Study of Adhesive Strength in Polymer Plate Heat and Mass Exchanger

by

Mohd Amirul Mukminin Bin Alias

Dissertation submitted in partial fulfillment of
the requirement for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

SEPTEMBER 2011

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Study of Adhesive Strength in Polymer Plate Heat and Mass Exchanger

by

Mohd Amirul Mukminin bin Alias

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
In partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

____

(Assoc. Prof. Ir Dr Mokhtar Che Ismail)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
September 2011

CERTIFICATION OF ORIGINALITY

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

MOHD AMIRUL MUKMININ BIN ALIAS

ABSTRACT

Open Cycle Liquid Desiccant Air Conditioner system is promising solution for air conditioning in hot and humid climates like a tropical region South East Asia. The system used cross flow type plate heat exchanger made by thin sheets of polymer for both dehumidification and cooling. However leakage between the polymer sheets is due to adhesive failure of joint between plastic sheet results in a decreasing of regenerator performance. The objectives of this project are to fabricate and simulate model of plate heat and mass exchanger and to study the adhesive strength used for heat and mass exchanger. The methodology for this project is started with the design of prototype plate heat and mass exchanger and material selection such as cyanoacrylate adhesive, silicon sealant and EVA Hot Melt Adhesive based on their properties and also polypropylene material as corrugated sheet and solid sheet material. Prior to adhesive test, heat treatment and surface roughening are prepared as surface preparation together with step to apply the adhesive to sample test. In order to test the maximum strength of the adhesive, the Single Lap Joint Shear Test is chosen for the adhesive test. After satisfying with the performance of adhesive, the fabrication of the heat and mass exchanger is started. Hydro testing of the model is conducted to test the leaking problem and also HMX working principle. 2D Design of Regenerator is designed to illustrate the model of plate heat and mass exchanger. Material selection for each component of regenerator is summarized by Bill of Material of Plate Heat and Mass Exchanger. From the single lap joint shear test, PP sample with treated surface bonded with cyanoacryalate adhesive achieved highest shear strength, 3.61MPa compared to untreated surface PP sample and other adhesive sample test. Besides, the result of hydro testing are also discussing about leaking problem of adhesive and also working principle of model. Most of leakage problem occurred due to improper fabrication technique and improper sealant used. Sealant of plastic joint is replaced from silicon sealant to EVA Hot Melt Adhesive. This adhesive able to fill the gap between the joint and resist the water from leaked. As a result, the leakage problem is minimized by using EVA Hot Melt Adhesive.

ACKNOWLEDGEMENT

The author wishes to take the opportunity to express utmost gratitude to Allah the Almighty upon the completion of this Final Year Project. Without His love and mercy, it is impossible to do anything related to this project.

A special thanks to respectable supervisor, Assoc. Prof. Ir. Dr Mokhtar Che Ismail for the opportunity given to the author to accomplish this project under his supervision. Also the same greeting goes to Dr Edward Halawa, as co – supervisor for this project. Attention, patience and knowledge shared by them had been really helpful in ensuring a steady progress of this project.

The author would like also to express his big gratitude towards Mr Manny Markogiannakis, Managing Director of Plastflute Industries Sdn Bhd, who is the sponsor of corrugated sheet to be use in fabrication of plate heat and mass exchanger model. Without his cooperation, the author might faces problem to find the corrugated sheets material.

A very special thanks goes to the Final Year Project Coordinator, Dr. Mohd Faizairi bin Mohd Nor for providing the author with all initial information required to perform the project.

Not to be forgotten, the author also want to express his gratitude towards the technicians in Mechanical Engineering department, Mr Irwan bin Othman, Mr Mohd Shairul bin Harun, Mr Jani bin Alang Ahmad and Mr Shaiful Hisham bin Samsudin for assisting the author in using the required laboratory facilities.

Last but not least, a very deepest thanks to family and friends for their love and support to the author throughout this project.

TABLE OF CONTENT

CHAPTER 4: RESULT AND DISCUSSION

CHAPTER 5: CONCLUSION AND RECOMMENDATION

APPENDICES

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Project Background

The open cycle liquid desiccant cooling system is a type of thermally driven cooling system with the condition cools and dehumidifies the ventilation air directly. It uses salt solution such as lithium chloride solution as absorbent material. The desiccant mainly is a substance that absorbs or adsorbs water combination between liquid chloride salt and also distilled water. It is most commonly used to remove humidity that would normally degrade or even destroy products sensitive to moisture. Open cycle liquid desiccant cooling system consists 3 of major elements as show in Figure 1.1 [1]:

a) Absorber
b) Regenerator
c) Interchange heat exchanger

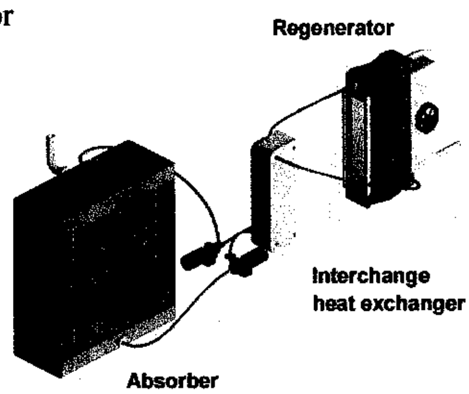


Figure 1.1: A Generic Liquid Desiccant Air Conditioner [1]

The regenerator using metal as construction material can be prone to corrosion due to contact with desiccant, moist, and dusty air. To avoid corrosion problems, the use of plastic has recently been proposed and used. The proposed heat and mass exchanger is made by the corrugated plastic (corflute) and polypropylene (PP) sheet. With the capability of polymer material characteristic to withstand the corrosion nature, it is suitable to be chosen as material for plate heat mass exchanger.

However leakage between the polymer sheets due to adhesive failure of joint between plastic sheet result in a decreasing of regenerator performance.

1.2 Problem Statement

The regenerator's manifold is clamped at the both ends of plate sheet. The problem is the water leakage at this position. The hot water spilled out from the plate through this adhesive joint.

When the water is allowed to flow inside the regenerator's corrugated plastic sheet, the water leaked at leakage position as shown in the Figure 1.2. The flow rate of the leak gradually increased as water pressure increased. The problem with the plate mass and heat exchanger is failure due to leaking adhesive joint.

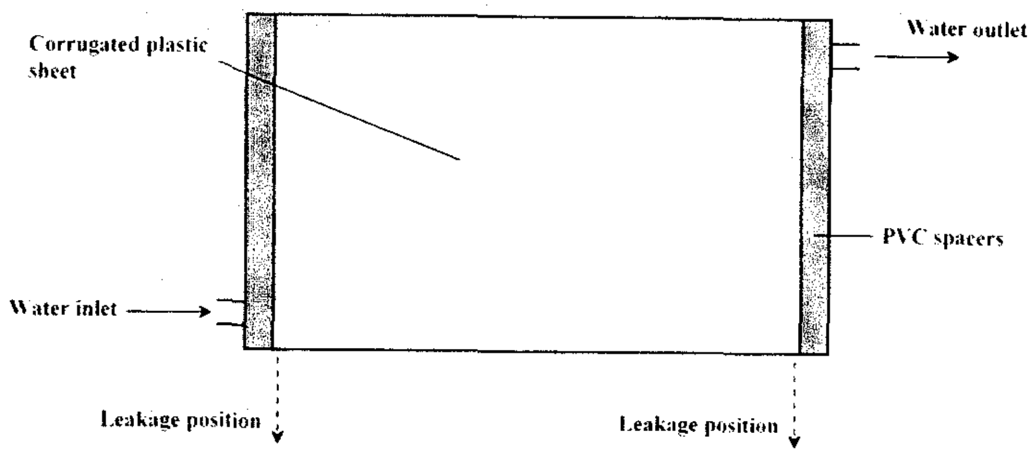


Figure 1.2: Leakage positions on the side view of the regenerator

The adhesive leaking caused the water flow into the passage of air and the liquid desiccant solution. This situation decreased the regenerator performance and efficiency. Type of adhesive used is unknown for the leaking regenerator.

1.3 Objective and Scope of Study

The objectives of this project are:

1. To fabricate model of plate heat and mass exchanger.
2. To study the adhesive strength used for heat and mass exchanger.
3. To simulate the regenerator system model with free leakage.

The Scope of study of this project is simplified as follows:

1. Heat and mass Transfer; Liquid Desiccant Open Cycle System
2. Polypropylene material properties for plate heat and mass exchanger.
3. Adhesion Testing Method, American Society Testing of Material (ASTM).

1.4 Feasibility and Relevancy

The feasibility of the project are depending a number of factors:

a) Source of Information
b) Manpower
c) Budget
d) Facilities

The information of the project will be collected from the books, journals by the researchers, and also from the supervisor. Comparison should be made to compare between the sources to avoid the contradiction. For manpower, the student is a main manpower for this project, and the guidance still be provided by the supervisor. In case of fabrication, the guidance from the technician is needed. The budget for this project is totally supported by the UTP. The project will undergo under the facilities in UTP, which is workshop facility for HMX fabrication and Heat & Mass Transfer Testing facility.

The relevancy of this project is cover by the recent domestic use of solar assister air conditioning system using liquid desiccant. This is promising project for development of polymer heat and mass exchanger for regenerator and increase the efficiency of liquid desiccant open cycle cooling and dehumidification. Furthermore, it is related with the material major taken which consist of Advance Polymer Engineering and Failure Analysis subjects.

CHAPTER 2

LITERATURE REVIEW

2.1 Operation of Liquid Desiccant Open Cycle System

The liquid desiccant open cycle systems are widely used in many industries cooling process like comfort air conditioning and dehumidification. The system used cross flow type plate heat exchanger for both dehumidification and cooling [2].The plate heat exchanger (PHE) is made by thin sheets of polymer, polyethylene sheets. Each thin plate provides a contact area for heat and mass transfer between the fluids flowing in each passage, besides separating the water – air passage from the desiccant solution – air passage.

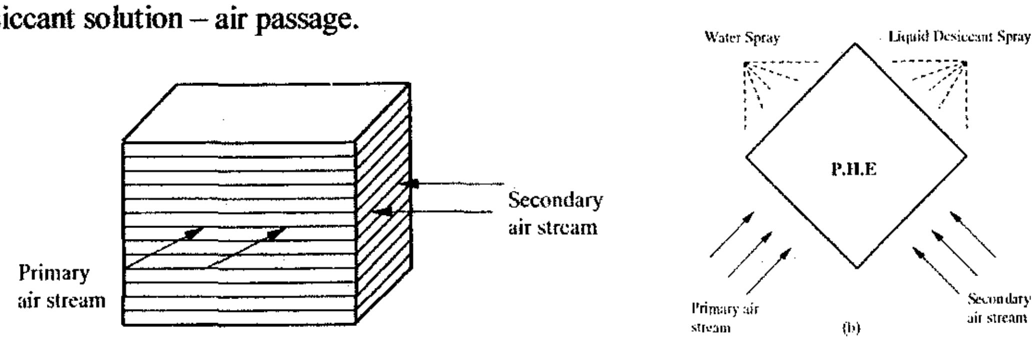


Figure 2.1: Plate Heat Exchanger (PHE)

The absorber and desorber, which are referred as conditioner and regenerator are almost similar in term of design and operation [3]. Both are designed as heat and mass exchanger working with three operating fluids which are moist air, desiccant, and water. The regenerator required a high temperature to desorb water vapor and concentrate the desiccant solution. So, the hot water is supplied to the regenerator desiccant flow to both providing heat for water to vaporize and also raising the temperature of the desiccant solution. The operation of the absorber and regenerator are complimentary, and when working in conjunction, they complete a thermodynamic cycle which can be used to dehumidify an air stream.

2.2 Polymer use for Plate Heat and Mass Exchanger

Due to corrosive nature, almost all metal are corroded by the most effective liquid desiccants, e.g. aqueous solutions of lithium chloride, particularly in the presence of oxygen[4]. Therefore, plastic construction is for regenerator plate heat and mass exchanger is build to avoid corrosion [5]. Plate heat and mass exchanger purpose is to have low air pressure losses. Beside, the polypropylene plates also are cheap plates with good heat transfer through plates and have high mechanical stability and also thermal resistance.

Polypropylene (PP) is rigidly constructed and is only prone to attack by oxidizing agents on the tertiary hydrogen [6]. It is non-toxic, non-staining, and exhibits excellent corrosion resistance. It has hard significant application in mechanical vapor compression desalination units.

Polypropylene is categorized as polyolefin plastic has low energy surfaces, therefore it is also called as hard to bond plastic [7]. In order to enhance adhesion, surface preparation like plasma or corona treatment, flame treatment , chemical etching or surface priming is required prior to joining. Flame treatment is commonly used when bonding with cyanoacrylate adhesives. Surface roughening results in increasing the bond strength of most adhesive technologies and recommended for hard to bond substrates.

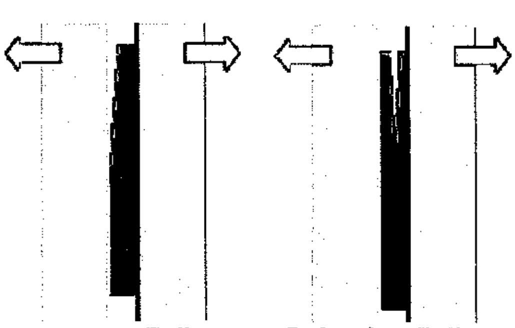


Figure 2.2: Interfacial/adhesive fracture and cohesive fracture

Referring the figure above, the type of adhesive failure for regenerator leaking can be either interfacial/adhesive fracture or cohesive fracture [8]. The interfacial fracture happened when debonding occurs among the adhesive and the polymeric material. The occurrence of interfacial fracture for a given adhesive goes along with smaller fracture toughness. It will result the separation of one of the substrate from the adhesive layer. While the cohesive fracture is internal failure of the adhesive layer due to fractures propagates in the in the bulk polymer. The crack may propagate in the centre of the layer or near an interface of polymer.

Adhesive failure occurs when the sealant detaches from the join wall, generally because of excessive tensile stresses [9].In the case of polymer substrates, some of additives in polymer formulation can migrate to critical interfaces to give poor adhesive bonds. The factors that might contribute to adhesive failure are oxidation degradation, chemical attack, entrapped solvent and stress.

2.3 Leaking Problem of Regenerator

Research from AIL Research, Inc reported that test for the chlorinated polyvinyl chloride (CPVC) plate regenerator facing the adhesive joint failure and heat transfer fluid leaked into the desiccant [10]. The identified principal problems included (1) incompatibility resin that was used to make the plates with hot water, (2) adhesion problems between Perspex (PMMA) adhesive and the manifold CPVC resin, and (3) stress concentration induced by differential thermal expansion within the regenerator.

2.4 Cyanoacrylate Adhesives

As a solution to hard bond plastic, the cyanoacrylates has exhibits high bond strength on typical difficult to bond plastic including PP, PE, acetal, fluoropolymers and TPV's. [7] The cyanoacrylate is a polar, linear molecules which undergo an anionic polymerization reaction. It is a weak base, such as moisture, triggers the reaction causing the linear chains to form. This adhesive is maintained in liquid form through addition of weak acids that act as stabilizers. Cyanoacrylates can withstand continuous exposure to test temperatures up to 250°F equal to 121°C.

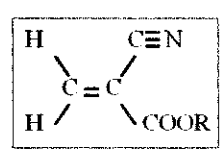


Figure 2.3: Cyanoacrylate monomer

2.5 Adhesive Testing by Lap Joint Shear Test

Shear test is very common because the sample are simple to made and very close to geometry and service condition for many structural adhesives [11]. Single lap shear specimens do not represent pure shear, but the testing is practical and also provide producible and usable results. As with tensile tests, the stress distribution is not uniform and conventionally appoints the failure shear stress as the load divided by the bonding area.

$$\tau_s = \frac{P_f}{A}$$

Depending on factors adhesive thickness and adherend stiffness, the failure of adhesive of joint can be dominated by either shear or tension load. For example, the ASTM D3163 helps to reduce the problem of adhesive extruding out from the edges of sample.

2.6 Hot Melt Adhesive for Polypropylene

Hot melt adhesives glue sticks are usually made from Ethylene-vinyl acetate (EVA), usually with additives like wax, tackifiers and resin [12]. Today's EVA copolymers based hot melt adhesive have the low-cost and most common material for the glue sticks. They provide sufficient strength between 30-50 °C but are limited below 60-80°C and have low creep resistance under load. The hot melts provide good moisture resistance, superior adhesion to polypropylene substrates and excellent resistance to polar solvents and acids. Hot melts have the ability to fill large gaps and provide high bond strength as soon as they cool. Therefore, the hot melt adhesive can be used as sealant to joint of plastic sheet for construction of regenerator plate heat and mass exchanger model. Polyolefin hot melts are a unique combination of base resins and tackifiers. This hot melt technology provides superior adhesion to polypropylene, a good barrier against moisture and water vapor, and excellent chemical resistance against polar solvents and solutions.

The polyolefin hot melt adhesive compositions having high performance properties which are prepared from low-cost material, which are terpene resin, atactic and isotactic polypropylene [13]. Hot melt adhesives produce a bond by simple cooling as distinguished from cross linking or other chemical reaction. Before heating, the adhesives are thermoplastic solid material and after heating, they melt rather sharply and flow freely and they can be remelted after cooling. More particularly, the hot melt adhesives can be used to bond the corrugating medium to the top and bottom facer sheets in the making of corrugated board. For application to a surface, the adhesive is heated to a temperature in the range of 250°F to 350°F.

CHAPTER 3

RESEARCH METHODOLOGY

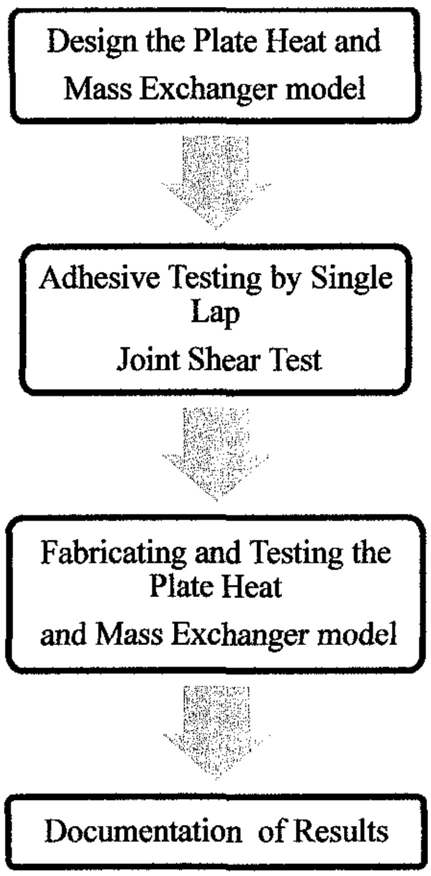


Figure 3.1: Flow Chart of the project

The project activities is started with design the Plate Heat and Mass Exchanger model in 2D view to capture all the geometric features of a model and to convey all the required information like dimension and component joint that will lead to fabrication of the model. The next activity is adhesive testing to test the bonding strength by Single Lap Joint Shear Test. The regenerator plate heat and mass exchanger model is fabricated using PP solid sheet and PP corrugated sheet. The hydro testing activity is to test the leakage of the model.

3.1 Design the Plate Heat and Mass Exchanger Model

3.1.1 General Design

To fabricate the model of Regenerator, design should be created. The design is made by software AutoCAD 2007 to illustrate the 2D view and also 3D view as shown in Figure 3.2 below. The corrugated plate in this model is about 14 plates and separated by spacer between the plates. The function of the spacer is to give the corrugated plate in fixed condition. The baffles plate function is to enable hot water pass through the passage without entering other passage and also allow hot water ability to move from lower passage to upper passage. Each of material and type of material used for every component are simplified as shown Table 1 below.

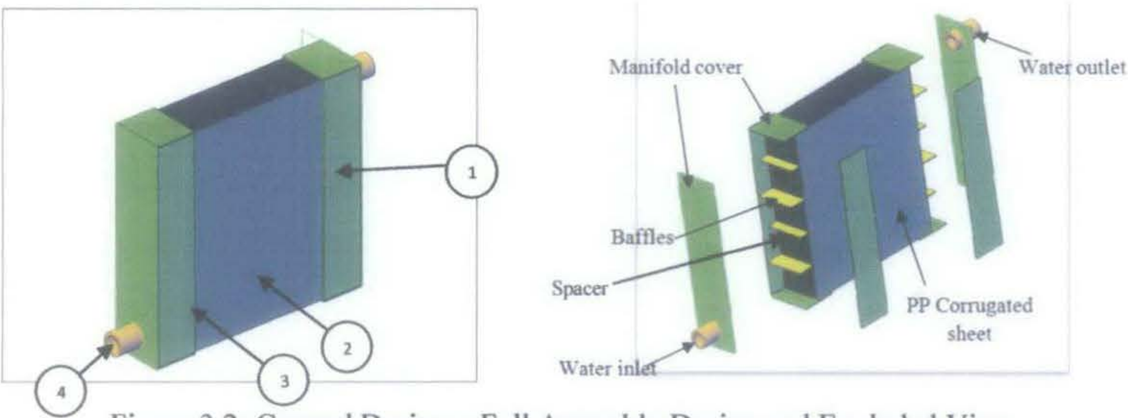


Figure 3.2: General Design – Full Assembly Design and Exploded View

Table 1: Main Material for Plate Heat and Mass Exchanger

Main Material for Plate Heat and Mass Exchanger			
No.	Material	Material Type	Component
1.	Solid Sheet	Polypropylene	Manifold Cover
			Baffle
			Spacer
2.	Corrugated Sheet	Polypropylene	PP Corrugated Sheet
3.	Adhesive	Cyanoacrylate	-
		Hot Melt Adhesive EVA	-
		Acetic cure Silicon Sealant	-
4.	Pipe	PVC	Water inlet
			Water outlet

3.1.2 Properties of Material

The properties of the material will be studied which are mechanical properties, thermal properties and other properties. This is important to know if the material suitable in the regenerator system which are influenced by moist air, desiccant and hot water. Below are the properties of Polypropylene (PP) material (Appendix A):

Polypropylene Properties

Table 2: Mechanical Properties

Properties	**Value**
Tensile Strength	31.05 MPa
Hardness (Rockwell)	95
Specific Gravity	0.90

Table 3: Thermal Properties

Properties	**Value**
Melting Point	170°C
Maximum service temperature	135°C

Table 4: Other Properties

UV Resistance	Poor
Autoclavable	YES
Resistance	Excellent Resistance to dilute acid, concentrated Acid, bases, Alcohol

The operation of the regenerator will have about 90°C of working temperature of hot water. PP material still able to operates within this temperature. Therefore, PP material is suitable to be used for plate heat exchanger model.

Cyanoacrylate Adhesive Properties

To bond the polypropylene plastic sheet, the cyanoacrylate adhesive is selected based on its properties. Due to high bond shear adhesive strength about 4.47 MPa and can sustain up to 121°C working temperature. It is also has fast setting time to PP material, which is approximately 5 second. Below are the properties of the adhesive. (Source taken from Three Bond Technical News, Appendix B and Appendix C)

Table 5: Properties of Cyanoacrylate

Properties	**Value**
Maximum Shear Adhesive Strength	4.47MPa
Maximum working Temperature	121°C
Setting time to PP	5sec

Table 6: Cyanoacrylate adhesive Curing Time vs Shear Adhesive Strength

Curing Time (hour)	**Shear Adhesive Strength (MPa)**
1	2.46
2	2.98
4	3.46
8	3.79
16	4.05
24	4.47

Cyanoacrylate has fast curing time, therefore the bonding process must be quick to prevent the adhesive curing before the joint start to bond. Otherwise, the joint will have a weaker strength than required.

Silicon Sealant Properties

To seal the plastic joint from water, the silicon sealant is chosen. It will bond to form a durable, flexible, waterproof seal on many common wet areas. It is also well suited for ventilators, air conditioning system and also plastic signs. Properties of silicon sealant are shown as Table 7 below (Appendix D):

Table 7: Properties of Silicon Sealant

Properties	**Value**
Specific Gravity	0.95
Curing Time	15 -25 minute
Application Temperature	-20 – 50°C
Service Temperature	-40 – 150°C

Hot Melt Adhesive Ethylene Vinyl Acetate (EVA) Properties

Due to properties of the polypropylene (PP) which has low surface energy plastic, this type of plastic is hard to bond with common adhesive. The hot melt adhesive is suitable to use for PP because of their chemical composition which that they can be used to directly bond some plastics with low surface energy which with other adhesive types require a surface pre-treatment. The properties of EVA Hot Melt Adhesive is shown as Table 8 below: (Appendix E)

Table 8: Properties of EVA Hot Melt Adhesive

Properties	**Value**
Density	0.93 g/cm^3
Melt Flow Rate	0.7 g/min
Melting Point	98°C
Maximum Processing Temperature	230°C
Resistance	Good moisture resistance, excellent resistance to polar solvent and acids, low creep resistance under load

3.2 Adhesive Testing

3.2.1 Surface Preparation

Prior to adhesive testing, the sample polypropylene (PP) sheets need to go through the surface preparation stage. The polypropylene material is known as hard to bond plastics, therefore the material has to be treated to increase the wettability of the plastic surface with adhesive

Sanding Process

Using 120 grit sand paper, the sample is sand in horizontal direction in oderate pressure. Begin moving the sandpaper back and forth over the surface of the object and use moderate pressure and continue sanding until the surface is almost smooth and level.

Figure 3.3: sanding process

Flame Treatment

After finishing sanding the surface of specimen, the sample will go under the flame treatment. The purpose of flame treatment is to change the surface characteristics of plastic. It involves passing the surface of the plastic through the oxidizing portion of a natural gas flame. The Polypropylene sample is put above the small flame, and is removed after 20 seconds. The sample is carefully handled without burning and melting.

Figure 3.4: Flame treatment

Applying Adhesive

The sample is needed to follow the specimen standard **ASTM D3163**, which is plastic lap joint. The sample is marked according to the dimension below:

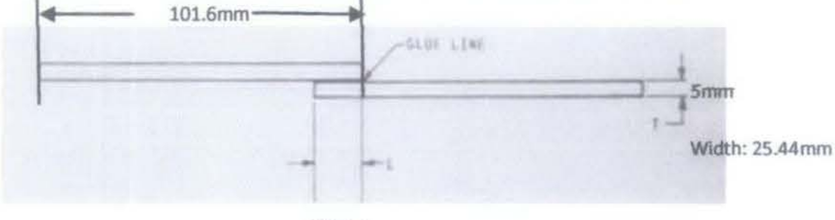


Figure 3.5: single lap joint dimension

Upon marking is completed, the adhesive are applied at the 20mm lap joint area as the figure above. Three types of adhesives is used for different specimen for lap shear joint testing purpose which are cyanoacrylate (super glue), Selleys Gel Grip (sealant) and Selleys All Clear (sealant). About 10 samples are prepared including reserved samples.

Cyanoacrylate is known as super glue and able to bond the plastics with high strength. While the Selley Gel Grip is chosen for this testing because of its ability to resist the high temperature and water resistance. Selley All Clear can seals out water and also can be used for many plastics. The testing for all these adhesives is to recognize the potential to be use for fabricating the model of plate heat and mass exchanger.

Figure 3.6: Applying adhesive

Figure 3.7: Making the lap joint

Step of applying adhesive:

1) The process is started in the room temperature, about 24°C and the humidity is between 40 – 60 % to allow the sample cure faster.
2) The adhesive is applied using its nozzle distribute around joint area. Put in moderate quantity and not very thin layer.
3) The adhesive is applied at both sheets sample in almost equal amount.
4) Combine the sheets which have been applying with adhesive just before, and apply the pressure at both sheet. Carefully putting the sheet each other without overlapping the dimensions required.
5) The sample is allowed to cure about 1 day before testing for maximum performance.

Immersion in Hot Water

To simulate the working condition of heat and mass exchanger for PP sheet, the sample lap joint is going to have immersion in hot water. This is to recognize the effect of temperature to adhesive through the lap joint shear test.

1) Hot water is prepared and poured in the basin.
2) Temperature is measured using thermometer and waited until 90°C.
3) The lap joint samples is immersed in the hot water when the temperature is dropping to 90°C
4) The samples are left about 30 minutes in hot water and were taking back after then.

Figure 3.8: Lap joints sample in hot water

3.2.2 Lap Joint Shear Test by Tension Loading

The lap shear test is the most commonly used standard test for determining the shear strength of adhesives for bonding materials when tested on a single-lap-joint specimen. The test is applicable for determining adhesive strengths, surface preparation parameters and adhesive environmental durability. The bond strength of bonded single lap joints on subjecting the substrates to loads is determined by lap shear forces in the direction of the bonded joint.

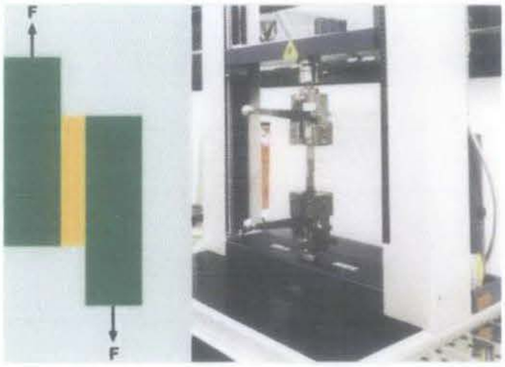


Figure 3.9: Universal Testing Machine

This test method is suitable for single lap shear adhesive joints of rigid plastic adherends. It is also useful for generating the comparative shear strength data for joints made from a number of plastic. Besides, it can also provide a means by which several plastic surface treatments can be compared. This test also limited to test temperatures below the softening point of the subject of the adherends. This shear test is based on **ASTM D3163**: Determining Strength of Adhesively Bonded Rigid Lap Shear Joints in Shear by Tension Loading. (Appendix H, I, and J)

The purpose of having this testing is to recognize the stress at maximum load can be achieved by each adhesive tested and also the load at the adhesive break.

The procedures of experiment are:

2. Two specimens, each 25.4 x 101.6 mm (1" x 4") are bonded together with adhesive so that the overlap is sufficient to provide failure in the adhesive, and not in the substrate. Typical overlaps are 12.7 mm and 25.4 mm (0.5" and 1").
3. Taking the actual measurement of length and width using the vernier caliper to get the area of adhesive, A whereby the shear test will be performed.
4. Length, width and cross head speed rate, 1.3mm/min data are inserted to the software.
5. The lap joint sample is fixed into the jig of Universal Testing Machine (UTM) (Figure 3.10).
6. To avoid the specimen to slip, the sample need to have good grip in contact with the jig. The grip is created at the contact surface of lap joint sample with the jig prior to testing.

Figure 3.10: Sample is fixed to the jig

Figure 3.11: Sample during puling process

7. Start the pulling of sample and the force increasing is observed (Figure 3.11). If the force is drop, the sample is considered to have slip condition at the jig. The force can be observed by the graph displayed by the software.
8. After the joint is breached, the force, F at the failure is observed. The load at the failure is calculated by the equation $P = F/A$. The sample is removed from the jig.
9. The experiment is running for the remaining samples with different adhesive to compare the strength of adhesive.
10. Using the micrometer, the thickness of adhesive is taken for each test sample.

3.3 Fabricating and Testing the Plate Heat and Mass Exchanger model

3.3.1 Fabricating the Plate Heat and Mass Exchanger model

1. Prior to fabricate the model, all the plastic sheets involving with joint parts will undergo to surface preparation as shown during surface preparation of Lap Joint Shear Test. Applying sanding process and heat treatment is important to increase the strength of bonding the plastic sheet.
2. The cyanoacrylate adhesive is applied between the spacer plastic sheet and also the corrugated sheet. The plastic sheet must be put simultaneously after the adhesive is applied due to fast curing of cyanoacrylate adhesive.
3. Upon the bonding process, the pressure has to be applied on the plastic sheet to ensure the adhesive is bonding between both spacer sheet and corrugated sheet.
4. The bonding process is repeated until 14 corrugated sheets are bonded together with spacer sheets.(Figure 3.12)

Figure 3.12: Corrugated sheets after bonding with spacer sheets

5. The PP sheet is cutting using hand saw to make baffles according to the dimension in the drawing. The debris of cutting process is removed by using file tool and also sand paper.
6. The both side manifold cover is attached to the corrugated sheets.
7. Baffles are bonded by cyanoacrylate adhesive between side cover manifold and also the plate heat exchanger sheet (Figure 3.14). Pressure is applied to enure the sheet is bonded.
8. The silicon sealant is put between baffles with corrugated sheets (Figure 3.15). The sealant has to be used due to inconsistency surface at the side of corrugated sheets and the spacers. The sealant need to put sufficiently filling the gap between the baffle and the side of corrugated sheet.

Figure 3.14: cyanoacrylate adhesive at baffle

Figure 3.15: Sealing the joint with silicon sealant

9. All the baffles are attached to the side of corrugated sheet as follow the plate heat and mass exchanger design. The pressure is applied simultaneously after the joint is bonded.
10. Each of every joint is observed to ensure there is no gap between the joint. If any gap found, sealant has to be put make sure the water did not leaked.
11. To ensure the joint is fully sealed, the water is pointed to the plate heat and mass exchanger in the direction as shown in the Figure 3.16 Each joint is observed and identified if the leakage occurred.

Figure 3.16: Side view of plate heat and mass exchanger

12. To allow the water flow into the model, the water inlet is made onto the side manifold cover. Hole with diameter 22 mm is made with drilling machine. (Figure 3.17)
13. The teflon pipe is wrapped to the PVC pipe to make sure the pipe is fixed to the hole created. The PVC pipe internal diameter is 15mm. (Figure 3.18)

Figure 3.17: drilling process

Figure 3.18: water inlet

14. PVC pipe is attached to the manifold cover sheet and bonded with cyanoacrylate adhesive (Figure 3.18). Then the sealant is put around between the PVC pipe and manifold cover sheet.
15. Upon completing the water inlet and also water outlet, the cover manifold sheet will be attached to the baffles and also side cover manifold. Sanding process need to be performed first to remove the debris and the sealant at the joint part.
16. The sealant has to be put at the baffle and the cyanoacrylate is applied at the manifold cover. The sheet is quickly put onto the baffles and side cover manifold since the cyanoacrylate is fast curing adhesive.
17. The pressure is applied onto the sheet to allow the bonding process between the sheets.
18. Upon finishing the joining the manifold cover sheets, the sealant is put along the outside joints.
19. All the sealant is observed to ensure the whole joint is covered with the sealant.
20. The sealing joints are allowed for curing process.

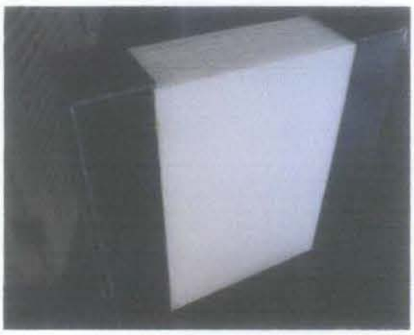


Figure 3.19: The regenerator model after fabrication complete

3.3.2 Hydro Testing of Plate Heat and Mass Exchanger model

The purpose of hydro testing of Plate Heat and Mass Exchanger model are:

a) To test the leakage of the plate heat and mass exchanger (HMX) model.
b) To observe the operation of water inside the model.

For this test, the source of water used is come from tap water. The water will be supplied into water inlet and released to water outlet.

Preparation to Hydro Testing

1. Prior to test, the hose connection ensure in tight condition by locking the hose to the tap.
2. The pipe elbow 90° is installed to the pipe to allow the water coming from bottom direction.
3. The connection between hose and also the PVC pipe is connected by the nozzle. The nozzle needs to ensure in tight connection with the pipe hose.

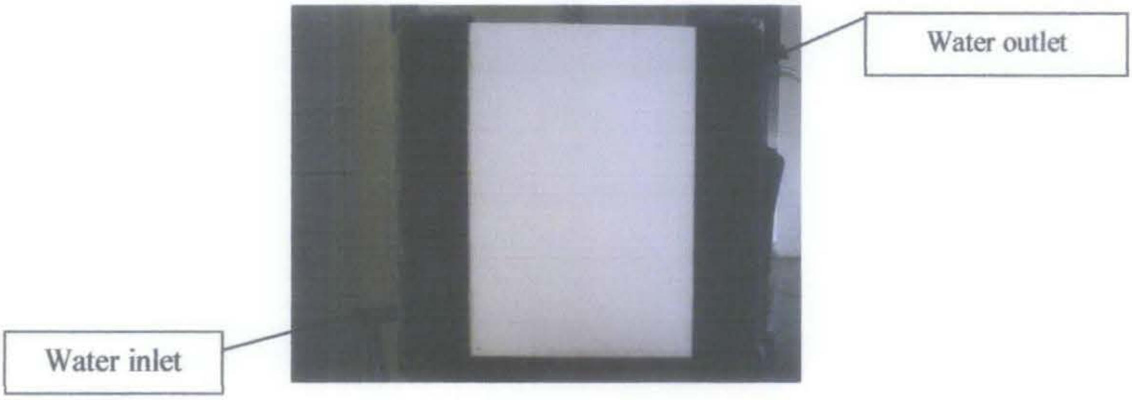


Figure 3.20: Plate Heat Exchanger Model during Hydro Testing

After all the preparation is completed, the tap water is opened and slowly increasing the pressure of tap water. The water flow is observed through from water inlet until water outlet.

The water is then allowed to flow about 20 minutes. The water leakage from the model also is observed and marked the leakage location to repair the problem.

The hydro testing is repeated again after the sealing problem is repaired.

3.4 Key Milestone

1) Completed Milestone

a) Design of prototype Plate heat and Mass Exchanger

b) Material selection, material receiving of adhesives, and plastic sheet

c) Surface preparation for adhesive test.

d) Adhesive test: lap joint shear testing

e) Fabricating the Plate Heat and Mass Exchanger prototype.

f) Prototype testing.

g) Result Documentation on Final Report

3.5 Gantt Chart

Table 9: FYP2 Gantt Chart

FYP 2																	
No.	**Detail/ Week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	Designing the regenerator model	■	■	■					Mid-Semester Break								
2.	Material Order	■	■	■	■	■	■	■									
3	Material Receiving									■							
4	Mechanical test of adhesive joint.									■	■						
5	Submission of Progress Report											●					
6	Fabricating the prototype plate heat and mass exchanger / Hydo Testing									■	■	■	■	■			
7	Submission of Draft Report													●			
8	Submission of Dissertation (soft bound)														●		
9	Submission of Technical Paper														●		
10	Oral Presentation															●	
11	Submission of Project Dissertation (Hard																●

● Suggested Milestone Progress

3.6 Tool / Equipment

Table 10: Tool / Equipment

Tool / Equipment		Function
Universal Testing Machine (UTM)		Use for mechanical test: Lap Joint Shear Test
Saw Machine		Use to cut the plastic material.
Hand Saw		Use to cut the plastic material.
Adhesives: 1) Wessbond ™ Cyanoacrylate 2) Selley All Clear 3) Selley Gel Grip 4) Silicon Sealant and Dispenser Gun 5) EVA Hot melt Adhesive	  	- To bond the plastic sheet. - water and heat resistance - Sealant purpose

CHAPTER 4

RESULT AND DISCUSSION

4.1 Model Design Plate Heat and Mass Exchanger

2D Design of Plate Heat and Mass Exchanger are shown as Figure 4.1 below. The color is illustrated to differentiate the component of plate heat and mass exchanger. Design below has 5 passage of water by installing the baffles to allow the water flowing from inlet to outlet. Water inlet and outlet are installed at lower passage and upper passage to enable water flowing in through the 5 passage in the model.

4.1.1Front View

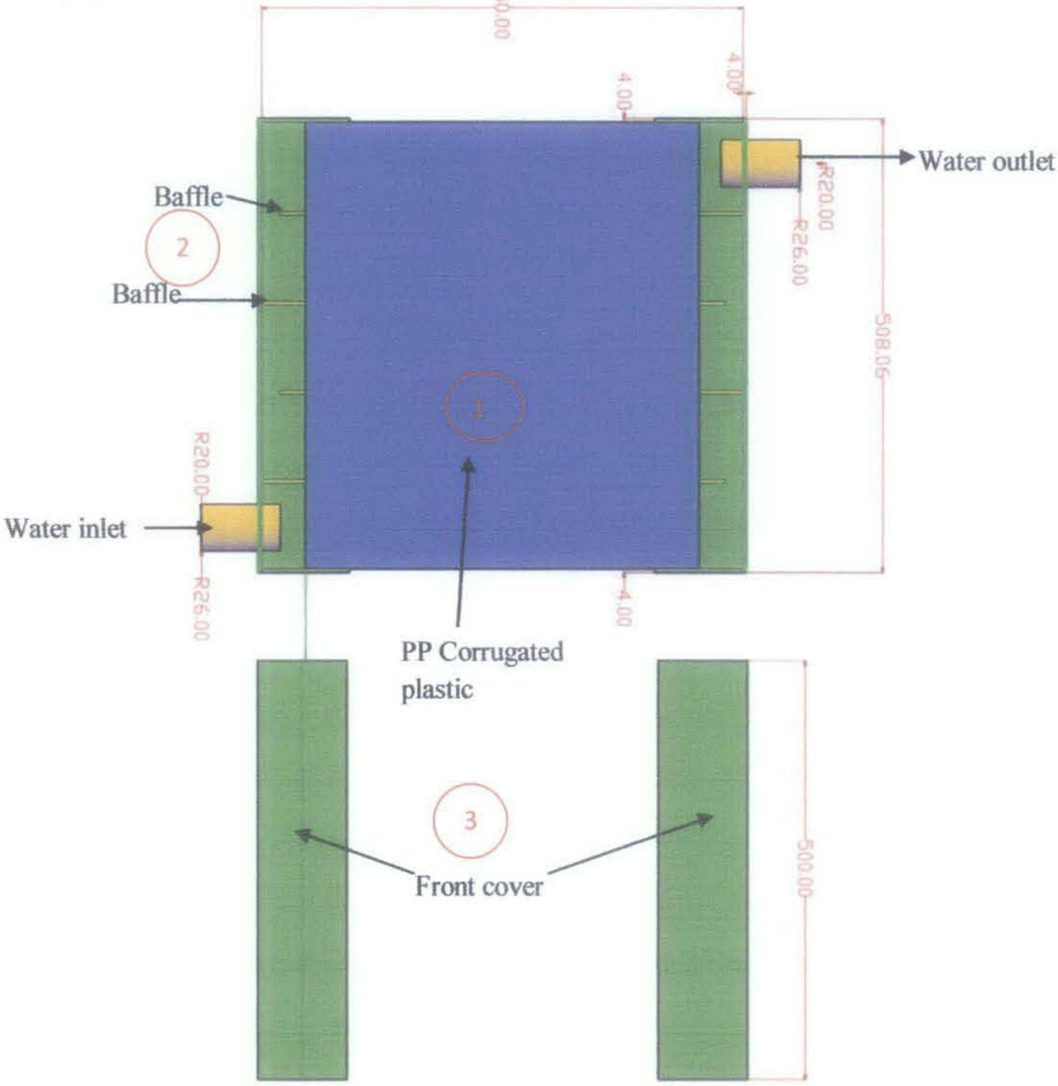


Figure 4.1: Model Front View

4.1.2 Top View

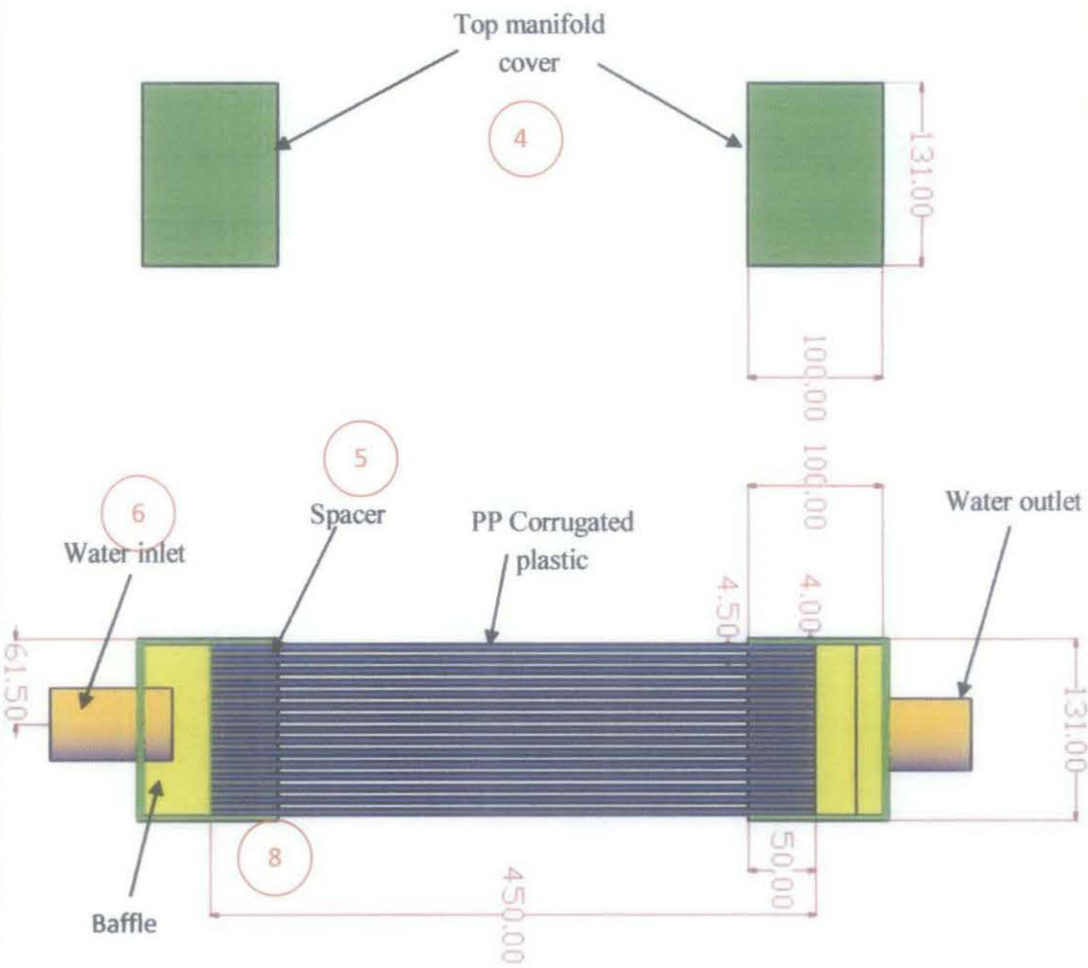


Figure 4.2: Model top view

4.1.3 Side View

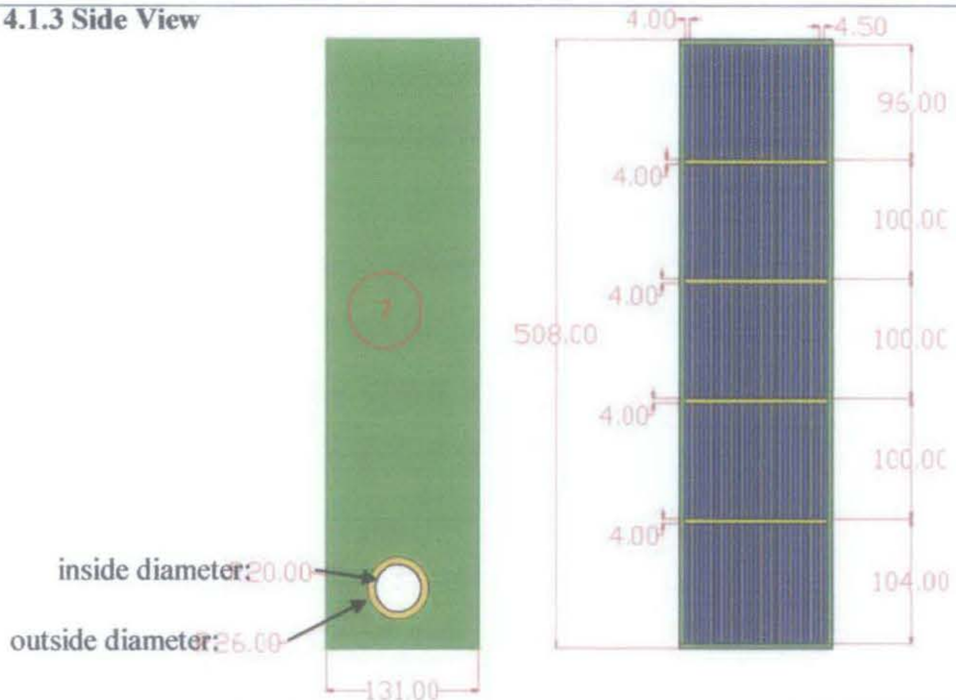


Figure 4.3: Model side view

Table 11: Bill of Material Plate Heat and Mass Exchanger

Bill of Material Plate Heat and Mass Exchanger				
No	Component	Material	Dimension	Quantity
1	Corrugated sheet	Polypropylene	500mm X 450 mm X 4mm(t)	14
2	Baffle	Polypropylene	128mm x 50mm x 4mm(t)	8
			128mm x 30mm x 4mm(t)	8
3	Front And Rear Manifold Cover	Polypropylene	508mm x 100mm x 4mm(t)	4
4	Top and Bottom Manifold cover	Polypropylene	131mm x 104mm x 4mm(t)	4
5	Spacer	Polypropylene	500mm x 50 mm x4.5mm(t)	28
6	Water inlet / water outlet	PVC	ID: 20mm OD: 26mm	2
7	Side Manifold Cover	Polypropylene	510mm x 135mm x 4mm(t)	4
8	Adhesive	Cyanoacrylate		10
		Hot Melt Adhesive EVA		5
		Acetic cure Silicon Sealant		1

4.2 Single Lap Joint Shear Test Results

The graphs below are the result from the Lap Joint Shear Test (ASTM D3163).

1) **Sample A: Treated surface Polypropylene solid sample with cyanoacrylate adhesive**

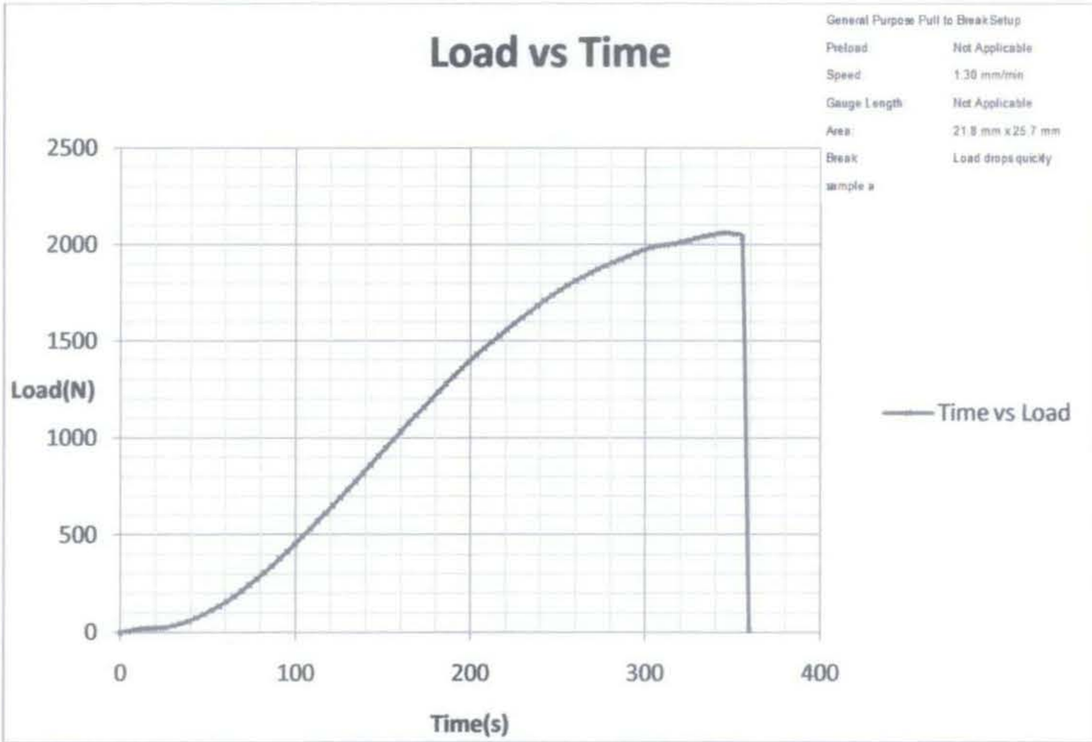


Figure 4.4: Sample A Load vs time

Cross head speed rate: 1.3mm/min   Adhesive thickness: 0.137mm

Area, A: 21.8mm x 25.7mm = 560.26mm^2

Maximum Load: 2060. 12 N

Stress at Maximum Load, $P = \frac{F}{A} = \frac{2060.12}{560.26} = 3.68 N/mm^2 = 3.68 MPa$

2) Sample B: Untreated surface PP lap joint sample with cyanoacrylate adhesive

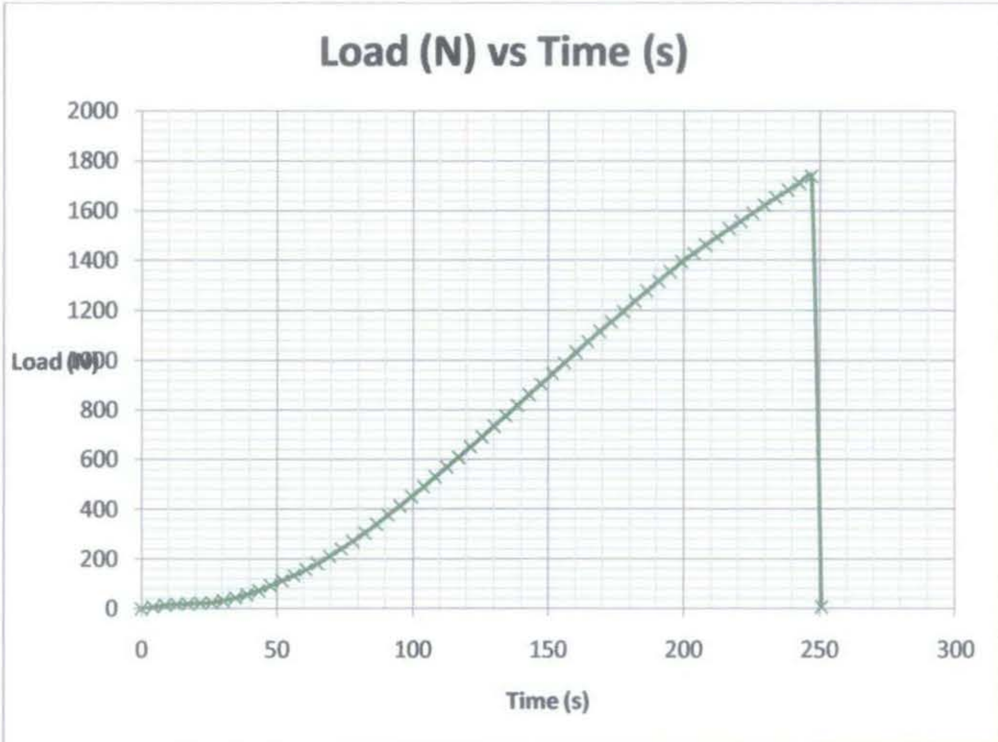


Figure 4.5: Sample B Load vs time graph

Cross head speed rate: 1.3mm/min Adhesive Thickness: 0.141mm

Area, A: 20.78mm x 25.6mm = 530 mm^2

Maximum Load: 1851.885 N

Stress at Maximum Load, $P = \frac{F}{A} = \frac{1737.791}{530} = 3.28$ MPa

3) Sample C: Polypropylene lap joint sample with Selley All Clear Adhesive

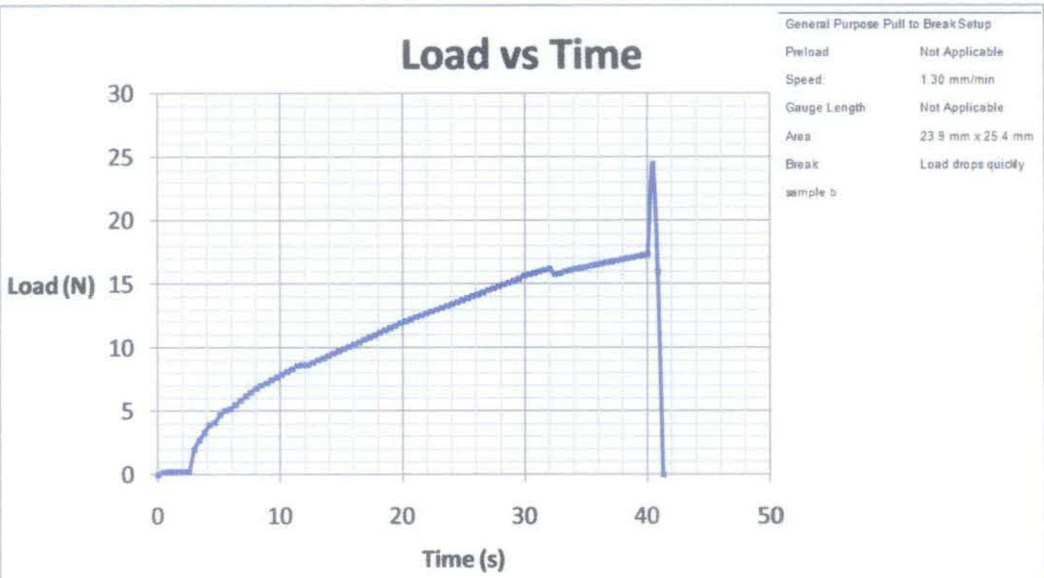


Figure 4.6: Sample C Load vs time graph

Cross head speed rate: 1.3mm/min

Adhesive Thickness: 0.139mm

Area, A: 23.9mm x 25.4mm = 607.06 mm^2

Maximum Load: 24.512 N

Stress at Maximum Load, $P = \frac{F}{A} = \frac{24.4512}{607.06} = 40.278$ KPa

4) Sample D: Polypropylene lap joint sample with Selley Gel Grip Adhesive

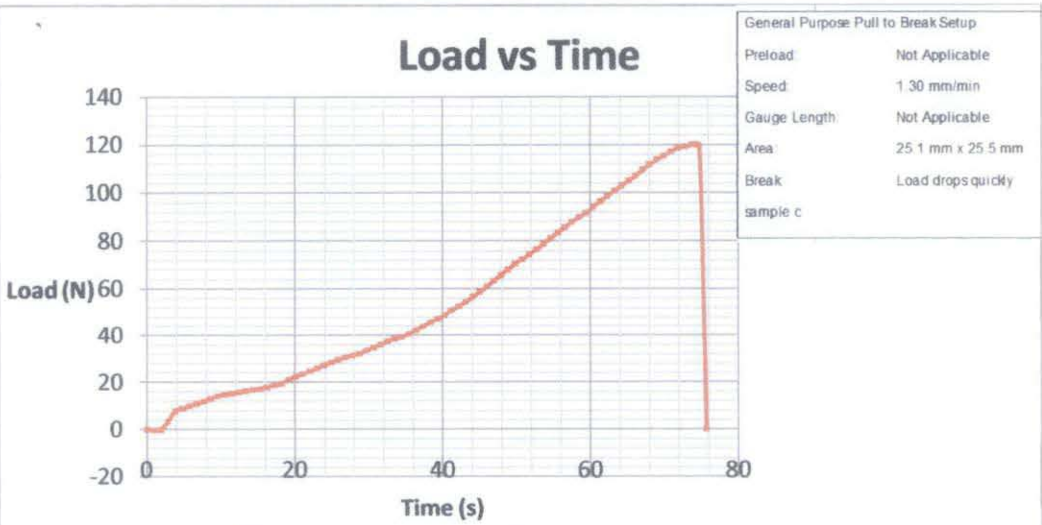


Figure 4.7: Sample D Load vs time graph

Area, A: 25.1 mm x 25.5mm = 640.05 mm^2

Adhesive Thickness: 0.149mm

Maximum Load: 120.59 N

Stress at Maximum Load, $P = \frac{F}{A} = \frac{120.59}{607.06} = 188.407$ KPa

4.2.1 Discussion on Lap Joint Shear Test

Based on three graphs Load vs Time before, the Stress at the maximum load can be calculated to compare the strength of each adhesive. Below are the results of stress at the maximum load. The highest stress achieved at the maximum load among the 4 types of sample are the Sample A, followed by Sample B, Sample D and Sample C.

Table 11: Stress at the Maximum load for each adhesive

Sample Label	Sample A	Sample B	Sample C	Sample D
Type of Adhesive	Cyanoacrylate (treated surface preparation)	Cyanoacrylate (untreated surface preparation)	Selley All Clear (treated surface)	Selley Gel Grip (treated surface)
Stress at the Maximum Load, P	3.68MPa	3.28 MPa	40.278 KPa	188.407 KPa
Area , A (mm^{2})	560.26	530	607.06	640.05
Adhesive Thickness, (mm)	0.137	0.141	0.139	0.149
Temperature / Humidity	22.9 °C / 62 %	22.9 °C / 62 %	22.9 °C / 62 %	22.9 °C / 62 %

From this table, the sample A with treated surface preparation has higher stress at maximum load than untreated surface preparation sample B. The surface tension of Polypropylene (PP) is known as low surface energy, about 29 mN/m compared to other type of plastic [14]. While the cyanoacrylate adhesive has 33mN/ m, higher surface tension than the PP test sample. For good wetting and therefore good adhesion, the adherends itself must increase the surface tension equal or more than the adhesive's surface tension. This including the sandpaper process to remove the layer of sample's surface and flame treatment to change surface characteristic of plastic. Therefore, it will increase the wettability and surface reactivity.

Besides, the source of errors might come from:

1) **Systematic Error** – the surface preparation is not good enough since the flame treatment should be using the plasma treatment and better procedure should be followed. It needs to have preheat treatment, and also post treatment too to stabilize the stress inside the test sample. Cleanliness of the sample still in doubt since the surface must be free from the debris and dirt prior to adhesion. The adhesive also need to be put in sufficient and even quantity to have maximum strength.
2) **Random Error** – the experiment should be run for at least 3 sample of each adhesive to prevent the random error. But the reserved sample is almost all being used since the slip between the test sample and the jig always occur during tension loading process.

   For example the 2nd time running test sample with cyanoacrylate, the stress at the maximum load is about 4.33MPa. But the result from the graph is not valid, since the slip is occur.
3) **Equipment Error** – the jig of the Universal Tensile Machine (UTM) could not hold longer the test sample due to slip problem. For example, the Sample A: PP test sample with cyanoacrylate adhesive has to run about 4 times due to slip problem. The load applied in the experiment subsequently dropped and the experiment needs to redo again.
4) **Parallax error** – error that occur during measuring the length and width during marking the adhesion area. Slight mistake in marking the area will contribute the different value of area compared to required area of adhesion.

4.2.2 Differences between Cyanoacrylates with other Adhesives.

When comparing the value of shear strength of cyanoacrylates between other strong adhesives, the cyanoacrylate is not much difference in term of shear strength. Although the cyanoacrylate adhesive is not the strongest adhesive among the listed adhesive above, but the cyanoacrylate can attained high shear strength with proper treatment of surface preparation.

Table 12: Comparison of adhesives for polypropylene

Type of Adhesive	Wessbond™ Cyanoacrylate	3M Hot Melt Adhesive 3731™	Loctite 770	Loctite 3101
Stress at the Maximum Load (shear stress)	3.68MPa	3.79 MPa	3.6 MPa	3.7 MPa
Price	RM 3.00/ bottle 20gm	RM 180 / with applicator gun	RM 200 / with applicator gun	RM 180 / with applicator

4.2.3 Solving the Slip Problem

The slip problem during lap joint shear test is occurred when the jig could not hold well the test sample since the surface of PP test sample is very slip. Even though the jig itself has a good grip but, it still has slip problem every time experiment is running. The other thing contribute to the slipping is, the bending of test sample lap joint. When the both ends of test sample is stretch out by the jig, the joint tend to have bending problem.

So, the solution for this problem is to make some modifications towards both ends of test sample.

1. A 1 inch solid sheet is attached to end of test sample with cyanoacrylate adhesive. The sample is being leave to cure about 1hour. (Figure 4.8)

Figure 4.8: modification of test sample

2. The surface is sanding using 80 grit sand paper to remove the layer of the surface.

3. The grid is created using hand knife at the new sheet attached to the end of the test sample.
4. The test sample is inserted into the jig of UTM machine and the test is redo again (Figure 4.9). The load is observed and the sample is removed once the joint is break.

Figure 4.9: Test sample after modification is inserted into jig.

4.3 Hydro Testing Performance of Plate Heat and Mass Exchanger Model

From the hydro testing, the flow of the water is observed through from water inlet to water outlet. The test is ran about 20 minutes and the model successfully operated as the working principle of plate heat and mass exchanger whereby the water able to passing through the 5 passages consisting of 14 corrugated sheets as followed the design drawing. In the mean word, the water is flow correctly from the inlet pipe and released through the water outlet as shown Figure 4.10.

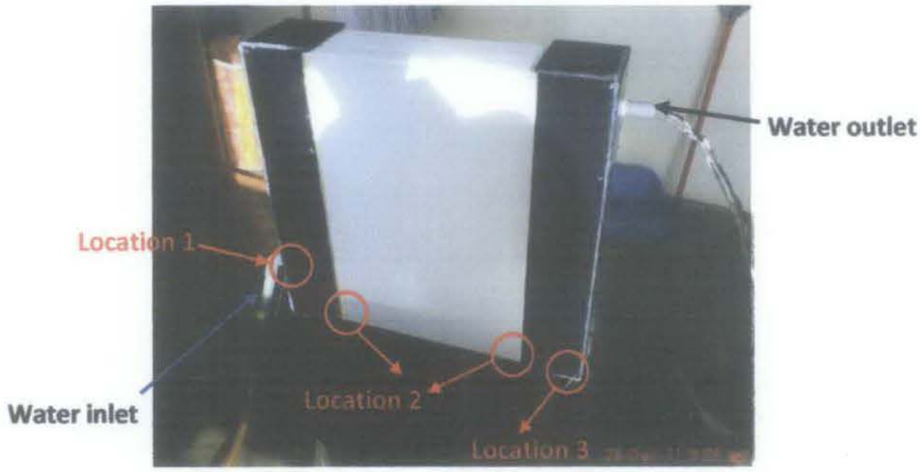


Figure 4.10: Plate heat and mass exchanger during 1st Hydro Testing

4.3.1 Water Leaking Problem

Although the working operation of plate heat and mass exchanger model is successfully achieved, but leakage problems are occurred at the some locations of sheet joints. The location of leakage is and marked for repairing process.

As shown in the Figure above, the red circles are the locations whereby the leaking problem occurred to Plate Heat and Mass Exchanger model:

1. Leaking at the joint between manifold cover sheets
2. Leaking from the spacers with corrugated sheets.
3. Leaking at bottom manifold cover sheets.

Upon the leakage location is identified, the problems of each leaking problem are identified. Some of the problems are:

1. Location 1 and Location 3: Incompatibility silicon sealant to seal the Polypropylene sheets joint at the Location 1 and Location 3 as shown in Figure 35. The silicon sealant did not have strong bonding strength with PP sheet, therefore the water still can penetrate through the bonding joint.
2. Location 2: The joint between spacers and corrugated sheet did not being sealed by the sealant. Therefore the water able to penetrate through the joint.

Poor bonding process using cyanoacrylate is also contributed to this problem. Due to fast curing of cyanoacrylate adhesive, the bonding strength between the plastic sheets will be decreasing if the bonding process is exceeded 5 to 10 seconds.

4.3.2 Solution to Leakage Problem

As a solution to resolve and minimizing the water leaking of the plate heat and mass exchanger, the silicon sealant at the outside manifold cover is removed and replaced by the hot melt adhesive. Ethylene-vinyl acetate (EVA) copolymers based hot melt adhesive is used together with the hot melt gun (Figure 4.11). To use the hot melt adhesive, the hot melt stick is reloaded to the gun and is allowed to heating process about 5 minutes. The sealing process using hot melts is same like using silicon sealant. Upon completing the sealing process, the adhesive is allowed to cure about 15 minutes.

Figure 4.11: Sealing process using Hot Melts

After completing the repair process, the hydro testing is repeated to test the leakage water of plate heat and mass exchanger model. (Figure 4.12) The test is run about 20 minutes and the model successfully operated as the working principle of plate heat and mass exchanger. The water is flow out from the outlet almost same pressure with water flowing in through inlet pipe.

Figure 4.12: 2^{nd} Time Hydro Testing

The water leaking is observed and only found major leakage at the same Location 2: the bottom part near to the spacers with corrugated sheets. Other than that, small leakage found at the joint between manifold covers whereby the leaking problem can be solved by adding more hot melts sealant.

For the leakage at Location 2, this problem is hard to solve since the sealant has to be put between the corrugated sheets with spacers whereby these parts already bonded by the cyanoacrylate adhesive. Therefore, the manifold cover sheets has to be open and breaking the bond between the sheets to fix this problem. Then the hot melt adhesives can be applied between the corrugated sheets with the spacer sheets to seal the water from penetrating the joint.

Some of the factors contributing to failure of heat and mass exchanger in term of water leakage are:

1) Poor cutting process by using hand saw tool and saw machine. Cutting the plastic using saw will creating un-flat surface if the saw tool is not constant during cutting process. This will resulting difficult to bond using cyanoacrylate

and has to be sealed using hot melt adhesive. So, the plastic should be cut using CNC Laser Cutting to achieve high quality cutting with good surface cutting.

2) Poor assembling process during bonding the plastic sheets. Due to large area to apply the cyanoacrylate adhesive, some part of adhesive area is cure first before the joint is bonded. Therefore, the adhesive strength is decreased, and the water able to penetrate through the joint since the sheets did not bonded properly. To prevent this problem, the adhesive has to be put in sufficient quantity and the bonding process must be doing in quick time.

3) The internal parts which are the joint between spacer sheets with corrugated sheets did not being sealed properly by using silicon sealant or hot melt adhesive. This will allow the water penetrating through the area which is not bonded properly. The sealant supposedly being put at all the plastic joint involving with the water flowing inside of plate heat and mass exchanger.

4) Sealing problem by using silicon sealant between the joint of plastic sheets. This sealant did not have high strength adhesion to PP plastic sheets, and the water able to penetrate and flowing though the joint although the sealant put in sufficient quantity.

   Therefore, the hot melt adhesive need to replace the silicon sealant since it has high ability to fill the gap of joint and also high strength adhesive.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Fabrication of heat and mass exchanger model is successfully done by using PP corrugated sheet, PP solid sheet, cyanoacrylate adhesive, silicon sealant and also EVA hot melt adhesive. PP material is very good in thermal resistance and has high mechanical properties. Throughout single lap joint test, sample test using cyanoacrylate adhesive with treated surface preparation has high shear strength, 3.68 MPa compared to untreated surface preparation sample test and other adhesive sample tests. The result of this mechanical test is satisfied since the cyanoacrylate could have maximum strength 3.68MPa, almost even with the others expensive adhesives strength. Therefore, surface preparation such as surface roughening and flame treatment prior making the bond joint is important to have high bonding strength by increasing the wettability of PP surface.

The model is successfully operated such as working principle of plate heat and mass exchanger. The water is able to flow smoothly from water inlet and passing by 5 passages until flowing out from water outlet. However, the model is leaked due to the incompatibility of silicon sealant to seal the joint, poor assembling process and also unsealed joint between the corrugated sheets with spacer sheets. The leakage is successfully minimized by using EVA hot melt adhesive. This is proven that hot melt adhesive is suitable adhesive to be used for joint sealing purpose compared to silicon sealant. This project is important as support for new type of cooling system in the market, other than using conventional heat ventilation air cooling system.

5.2 Recommendation

The first step that needs to be done to ensure a better fabrication model is the preparation for joining part. All the debris needs to be remove and each surface need to be made even. During the bonding process, the cyanoacrylate adhesive has to be put sufficiently to avoid low bonding strength and fast cure time. After the bonding process of plastic joint, all the joint must be seal off sufficiently using hot melt adhesive. This is important process to prevent the water from penetrating the plastic joint when the operation of plate heat and mass exchanger is running.

Polyolefin based hot melt adhesive is more suitable to be used as sealant for plastic joint since the bonding strength are higher than Ethylene-vinyl acetate (EVA) hot melt adhesive. The example of polyolefin based hot melt adhesive is 3M Polyolefin Hot Melt Adhesive 3731. Besides, this hot melt adhesive is proven to be able to work in high temperature and has high shear strength when bonding with polypropylene which is approximately 3.73MPa (See Appendix K and L for Material Datasheet and Performance Properties). At first, the author planned to use this adhesive as sealant of plastic joint. However, due to the limitation of budget and the high cost of polyolefin based hot melt adhesive, author has to find another alternatives for sealant purpose.

Throughout this project, the author has identified the problem and weakness regarding the equipment, methodology and fabrication techniques of the regenerator model. Some modifications are needed to enhance the result of the project and avoiding the leakage failure.

REFERENCES

1. M.V. Rane, 2009: *Solar Liquid Desiccant Systems,* Workshop on Solar Cooling at TERI New Delhi
2. Saman & Alizadeh, 2000*: Modelling Performance Analysis of a Cross-Flow Type Plate Heat Exchanger for Dehumidification/Cooling,* Solar Energy Vol.70
3. Marcus Jones, 2004: *First Results of A Solar Thermal Liquid-Desiccant Air Conditioning Concept*
4. Manuel Conde, 2007: *Liquid Desiccant-Based Air-Conditioning Systems - LDACS*
5. M.Krause, 2005: *Open Cycle Liquid Desiccant Air Conditioning Systems – Theoretical and Experimental Investigations*
6. Alper, Mark, D,2011: *Hot Melt Adhesive Based On Olefin Block Copolymers.*PCT WO 2011/011729 A1
7. Christine Marotta, Mike Williams, Nicole Laput, 2005: *Adhesives for the Assembly of Hard To Bond Plastic*
8. http://www.theadhesiveworld.com/failureoftheadhesivejoint.html: *Failure of Adhesion Joint*
9. John Scheirs,2000 : *Compositional and failure analysis of polymers: a practical approach*
10. Andrew Lowenstein,2005: *High Efficiency Liquid-Desiccant Regenerator for Air Conditioning and IndustrialDrying*
11. Sina Ebnesajjad , 2004: *Adhesives Technology Handbook,* page 274.
12. Scott Tremblay, *Advance in Hot Melt Technology Yield High Performance Structural Adhesives*
13. Melvin E Peterkin,1967 : *Hot Melt Adhesive Comprising Polypropylene and a Polyterpene.* US Patent 3 341 626
14. Bob Goss, 2010: *Practical Guide to Adhesive Bonding of Small Engineering Plastic and Rubber Parts,* Chapter 6, Page 96

APPENDICES

APPENDIX A – CHEMICAL RESISTANCE AND PHYSICAL PROPERTIES OF POLYMERS BY DYNALAB CORP

Chemical Resistance and Physical Properties

Excellent resistance, no attack. | Good resistance, minor attack. | Limited resistance, moderate attack, suitable for short term use only.

Poor resistance, not recommended. | – No information available.

Transparency: C Clear | TL Translucent | O Opaque

Flexibility: EX Excellent | R Rigid

Dynalab
Supplying Science and Education

	LDPE	HDPE	PP	PPCO	PS	ACRYLIC	PTFE	PMP	PVC	PC	PFA
Acids - dilute	Excellent	Excellent	Excellent	Excellent	Excellent	Good	Excellent	Excellent	Excellent	Excellent	Excellent
Acids - concentrated	Excellent	Excellent	Excellent	Excellent	Limited	Poor	Excellent	Excellent	Excellent	Poor	Excellent
Alcohols	Excellent	Excellent	Excellent	Excellent	Excellent	Poor	Excellent	Excellent	Excellent	Good	Excellent
Aldehydes	Good	Good	Good	Good	Poor	Good	Excellent	Good	Poor	Limited	Excellent
Bases	Excellent	Excellent	Excellent	Excellent	Excellent	Limited	Excellent	Excellent	Excellent	Poor	Excellent
Esters	Excellent	Good	Good	Excellent	Poor	Poor	Excellent	Good	Poor	Poor	Excellent
Hydrocarbons Aliphatic	Limited	Good	Good	Good	Poor	Good	Excellent	Limited	Excellent	Poor	Excellent
Hydrocarbons Aromatics	Limited	Good	Limited	Limited	Poor	Poor	Excellent	Limited	Poor	Poor	Excellent
Hydrocarbons Halogenated	Poor	Limited	Limited	Limited	Poor	Poor	Excellent	Poor	Poor	Poor	Excellent
Ketones	Good	Good	Good	Good	Poor	Poor	Excellent	Limited	Poor	Poor	Excellent
Oils, Minerals	Limited	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Oil, Vegetable	Good	Good	Good	Good	Good	Poor	Excellent	Good	Good	Good	Excellent
Oxidizing Agents	Limited	Limited	Limited	Limited	Poor	Poor	Excellent	Limited	Good	Poor	Excellent
Max Temp. °C	80	120	135	121	70	90	300	145	70	130	270
Min Temp. °C	-50	-100	0	-40	0	-60	-200	0	-25	-135	-280
Autoclavable	NO	NO	YES	YES	NO	NO	YES	YES	NO	YES	YES
Microwavability	YES	NO	YES	YES**	NO	NO	YES	YES	YES	YES**	YES
Gas Sterilization	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Dry Heat Sterilization	NO	NO	NO	NO	NO	NO	YES	YES	NO	NO	YES
Gamma Irradiation Sterilization	YES	YES	NO	NO	YES	YES	NO	YES	NO	YES	YES
Chemical Disinfectant Sterilization	YES	YES	YES	YES	NO	NO	YES	YES	YES	YES	YES
Transparency	TL	TL	TL	TL	C	C	O	C	C	C	TL
Flexibility	EX	R	R	R	R	R	R	R	R	R	R
Gas Permeability N_2	20	3	4.4	4.2	3	-	-	65	0.4	3	-
Gas Permeability CO_2	280	45	92	65	75	-	-	-	10.2	85	-
Gas Permeability O_2	60	10	28	24	15	-	-	270	1.2	20	-
Water Absorption %	<0.01	<0.01	<0.02	<0.02	0.05	0.3	0.3	<0.01	0.06	0.35	<0.03
Resistivity Ohm CM²	>10[illegible]	>10[illegible]	$>10^{16}$	$>10^{16}$	$>10^{16}$	$>10^{14}$	$>10^{18}$	$>10^{16}$	<10[illegible]	2×10[illegible]	10[illegible]
Non-Cytotoxicity*	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Specific Gravity	0.92	0.95	0.90	0.90	1.05	1.18	2.2	0.83	1.34	1.20	2.16

* "YES" is based on the material being determined to be non-cytotoxic based on USP and ASTM biocompatibility testing standards using an MEM elution technique on a WI38 human diploid lung cell line.

** Material will absorb heat.

APPENDIX B – CYANOACRYLATE SETTING TIME AND SHEARING ADHESIVE STRENGTH PERFORMANCE BY THREE BOND TECHNICAL NEWS

5. ThreeBond 1797 - an adhesive primer for hard-to-bond materials (for instant adhesives)

Even in today's fast-developing world of chemistry, no adhesive has yet been developed for securely bonding polyethylene, polypropylene, and fluoroplastic materials.

One method for bonding these hard-to-bond materials is to activate the substrate surface temporarily by acid, thermal, or radiation treatment before applying the adhesive. However, all three methods are impractical as they pose health hazards, require a specialized facility, and involve complicated procedures. In this section, a simple pre-treatment method using a primer will be introduced for securely bonding hard-to-bond materials while avoiding the above-cited difficulties.

5-1. Outline

ThreeBond 1797 is a specialized primer for securely bonding hard-to-bond materials-such as polypropylene, polyethylene, polyacetal, and EPT rubber - using instant adhesives in the TB 1700 series.

The conventional method of bonding polypropylene, polyethylene, etc. involved pre-treatment by strong acid, strong alkalis, or heat, to give the adhesiveness. However, these treatments were considered impractical in application as they involved complicated, time-consuming, and hazardous procedures. ThreeBond 1797 is an adhesive primer that enhances bonding performance at room temperature, and was developed in order to eliminate the workload for such pre-treatment processes.

5-2. Characteristics

1. It displays high adhesive performance with polypropylene, polyethylene, and polyacetal materials. It is also significantly effective in bonding EPT rubber, polyurethane, and soft PVC materials.
2. Since it is quick-drying, bonding may be performed immediately after surface application.
3. It also acts as a curing accelerator, so that setting time is reduced.
4. It cures quickly at room temperatures and increases the speed and productivity of the assembling process.
5. It can be used with all instant adhesives of the TB 1700 series.

5-3. Properties

Items \ Product name	ThreeBond 1797
Color and appearance	Lemon yellow liquid
Viscosity (cP/25°C)	0.85
Specific gravity (25°C)	0.80
Main constituent	Amine accelerator

5-4. Performance

(a) Setting time (for bonding between the same materials and between different materials) (seconds)

Materials \ Materials	Polypropylene	Polyethylene	Polyacetal	Iron
Polypropylene	5	5	5	10
Polyethylene	-	5	5	10
Polyacetal	-	-	5	10
Iron	-	-	-	15

(b) Shearing adhesive strength (for bonding between the same materials and between different materials) (kgf/cm²)

Materials \ Materials	Polypropylene	Polyethylene	Polyacetal	Iron
Polypropylene	45.6*	39.0*	49.6*	28.1
Polyethylene	-	33.0	36.5	21.5
Polyacetal	-	-	47.1	31.2
Iron	-	-	-	130.5

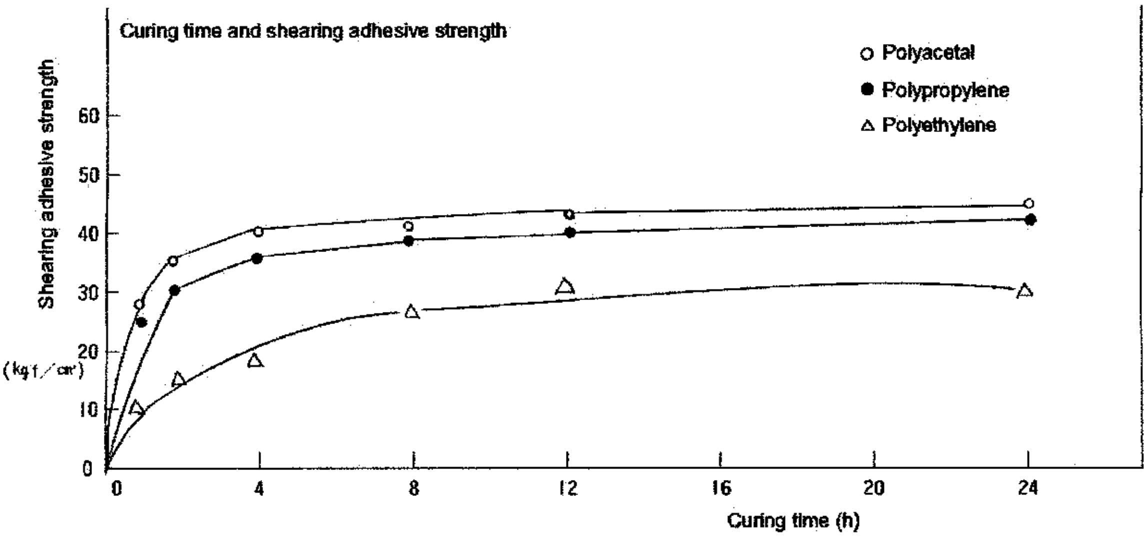
* Material fracture   25°C × 24-hour curing

ATTACHMENT C – CYANOACRYLATE CURINF TIME AND SHEARING ADHESIVE STRENGTH BY THREE BOND TECHNICAL NEWS

(c) Curing time and shearing adhesive strength (kgf/cm²)

Time (h) / Materials	1	2	4	8	12	24	72
Polypropylene	25.1	30.4*	35.3*	38.7*	41.4*	45.6*	46.0*
Polyethylene	11.1	17.0	20.0	27.2	33.0	32.5	33.0
Polyacetal	28.1	36.2	40.2*	41.5*	45.2*	47.1*	46.2*

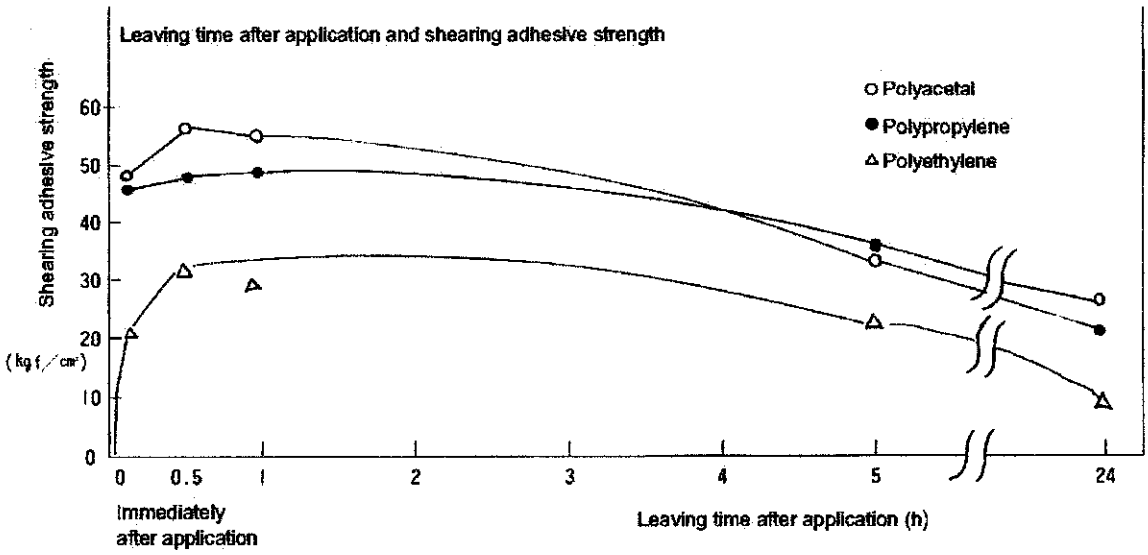
* Material fracture   25°C curing



(d) Leaving time after application of TB 1797 and shearing adhesive strength (kgf/cm²)

Time (h) / Materials	Immediately after application	0.5	1	5	24
Polypropylene	45.6*	48.4*	49.4*	35.2*	21.3*
Polyethylene	21.5	31.6	30.0	21.0	10.6
Polyacetal	47.1*	56.7*	55.0	34.7	24.8

* Material fracture   25°C × 24-hour curing



ATTACHMENT D – VT-201 Silicon Sealant Datasheet

V-tech	VITAL TECHNICAL SDN. BHD.	AFAQ / UKAS	Issue No.:	2
	Technical Data Sheet		Issued Date:	31/03/08
	VT-201		Revision No.:	0
	All Purpose Sealant		Revised Date:	-
			Page:	1 Of 2

Product Specification:

Curing System	Acetoxy
Appearance	Paste
Odour	Vinegar Smell
Specific Gravity	0.95
Tack Free Time	8 - 25 minutes
Application Temperature	-20℃ to 50℃
Service Temperature	-40℃ to 150℃
Shelf Life	12 months

Product Description:

A one component, versatile, acetic cure silicone sealant formulated for general purpose glazing and sealing applications where long term reliability is required. It will bond to form a durable, flexible, waterproof seal on many common wet area building materials. It is suitable for both indoor and outdoor applications.

Applications:

Well-suited for general sealing applications such as sheet metal, skylights, ventilators, air-conditioning systems, metal / plastic signs, glass block structures and as a bedding for marine hardware.

Directions:

1. Surfaces must be clean, dry and free of dirt, grease, oil or water.
2. Surfaces should be cleaned with alcohol, M.E.K. or other suitable solvent. Soap or detergent and water treatments are not recommended.
3. For a neat finish, apply masking tape and remove it before sealant has skinned over.
4. Cut nozzle at 45° angle to desired bead-width and apply to substrate with cartridge gun.
5. Tooling time is 5 minutes; tack free time is 15 minutes.
6. Uncured sealant can be cleaned up with mineral spirits.
7. Use approved backing material for joints over 10mm deep.

Limitations:

VT-201 All Purpose Sealant is an acetic acid curing silicone and is not suitable where the acetic acid component will corrode the base material.
Not for: Traffic areas or areas subject to abrasion.
Not for: Structural glazing.
Not for: On marble, quartzite or natural stones.

ATTACHMENT E – Kleiberit EVA Hot Melt Adhesive Material Datasheet

KLEIBERIT®
KLEBSTOFFE • ADHESIVES

EVA Hot Melt Adhesive 743.7

Fields of application

- Wrapping of resin-impregnated paper foils on wood and wood based materials, such as fine grained particle boards and MDF boards
- Pre-coating of resin impregnated paper films for surface laminating of MDF and other fine grained boards.
- Laminating of foamed material on textile fabric.

Advantages

- Advantageous working viscosity
- Very economical with good surface quality on thin papers
- No stringing on the application roll
- Good for high line speeds up to 50 m/ minute

Properties of the bond

- High film strength
- Excellent ageing resistance

Properties of the adhesive

Base:	EVA-Copolymers
Specific weight:	approx. 1.04 g/cm³
Colour:	beige
Viscosity Brookfield HBTD:	
at 160° C:	approx. 5.500 ± 800 mPa s
at 180° C:	approx. 3.500 ± 600 mPa s
at 200° C:	approx. 2.000 ± 300 mPa s
Melting index according to DIN 53 735 (MFI 120/1.2):	200 ± 20 g/10 minutes
Softening point (ring and ball):	90 ± 5 °C
Working temperature:	200 °C
Activation temperature:	160-200 °C
Identification:	not required according to the German hazardous substances regulations GefStoffV (see our safety data sheet)

Attention:
When hot melt adhesives are melted and applied, vapours are set free and an unpleasant odour can occur, even if the recommended working temperature has been observed. Moreover if the prescribed working temperature is exceeded over a longer period, harmful decomposition products can develop. Precautions should be taken to eliminate the vapours, e.g. by using a suitable ventilation system.

Application devices

- Wrapping machines of the following manufacturers:
  Barberan, Duespohl, Friz Maschinenbau, PZ
- Hot melt applicator equipment to coat papers: e. g. Nordson
- Hot press laminating of precoated foils: e. g. Friz Maschinenbau

Application techniques

Profile wrapping

Application quantity:	50 - 100 g/ m²
Working temperature:	160 - 200 °C
Line speed:	20-50 m/minute

The rate of feed is dependent upon the materials used and the shape of the profile.

The materials must be dry, free from dust and acclimatized. For process lengths exceeding 2 m and for complicated wrapping additional reactivation may be required by means of radiant heat or hot air blowers.
Resin-impregnated paper foils have varying structures, please test the adhesion individually.

Surface coating / Laminating

Application quantity on thin papers:	30-50 g/ m²
Application quantity on textiles: (depending on the textile substrate)	5-20 g/ m²
Working temperature:	160-180° C
Line speed:	15-25 m/ minute

If required use cold rollers.

Cleaning

Work tools can be cleaned with KLEIBERIT Cleaner 827.0.

KLEBCHEMIE M. G. Becker GmbH + Co KG • P.O.Box 1204 • D-76353 Weingarten
tel. +49 7244 620 • fax +49 7244 7000 • E-Mail info@kleiberit.com, http://www.kleiberit.com

APPENDIX F – BILL OF MATERIAL PART 1

Purchase Order To Associated Airpak Industries S/B

Bill Of Material (Regenerator Model)							
No	Material	Material Type	Quantity	Dimension	Price Per Unit	Amount	Remark
1	Spacer	Pp Solid Sheet	28	500mm X 50 Mm X 4.5mm(T)	Rm8.45/Pc	Rm 236.00	
2	Baffle (Long)	Pp Solid Sheet	8	128mm X 50mm X 4mm(T)	Rm 2.95/Pc	Rm 23.60	
3	Baffle (Short)	Pp Solid Sheet	8	128mm X 30mm X 4mm(T)	Rm 1.76/Pc	Rm 14.08	
4	Top And Bottom Manifold Cover	Pp Solid Sheet	4	131mm X 104mm X 4mm(T)	Rm3.90/Pc	Rm 15.60	
5	Front And Rear Manifold Cover	Pp Solid Sheet	4	508mm X 100mm X 4mm(T)	Rm14.30/Pc	Rm 57.20	
6	Side Manifold Cover	Pp Solid Sheet	2	510mm X 135mm X 4mm(T)	Rm20.15/Pc	Rm 40.40	
7	ASTM D3163 Sample Test Purpose	Polypropylene (Pp) Solid Sheet	20	101.6mm (L) X 25.4mm (W)X 4mm (T)	Rm 1.56	Rm 31.20	
					Total = **Sales Tax 10%** **Total Amount**	**Rm 418.58** **Rm 41.86** **Rm 460.44**	

APPENDIX G – BILL OF MATERIAL PART 2

Purchase Order To Plastflute (M) Sdn Bhd

Bill Of Material (Regenerator Model)						
No	Material	Material Type	Quantity	Dimension	Price	Remark
1	PP Corrugated Sheet	PP	20	500mm X 450 mm X 4mm(T)	**Free Of Charge (FOC)**	

Bill Of Material (Adhesives)						
No	Material	Quantity	Size	Price Per Unit	Amount	Remark
1	VT-201 Silicon Sealant and Sealant Gun	1		RM 13.50	RM 13.50	
2	EVA Hot Melt Adhesive and Hot Melt Gun	1		RM 15.00	RM 15.00	
3	Wessbond Cyanoacrylate Acid Ester	10	20 G	Rm3.00 /Pc	Rm 30.00	
4	Selley All Clear Sealant	1	75 G	Rm 16,30/Pc	Rm 16.30	
5	Selley Gel Grip Sealant	1	40 G	Rm 17.50/Pc	Rm 17.50	
					Total = Rm 92.30	

Designation: D 3163 – 96

Standard Test Method for Determining Strength of Adhesively Bonded Rigid Plastic Lap-Shear Joints in Shear by Tension Loading[1]

1. Scope

1.1 This test method is intended to complement Test Method D 1002 and extend its application to single-lap shear adhesive joints of rigid plastic adherends. The test method is useful for generating comparative shear strength data for joints made from a number of plastics. It can also provide a means by which several plastic surface treatments can be compared.

1.2 The values stated in SI units are to be regarded as the standard. The values in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 907 Terminology of Adhesives[2]

D 1002 Test Method for Apparent Shear Strength of Single-Lap-Joint Adhesively Bonded Metal Specimens by Tension Loading (Metal-to-Metal)[2]

D 2093 Practice for Preparation of Surfaces of Plastics Prior to Adhesive Bonding[2]

D 4896 Guide for Use of Adhesive-Bonded Single Lap-Joint Specimen Test Results[2]

3. Terminology

3.1 *Definitions*—Many of the terms used in this test method are defined in Terminology D 907.

4. Significance and Use

4.1 Due to the increased use of adhesive-bonded plastics as a result of the inherent advantages afforded by bonded rather than mechanically fastened joints, particularly the alleviation of stress raisers and stress cracking, there is a need for standard tests by which joints of various plastic substrates and adhesives can be compared. This test method is intended to meet such a need.

4.2 This test method is limited to test temperatures below the softening point of the subject adherends, and is not intended for use on anisotropic adherends such as reinforced plastic laminates.

4.3 The misuse of strength values obtained from this test method as allowable design-stress values for structural joints could lead to product failure, property damage, and human injury. The apparent shear strength of an adhesive obtained from a given small single-lap specimen may differ from that obtained from a joint made with different adherends or by a different bonding process. The normal variation of temperature and moisture in the service environment causes the adherends and the adhesive to swell and shrink. The adherends and adhesive are likely to have different thermal and moisture coefficients of expansion. Even in small specimens, short-term environmental changes can induce internal stresses or chemical changes in the adhesive that permanently affect the apparent strength and other mechanical properties of the adhesive. The problem of predicting joint behavior in a changing environment is even more difficult if a different type of adherend is used in a larger structural joint than was used in the small specimen.

4.3.1 The apparent shear strength measured with a single-lap specimen is not suitable for determining allowable design stresses for designing structural joints that differ in any manner from the joints tested without thorough analysis and understanding of the joint and adhesive behaviors.

4.3.2 Single-lap tests may be used for comparing and selecting adhesives or bonding processes for susceptibility to fatigue and environmental changes, but such comparisons must be made with great caution since different adhesives may respond differently in different joints. See Guide D 4896 for further discussion of the concepts relative to interpretation of adhesive bonded single-lap joints.

5. Apparatus

5.1 *Testing Machine*, conforming to the requirements of and having the capabilities of the machine prescribed in Test Method D 1002. The grips are self-aligning and capable of securely grasping the specimen throughout the test, without allowing the specimen to slip.

[1] This test method is under the jurisdiction of ASTM Committee D-14 on Adhesives and is the direct responsibility of Subcommittee D14.40 on Adhesives for Plastics.

Current edition approved Sept. 10, 1996. Published November 1996. Originally published as D 3163 – 73. Last previous edition D 3163 – 92.

[2] *Annual Book of ASTM Standards*, Vol 15.06.

5.2 *Temperature-Controlling Equipment*, capable of maintaining the test temperature to ±3°C (±5°F). If ambient laboratory conditions are employed the same degree of control is required.

6. Test Specimen

6.1 Make specimens that conform to the form and dimensions set forth in Test Method D 1002 where possible. However, due to the low yield points in plastics compared with those of metals, it may not always be feasible to limit test specimen geometry to that called for in Test Method D 1002. Therefore adherend thicknesses and joint overlaps must be chosen so that failure occurs preferentially in the joint and not in the substrate. Thicker adherends allow the stress on the bonded area to be increased, before either tensile failure or yield occurs in the adherend. Recognize, however, that depending on the surface treatment and adhesive used, the bond strength may often be greater than the tensile yield strength of the adherend. Use data collected by this test method only for comparative purposes when the investigator is certain that the specimen configurations and joint geometries of the specimens being compared are identical.

6.2 The surface preparation used on the adherend depends on the subject plastic adherend. Procedures such as those recommended in Practice D 2093 serve as a useful guide.

6.3 Apply the adhesives in accordance with the manufacturer's recommendations. Choose adhesives such that the cure temperature does not adversely affect the mechanical properties of the adherends.

6.4 Cut test specimens from the bonded panels pictured in Fig. 1. Cut the specimens without overheating or otherwise physically damaging the adherend or bonded interface. Individual specimens may also be prepared if desired.

7. Procedure

7.1 Place the specimens in the grips of the testing machine so that the applied load coincides with the long axis of the test specimen. Load the specimen to failure at a rate of 8.3 to 9.7 MPa (1200 to 1400 psi) of shear area per minute (approximately 0.05 in./min cross head speed).

7.2 Condition specimens for definite periods of time under specified conditions before testing if desired. After conditioning, it is recommended that all specimens be stabilized in the test environment for 1 h before testing.

8. Calculation

8.1 Calculate the bond area to the nearest 0.01 $in.^2$ (0.06 cm^2). Record both load at failure and type of failure (percent cohesive and apparent adhesive). Calculate failing stress in pounds-force per square inch (or megapascals) of shear area

9. Report

9.1 Report the following information:

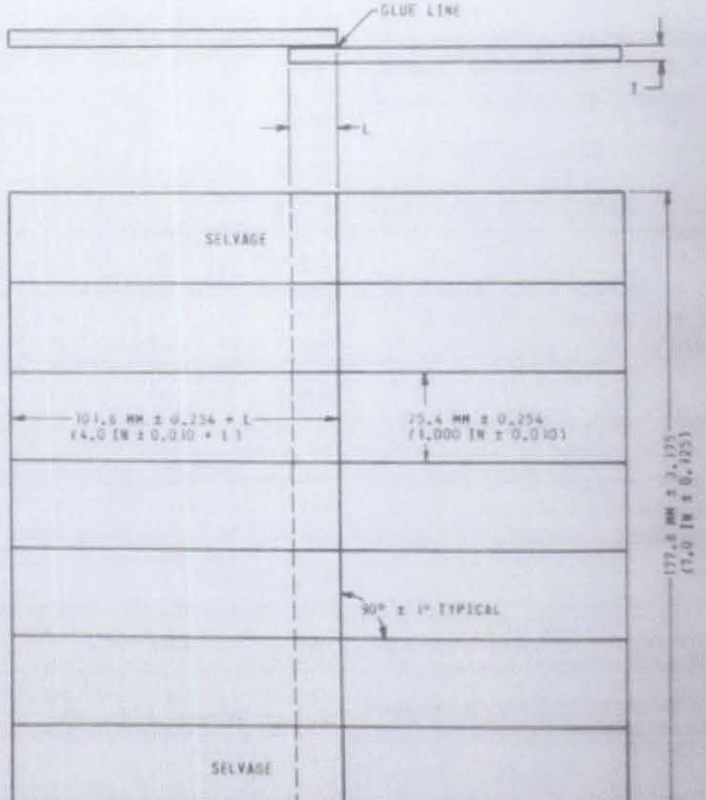


FIG. 1 Standard Test Panel and Specimen Configuration

9.1.1 Complete identification of the adhesive tested, including type, source, date manufactured, manufacturer's code number, form, etc.

9.1.2 Complete identification of the plastic used, its thickness, and the method of cleaning and preparing its surface prior to bonding.

9.1.3 Method of adhesive application (brush, spray, roller coat, tape, etc.).

9.1.4 Conditions present at time of bonding (temperature, etc.).

9.1.5 Length of overlap used.

9.1.6 Conditioning of joint prior to testing.

9.1.7 Maximum, minimum, and average values of the failing load.

9.1.8 Number of test specimens tested.

9.1.9 Type of failure. Include estimated percent cohesive failure in the adhesive, unbonded area, apparent failure in adhesion, and failure in the adherend.

9.1.10 Test temperature employed.

9.1.11 Average thickness of adhesive layer after formation of the joint, within 0.0005 in. (0.0127 mm). Describe the method of obtaining the thickness of the adhesive layer including procedure, location of measurements, and range of measurements.

NOTE 1—The length of overlap, *L*, may be varied where necessary. The length of the test specimen in the jaws, however, must not be varied. The distance from the end of the overlap to the end of the jaws should be 63 mm (2½ in.) in all tests.

NOTE 2—The thickness of the adherend, *t*, may be varied to strengthen the adherend relative to the strength of the bonded area. A maximum thickness of 4.76 mm (3/16 in.) is recommended, however, to minimize the effects of offset.

10. Precision and Bias

10.1 No information is presented about precision or bias of this test method because resources necessary for testing have not been forthcoming.

11. Keywords

11.1 adhesive bonds; plastic; shear strength; tension

APPENDIX K – MATERIAL DATASHEET OF POLYOLEFIN HOT MELT ADHESIVE 3M 3731

3M

Material Safety Data Sheet

SECTION 1: PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: 3M(TM) Scotch-Weld(TM) Hot Melt Adhesive 3731-AE, 3731-B, 3731-PG, 3731-Q, 3731-TC
MANUFACTURER: 3M
DIVISION: Industrial Adhesives and Tapes

ADDRESS: 3M Center
St. Paul, MN 55144-1000

EMERGENCY PHONE: 1-800-364-3577 or (651) 737-6501 (24 hours)

Issue Date: 03/27/2006
Supercedes Date: 04/13/2005

Document Group: 17-9908-9

Product Use:
Specific Use: Hot Melt Adhesive

SECTION 2: INGREDIENTS

Ingredient	C.A.S. No.	% by Wt
POLYPROPYLENE COPOLYMERS	9010-79-1	30 - 45
HYDROCARBON RESINS	68132-00-3	10 - 20
POLYOLEFIN WAX	Mixture	5 - 15
POLYETHYLENE	9002-88-4	5 - 15
ETHYLENE-PROPENE COPOLYMER	Trade Secret	5 - 15
STABILIZED ROSIN ESTER	Unknown	7 - 13
POLYPROPYLENE	9003-07-0	5 - 10
STYRENE-BUTADIENE POLYMER	66070-58-4	5 - 10

SECTION 3: HAZARDS IDENTIFICATION

3.1 EMERGENCY OVERVIEW

Specific Physical Form: Waxy Solid
Odor, Color, Grade: tan, slight resinous odor
General Physical Form: Solid
Immediate health, physical, and environmental hazards: May cause thermal burns.

APPENDIX L – PERFORMANCE PROPERTIES OF POLYOLEFIN HOT MELT ADHESIVE 3M 3731

3M™ Jet-melt™
Polyolefin Bonding Adhesive
3731

Typical Performance Properties

Note: The following technical information and data should be considered representative or typical only and should not be used for specification purposes.

Heat Resistance

Load (PSI)	Temperature
.33 lbs (150 grams)	305°F (152°C)
1 lbs (454 grams)	275°F (135°C)
2 lbs (908 grams)	265°F (129°C)

Overlap Shear Strength

Substrate	Value (Pounds Per Square Inch)
Polypropylene	550 PSI
HDPE	420 PSI
ABS	450 PSI
P.V.C. (Rigid)	430 PSI
Polystyrene (High Impact)	257 PSI
Polycarbonate	430 PSI
Nylon 66	475 PSI
Douglas Fir	490 PSI
Cold Rolled Steel	390 PSI

180° Peel Adhesion (Canvas bonded to various substrates)

Substrate	Value (Pounds Per Inch Width)
Polypropylene	22 PIW
HDPE	23 PIW
ABS	23 PIW
P.V.C. (Rigid)	18 PIW
Polystyrene (High Impact)	15 PIW
Polycarbonate	22 PIW
Nylon 66	19 PIW
Cold Rolled Steel	15 PIW