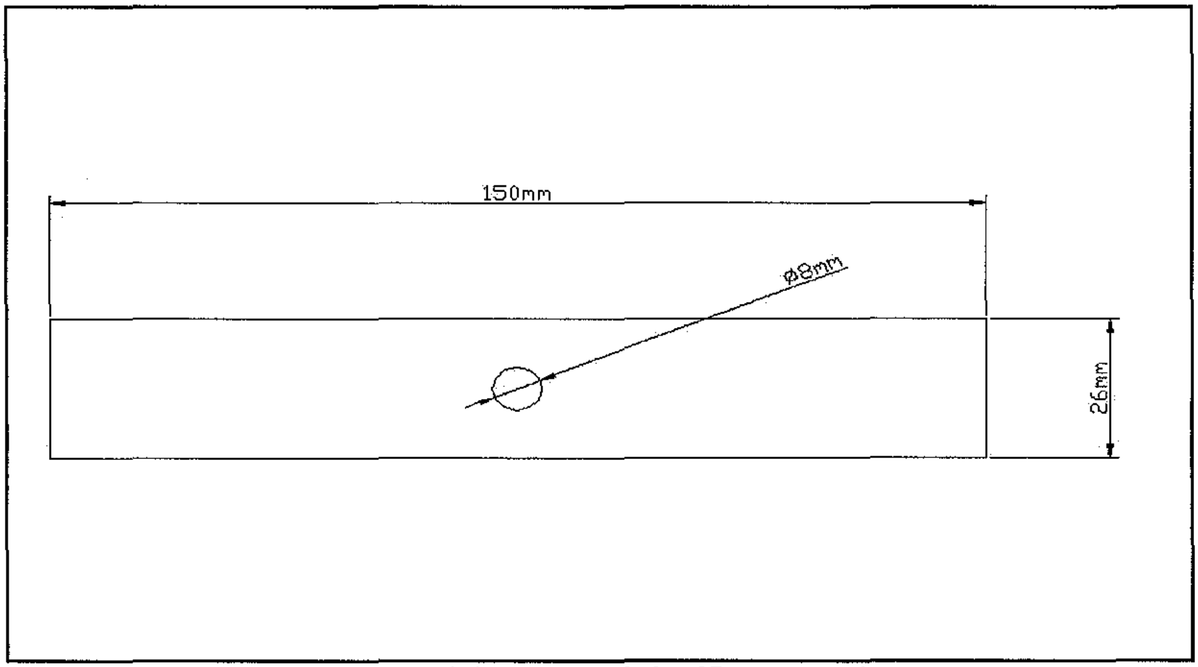


Figure 2.4: Characteristic of Parent Laminate

2.3 TEST METHOD

2.3.1 Proposed Test Method

The flexural test was conducted under ASTM Standards test method that is D 790: Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Material. The test was conducted by using Instron Universal Testing Machine.

2.4 DESCRIPTION OF THE FLEXURAL TEST

2.4.1 Scope

This test method cover the determination of flexural properties of unreinforced and reinforced plastics, including high-modulus composites and electrical insulating materials in form of rectangular bars molded directly or cut from sheets, plates or molded shapes.

However, flexural strength cannot be determined for those materials that do not break in the outer fibers within the 5.0% strain limit of this test method. This method use a three-point loading system applied to a simply supported beam that is available on the Instron Universal Testing Machine. The figure of the test machine can be referred in the Appendix 1.1.

2.4.2 Test Specimens Requirement

The specimens may be cut from sheets, plates or molded shapes, or may be molded to the desired finished dimensions. For materials 1.6mm or greater in thickness, the depth of the specimen shall be the thickness of the materials (flatwise test). For edgewise test, the width of the specimen shall be the thickness of the sheet, and the depth shall not exceed the width. For flexural test, the specimen structure is single patch bonded. Example of test specimen for flexural test is shown in Figure 2.5.

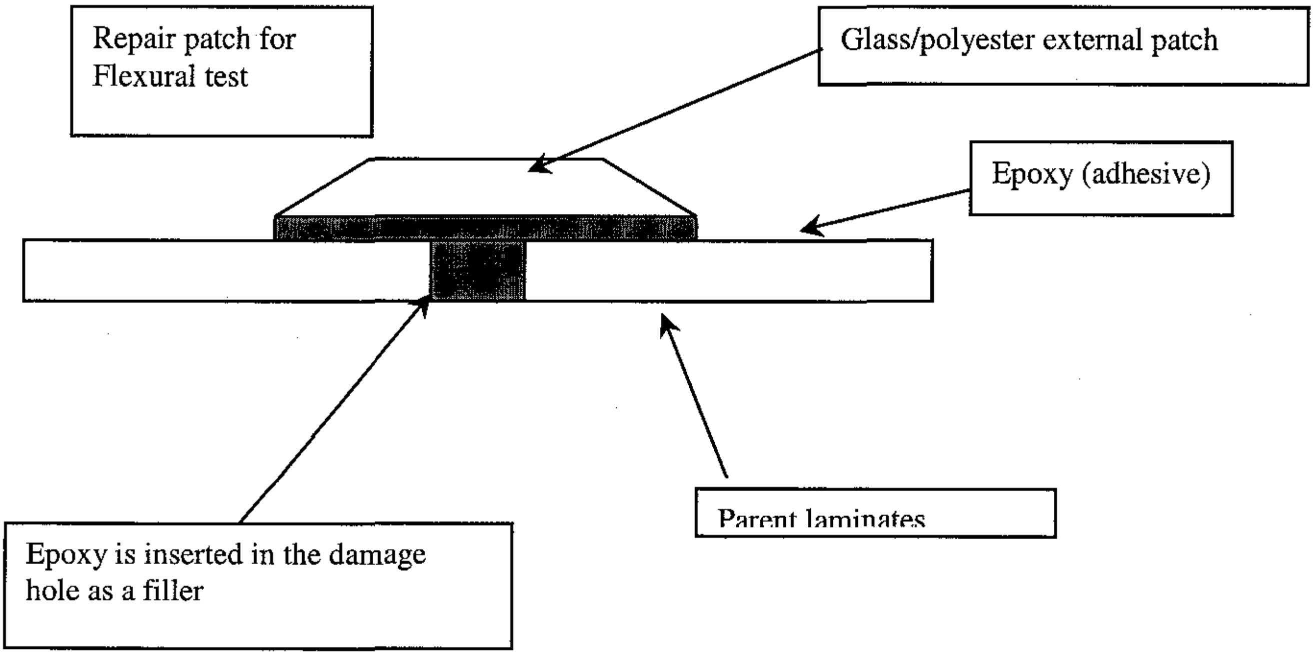


Figure 2.5: Test Specimen for Flexural Test

2.4.3 Calculation

When a homogeneous elastic material is tested in flexure as a simple beam supported at two points and loaded at the midpoint, the maximum stress may be calculated for any point on the load-deflection curve by below equation:

$$S = 3PL/2bd^2$$ **(Equation 1.1)**

Where:

S = stress in the outer fibers at midspan, MPa (Flexural Strength)

P = load at a given point on the load-deflection curve, N

L = support span, mm

b = width of beam tested, mm

d = depth of beam tested, mm

CHAPTER 3

RESULT AND DISCUSSION

3.1 RESULTS

All the data from the flexural testing of undamaged laminate samples, damaged laminate sample, square patches samples and octagon patches samples is shown in tables below. For further clarification of the raw data, referred to the Appendix 2.1, 2.2, 2.3 and 2.4.

Table 3.1: Undamaged Laminate Samples Data (mean of three specimens)

Displacement at Yield (mm)	Load at Yield (N)	Stress at Yield (MPa)	Young Modulus (GPa)	Flexural Yield Strength (Mpa)
2.63	514.96	241.43	25.71	194.16

Table 3.2: Damaged Laminate Samples Data (mean of three specimens)

Displacement at Yield (mm)	Load at Yield (N)	Stress at Yield (MPa)	Young Modulus (GPa)	Flexural Yield Strength (Mpa)
2.31	386.47	169.07	19.45	137.09

Table 3.3: Square Patch Samples Data (mean of three specimens)

Patch Surface Area (mm)^2	Displacement at Yield (mm)	Load at Yield (N)	Stress at Yield (MPa)	Young Modulus (GPa)	Flexural Yield Strength (Mpa)
289	2.34	779.08	321.54	42.20	273.41
361	2.75	712.77	292.75	45.26	248.09
441	2.90	800.88	332.17	52.60	279.40
529	1.83	793.85	322.55	57.87	274.77
625	2.12	1009.50	444.23	103.02	355.33

Table 3.4: Octagon Patch Samples Data (mean of three specimens)

Patch Surface Area (mm)^2	Displacement at Yield (mm)	Load at Yield (N)	Stress at Yield (MPa)	Young Modulus (GPa)	Flexural Yield Strength (Mpa)
274	2.12	669.05	291.66	44.33	242.36
350	2.62	880.15	388.62	63.37	318.59
434	2.32	878.22	398.74	73.67	324.52
526	2.28	971.32	425.80	81.18	351.03
626	2.21	1067.31	437.17	79.28	366.57

From the above data, the efficiency of flexural yield strength for each patch sample is calculated by using below equation:

$$Efficiency = \frac{F.Y.S\ of\ repair\ \ sample}{F.Y.S\ of\ original\ \ sample} X100\%$$

Table 3.5: Efficiency for Square Patch Specimens

Patch Surface Area $(mm)^2$	Efficiency (%)
289	140
361	127
441	143
529	141
625	183

Table 3.6: Efficiency for Octagon Patch Specimens

Patch Surface Area $(mm)^2$	Efficiency (%)
274	124
350	164
434	167
526	180
626	188

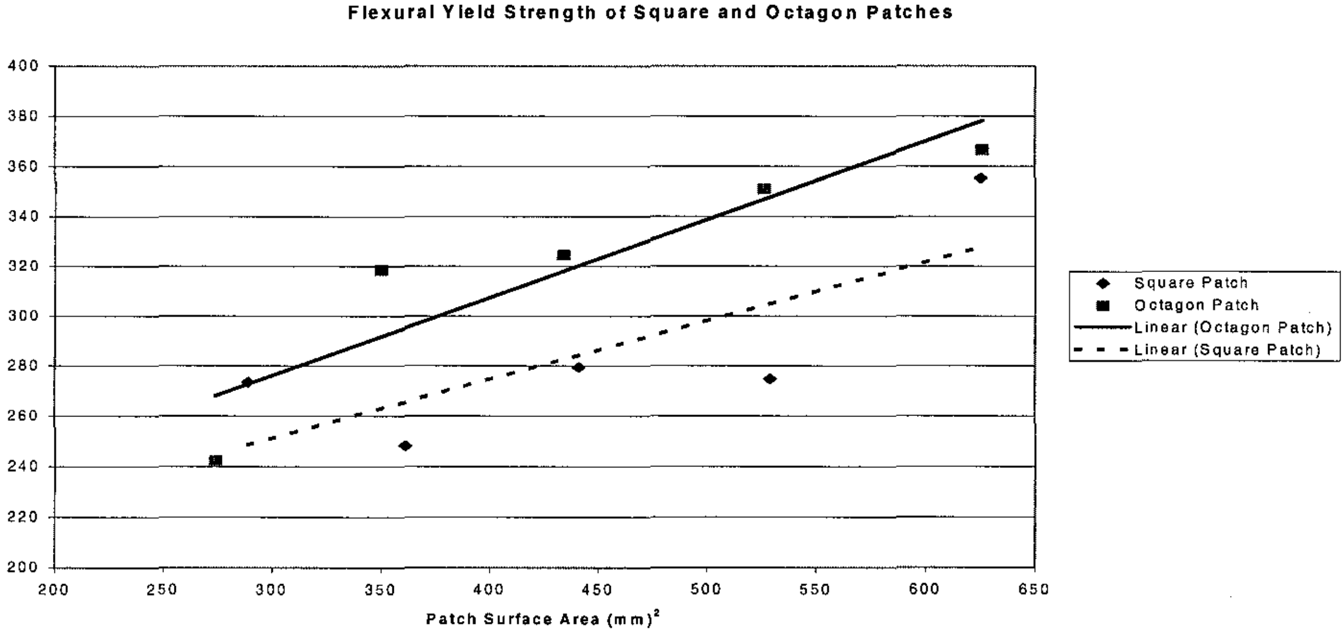


Figure 3.1: Flexural Yield Strength of Square and Octagon Patches

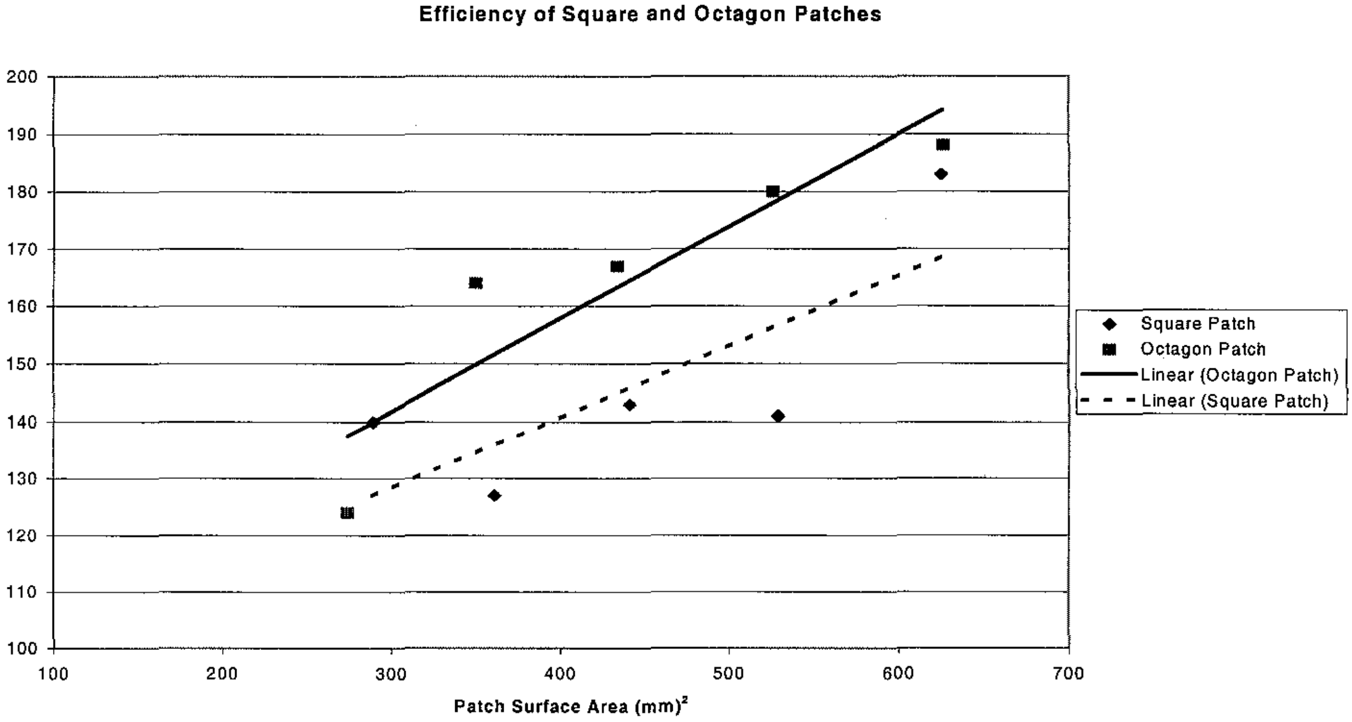


Figure 3.2: Efficiency of Square and Octagon Patches

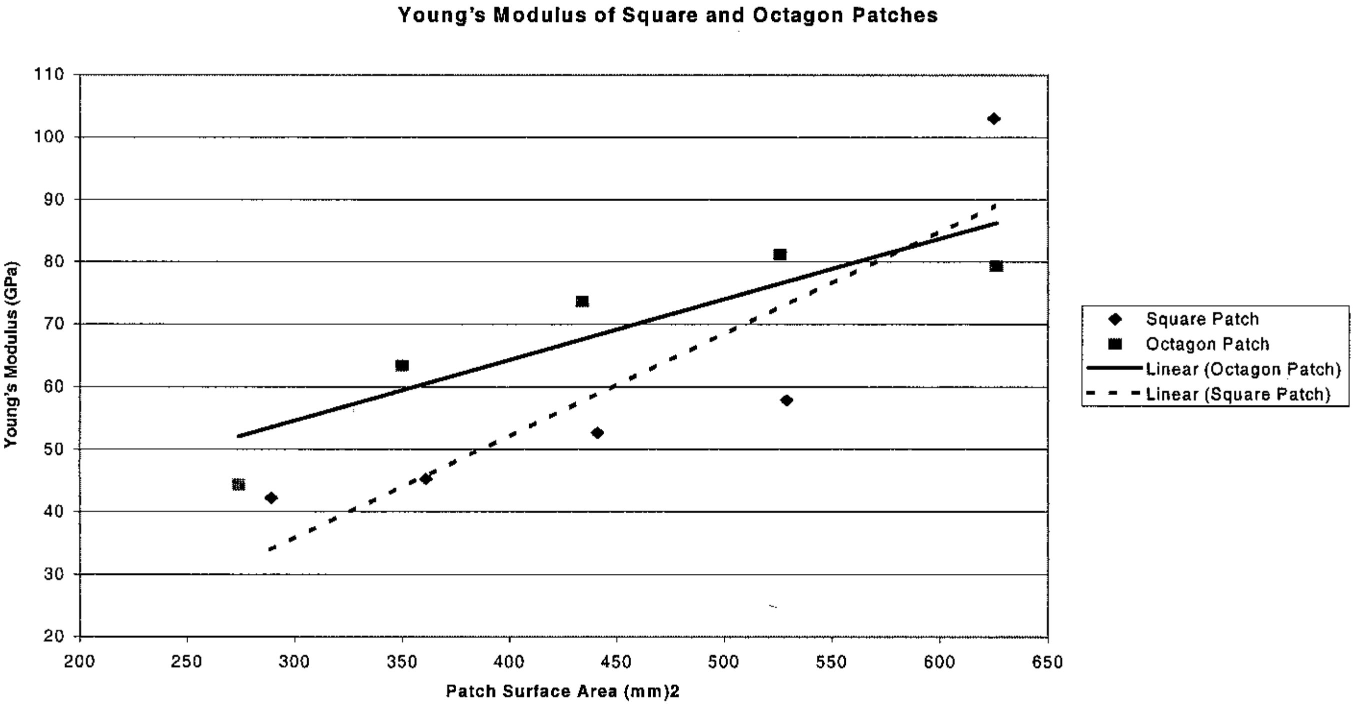


Figure 3.3: Young's Modulus of Square and Octagon Patches

3.2 DISCUSSION

During the testing, a few assumptions have to be made to simplify the scope analysis of this project. First, glass fiber in form of woven roving mat is assumed to have bi-directional orientation along the loading direction. This assumption complies with all the specimens that are going to be tested. Second, the patch and parent laminate are perfectly bonded together. Lastly, the adhesive layer is thin that the shear stress is constant through the thickness.

3.2.1 Calculation of the Flexural Yield Strength

In analyzing the data of all specimens, the author has found that the value of calculated flexural strength by using Equation 1.1 is not same as the value given by the Instron Testing Machine, which is stress at yield. According to ASTM Standard D790, the value calculated by Equation 1.1 will only be the same as the value given by the testing machine, if the stress of the test specimens linearly proportional to strain up to the point of rupture. In other words, the materials exhibits true Hookean behaviour.

However, from the writer's experiment, it was found that all the test specimen does not break up to point of rupture due to the introduction of patch. Thus, many of these specimens do not obey Hookean behaviour. This behaviour can be observed in the raw data graph in appendix for all test specimens.

According to the ASTM Standard also, if the specimens do not break up to rupture, it is suggested that flexural yield strength be calculated instead of flexural strength. Thus, the writer will used flexural yield strength value calculated by using Equation 1.1 throughout the whole discussion.

3.2.2 Flexural Yield Strength for Square Patches

As expected, the flexural yield strength of glass/polyester square patch repair composite is higher than the flexural yield strength of the undamaged laminate (194.16MPa) and damaged laminate (137.09MPa) (refer Figure 3.1). Apart from recovery of the strength, the introduction of patch also improve the strength of the parent laminate. It can be said that square patch can recover back the strength of the damage and parent laminate with a very high percent of efficiency (Figure 3.2).

However, the value of the flexural yield strength for square patch is varied from one surface to another surface area. For square, the flexural yield strength is not increase proportionally with the increasing of patch surface area. According to the patch repair theory, bigger surface area will give higher value of strength [1]. However, this is not the case of square patch result testing. From the experiment, the writer has found that the lowest value of flexural yield strength is shown by patch 361mm^2 (248.09M Pa) while the highest value of flexural yield strength is shown by patch 625mm^2 (355.33MPa).

This behaviour might be due to many reasons. One of it is the void (especially air bubbles) exist in the test specimen. The void will distort the load distribution on the test specimen when testing is implemented. The writer found that few specimens from 361mm^2 sample batch was unevenly bend during the testing. Further observation after the testing also found that the crack is at the edge of the patch, not in the middle of it. The edge will act like a stress concentrator and thus results in a premature failure to the test specimen, given a lower value of load (sample batch no.2, patch 361mm^2). Few specimens from other square patch samples such as sample 529mm^2 also gave a similar effect, but the difference in flexural yield strength is small compare to 361mm^2 sample batch.

Apart from that, the shape of square patch itself promotes to the inconsistency of the value of flexural yield strength. Any load that is applied to the square shape will unevenly be distributed to the parent laminate due to the present of four sharp corners. Again, same as the previous reason stated by the writer, the edges act as a stress concentrator to the patch and result in lower value of flexural yield strength. This corresponds to the study by R.L Evans and M. Heller [6] which stated that stress concentration is much higher for a more sided patch.

3.2.3 Flexural Yield Strength for Octagon Patches

Again, the same observation as square patch has been observed during the octagonal patch samples testing where higher surface area will increase the flexural yield strength of repair patch. However, a more consistent value of flexural testing is observed compare than square patch samples. The value of flexural yield strength for octagonal patch increases proportionally with the increasing of patch surface area. The lowest value of flexural yield strength is 242.36MPa for 274mm^2 patch while the highest value is 366.57MPa for 626mm^2 patch.

This consistent value of flexural yield strength might be due to non-defective specimen produced for octagonal testing where amount voids might be reduced. Apart from that, the shape of octagonal patch itself promotes to a more consistent reading. Load distribution on the octagonal shape is more uniform along the surface area of the patch compare to the square shape because there is no shape edges on the patch which result in lower stress concentration. In other words, octagon patch is more slender than the square patch, which is corresponds to the study by R.L Evans and M. Heller [6]. Thus, due to these reasons, the octagonal patch repair composite gave a higher value of flexural yield strength than the square patch repair composite (Figure 3.1).

3.2.4 Efficiency of Square and Octagon Patches

The efficiency of square patch also has shown the same result as its flexural yield strength. The lowest efficiency was shown by 361mm^2 sample batch (127%) while the highest efficiency (183%) was shown by 625mm^2 sample batch. From this, it can be said that all square patches have recovered back all the flexural yield strength of damage laminate more than 100%. However, the efficiency reading is not consistent from one surface area to another. Again, it corresponds to the value of flexural yield strength which also do not increase proportionally with its surface area.

The efficiency reading of octagonal patch repair is more consistent than the efficiency of square patch repair. Furthermore, the efficiency of this shape is also higher than square patch sample batches for every increases of surface area (Figure 3.2). The lowest efficiency of octagonal patch is 274mm^2 sample batch (124%) and the highest is 626mm^2 sample batch (188%). Again, it had been observed that all octagon patches have recovered back all the flexural yield strength of damage laminate more than 100%.

3.2.5 Young's Modulus for Square and Octagon Patches

The writer also had discovered the Young Modulus properties of both square and octagonal patch repair specimen. For square patch sample batch, it was found that the lowest value of Young's modulus is shown by 289mm^2 (42.20GPa) and the highest value is shown by square 625mm^2 (103.02GPa) (Figure 3.3). The value of Young's modulus of square patch also increased proportionally with the increasing of surface area.

However, observation on Young's modulus for octagonal patch repair specimen is a bit different from the square patch. The lowest value of Young's modulus is produced by octagonal 274mm^2 (44.33MPa) while the highest Young's modulus value is shown by octagonal 526mm^2 (81.18MPa) (Figure 3.3). Thus, the modulus value is not proportional to the increasing of surface area. This behavior might be due to the premature failure of ply that gave a much lower value of Young's modulus. Yet, a lower value of modulus do not affect the flexural strength of the specimen since woven roving glass fibers composite can retain the its ply by ply strengthening mechanism.

Another interesting fact that has been discovered by the writer for this observation is that the highest value of Young's modulus by square patch is bigger than the highest value of Young's modulus for octagon patch. In other words, the square patch is much stiffer than the octagon patch.

This observation can be explained further by looking at the slope of the tangent to the initial line portion of the load-deflection curve, N/mm for square patch (refer Appendix 2.3). The slope is much steeper than the octagon patch, which results in higher value of Young's Modulus.

3.2.6 Test Specimen Failure Observation

Apart from flexural yield strength analysis, the writer had observed a distinctive failure mode from the test samples. The writer found that each sample fail ply by ply during the testing. This phenomena is noticed by the sound of 'crack' produced by the sample when load is applied to it.

Although the test specimen failed in this manner, it still held the strength until the entire ply has ruptured. This observation actually shown the unique failure mode of woven roving glass fibers and is proved by the graph load versus displacement produces by Instron Universal Testing Machine (refer Appendix 2.1, 2.2, 2.3, and 2.4). Besides that, it was also discovered that parent laminate failed first before the patch. This observation can be explain by using below figure:

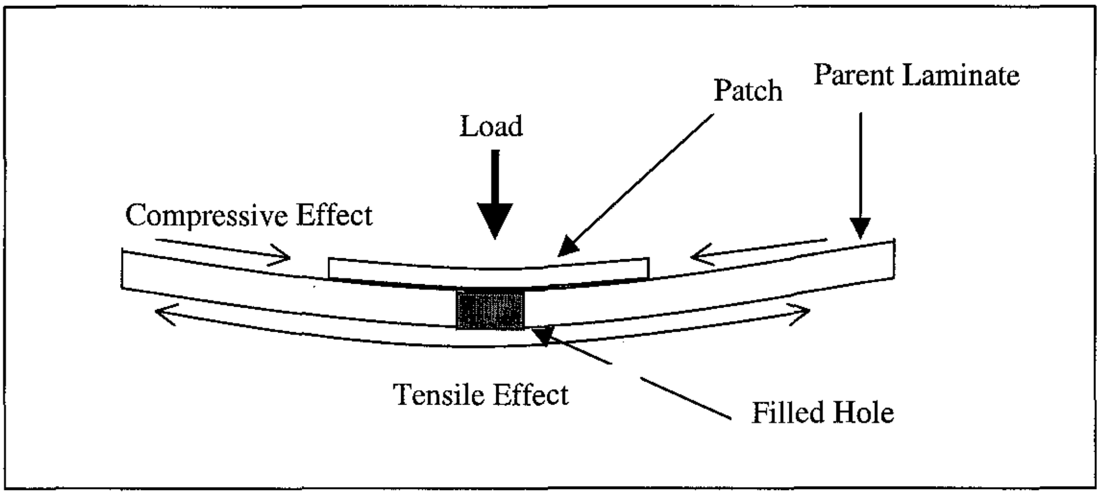


Figure 3.4: Effect of Load to the Test Specimen

When load is applied, the test specimen will bend into the above condition. The topside (patch) of the specimen will experience a compressive stress while the below side (parent laminate) of the test specimen will experience a tensile stress. Parent laminate will fail first due to the introduction of the damage hole on the surface of it.

The topside of the specimen will retain higher strength before failure occurs due to the introduction of the patch. The crack that has been observed on the surface of the parent laminate is shown in Figure 4.6. The crack occurs along the damage hole of the parent laminate. This type of crack is due to the tensile stress which is experienced by the below side of the test specimen.

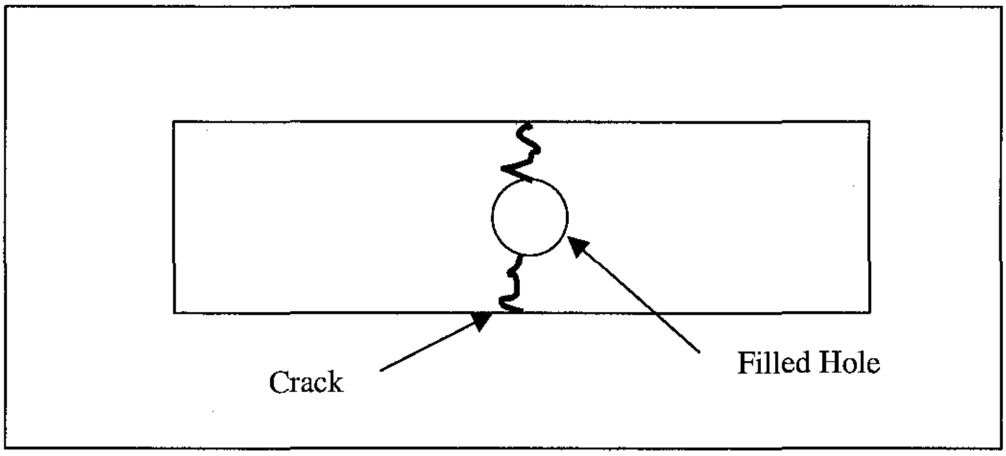


Figure 3.5: Failure Mode of the Parent Laminate

3.2.7 Effect of Epoxy Adhesive and Filler to the Strength of the Repair Patch

Basically, the purpose of epoxy adhesive is not only to bond the patch with the parent laminate but also important to transfer the load from the patch to the repair structure. Therefore, for this flexural test, the writer believed that epoxy adhesive affects the strength of the repair structure. The effect of the epoxy adhesive can be taken into account if the patch and the repair structure are perfectly bonded together. This is because the perfect bond between both structures promoted to the more evenly distribution of stress from the patch to the repair structure, and thus increased the strength of the repair structure. However, the majority of the strength of repair structure is still domain by the patch itself.

Another important aspect that must taken into consideration is the effect of epoxy filler inside the damage hole. The writer suspected that the epoxy filler might affect the strength of whole repair structure. However, the strength contributed by the filler is much smaller compared to the strength provided by the patch itself.

This phenomenon can be explained more clearly by considering the stress concentration around the damage hole. Basically, when the damaged hole is introduced by drilling, stress concentrator will occur around the hole. Therefore, by applying the epoxy filler, it actually reduced the stress concentration around the damage hole and as the results, increased the strength of the repair structure. Yet, the value of the strength provided by the epoxy filler cannot be determined accurately because there is no known calculation method to determined the strength of it except by employing finite element analysis.

CHAPTER 4

CONCLUSION

Basically, the shape and area of the patch affect the flexural yield strength of the repair laminate. During the flexural testing, the writer has found that by increasing the surface area of the patch, the flexural yield strength of the repair test structure is also increased. This observation complies with the theory of patch repair technique. Apart from that, the efficiency of the repair structure is higher compared to the original structure. The efficiency can reach up to 183% for square and 188% for octagonal. The writer also found that octagonal patch produce higher flexural yield strength than the square patch. However, the data available from the test might be more accurate if the problems stated before can be overcome. Yet, this project can still be developed into a more practical solution for composite repair structure in the future.

CHAPTER 5

ISSUES AND RECOMMENDATION

5.1 ISSUES

There are few issues that have to be delivered by the writer in improving this project. All the issues can be classified into two which are sample preparation and sample cutting.

5.1.1 Issues during Sample Preparation

The writer had encountered a few constraints during sample preparation of glass/polyester composite. One of the issues was the void that produced during preparation of master batch of polyester resin. The voids will remain between the layer of the fiberglass and difficult to remove, thus affected the properties of the composite. To minimize the voids, the writer suggests that pouring process of the polyester resin to the fiberglass sheet should be practiced carefully.

Second, there is no proper labeling of raw materials on its container that has been used for the sample preparation. The writer found that it is difficult to recognize between each material, especially the resin. Thus, it is difficult for the writer when he want to refer for a specific properties of the raw materials such as density and Young's

Modulus for further clarification. To overcome this constraint, the writer suggests that labeling of the raw material should be implemented systematically to avoid confusion during the experimental work.

Third, there is no suitable measuring apparatus to measure the quantity of resin and catalyst during sample preparation. This could affect the curing process and volume fraction of fibers with the resin. To overcome this, a more suitable measuring apparatus should be provided in the laboratory to avoid mistake during preparation of master batch mixture.

Fourth, the protection apparatus such as gloves and gas mask is not effective to use during sample preparation. This might endanger anyone who is dealing with these toxic materials. The writer recommends that a more appropriate gloves and gas mask should be used as a safety precaution.

Fifth, it is difficult to clean and remove the remaining resin that stick at the tools (brush, roller) by using acetone, especially after the resin has cured. This will affect the quality of the composite when tools are used again. To overcome this problem, all the tools should be clean directly after work by acetone so that the resin does not cure with them.

Sixth, the surface roughness between the top layer and below layer is not uniform. This is due to the top glass sheet that is not pressed strongly against the below glass sheet. The writer suggests for future work, top glass sheet can be pressed by applying heavy mass on it.

Lastly, the writer has found that it is difficult to get a uniform thickness of sample throughout the whole process. However, the difference is small and can be neglected.

5.1.2 Issues during Cutting and Bonding the Test Specimen

There is no proper cutting tool to cut the glass/polyester composite. The writer only manages to cut the sample of parent laminate by using jigsaw machine. This had affected the sample dimension since it is hard to get a smooth and uniform dimension from one sample to the another. For future work, the writer suggests that a more suitable cutting machine that specifically for composite material should be used. This is important in producing a more accurate dimension of specimen for the test.

The cutting process for square and octagonal patch shape is another difficult task and time consuming. All the patch specimens have to be measured carefully before being cut. Furthermore, the writer only use handsaw since other tools is not suitable to cut such a small specimen. To overcome this problem, the writer suggests the used of high-pressure stamping equipment or computer numerical control cutting machine to create a much precise shape and dimension.

The writer also has to skip the taper edges that going to be implemented to the entire patch test specimens. Again, there is no suitable tool to be used to make the taper edges. The writer suggests that specific taper maker equipment can be used for implementation of the taper along the patch edges.

Lastly, during the bonding of the patch to the parent laminate, the writer faces a difficulty when applying the epoxy adhesive to both parts. This is because it was hard to control the thickness of the epoxy layer since there is no tools to inspect the amount of epoxy that has been applied to the test specimen. This problem can be overcome by careful and precise pouring of the resin by using a small piece of spoon.

5.2 RECOMMENDATIONS FOR FUTURE WORK

The writer would like to suggest a few recommendations for future work as a continuation for this project.

First, other patch shapes such as circle, hexagon or oval can be introduced for further study. This is relevant in determining whether the shape of the patch give a significant effect on the strength of the particular repair structure. Hence, the introduction of other patch shapes can contributed to a more convincing result during testing.

Second recommendation is an introduction of taper edges on the patch under investigation. This is very important because the function of the taper is not only for aesthetic reasons but also important in reducing the stress concentration along the patch end. Thus, it can promote to a more accurate result by avoiding premature failure from happening to the test specimen.

Third recommendation is to introduce various thickness of the patch bonded repair structure. By increasing the thickness of the patch, it will increase the strength of the repair structure.

Fourth recommendation is to invert the arrangement of the repair structure during testing. Instead uses the arrangement as shown in Figure 2.5 where the patch is at the topside, it is suggested that a new arrangement where the patch is in below side (refer Figure 4.1) can be implemented during testing. In this way, the behavior of the patch under difference flexural loading can be observed.

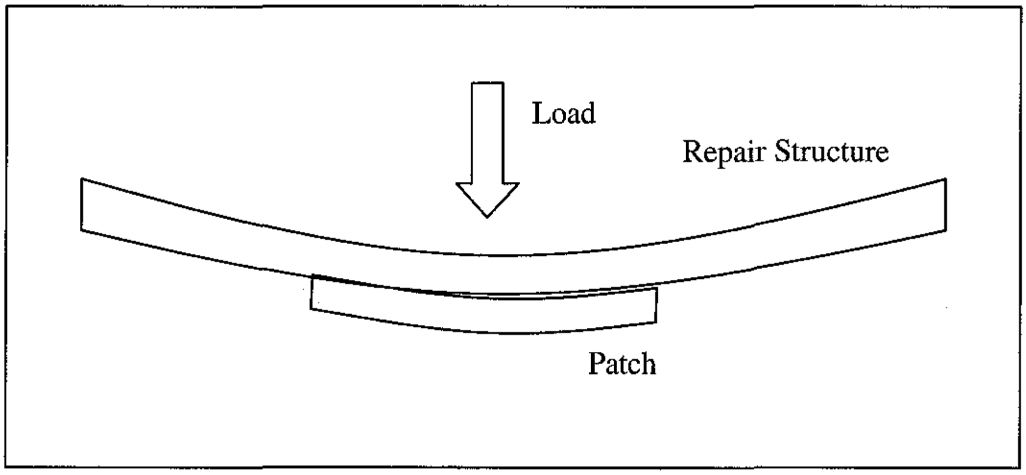


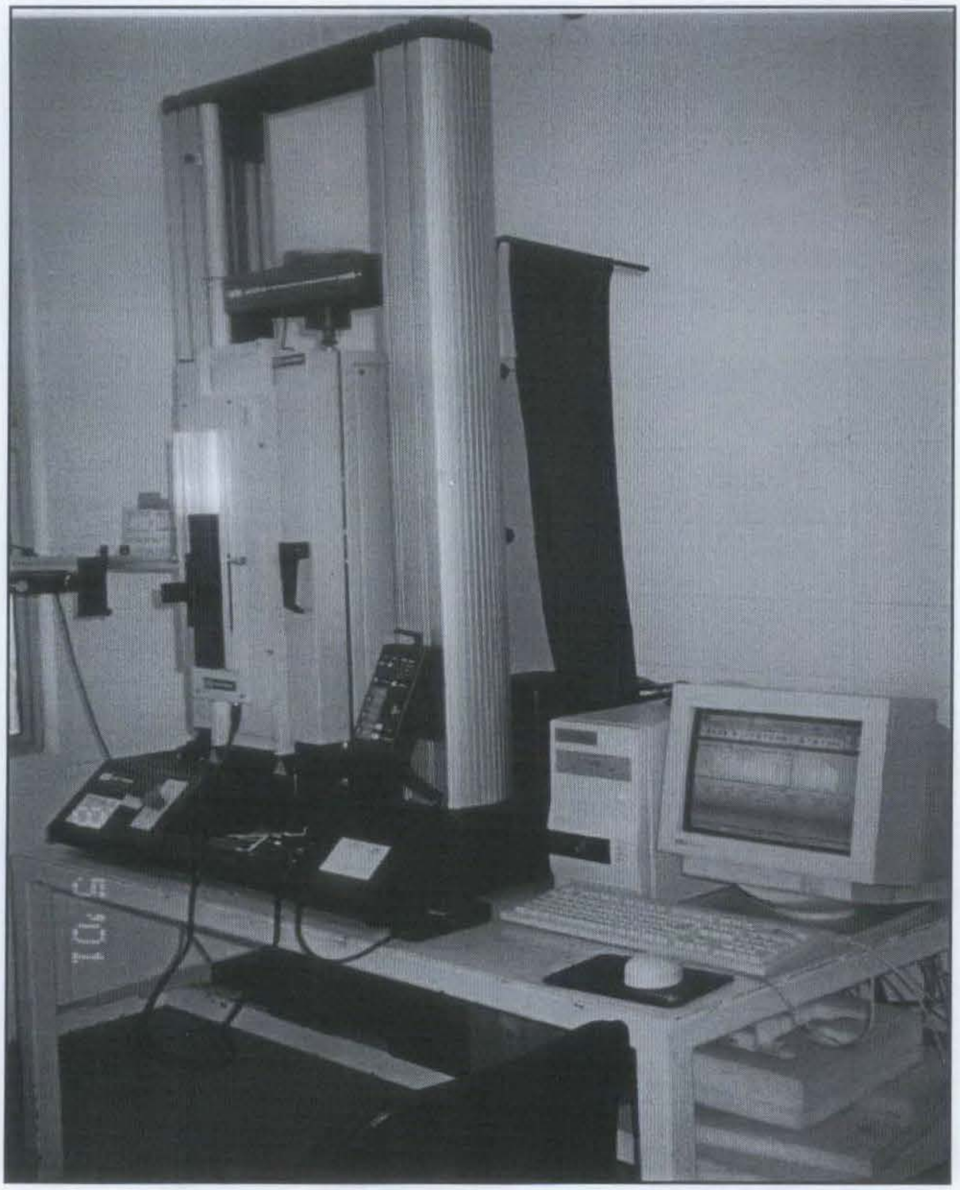
Figure 4.1: New Arrangement of Test Specimen

Last but not least, the writer would like to recommend that finite element analysis (FEA) for modeling the patch bonded repair under flexural stress is implemented for further analysis. This analysis can be done by using ANYSS software or by using other software specifically used to finite element analysis of patch bonded repair structure such as PC-based design package BondRep. This software can be used to analyze bondline stresses and predict failure load and mode of the bonded joint.

REFERENCES

1. Fibre Glass Developments Corporation http://www.fibreglast.com /Bro%25201087Repair.htm
2. Schwartz, Mel; *Composite Materials Handbook,* 2nd Edition, 1992, p.148-156, McGraw-Hill, Inc,
3. Hollaway, Leonard; *Handbook of Polymer Composite for Engineers*, 1994, p. 178-190, Woodhead Publishing Ltd.
4. Baker, A.A; Joining Advanced Fibre Composites, *Composite Material for Aircraft Structure*, 1986, p.115-140, American Institute of Aeronautical Inc, New York.
5. Goering, J. and K, Griffiths; Design and Analysis Techniques for Aircraft Battle Damage Repair of Advanced Composite Structures, *Composites Materials, Properties, Nondestructive Testing and Repair*, 1991, p. 281, Prentice Hall.
6. R.L., Evans and M. Heller; Effect on Bonded Insert Shape and Adhesive Thickness on Critical Stress in All Loaded Plate, 1998, p. 2-8, Australian Aeronautical Service Center. http://www.dsto.defence.gov.au/corporate/history/jubilee/sixtyyears9.html
7. Jacky, C. Prucz, Constantine, C. Spyrakos, Bruce, Henderson; A New Concept for Efficiency Enhancement of Adhesive Joints, *American-Japanese International Conference on Composite*, **Vol.6**, 1988, p. 815-824.
8. Schwartz, Mel; *Composites Materials, Properties, Nondestructive Testing and Repair*, 1996, p. 275-307, Prentice Hall.
9. Richardson, Terry; *Composite Design Guide*, 1987, p.153-155, Industrial Press Inc.

APPENDIX 1-1



DATA OBTAINED FROM THE TEST

1.Set of Data for Undamaged Laminate

Petronas PRSS

Process & Product

erator name: leikun

nple Identification: 1 (Undamaged Laminate).

t Method Number: 3

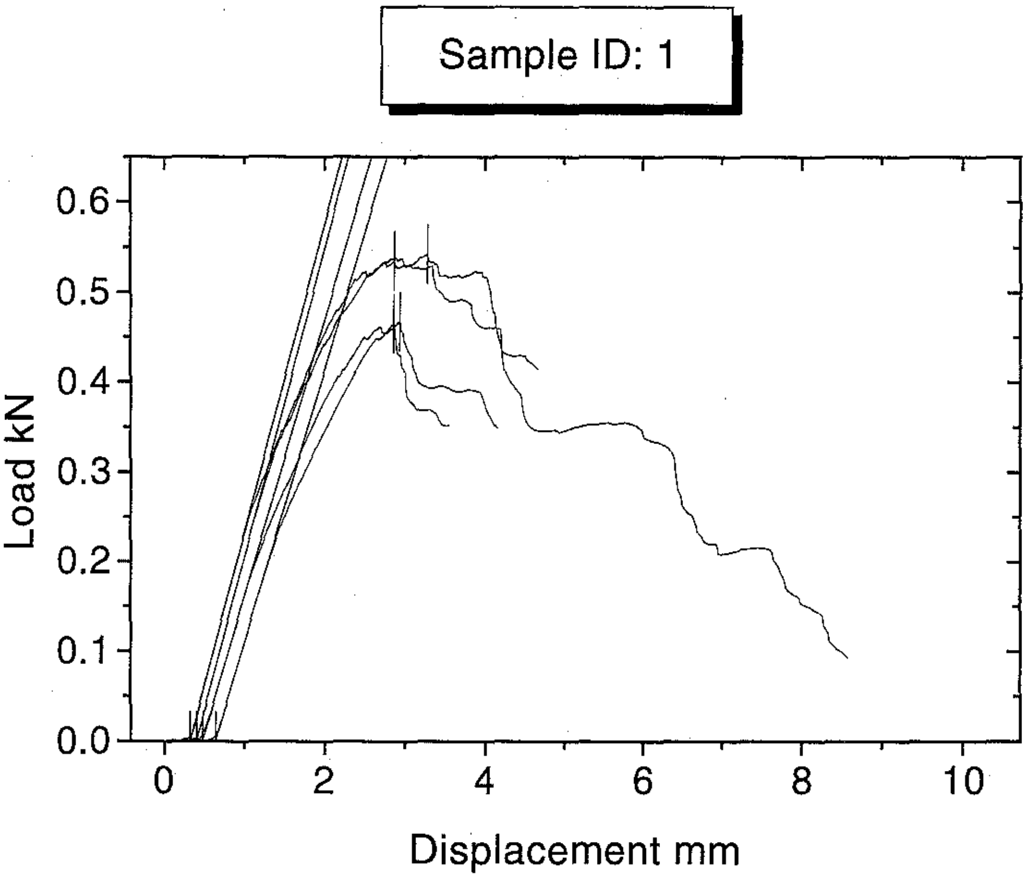
ent CMS

nple ID

AWC3-point

Test Date:	Tuesday, 08 May, 1901
Interface Type:	5500
Crosshead Speed:	1.0200 mm/min
Sample Rate (pts/secs):	10.0000
Temperature:	23 C
Humidity (%):	50
Specimen G. L.:	100.0000mm
Span:	50.0000 mm

	Displcment at Yield (mm)	Load at Yield (N)	Stress at Yield (MPa)	Width (mm)	Depth (mm)	Modulus (AutYoung) (MPa)
1	~~2.223~~	~~465.509~~	~~246.259~~	~~24.820~~	~~2.390~~	~~28014.342~~
2	2.471	535.272	259.559	24.550	2.510	27534.850
3	2.457	467.496	223.534	25.710	2.470	24904.443
4	2.964	542.101	241.210	25.520	2.570	24693.492
Mean	2.529	502.594	242.640	25.150	2.485	26286.781
S.D.	0.312	41.776	14.905	0.554	0.075	1731.239
C.V.	12.335	8.312	6.143	2.201	3.038	6.586
Mean +2.00 SD	3.152	586.147	272.450	26.257	2.636	29749.260
Mean -2.00 SD	1.905	419.042	212.831	24.043	2.334	22824.305
Minimum	2.223	465.509	223.534	24.550	2.390	24693.492
Maximum	2.964	542.101	259.559	25.710	2.570	28014.342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0.3
0.4
0.5
0.6
Displacement mm
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2
4
6
8
10

2.Set of Data for Damaged Laminate

Petronas PRSS

Process & Product

erator name: faizal

AWC3-point

nple Identification: DAMAGE LAMINATE NO·1

t Method Number: 3

ent CMS

nple ID

Test Date: Tuesday, 08 May, 1901

Interface Type: 5500

Crosshead Speed: 2.0000 mm/min

Sample Rate (pts/secs): 10.0000

Temperature: 23 C

Humidity (%): 50

Specimen G. L.: 100.0000mm

Span: 50.0000 mm

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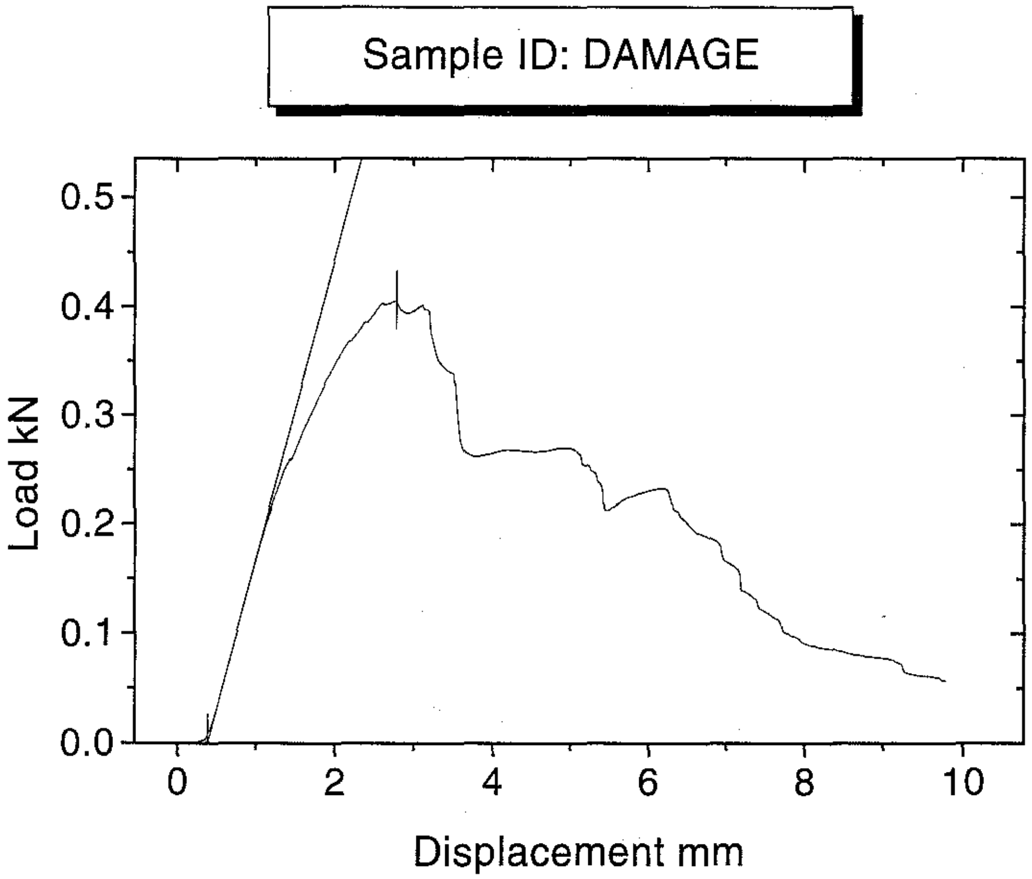
*1	~~0~~	~~0.225~~	~~0.156~~	~~12.000~~	~~3.000~~	
2	2.400	405.906	196.696	26.870	2.400	23093.410
Mean	2.400	405.906	196.696	26.870	2.400	23093.410
S.D.	0	0	0	0	0	0
C.V.	0	0	0	0	0	0
Mean +2.00 SD	0	0	0	0	0	0
Mean -2.00 SD	0	0	0	0	0	0
Minimum	2.400	405.906	196.696	26.870	2.400	23093.410
Maximum	2.400	405.906	196.696	26.870	2.400	23093.410


Sample ID: DAMAGE
Load kN
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0.2
0.3
0.4
0.5
0
2
4
6
8
10
Displacement mm

Petronas PRSS

Process & Product

erator name: faizal

AWC3-point

nple Identification: DAMAGES LAMINATE NO.2 AND NO.3

st Method Number: 3

ent CMS

nple ID

Test Date: Tuesday, 08 May, 1901

Interface Type: 5500

Crosshead Speed: 1.1000 mm/min

Sample Rate (pts/secs): 10.0000

Temperature: 23 C

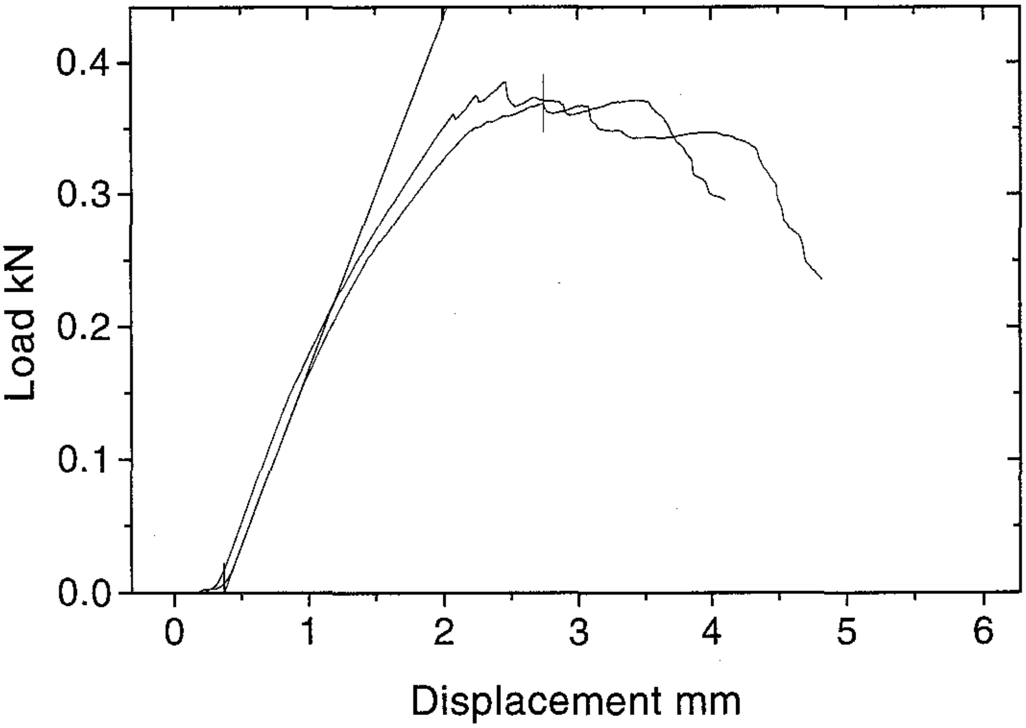
Humidity (%): 50

Specimen G. L.: 100.0000mm

Span: 50.0000 mm

	Displcment at Yield (mm)	Load at Yield (N)	Stress at Yield (MPa)	Width (mm)	Depth (mm)	Modulus (AutYoung) (MPa)
1	2.150	384.880	153.949	26.500	2.660	17226.285
2	2.370	368.624	156.577	25.920	2.610	18037.322
Mean	2.260	376.752	155.263	26.210	2.635	17631.803
S.D.	0.156	11.495	1.858	0.410	0.035	573.490
C.V.	6.893	3.051	1.197	1.565	1.342	3.253
Mean +2.00 SD	2.572	399.741	158.980	27.030	2.706	18778.783
Mean -2.00 SD	1.948	353.763	151.546	25.390	2.564	16484.824
Minimum	2.150	368.624	153.949	25.920	2.610	17226.285
Maximum	2.370	384.880	156.577	26.500	2.660	18037.322

Sample ID: DAMAGE1



3.Set of Data for Square Patch

Petronas PRSS

Process & Product

erator name: faizal

nple Identification: SQUARE17

t Method Number: 3

ent CMS

nple ID

AWC3-point

Test Date:	Tuesday, 08 May, 1901
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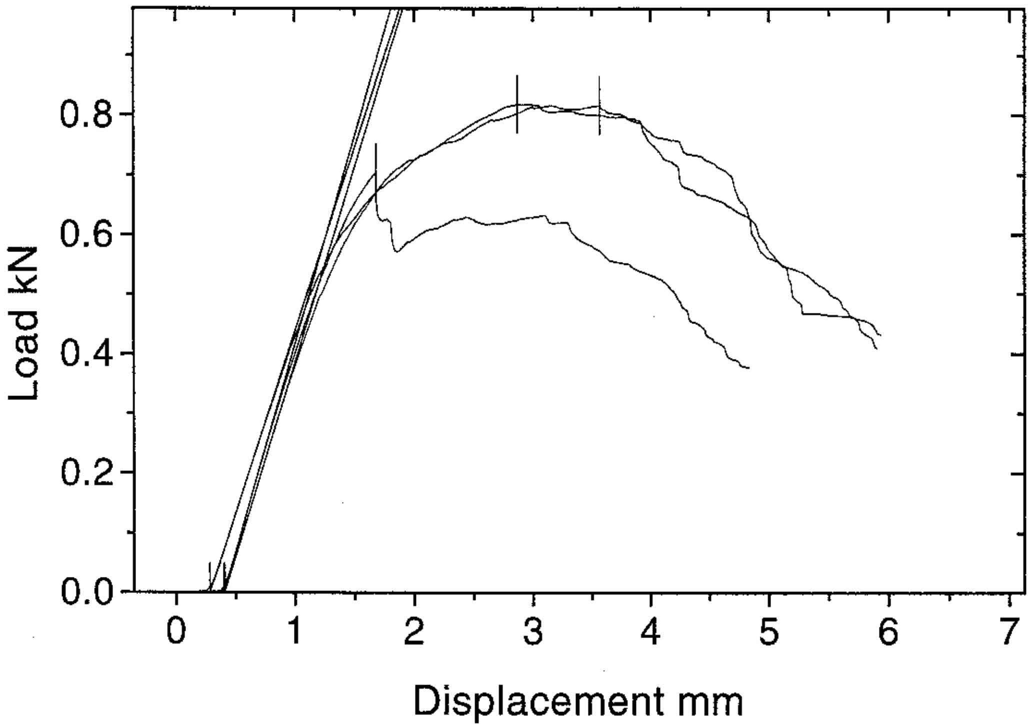
Sample Rate (pts/secs):	10.0000
Temperature:	23 C
Humidity (%):	50
Specimen G. L.:	100.0000mm
Span:	50.0000 mm

	Displcment at Yield (mm)	Load at Yield (N)	Stress at Yield (MPa)	Width (mm)	Depth (mm)	Modulus (AutYoung) (MPa)	
1	3.158	816.049	345.998	25.000	2.660	43360.625	✓
2	2.587	817.755	333.386	26.000	2.660	39056.211	✓
3	1.281	703.429	285.241	26.140	2.660	44171.539	
Mean	2.342	779.077	321.542	25.713	2.660	42196.125	
S.D.	0.962	65.519	32.064	0.622	0	2749.308	
C.V.	41.075	8.410	9.972	2.418	0	6.516	
Mean +2.00 SD	4.266	910.116	385.669	26.957	2.660	47694.742	
Mean -2.00 SD	0.418	648.039	257.415	24.470	2.660	36697.512	
Minimum	1.281	703.429	285.241	25.000	2.660	39056.211	
Maximum	3.158	817.755	345.998	26.140	2.660	44171.539	

Sample ID: SQUARE17



Petronas PRSS

Process & Product

erator name: faizal

nple Identification: SQUARE19

:t Method Number: 3

ent CMS

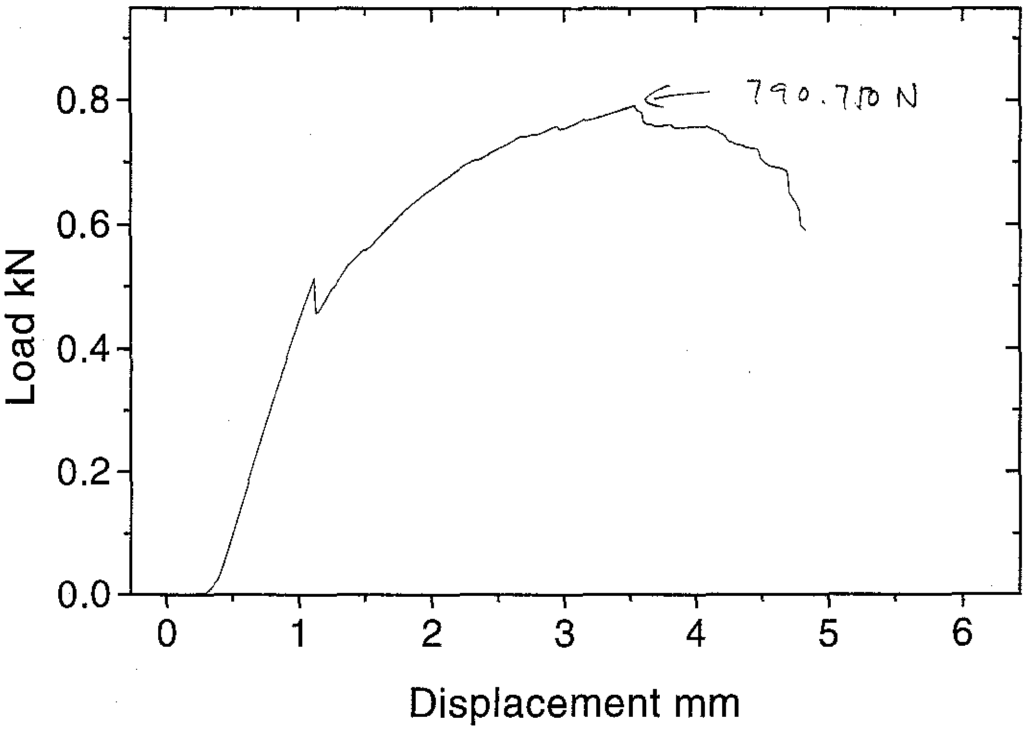
nple ID

AWC3-point

Test Date:	Tuesday, 08 May, 1901	
Interface Type:	5500	
Crosshead Speed:	1.1300	mm/min
Sample Rate (pts/secs):	10.0000	
Temperature:	23 C	
Humidity (%):	50	
Specimen G. L.:	100.0000mm	
Span:	50.0000 mm	

	Displcment at Yield (mm)	Load at Yield (N)	Stress at Yield (MPa)	Width (mm)	Depth (mm)	Modulus (AutYoung) (MPa)
1	2.893	696.780	280.400	26.340	2.660	43788.633
2	2.167	650.768	289.784	25.700	2.560	49279.602
3	3.181	790.750	308.074	26.020	2.720	42717.793
Mean	2.747	712.766	292.753	26.020	2.647	45262.008
S.D.	0.522	71.347	14.074	0.320	0.081	3520.293
C.V.	19.018	10.010	4.807	1.230	3.054	7.778
Mean +2.00 SD	3.791	855.460	320.900	26.660	2.808	52302.594
Mean -2.00 SD	1.702	570.072	264.605	25.380	2.485	38221.422
Minimum	2.167	650.768	280.400	25.700	2.560	42717.793
Maximum	3.181	790.750	308.074	26.340	2.720	49279.602

Sample ID: SQUARE19



Petronas PRSS

Process & Product

erator name: faizal

nple Identification: SQUARE21

t Method Number: 3

ent CMS

nple ID

AWC3-point

Test Date: Tuesday, 08 May, 1901

Interface Type: 5500

Crosshead Speed: 1.1300 mm/min

Sample Rate (pts/secs): 10.0000

Temperature: 23 C

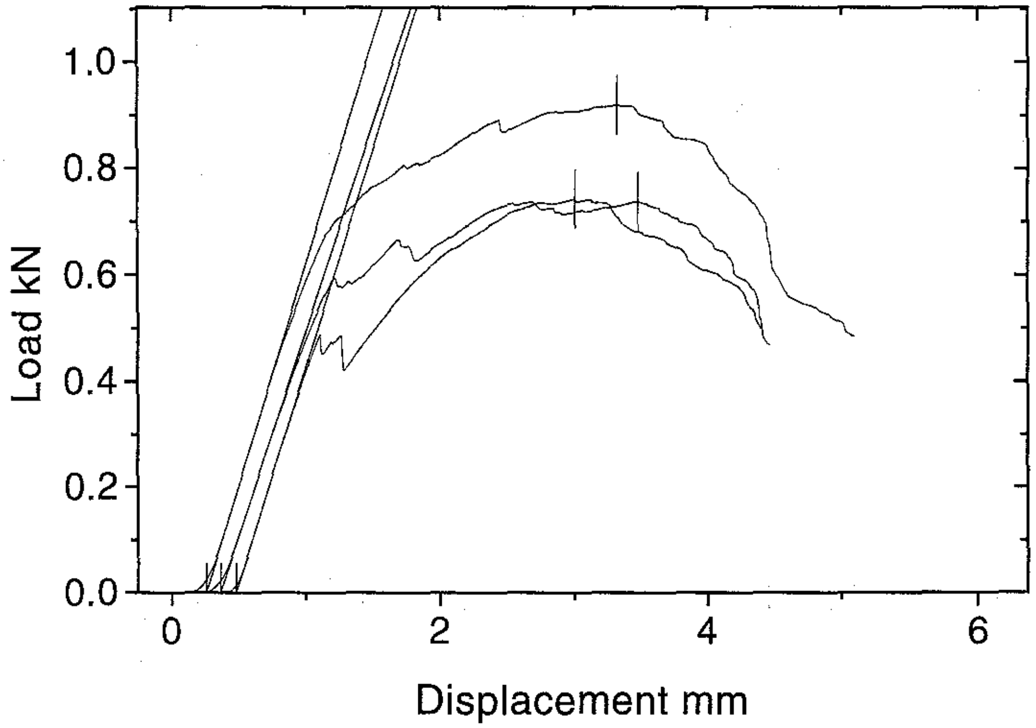
Humidity (%): 50

Specimen G. L.: 100.0000 mm

Span: 50.0000 mm

	Displcment at Yield (mm)	Load at Yield (N)	Stress at Yield (MPa)	Width (mm)	Depth (mm)	Modulus (AutYoung) (MPa)	→ Flexural modulus.
1	3.061	919.656	401.631	25.800	2.580	58781.672	✓
2	2.524	743.898	304.447	25.900	2.660	52208.402	
3	3.115	739.079	290.439	26.180	2.700	46823.344	✓
Mean	2.900	800.878	332.172	25.960	2.647	52604.473	
S.D.	0.327	102.893	60.560	0.197	0.061	5988.995	
C.V.	11.261	12.848	18.231	0.759	2.309	11.385	
Mean +2.00 SD	3.553	1006.664	453.292	26.354	2.769	64582.465	
Mean -2.00 SD	2.247	595.091	211.053	25.566	2.524	40626.484	
Minimum	2.524	739.079	290.439	25.800	2.580	46823.344	
Maximum	3.115	919.656	401.631	26.180	2.700	58781.672	

Sample ID: SQUARE21



Petronas PRSS

Process & Product

erator name: faizal

nple Identification: SQUARE23

st Method Number: 3

ent UTP

nple ID

AWC3-point

Test Date: Wednesday, 09 May, 1901

Interface Type: 5500

Crosshead Speed: 1.1400 mm/min

Sample Rate (pts/secs): 10.0000

Temperature: 23 C

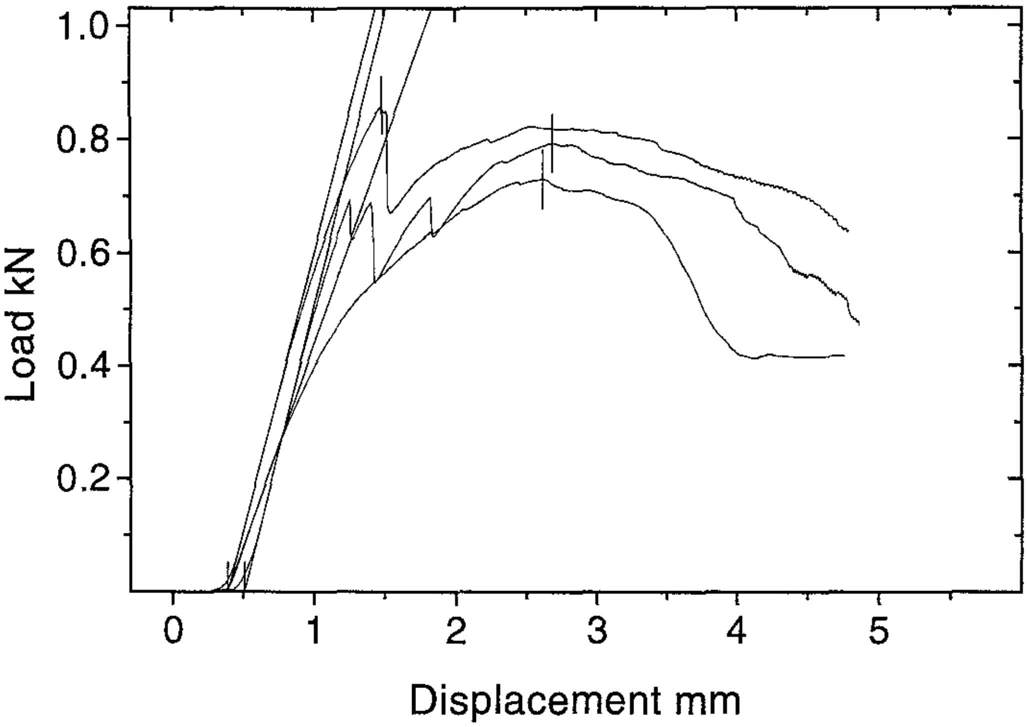
Humidity (%): 50

Specimen G. L.: 100.0000mm

Span: 50.0000 mm

	Displcment at Yield (mm)	Load at Yield (N)	Stress at Yield (MPa)	Width (mm)	Depth (mm)	Modulus (AutYoung) (MPa)	
1	1.095	859.676	372.571	25.600	2.600	68221.367	✓
2	2.229	729.196	278.271	25.800	2.760	41092.121	
3	2.175	792.666	316.822	26.520	2.660	64284.445	✓
Mean	1.833	793.846	322.554	25.973	2.673	57865.980	
S.D.	0.640	65.248	47.411	0.484	0.081	14659.350	
C.V.	34.888	8.219	14.699	1.863	3.024	25.333	
Mean +2.00 SD	3.112	924.342	417.376	26.941	2.835	87184.680	
Mean -2.00 SD	0.554	663.350	227.733	25.006	2.512	28547.277	
Minimum	1.095	729.196	278.271	25.600	2.600	41092.121	
Maximum	2.229	859.676	372.571	26.520	2.760	68221.367	

Sample ID: SQUARE23



Petronas PRSS

Process & Product

erator name: faizal

nple Identification: SQUARE25

t Method Number: 3

ent UTP

nple ID

AWC3-point

Test Date: Wednesday, 09 May, 1901

Interface Type: 5500

Crosshead Speed: 1.0700 mm/min

Sample Rate (pts/secs): 10.0000

Temperature: 23 C

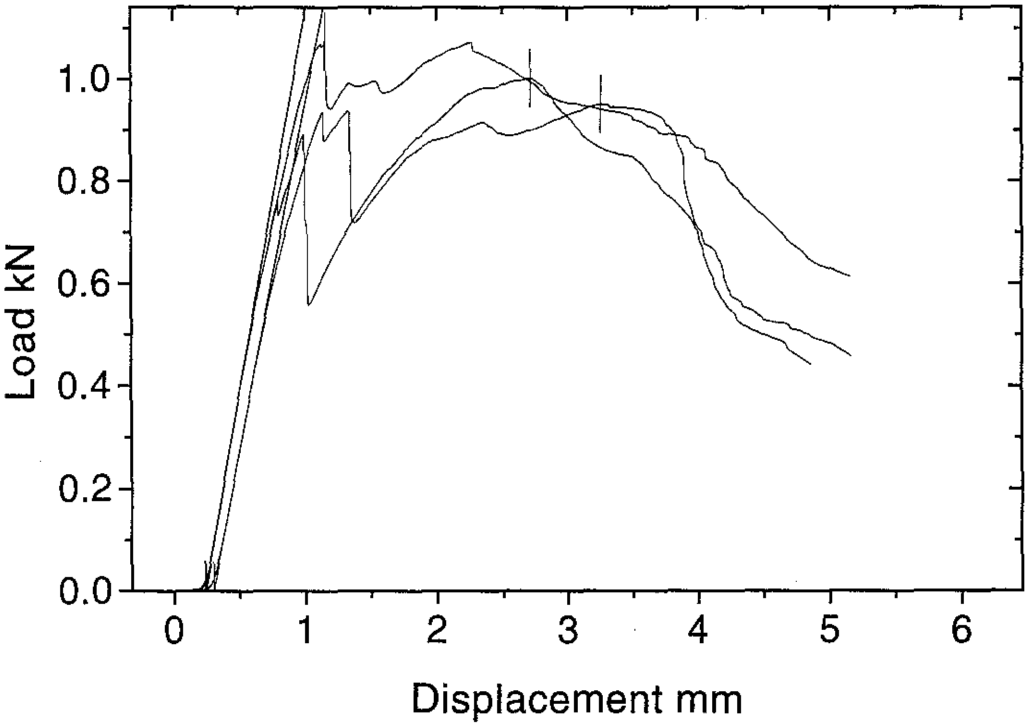
Humidity (%): 50

Specimen G. L.: 100.0000mm

Span: 50.0000 mm

	Displcment at Yield (mm)	Load at Yield (N)	Stress at Yield (MPa)	Width (mm)	Depth (mm)	Modulus (AutYoung) (MPa)	
1	2.958	951.731	418.589	26.020	2.560	97173.586	
2	0.916	1074.120	472.782	26.000	2.560	106536.500	✓
3	2.482	1002.656	441.326	26.000	2.560	105336.758	✓
Mean	2.119	1009.502	444.233	26.007	2.560	103015.617	
S.D.	1.069	61.481	27.213	0.012	0	5094.784	
C.V.	50.446	6.090	6.126	0.044	0	4.946	
Mean +2.00 SD	4.256	1132.464	498.658	26.030	2.560	113205.187	
Mean -2.00 SD	-0.019	886.541	389.807	25.984	2.560	92826.055	
Minimum	0.916	951.731	418.589	26.000	2.560	97173.586	
Maximum	2.958	1074.120	472.782	26.020	2.560	106536.500	

Sample ID: SQUARE25



4.Set of Data for Octagon Patch

Petronas PRSS

Process & Product

erator name: faizal

nple Identification: OCTA18

:t Method Number: 3

ent UTP

nple ID

AWC3-point

Test Date: Wednesday, 09 May, 1901

Interface Type: 5500

Crosshead Speed: 1.1100 mm/min

Sample Rate (pts/secs): 10.0000

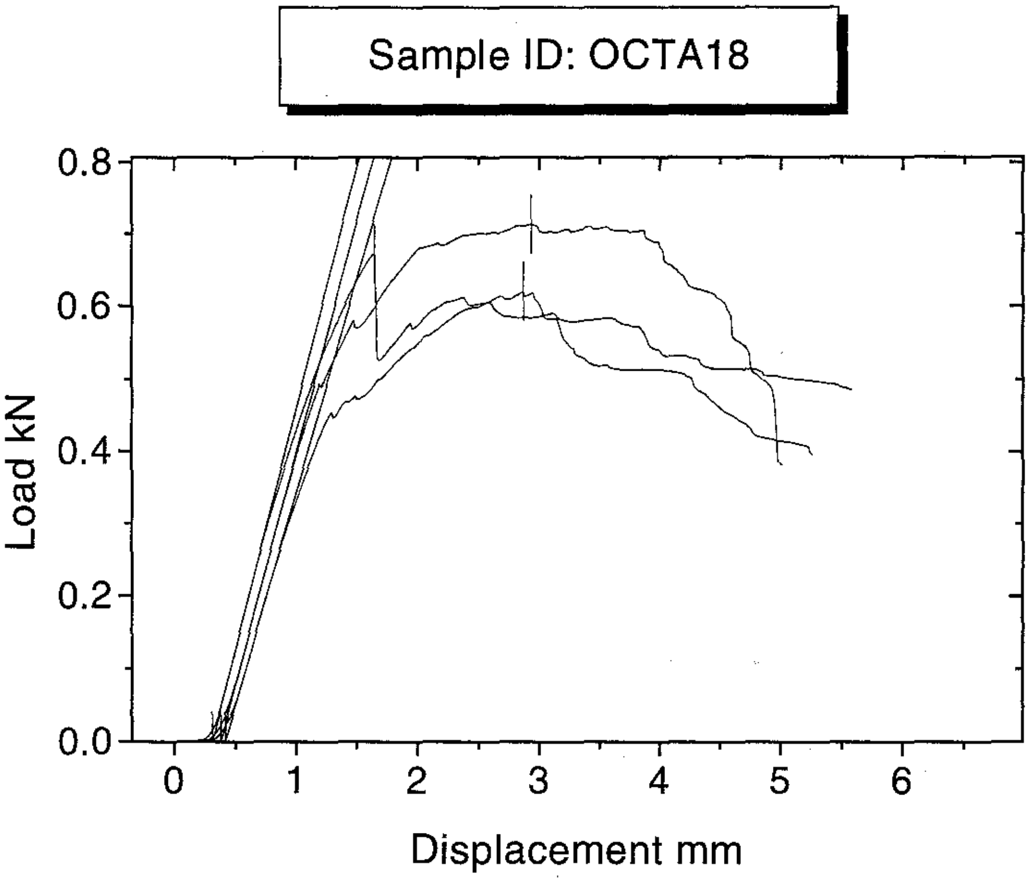
Temperature: 23 C

Humidity (%): 50

Specimen G. L.: 100.0000mm

Span: 50.0000 mm

	Displcment at Yield (mm)	Load at Yield (N)	Stress at Yield (MPa)	Width (mm)	Depth (mm)	Modulus (AutYoung) (MPa)	
1	1.335	672.791	284.588	25.440	2.640	44394.457	✓
2	2.454	620.667	297.685	25.840	2.460	47784.023	
3	2.554	713.688	292.713	25.460	2.680	40824.266	✓
Mean	2.115	669.049	291.662	25.580	2.593	44334.250	
S.D.	0.677	46.623	6.612	0.225	0.117	3480.269	
C.V.	31.999	6.969	2.267	0.881	4.519	7.850	
Mean +2.00 SD	3.468	762.295	304.885	26.031	2.828	51294.789	
Mean -2.00 SD	0.761	575.802	278.439	25.129	2.359	37373.711	
Minimum	1.335	620.667	284.588	25.440	2.460	40824.266	
Maximum	2.554	713.688	297.685	25.840	2.680	47784.023	


Sample ID: OCTA18
Load kN
0.0
0.2
0.4
0.6
0.8
Displacement mm
0
1
2
3
4
5
6

Petronas PRSS

Process & Product

erator name: faizal

nple Identification: OCTA20

t Method Number: 3

ent UTP

nple ID

AWC3-point

Test Date: Wednesday, 09 May, 1901

Interface Type: 5500

Crosshead Speed: 1.0900 mm/min

Sample Rate (pts/secs): 10.0000

Temperature: 23 C

Humidity (%): 50

Specimen G. L.: 100.0000mm

Span: 50.0000 mm

	Displcment at Yield (mm)	Load at Yield (N)	Stress at Yield (MPa)	Width (mm)	Depth (mm)	Modulus (AutYoung) (MPa)	
1	2.855	804.631	366.574	26.340	2.500	66371.734	
2	2.768	899.013	403.466	25.500	2.560	64438.434	✓
3	2.227	936.820	395.810	25.860	2.620	59278.785	✓
Mean	2.617	880.155	388.617	25.900	2.560	63362.984	
S.D.	0.340	68.082	19.469	0.421	0.060	3666.734	
C.V.	13.008	7.735	5.010	1.627	2.344	5.787	
Mean +2.00 SD	3.298	1016.320	427.555	26.743	2.680	70696.453	
Mean -2.00 SD	1.936	743.990	349.678	25.057	2.440	56029.516	
Minimum	2.227	804.631	366.574	25.500	2.500	59278.785	
Maximum	2.855	936.820	403.466	26.340	2.620	66371.734	

Petronas PRSS

Process & Product

:rator name: faizal

ıple Identification: OCTA22

t Method Number: 3

:nt UTP

ıple ID

AWC3-point

Test Date: Wednesday, 09 May, 1901

Interface Type: 5500

Crosshead Speed: 1.0900 mm/min

Sample Rate (pts/secs): 10.0000

Temperature: 23 C

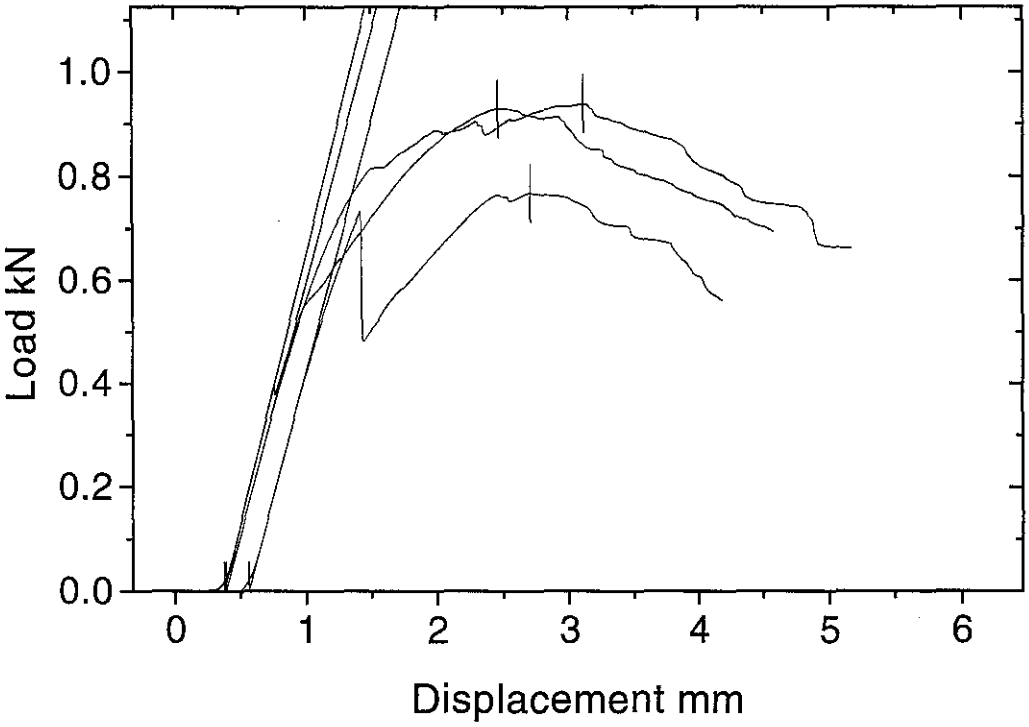
Humidity (%): 50

Specimen G. L.: 100.0000mm

Span: 50.0000 mm

	Displcment at Yield (mm)	Load at Yield (N)	Stress at Yield (MPa)	Width (mm)	Depth (mm)	Modulus (AutYoung) (MPa)	
1	2.729	938.066	404.962	25.700	2.600	66840.953	✓
2	2.088	928.380	436.885	25.500	2.500	81296.422	✓
3	2.145	768.207	354.382	25.200	2.540	72882.125	
Mean	2.321	878.218	398.743	25.467	2.547	73673.164	
S.D.	0.355	95.395	41.602	0.252	0.050	7260.125	
C.V.	15.295	10.862	10.433	0.988	1.976	9.855	
Mean +2.00 SD	3.031	1069.008	481.946	25.970	2.647	88193.414	
Mean -2.00 SD	1.611	687.428	315.540	24.963	2.446	59152.914	
Minimum	2.088	768.207	354.382	25.200	2.500	66840.953	
Maximum	2.729	938.066	436.885	25.700	2.600	81296.422	

Sample ID: OCTA22



Petronas PRSS

Process & Product

rator name: faizal

ple Identification: OCTA24

t Method Number: 3

nt UTP

ple ID

AWC3-point

Test Date: Wednesday, 09 May, 1901

Interface Type: 5500

Crosshead Speed: 1.1000 mm/min

Sample Rate (pts/secs): 10.0000

Temperature: 23 C

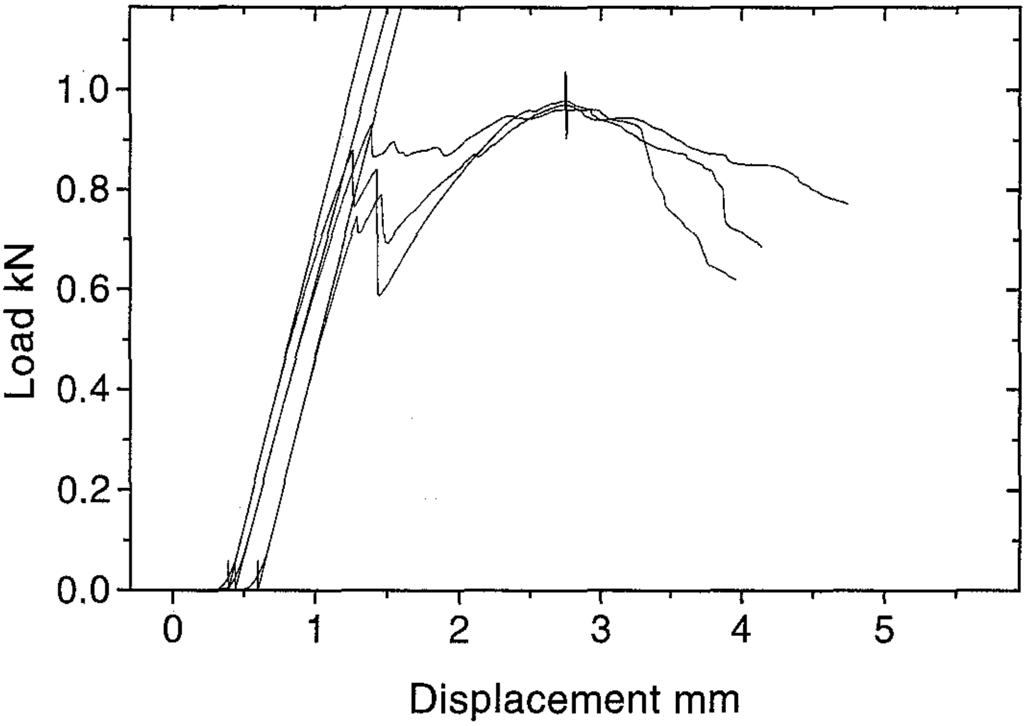
Humidity (%): 50

Specimen G. L.: 100.0000mm

Span: 50.0000 mm

	Displcment at Yield (mm)	Load at Yield (N)	Stress at Yield (MPa)	Width (mm)	Depth (mm)	Modulus (AutYoung) (MPa)	
1	2.161	971.978	451.732	25.820	2.500	90398.266	
2	2.360	980.110	413.932	25.480	2.640	78000.328	✓
3	2.315	961.893	411.724	25.920	2.600	75155.938	✓
Mean	2.279	971.327	425.796	25.740	2.580	81184.844	
S.D.	0.104	9.126	22.489	0.231	0.072	8104.811	
C.V.	4.579	0.940	5.282	0.896	2.795	9.983	
Mean +2.00 SD	2.487	989.579	470.773	26.201	2.724	97394.461	
Mean -2.00 SD	2.070	953.074	380.819	25.279	2.436	64975.219	
Minimum	2.161	961.893	411.724	25.480	2.500	75155.938	
Maximum	2.360	980.110	451.732	25.920	2.640	90398.266	

Sample ID: OCTA24



Petronas PRSS

Process & Product

rator name: faizal

ıple Identification: OCTA26

t Method Number: 3

nt UTP

ıple ID

AWC3-point

Test Date: Wednesday, 09 May, 1901

Interface Type: 5500

Crosshead Speed: 1.1200 mm/min

Sample Rate (pts/secs): 10.0000

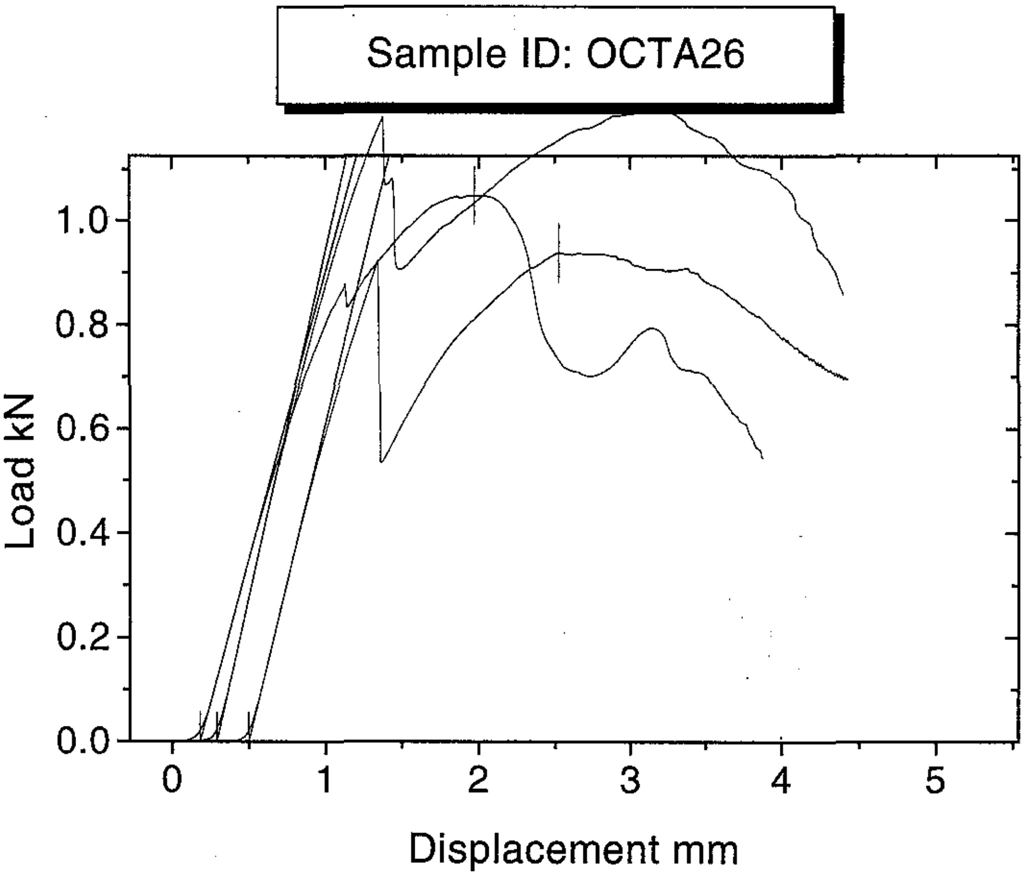
Temperature: 23 C

Humidity (%): 50

Specimen G. L.: 100.0000mm

Span: 50.0000 mm

	Displcment at Yield (mm)	Load at Yield (N)	Stress at Yield (MPa)	Width (mm)	Depth (mm)	Modulus (AutYoung) (MPa)	
1	2.028	938.710	382.697	26.800	2.620	79714.211	
2	2.820	1213.892	504.293	26.300	2.620	87777.094	✓
3	1.790	1049.330	424.506	26.600	2.640	70361.625	✓
Mean	2.213	1067.311	437.165	26.567	2.627	79284.305	
S.D.	0.539	138.469	61.778	0.252	0.012	8715.692	
C.V.	24.372	12.974	14.132	0.947	0.440	10.993	
Mean +2.00 SD	3.292	1344.250	560.722	27.070	2.650	96715.695	
Mean -2.00 SD	1.134	790.372	313.609	26.063	2.604	61852.926	
Minimum	1.790	938.710	382.697	26.300	2.620	70361.625	
Maximum	2.820	1213.892	504.293	26.800	2.640	87777.094	


Sample ID: OCTA26
Load kN
0.0
0.2
0.4
0.6
0.8
1.0
0
1
2
3
4
5
Displacement mm