Investigation of the Environmental Effect on Adhesive Bonds

by

Manuel MASA ALOGO BINDANG

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

JANUARY 2008

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Investigation of the Environmental Effects on Adhesives Bonds

by

Manuel MASA ALOGO BINDANG

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,

(Mr. Kee Kok Eng)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JANUARY 2008

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.

(Manuel MASA ALOGO BINDANG)

ABSTRACT

Adhesively bonded joints are increasingly being used in joining various structural components in a variety of industries (Marine, aerospace, automotive, etc.). Adequate understanding of the behavior of adhesively bonded joints under the environmental effects is necessary to ensure efficiency, safety and reliability of such joints. Therefore, the aim of this project is to investigate the degradation of adhesive bonded joints due to the environmental effects on a single lap joint, which consists of two adherent joint together by an adhesive, and it is widely used for producing in-situ shear strength data on adhesively bonded joints tests. The materials used in this project for such tests are Aluminum and steel sheet as adherent, while Devcon epoxy and Rill super glue are used as adhesive, they are specially formulated for use on metals and other materials. Two sets of specimens and joints will be fabricated as recommended by ASTM D1002 and tested for shear strength; a set of specimens will be tested for shear strength under normal conditions, while the second set of jointed specimens will undergo corrosive environment (salt spray) then be tested for shear strength. The results obtained from the experimental tests, will be used to analyze and compare the variation on the joints strength under normal and corrosive environment. The average shear strength of aluminum sheets bonded with Devcon epoxy under normal and corrosive conditions is 16.43 MPa and 10.54 MPa respectively, while aluminum bonded with Rill super glue under normal and corrosive environment is 12.50 MPa and 4.54 MPa respectively; steel sheets bonded with Devcon epoxy presented 14.66MPa and 6.19MPa of joint strength under normal and corrosive environment respectively, while bonded with Rill super glue, the strength is found to be 18.01MPa and 13.38MPa under normal and corrosive environment respectively. Therefore, it can be concluded that using aluminum as adherent, best results are obtained when bonded together with Devcon epoxy, while using Steel as adherent, best results are obtained when bonded with Rill super glue. Further studies on more different types of adhesives will need to be done to provide better alternative for adhesives selection with respect to the working environment.

ACKNOWLEDGEMENT

First of all, I would like to express my deepest thankfulness to my supervisor, Mr. Kee Kok Eng for his precious guidance and support throughout the completion of this Final Year Project. Special thanks are also dedicated to all the respected and knowledgeable UTP lecturers and staffs for their valuable advices, comments and suggestions.

I am also very grateful to the technician of Manufacturing and Material Lab, particularly Mr. Jani Alang Ahmad and others technician in UTP that had helped me in one way or another to understand and complete this project by giving their fullest commitment, as well as, sharing their experience with me without an hesitation.

I would also like to acknowledge all my colleagues, particularly Mr. Thaweesak Hemchi, Secundino Ntutumu Mba and Pascoa Dos Santos Magaia for their help and cooperation directly or indirectly during the project development.

Last but no least, I would like to express my gratitude to all my family, particularly to my loving parents, my brothers Felipe Nsue Alogo Bindang and Daniel Alogo Alogo Bindang for their moral and economical support throughout my entire career at UTP.

TABLE OF CONTENTS

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviations	**Meaning**
A-DE	Aluminum bonded with Devcon Epoxy
A-DE-C	Aluminum bonded with Devcon Epoxy under Corrosion
A-RI	Aluminum bonded with Rill super glue
A-RI-C	Aluminum bonded with Rill super glue under Corrosion
S-DE	Steel bonded with Devcon Epoxy
S-DE-C	Steel bonded with Devcon Epoxy under Corrosion
S-RI	Steel bonded with Rill super glue
S-RI-C	Steel bonded with Rill super glue under Corrosion
MSDS	Material Safety Data Sheet

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Adhesives joints have been used often in the automotive, naval, aerospace, electronic and many more industries. Adhesives are increasingly being used in joining various structural components such as: Metals, fibers, glasses, and combination of those.

Adhesive bonding is emerging as one of the most interesting way to fasten structural members. This method is, in fact, economic and very efficient. Fastened structures are often mechanically equivalent or stronger than traditional assemblies with overall advantage in weight and costs. Accordingly, this technique covers a wide range of possible applications in a great variety of industries, such as aerospace, automotive, marine, civil, sports and dental [1]. In the aerospace industry many applications of adhesive bond technology can be found in order to achieve high stiffness and strength-to-weight ratios, prolonging at the same time aircraft life. In this field, adhesive techniques are mostly used to manufacture honeycomb sandwich structures which are attached to stiffen structural elements like wings or fuselage skins. In the first case, a honeycomb core is lined with two adhesively bonded sheets of materials for loads to be transmitted from one facing to the other. The resulting structure is excellently stiff and characterized by an optimum weight-to-ratio factor. In the second case, adhesives are employed to attach stiffening stringers to the wings and/or fuselage skins.

Further, in the naval industry the application of adhesives can be found from wooden boats to fiber glass reinforced plastic ones. There are also various applications of adhesives in vessels [2]. Also, bonded repair of metal superstructures represents another important structural application. Joints become necessary in the structures of boats made of fiber glass because large hull surfaces cannot be formed in a single process. Therefore, structural members have to be connected without creating a weakness potential zone for the structure itself. Adhesive bonding is emerging as the best, and often unique, solution.

Cost and weight criteria are becoming increasingly important also in the automotive industry. The aim of building a unitary construction car from aluminum alloys or composite materials gives to the joining method a great importance. As joint represents a critical element from a design point of view, adhesive bonding technique could then represent a valid alternative to the steel bodyworks welding assembly.

Finally, in the construction industry the majority of adhesive bonding applications are traditionally concerned with fastening decorative finishing materials of buildings interiors. Nevertheless, an increasing number of adhesive applications can be found to repair and strengthen defective civil structures.

This brief overview on some adhesive-bonding applications well explain why this topic is of great interest, [3]

1.2 Problem Statement

Adhesively bonded joints are increasingly being used in various structural components. Adequate understanding of their behavior under the environmental effects is necessary, since adhesively bonded joints may suffer a loss in joint strength when exposed to high humidity, and/or high temperatures. Water may affect both the chemical and physical properties of the adhesive; therefore it is necessary to understand their behavior under such condition to ensure efficiency, safety and reliability of such joints.

1.3 Objectives

The objectives of this project are:

- To investigate the degradation of adhesively bonded joints due to environmental effects

- To investigate the effects of corrosion (salt spray) on adhesive bonded joint

- To investigate shear strength of different types of adhesives on different type of materials (Aluminum and Steel)

- To determine the shear strength of adhesive single lap joint of Aluminum and steel plate

1.4 Scope of Work

The following is the scope of this research project.

For the first part of the project, work will be done on:

- The overall literature review,
- Familiarize with the equipments
- Material Selection
- The initial testing.

For the second part, work will be done on:

- Fabrication of Specimens,
- Laboratory experiments
  - ➢ Salt spray test
  - ➢ Shear test for single lap joint
- Data analysis
- Documenting and reporting
- Conclusion

CHAPTER 2

LITERATURE REVIEW

2.1 Adhesive

An adhesive is a compound that adheres or bonds two or more items together. Adhesives may come from either natural or synthetic sources. Some modern adhesives are extremely strong, and are becoming increasingly important in modern construction and industry. [4]

2.2 Type of Adhesives

There are many type of adhesive:

- Natural Adhesives
- Synthetic Adhesives
- Drying Adhesives
- Contact Adhesives
- Hot Adhesives
- UV and Light Curing Adhesives
- Pressure Adhesives

The types of adhesives that will be used in this project are:

2.2.1 Drying Adhesives

These adhesives are a mixture of ingredients (typically polymers) dissolved in a solvent. Glues such as white glue, and rubber cements are members of the *drying adhesive* family. As the solvent evaporates, the adhesive hardens. Depending on the chemical composition of the adhesive, they will adhere to different materials to greater or lesser degrees [4].

2.2.2 Contact Adhesives

Contact adhesive is one which must be applied to both surfaces and allowed some time to dry before the two surfaces are pushed together. Some contact adhesives require as long as 24 hours to dry before the surfaces are to be held together. Once the surfaces are pushed together the bond forms very quickly, hence it is usually not necessary to apply pressure for a long time. This means that there is no need to use clamps, which is convenient.

Natural rubber and poly-chloroprene (Neoprene) are commonly used contact adhesives. Both of these elastomers undergo strain crystallization. When an adhesive bond containing either of these materials is pulled apart, the elastomer is strained, develops crystallites, and actually becomes stronger than in the original, unstressed, state [4].

2.3 Mechanism of Adhesion

The mechanism of adhesion has been investigated for years; several theories have been proposed in an attempt to provide an explanation for adhesion phenomena [5].

The bonding of an adhesive to an object or a surface is the sum of a number of mechanical, physical, and chemical forces that overlap and influence one another. As it is not possible to separate these forces from one another, it is distinguished between:

2.3.1 Mechanical Interlocking

The mechanical interlocking theory of adhesion states that good adhesion occurs only when an adhesive penetrates into the pores, holes and crevices and other irregularities of the adhered surface of a substrate, and locks mechanically to the substrate.

Pretreatment methods applied on surfaces enhance adhesion. These pretreatments (especially plastic surface treatments) result in micro-roughness on the adherent surface, which can improve bond strength and durability by providing mechanical interlocking [6].

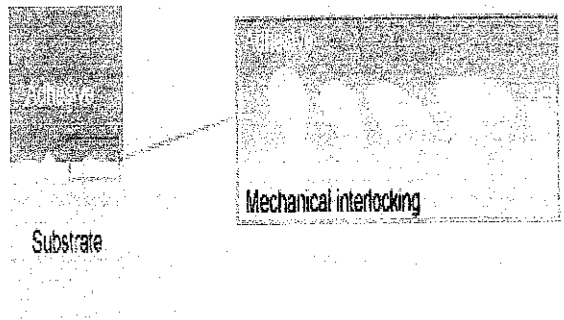


Figure 2.1: Mechanical Interlocking during adhesion

2.3.2 Electrostatic Forces

The basis of the electrostatic theory of adhesion is the difference in electro-negativities of adhering materials. Adhesive force is attributed to the transfer of electrons across the interface creating positive and negative charges that attract one another[6].

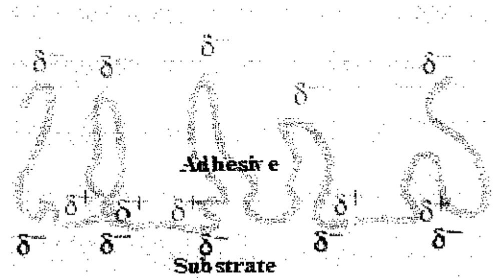


Figure 2.2: Electrostatic forces

2.3.3 Chemical Bonding forces

Occur at the interfaces of heterogeneous systems. This theory states that adhesion results from intimate intermolecular contact between two materials, and involves surface forces that develop between the atoms in the two surfaces.

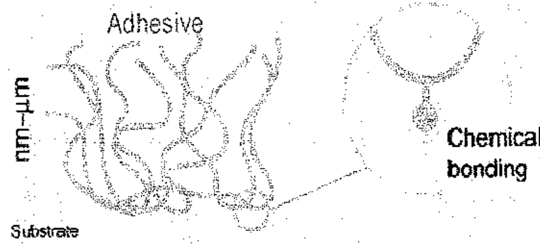


Figure 2.3: Chemical Bonding forces

2.4 Advantages of Adhesives Bonding

The advantages of adhesive bonding over traditional joining techniques are now well accepted. Compared with other joining techniques such as the use of screws or rivets, the adhesive bond can distribute load over a much wider area, reduce stress concentrations, increase fatigue resistance and corrosion resistance of the bonded joints, as well as provide weight savings to the whole structure and the ability to join different materials. So they have been used often in the automotive, aerospace, electronic and packaging industries.

Fiber-reinforced polymer (FRP) composites are increasingly replacing metals in primary load carrying members, resulting in many advantages, but also introducing new challenges. Because no structure is built as a single monolithic unit, various members must be joined adequately to ensure the structure's safety and performance. Unlike metals, structural thermo set-FRP members cannot be welded, and lack the ductility needed for efficient mechanical fastening, making adhesive-bonding the only efficient alternative. However, an adequate understanding of the behavior of adhesively bonded joints is necessary to ensure not only efficiency, but also safety and reliability. The overwhelming majority of the work on the subject of adhesive bonding has focused on the single-lap configuration. The earliest work by Volkersen ignored the inherent eccentricity present in the joint, and the resulting peel stresses. Goland and Reissner [7] studied the deformations and stresses in balanced single-lap joints. Similar, yet more detailed, works were performed by Oplinger [8], and relatively by Li [9]. To a lesser extent, the behavior of double- strap joints has been studied by Hart-Smith [10] and others.

2.5 Type of Adhesive Bonded Joints

There are two type of adhesive bonded joint; the single and double lap joints and, they have been used as a testing specimen to determine the mechanical properties of the adhesive agents and a structural member. The stress and deformation states and the design of the adhesively bonded joints have attracted the researchers.

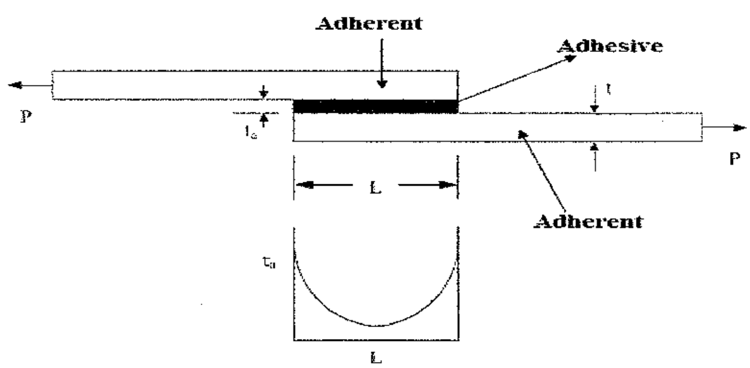
In general, the elastic, elasto-plastic or visco-elastic models for the adhesive layer have been presented and the stress and deformation states of the adhesive layer, as well as adherents have been investigated.

2.5.1 Single Lap Joints

Single lap joint consists of two adherent joint together with an adhesive; it is widely used for producing in-situ shear strength data on adhesively bonded joints tests. The simplicity and low costs associated with specimen manufacture, testing and data analysis has contributed to the widespread use of this method for assessing environmental and fatigue resistance.

Lap joint theories for adhesive-bonded single-lap joints have been developed to analyze the stresses in the adhesive and to predict the strength of the joints. Basing on the pioneer work by Goland and Reissner [11], many authors have made various assumptions regarding the behavior of the adhesive and adherents to yield tractable differential equations, and have investigated the effects of various factors on the stresses in the adhesive layer and the joint strength.

Single lap joints create bending loads in the adherents and tensile stresses in the adhesive [12]. These stresses are highly non-linear as shown in the figure bellow, increasing rapidly near the ends.



Shear stress along adhesive

Figure 2.4: Schematic of single-lap joint

2.5.2 Double Lap Joints

Double-lap joint is widely used today in aeronautical and other industries for avoiding the great eccentricity of stress that occurred in the single-lap joint. In practice, a hole or gap in the adhesive is often discovered by the non-destructive test (NDT) and the load-carrying capacity of the joint is significantly affected by these, holes and gaps.

It is necessary to study the mechanical behavior of the double-lap joint with a gap and see how significant it is [13].

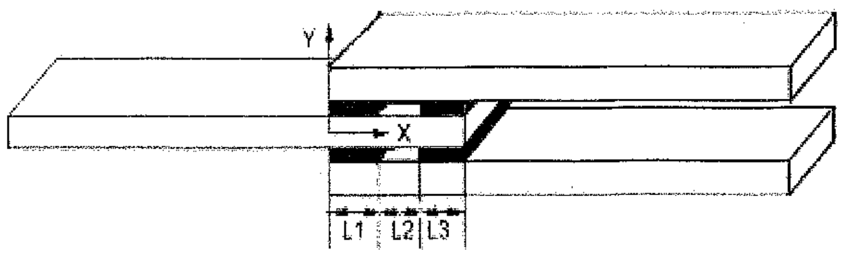


Figure 2.5: Schematic of Double-Lap Joint

2.6 Degradation of Adhesives Bonded Joints

Short-term environmental changes may 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 adherent is used in a larger structural joint [14].

Many kinds of experimental techniques have been undertaken to study the durability of adhesively bonded joints. It has been found that the degradation of the bonded joint depends on the type of substrate and adhesive, the type of surface pretreatment, the loading configuration and the ageing environment [15].

2.6.1 Types of Failures on Adhesives Bonded Joints

When subjected to loading, debonding may occur at different locations in the adhesive joint. The major fracture types are: Adhesive or Interfacial and Cohesive. In these two circumstances, failure sites are at the adhesive/substrate interface, or cohesively within the adhesive.

2.6.1.1 Cohesive Failure

Cohesive fracture or failure is obtained if a crack propagates in the bulk polymer which constitutes the adhesive. In this case the surfaces of both adherents after debonding will be covered by fractured adhesive. The crack may propagate in the centre of the layer or near an interface. For this last case, the cohesive fracture can be said to be cohesive near the interface [7].

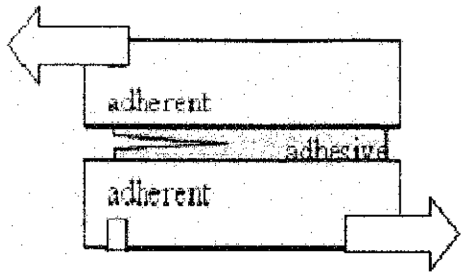


Figure 2.6: Cohesive crack

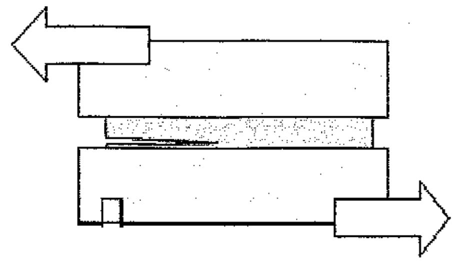


Figure 2.7: Cohesive near interface

2.6.1.2 Adhesive or Interfacial failure

The fracture is adhesive or interfacial when debonding occurs between the adhesive and the adherent. In most cases, the occurrence of interfacial fracture for a given adhesive goes along with smaller fracture toughness. The interfacial character of a fracture surface is usually detected by visual inspection and, it is more commonly noticed after prolonged exposure to moisture [4].

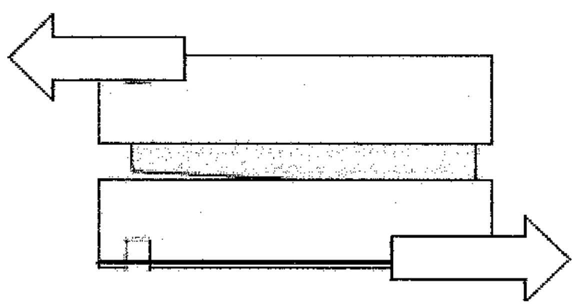


Figure 2.8: Adhesive or Interfacial failure

It is well accepted now that the rate of degradation of a joint is governed by the moisture absorption performance of the adhesive. It is necessary to measure and characterize the uptake behavior of an adhesive during environmental degradation. The factors that influence the moisture diffusion characteristics include temperature, moisture content of the environment and the type of adhesive [16]. Although no universal diffusion model is available, analytical solutions of moisture diffusion have been developed based on Fick's law [17], and are widely used in modeling the degradation in adhesively bonded structures.

Numerous test methods have been developed to characterize the moisture dependent mechanical properties of the adhesive [16] from bulk adhesive specimens or from specially designed bonded joints such as the thick adherent shear test (TAST). These constitutive properties include shear modulus, tensile modulus, Poisson's ratio, yield and ultimate stresses of the adhesive.

Fracture energy is characterized using fracture tests [16] and it may be dependent on the type of joint and surface treatment.

2.7 Criteria for Obtaining a Good Adhesive Bond

There are accepted conditions which result in higher adhesive bond strengths as listed below:

- **Cleanliness of surfaces.**
  The bond surface is ideally cleaned of loose matter and also cleaned of surface oxides and adsorbed gases.

- **The choice of adhesive.**
  It should be such that it wets the adherent surface and also solidifies under an acceptable regime of time, temperature and pressure.

- **The adhesive bonding conditions**
  It should be selected to suit the service conditions of environment and temperature. It should be noted that the difference in coefficient of thermal expansion between the adhesive and adherent can have an important effect on the joint design working over a significant temperature range

- **Adherent.**
  In the preparation of the adherent surface, it is necessary to ensure that the surface has microscopic roughness [18]

CHAPTER 3

METHODOLOGY

3.1 Project Planning

Any project requires proper planning in order for the success of the project and to ensure the project can be completed within the time frame. Suggested plan and schedule for this project is presented in the work flow diagram bellow.

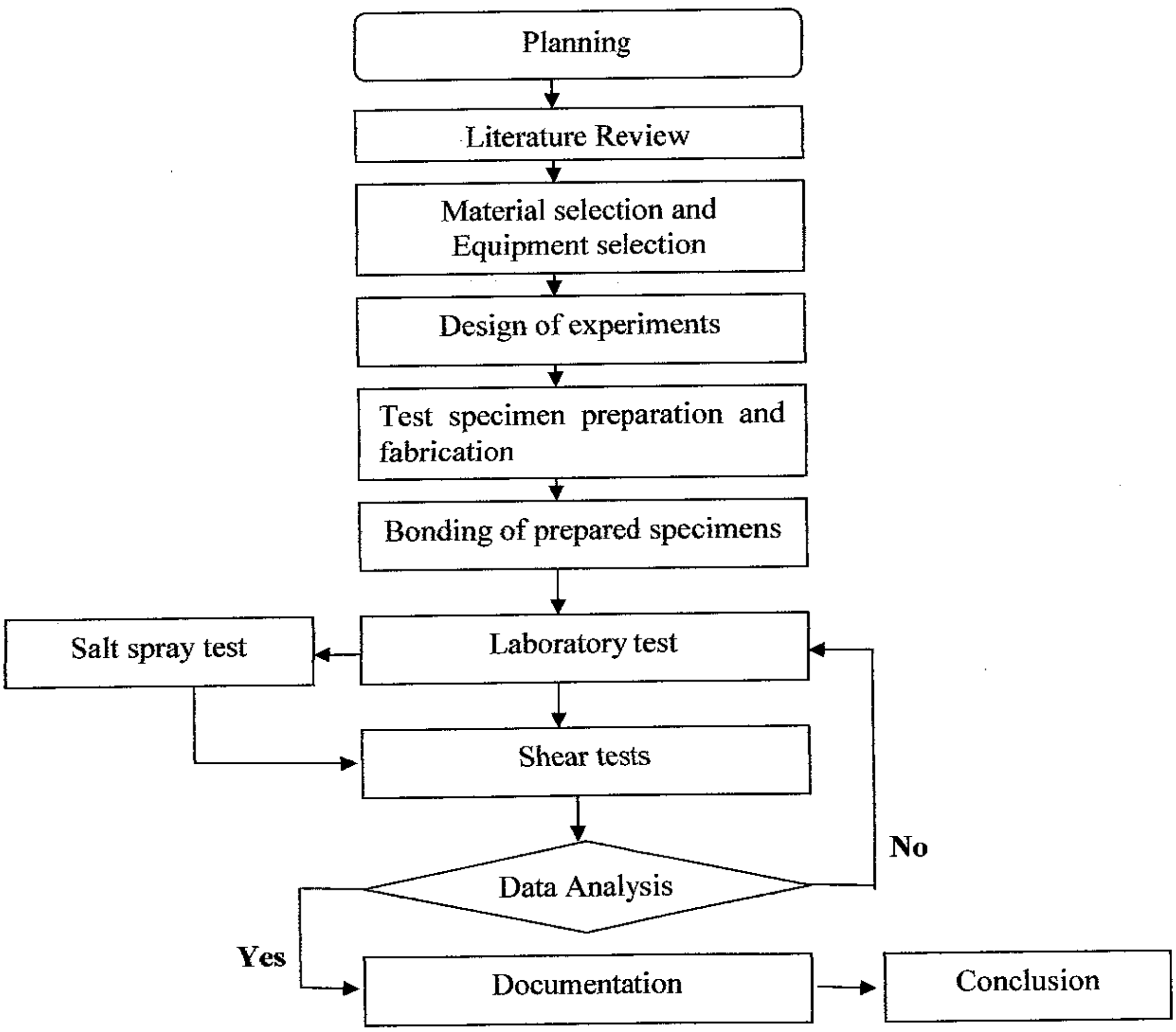


Figure 3.1: Project work flow

3.1.1 Fabrication and Testing Plan

The test specimens will be fabricated from steel and aluminum plates of about 3mm thickness. To achieve the required dimensions of test specimens as prescribed by the ASTM D1002 (thickness 1.6±0.125mm; width 25.4mm; length 101.6mm) and, to proceed with the testing of the jointed specimens, the following steps will be taken:

a) Mill the 3mm thickness of metals using a universal milling machine to obtain the required thickness of about 1.6mm,

b) Having obtained the required thickness, a universal shearing machine will be used to cut the metals to the required specimen dimensions.

c) For the result acquisition, two set of test specimen will be taken; one set of specimens will be tasted for shear strength under normal conditions, while the other will be tasted for shear strength under corrosion effects, to determine the effect of corrosion on adhesive bonded joints. Three types of adhesives will be used to observe the effects of corrosion on different type of adhesive bonded joints
    - Epoxy adhesive (Devcon Epoxy)
    - Super Glue adhesive (Rill Super Glue)
    - The mixture of 50% Devcon epoxy and 50% Rill Super glue

d) For average results, 4 readings of each type of adhesive bond will be taken, and the corresponding results are tabulated in the following pages:

3.1.2 Project Schedule

In the scheduling phase, it is determined when activities are going to be done (on detailed level)

The scheduling of the first part of this Final Year Project is as presented in the following Gantt chart. (Refer to **Appendix A**)

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11		12	13	14
1	Selection of Project Topic	■	■													
2	Preliminary Research Work		■	■	■								B			
3	Submission of Preliminary Report				●								R			
4	Seminar 1 (optional)					■	■	■								
5	Project Work						■	■	■				E			
6	Submission of Progress Report									●			A			
7	Seminar 2 (compulsory)									■	■	■				
8	Project work continues										■	■	K	■		
9	Submission of Interim Report Final Draft														●	
10	Oral Presentation															●

● Suggested milestone
■ Process

Figure 3.2: Project's Gantt chart

3.2 Materials and Equipments Required

The following materials and equipments will be required for the completion of the tests:

3.2.1 Equipment

- Milling Machine; will be used to mill the aluminum and steel plate to the required thickness. **(Figure B2)**
- Shearing Machine; will be used to shear or cut the plates to the required dimensions. **(Figure B3)**
- Corrosion chamber; will be used for some specimens to undergo the corrosion testing. **(Figure 3.9)**
- Shear strength test machine; will be used to test the tensile strength of the joints. **(Figure 3.10)**

3.2.2 Materials

- Aluminum (B 209, Alloy 2024, T3 temper); see **Figure B4**
- Steel (A 109, Grade 2); see **Figure B5**
- Adhesive (Epoxy) see **Figure 3.11**
- Super Glue Adhesive; see **Figure 3.12**

3.3 Recommended Dimensions for Test Specimens (ASTM D1002)

Test specimens shall conform to the form and dimensions of the ASTM D1002 as shown in **Figure 3.3**. The recommended thickness of the sheets is 1.62 $\pm$ 0.25 mm. The recommended length of overlap for most metals of 1.62 mm in thickness is 12.7 $\pm$ 0.25 mm.

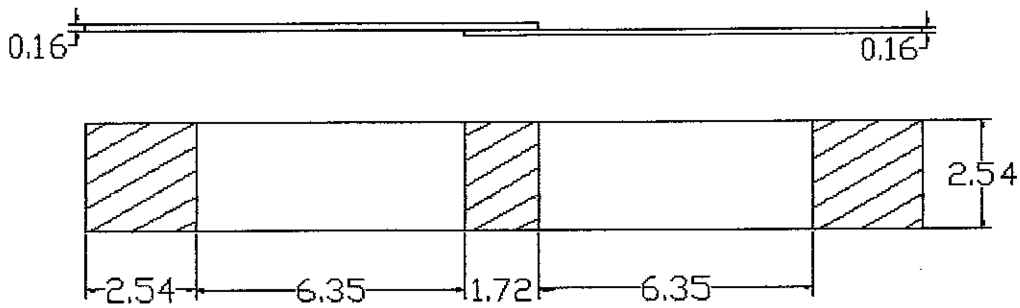


Figure 3.3: Form and Dimensions of test specimen

(All dimensions are in cm)

3.4 Preparation of Test Joints

The following procedures were done in the preparation of the test joints according to the ASTM D1002:

1. The test specimens are to be made up in multiples and then cut into individual test specimens as shown in **Figure 3.3.**

2. Cut sheets of metals prescribed in the recommended dimension for test specimens. (refer to **Appendix B)**

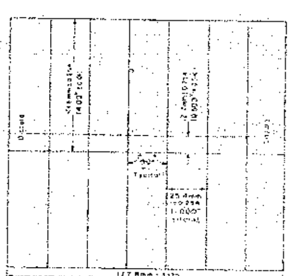


Figure3.4: Test panel

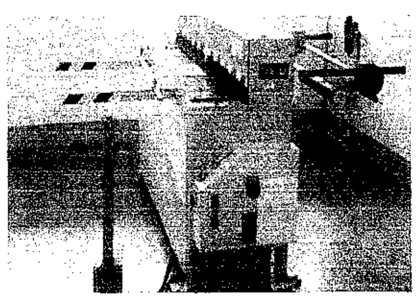


Figure3.5: shearing machine

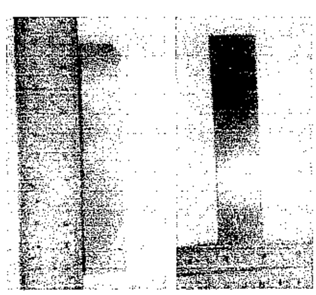


Figure3.6: Test specimens

3. All edges of the metal panels and specimens which will be within (or which will bound) the lap joints shall be machined true (without burrs or bevels and at right angles to faces) and smooth before the panels are surface treated and bonded.

4. Clean and dry the sheets carefully, according to the procedure prescribed by the manufacturer of the adhesive.

5. Prepare and apply the adhesive according to the recommendations of the manufacturer of the adhesive.

6. Apply adhesive to a sufficient length in the area across the end of one or both metal sheets so that the adhesive will cover a space approximately 6 mm longer than the overlap.

7. Assemble the sheets so that they will be held rigidly so that the length of overlap will be controlled as shown in the figure below.

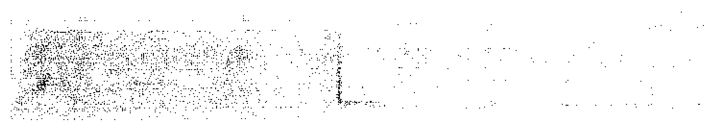


Figure 3.7: Jointed specimen

8. Allow the adhesive to cure as prescribed by the manufacturer of the adhesive.

3.5 Salt Spray Test [20]

Salt spray chamber is used to simulate a corrosive environment; some bonded specimens will undergo the salt spray testing to determine the effects of corrosive environment on the adhesives bonded joint. For the salt spray testing, the concentration of the salt solution as well as, the conditions in the salt spray chamber, will be followed as prescribed in the ASTM B117 – 97 procedures.

3.5.1 Salt Solution

The salt solution shall be prepared by dissolving 5 $\pm$ 1 parts by mass of sodium chloride in 95 parts of water conforming to type IV in specification D 1193 of the ASTM.

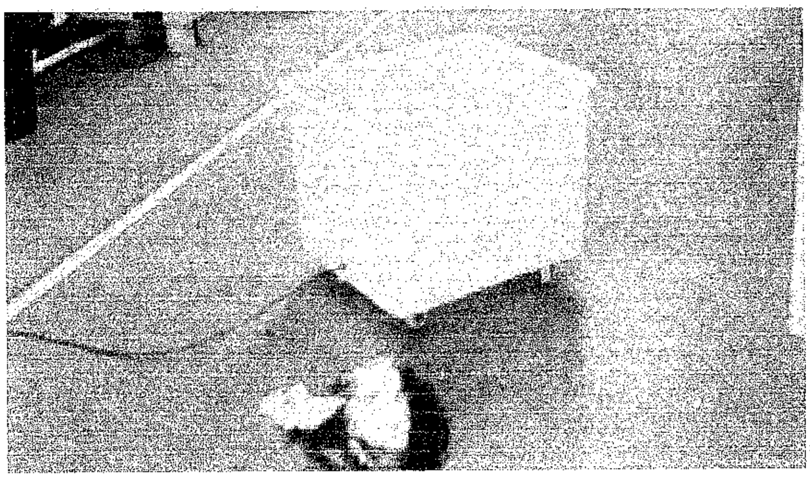


Figure 3.8: Salt solution

3.5.2 Condition in the Salt Spray Chamber

The temperature in the exposure zone of the salt spray chamber shall be maintained at 35 +1.1 – 1.7°C and the nozzle shall be so directed or baffled that none of the spray can interrupt directly on the test specimen

The compressed air supply to the nozzle or nozzles for atomizing the salt solution shall be free of oil and dirt and maintained between 69 and 172kPa/m^2 (10 and 25psi); and the exposure period for specimens was around 240 hours (10days)

3.5.3 Position of Specimens During Exposure

The position of the specimens in the salt spray chamber during the test shall be such that:

i. The specimens shall be supported or suspended between 15 to 30° from the vertical and preferably parallel to the principal direction of the flow of the fog through the chamber.
ii. The specimens shall not contact each other or any metallic material or any material capable of acting as a wick.
iii. Each specimen shall be so placed as to permit free settling of fog on all specimens.
iv. Salt solution from one specimen shall not drip on any other specimen

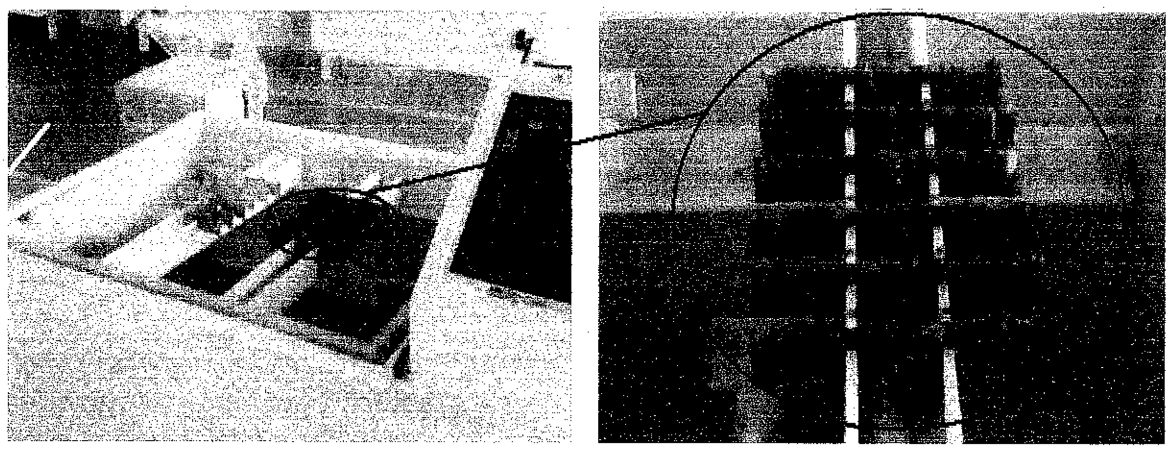


Figure 3.9: Corrosion Chamber (Model SF/450/CCT)

3.6 Shear Test

The shear test will be used to determine the shear strength of the bonded specimens; the jointed specimens will be tested for shear till the failure using the shear test machine shown in **Figure 3.10**, which will help in determining the type of joint failure on the bonded parts. For the shear test, the condition of the shearing machine, as well as, the position of the specimens during the test, will be following the procedures prescribed by the ASTM D1200.

3.6.1 Procedures of Shear Testing

i. Test the specimens, prepared as prescribed in the methodology, as soon after preparation as possible. The manufacturer of the adhesive may, however, prescribe a definite period of conditioning under specific conditions before testing.

ii. Place the specimens in the grips of the testing machine so that the outer 25mm of each end are in contact with the jaws and so that the long axis of the test specimen coincides with the direction of applied pull through the center line of the grip assembly.

iii. Apply the loading immediately to the specimen at the rate of 80 to 100Kg/cm^2 (1200 to 1400 psi) of the shear area per minute. Continue the load to failure.

iv. The machine should be set to approach the rate of loading approximately at 0.05in. /min. (1.3mm/min)

v. There shall be at least 3 specimens for each test for more accurate results and, all dimensions should be as prescribed by ASTM D 1002. [19]

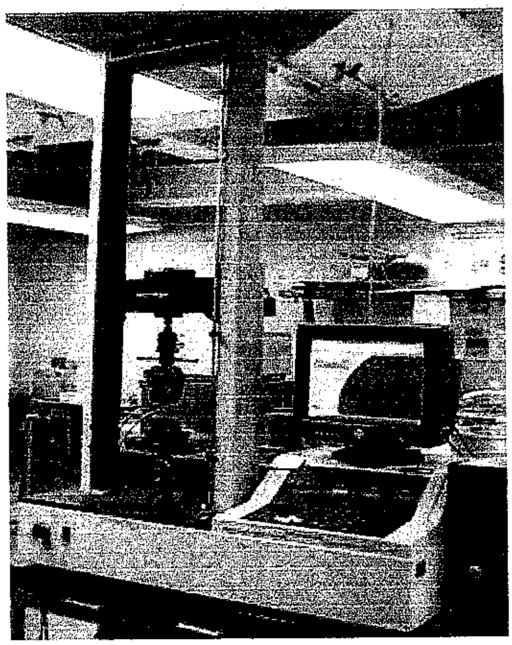


Figure 3.10: Shear Test Machine
(Model Lloyd LR 5k)

3.7 Adhesives Specifications

There are many types of adhesives, but for this experiment, the adhesives used are Devcon epoxy and Rill super glue adhesive. It is necessary to know the specifications of the adhesives to be used; fro safety purposes as well as, for performance purposes; technical information of an adhesives, enables us to predict the strength of the joints, as well as, other characteristics that could be affected by the working environment, such as the temperature, the exposure to chemical, etc. and consequently that could helps in the choosing of the adhesives as well as, in avoiding or reducing failures.

3.7.1 DEVCON Epoxy

As shown in the **Figure 3.11**, Devcon epoxy is a high-clarity, non-shrink adhesive/potting compound that provides a strong bond to metals, glass, rigid plastics, concrete and wood. The adhesive bond is resistant to weathering, and wide variations in temperature. To obtain the maximum strength of the joints using Devcon epoxy, the procedures prescribed by the manufacturer of the adhesive should be followed:

a) Surface pre-treatment

Devcon epoxy works best on clean surfaces. If surface is oily or greasy, use Devcon Fast Cleaner 2000 Spray/Cleaner Blend 300 to degrease the surface. Surfaces should be free of heavy deposits of grease, oil, dirt or other contaminants or cleaned with industrial cleaning equipment such as vapor degreasers or hot aqueous baths. Abrading or roughing the surfaces of metals will increase the microscopic bond area significantly and optimize the bond strength.

b)Application of Devcon Epoxy

Apply mixed (50% epoxy & 50% Hardener) epoxy directly to one surface in an even film or as a bead. Assemble with the mating part within the recommended working time. Obtain firm contact between the parts to minimize any gap and ensure good contact of the epoxy with the mating part. A small fillet of epoxy should flow out the edges to show there is adequate gap filling. Let bonded assemblies stand for the recommended functional cure time before handling.

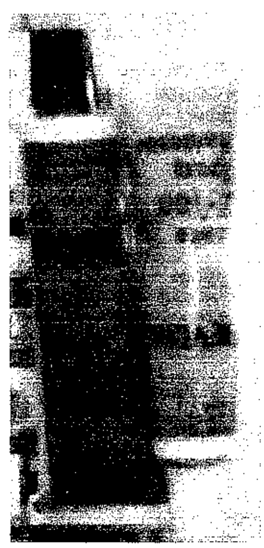


Figure 3.11: Devcon Epoxy

Table 3.1: DEVCON Epoxy Technical Information [21]

Chemical family: Polyamine adduct		Packaging	2x28g Devtube
Viscosity (cP)	5000	Tariff Code	78143 30345
Temperature resistance:	-40°C to 160°C	Shelf life:	3 years
Specific Volume (cm^3/kg):	907	**Chemical resistance:**	
Specific weight (g/cm^3):	1.4	Kerosene	Very Good
MSDS	Yes	Methanol	Fair
Overlap shear on aluminum	18MPa	Hydrochloric Acid	Fair
Overlap shear on steel	15MPa	Toluene	Very Good
Cure time at 24°C	16hours		

3.7.2 Rill Super Glue Adhesive

Rill super glue as shown in **Figure 3.12** is a specialized series of single component, solvent free liquids that are individually formulated for instant bonding of mated metal, plastic, rubber and other non-porous parts and assemblies. Rill super glues cure at room temperature without pressure to provide exceedingly high bond strengths. Cure is catalyzed by weak alkaline materials including trace amounts of moisture on the surface of parts to be bonded. Shrinkage is negligible because Rill super glues contain 100% reactive materials. For the achievement of a maximum strength on the joints using Rill super glue, the procedures prescribed by the manufacturer of Rill super glue should be followed.

a) Surface pre-treatment

Rill super glue works best on clean surfaces. Complete remove moisture, oil, rust, mold release agent and other contaminants from both surfaces; the surface pretreatment is an essential factor for ensuring satisfactory bonding strength.

b)Application of Rill Super Glue

Rill super glues are single component adhesives, they required no mixing. So apply Rill super glue on the surfaces to be bonded, lap them together to obtain firm contact between the parts minimizing any gap and ensure good contact of the adhesive with the mating parts. Let bonded assemblies stand for the recommended functional cure time before handling.

Table 3.2: RILL (Super Glue) Technical Information [22]

Chemical family: Cyanoacrylate Acid		Color: Colorless
Viscosity (cP):	80 to 120	Shelf life: 3g tube/Matic: 3 years
Temperature resistance:	-50°C to 80°C	
Specific Gravity:	1.05	Fixturing time (sec): Steel: 10 to 30 Aluminium: 5 to 15
MSDS	Yes	
Shear Strength on aluminum	15MPa	Solubility in water (20°C): Non-solubility
Shear Strength on steel	22MPa	
Cured time (full strength) 22°C	24 hours	

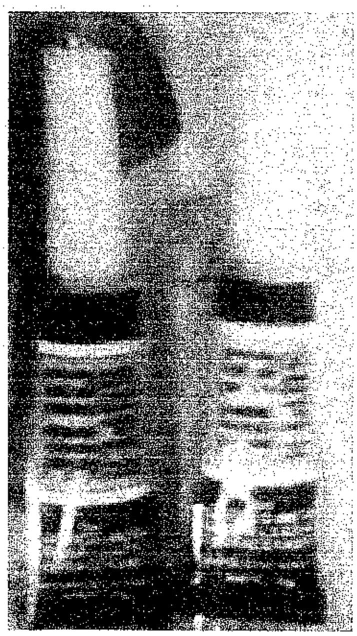


Figure 3.12: Rill Super Glue

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

As stated earlier on the testing plan, for data acquisition, two set of test specimen were taken, one set of specimens was tasted for shear strength under normal conditions, while the other were tested for shear strength under corrosion effects. Two different types of adhesives were used to determine the effects of corrosion on different type of adhesive bonded joints:

- Epoxy adhesive (Devcon Epoxy)
- Super Glue adhesive (Rill Super Glue)

For more accurate results, 4 readings of each type of adhesive bond were taken, and the average of each type of adhesive bonded joint was compared to the theoretical value of such type of joint strength (shown in the **Table 4.1**) in order to determine the achieved strength on joints under normal conditions, as well as, under corroded conditions. The corresponding results are tabulated in the following pages:

Table 4.1: Theoretical Shear Strength Values

	Theoretical shear strength Values (MPa)
Aluminum bonded with Devcon epoxy *(A-DE)*	18
Aluminum bonded with Rill super glue *(A-RI)*	15
Steel bonded with Devcon epoxy *(S-DE)*	15
Steel bonded with Rill super glue *(S-DE)*	22

4.1.1 Results of Adhesives Bonded Joints on Aluminum sheets

The experimental results of the single lap joint strength of aluminum with each of the two different types of adhesives were determined and tabulated as bellow:

Table 4.2: Aluminum single lap joint with Devcon epoxy

Aluminium bonded with Epoxy	Average Shear Strength (MPa)	Level of Theoretical Strength achieved (%)	Failure Type
Non-corroded	16.43	91.3	Cohesive
Corroded	10.54	58.6	Mixture of cohesive and adhesive
strength reduction	5.89	32.7	

Table 4.3: Aluminum single lap joint with Rill super glue

Aluminium bonded with Rill super glue	Average Shear Strength (MPa)	Level of Theoretical Strength achieved (%)	Failure Type
Non-corroded	12.50	83.3	Adhesive
Corroded	4.54	30.3	Adhesive
strength reduction	7.96	53	

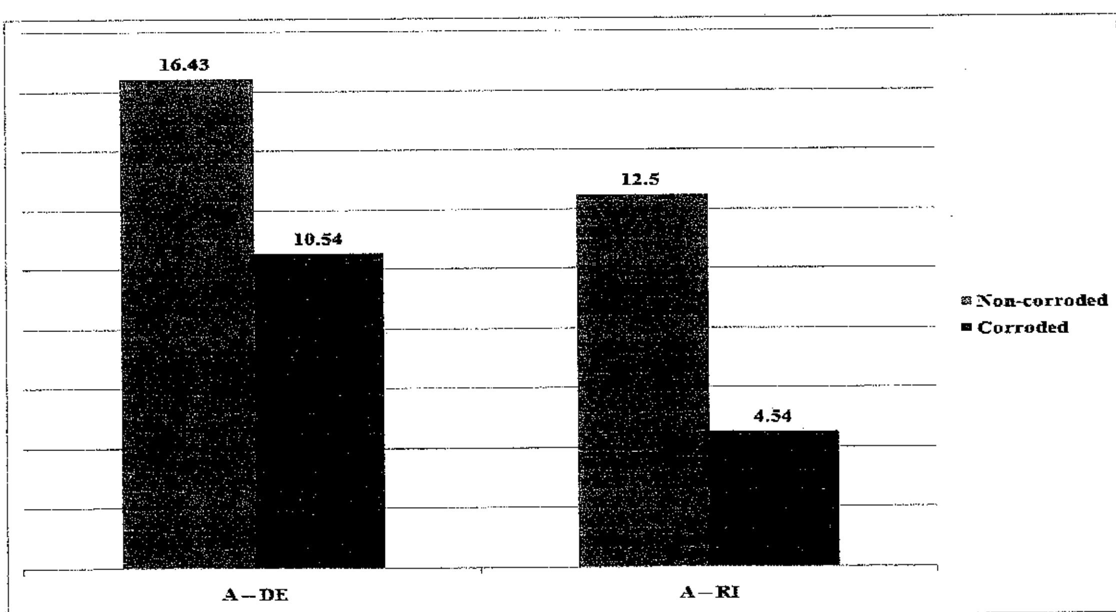


Figure 4.1: Results of Adhesive Bonded joints on Aluminum

4.1.2 Results of Adhesives Bonded Joints on Steel sheets

The results of the strength and the failure type of the steel single lap joint with each, of the two types of adhesives used in the experiment were tabulated as bellow:

Table 4.4: Steel single lap joint with Devcon epoxy

Steel bonded with Devcon Epoxy	Average Shear Strength (MPa)	Level of Theoretical Strength achieved (%)	Failure Type
Non-corroded	14.66	97.7	Cohesive
Corroded	6.19	41.3	Adhesive
strength reduction	8.47	56.4	

Table 4.5: Steel single lap joint with Rill super glue

Steel bonded with Rill super glue	Average Shear Strength (MPa)	Level of Theoretical Strength achieved (%)	Failure Type
Non-corroded	18.01	81.8	Adhesive
Corroded	13.38	60	Adhesive
strength reduction	4.63	21	

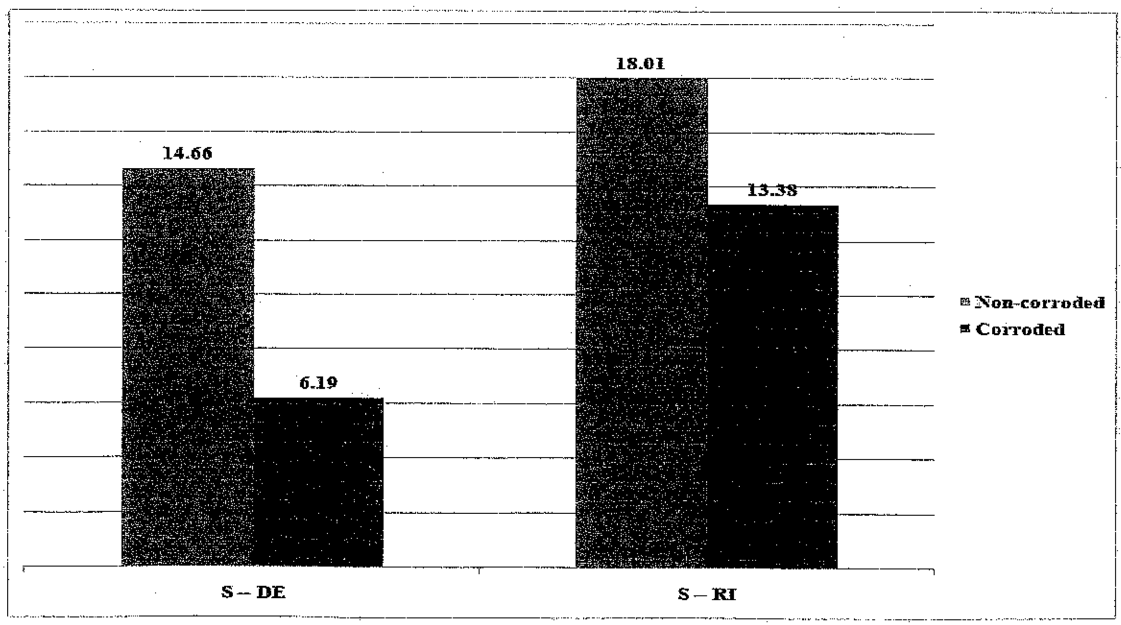


Figure 4.2: Results of Adhesive Bonded joints on Steel sheets

4.2 Discussion

From the results obtained from the experimental tests of the study of the degradation of adhesive bonded joints strength under corrosive environment, and tabulated as shown bellow, the following were observed:

Table 4.6: Summary of results

Aluminum				Steel			
Type of bonded joint	Average Shear Strength (MPa)	Level of theoretical Strength achieved (%)	Type of Failure	Type of bonded joint	Average Shear Strength (MPa)	Level of theoretical Strength achieved (%)	Type of Failure
A - DE	16.43	91.3	Cohesive	S - DE	14.66	97.7	Cohesive
A-DE-C	10.54	58.6	Mixture of cohesive and adhesive	S-DE-C	6.19	41.3	Adhesive
A-RI	12.50	83.3	Adhesive	S-RI	18.01	81.8	Adhesive
A-RI-C	4.54	30.3	Adhesive	S-RI-C	13.38	60.8	Adhesive

4.2.1 Aluminum sheets Jointed with Devcon Epoxy

From **Table 4.6**, the level of theoretical strength achieved on the joints of aluminum sheets under normal conditions was around 16.43MPa, which represent the 91.3% of the theoretical strength of a single lap joint of aluminum sheets with Devcon epoxy, this high percentage of strength achievement is due to the condition of the sheet metals surfaces and the conditions of the adhesive; as the surfaces pretreatment were carefully carried out, as well as, the application of the adhesive on the sheet metal and, in the absence of possible impurities that may negatively affect the chemical and/or mechanical properties of the adhesives. All those factors lead to the optimization of the joint strength.

After the joint has undergone corrosion effects, the strength of the joint reduced to 10.54MPa, representing the 58.6% of the single lap joint of aluminum with Devcon epoxy; this reduction in the joint strength, may be due to the corrosive components that affects negatively the surfaces of the jointed specimens and possibly the properties of the adhesive, leading to the weaken of the joint strength.

The type of joint failure presented under normal conditions, was entirely cohesive as the fracture propagated within the adhesive as can be seen in **Figure 4.3,** this indicates a good adhesion of the adhesive on the adherent, while for jointed sheets under corrosion effects, the type of joint failure presented was mixed between Cohesive and Adhesive or Interfacial failure, since the fracture propagated at some spots in an adhesive and in others in a cohesive manner as can be seen in **Figure 4.4**

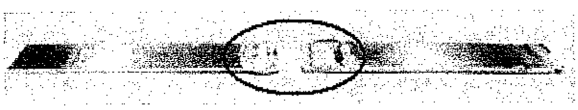


Figure 4.3: Cohesive failure (A-DE)

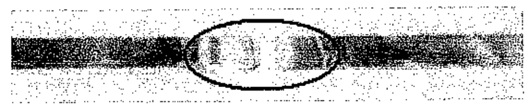


Figure 4.4: Mixture of cohesive & Adhesive (A-DE-C)

4.2.2 Aluminum sheets Jointed with Rill Super glue

Based on the results obtained from the experiments and plotted in **Table 4.6**, the shear strength achieved on the joints of aluminum sheets under normal conditions was around 12.5MPa, representing the 83.3% of the theoretical strength of a single lap joint of aluminum sheets with Rill super glue, the high percentage of strength achievement is due to the condition of the sheet metals surfaces and the conditions of the adhesive; as the surfaces pretreatment were carefully carried out as prescribed by the manufacturer of the adhesive, as well as, the application of the adhesive on the sheet metal and, in the absence of possible impurities that may negatively affect the chemical and/or mechanical properties of the adhesives. All those factors lead to the achievement of high joint strength.

For the joint undergone corrosive environment, the strength of the joint reduced to 4.54MPa, which represents the 30.3% of the single lap joint of aluminum with Rill super glue; the reduction in the joint strength, may be due to the corrosive components that affects negatively the surfaces of the jointed specimens and possibly the properties of the adhesive, and consequently weaken of the joint strength.

The type of joint failure presented under normal conditions, as well as, under corroded effects, was entirely adhesive or interfacial since the fracture propagated between the adhesive and the adherent as can be seen in **Figure 4.5**, and **Figure 4.6,** this type of failure may be because of the chemical properties of the adhesives, which tend to be in-elastic after it has cured on the joint.

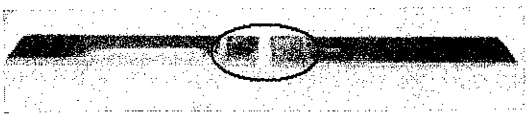


Figure 4.5: Adhesive failure (A-RI)

Figure 4.6: Adhesive failure (A-RI-C)

4.2.4 Steel sheets Joint with Devcon Epoxy

By referring to **Table 4.6**, the shear strength achieved on the joints of aluminum sheets under normal conditions was around 14.66MPa, which represent the 97.7% of the theoretical strength of a single lap joint of steel sheets with Devcon epoxy, this high percentage of strength achievement is due to the condition of the sheet metals surfaces and the conditions of the adhesive; as the surfaces pretreatment were carefully carried out, as well as, the application of the adhesive on the sheet metal and, in the absence of possible impurities that may negatively affect the chemical and/or mechanical properties of the adhesives. All those factors lead to the optimization of the joint strength.

After the joint has undergone corrosion effects, the strength of the joint reduced to 6.19MPa, representing the 41.3% of the theoretical strength of a single lap joint of aluminum with Devcon epoxy; this reduction in the joint strength, is due to the corrosive components (rusting) that affects negatively the surfaces of the jointed specimens and possibly the properties of the adhesive, leading to the weaken of the joint strength.

The type of joint failure presented under normal conditions, was entirely cohesive as the fracture propagated within the adhesive as can be seen in **Figure 4.7,** this indicates a good adhesion of the adhesive on the adherent, while for jointed plate under corrosion effects, the type of joint failure presented was entirely Adhesive or Interfacial, since the fracture propagated between the adhesive and the adherent due to the rusting on the surfaces of the metal which leaded to that type of failure as it can be seen in **Figure 4.8**

Figure 4.7: Cohesive failure (S-DE)

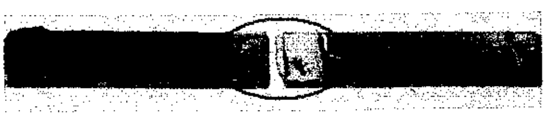


Figure 4.8: Adhesive failure (S-DE-C)

4.2.5 Steel sheets Jointed with Rill super glue

The results obtained from the tests experiments and tabulated in **Table 4.6**, indicates that the shear strength achieved on the joints of steel sheets under normal conditions was around 18.01MPa, representing the 81.8% of the theoretical strength of a single lap joint of steel sheets with Rill super glue, the high percentage of strength achievement is due to the condition of the sheet metals surfaces and the conditions of the adhesive; as the surfaces pretreatment were carefully carried out as prescribed by the manufacturer of the adhesive, as well as, the application of the adhesive on the sheet metal and, in the absence of possible impurities that may negatively affect the chemical and/or mechanical properties of the adhesives. All those factors lead to the achievement of high joint strength.

For the joint undergone corrosive environment, the strength of the joint reduced to 13.38MPa, which represents the 60.8% of the theoretical strength of single lap joint of steel with Rill super glue; the reduction in the joint strength, may be due to the corrosive components that affects negatively the surfaces of the jointed specimens and possibly the properties of the adhesive, and consequently weaken of the joint strength.

The type of joint failure presented under normal conditions, as well as, under corroded effects, was entirely adhesive or interfacial since the fracture propagated between the adhesive and the adherent as can be seen in **Figure 4.9,** and **Figure 4.10,** this type of failure may be because of the chemical properties of the adhesives, which tend to be in-elastic after it has cured on the joint or, because of the rust on the corroded jointed specimens.

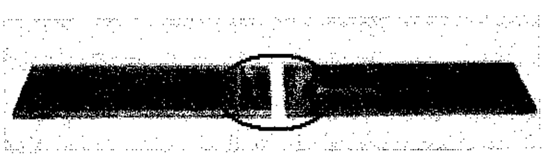


Figure 4.9: Adhesive failure (S-RI)

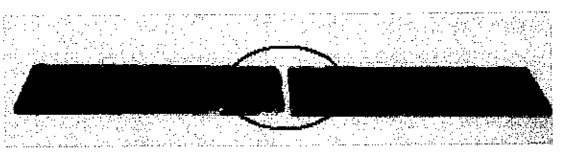


Figure 4.10: Adhesive failure (S-RI-C)

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

From the observation and analysis of the results from the experiments of adhesives bonded joint, it can be concluded that adhesives bonded joints will suffer a loss in joint strength when exposed to high humidity, and/or high temperatures, water also affects both the chemical and mechanical properties of the adhesive and consequently, weaken the joint strength as it can be observed in the results obtained from the texts experiments.

Using aluminum sheets as adherent, it gives better results when bonded together with Devcon epoxy compared to Rill super glue as the adhesive, since the joint of aluminum with Devcon epoxy presented higher joint strength in normal conditions, as well as, lesser reduction in the joint strength when exposed to corrosives environment. Further studies on other characteristics such as working temperature, working environment, the required joint strength, will need to be done, for the best selection of the adhesive.

For steel sheets as adherent, the best result is obtained when jointed together with Rill super glue and maintained at normal conditions, as it presented higher joint strength achieved compared to the joint of steel sheets Devcon epoxy; as well as, higher joint strength after having been exposed to corrosive environment. But, it will be necessary to study other characteristic such as, the working temperature, the environment, for better selection of the adhesive.

5.2 RECOMMENDATIONS

For adhesive joints, it is recommended to follow the prescriptions of the manufacturer of the adhesive to, achieve the maximum strength on the joint. From the investigation conducted and the results obtained, the author would like to recommend the following:

- Due to the considerably losses in joint strength of adhesive bond under corrosive environment, it is recommended to continuously monitor the joints to avoid premature failures, as well as, to avoid the losses of equipments and/or personnel.

- This investigation project can be more expanded by covering more types of adhesives, as well as, adherent to develop a better analysis of the degradation of the adhesive joint strength under environmental effects, as well as, to provide better alternative for adhesives selection with respect to the working environment.

- Investigate the degradation of adhesive bonded joints in more different type of environments, such as: rain, sun, cold etc… for better analysis of the environmental effects on adhesives bonded joints.

- Investigate on possible adhesive or mixture of adhesives that could enhance the strength of adhesives joints under corrosives environment

- The usage of computer and software for the simulation of the adhesive bonded joint strength will result in, more relevant and accurate data, as well as, in better selection of adhesive, with respect to the working environment.

REFERENCES:

[1] Tong L, Steven GP. Analysis and Design of Structural Bonded Joints. Dordrecht: Kluwer Academic Publishers; 1999.

[2] Pei JH, Shenoi RA. Examination of key aspects defining the performance characteristics of out-of-plane joints in FRP marine structures. Comp: A Appl Sci Manuf 1996;27A(2):89–103.

[3] Mackerle J. Finite element analysis and simulation of adhesive bonding. soldering and brazing—an addendum: a bibliography (1996–2002). Modelling Simul Mater Sci Eng 2002;10:637–71.

[4] en.wikipedia.org/wiki/Adhesive

[5]http://www.specialchem4adhesives.com/resources/adhesionguide/index.aspx?id=theory

[6] Goland M, Reissner E. The stresses in cemented joints J Appl Mech 1944;11:A17–27.

[7] Oplinger DW. Effects of adherend deflections in single lap joints. Int J Solids Struct 1994;31(18):2565–87.

[8] Li G. Deformations of balanced and unbalanced adhesively bonded single-lap joints, PhD thesis, The University of New Brunswick, Canada; 2000.

[9] Hart-Smith LJ. Adhesive-bonded double-lap joints, NASA CR-112235, National Aeronautics and Space Administration; 1973

[10] Beevers A. Int J Mater Prod Technol 1999;14:373–84.

[11] Goland, M., Reissner, E.: The stresses in cemented joints. ASME J. Appl. Mech. 11, A 17- 27 (1944)

[12] www.npl.co.uk

[13] Keller T, Vallee T. Adhesively bonded lap joints from pultruded GFRP profiles. Part I: Stress–Strain Analysis and Failure Modes. Composites: Part B 2005;36:331–40.

[14] Wentworth SE, Bergquist PR, Sennett MS, Proceedings of Adhesion '93. York, UK: The Inst of Materials, 1993. p.6}13

[15] Crocombe AD. Int J Adhes 1997;17:229–38.

[16] Loh WK, Crocombe AD, Abdel-Wahab MM, Ashcroft IA. J Adhes 2003;79:1135-60.

[17] Abdel Wahab MM, Crocombe AD, Beevers A, Ebtehaj K. Int J Adhes Adhes 2002;22:61–73.

[18] http://www.umaine.edu/adhesion/gardner/540lecture/adhesion%20lecture9.pdf

[19] ASTM D1002

[20] ASTM B117 – 97

[21] http://devcon.ee/tech/acp.php

[22]http://www.barnhillbolt.com/specs/loctite404tds.pdf

APPENDICES

APPENDIX A

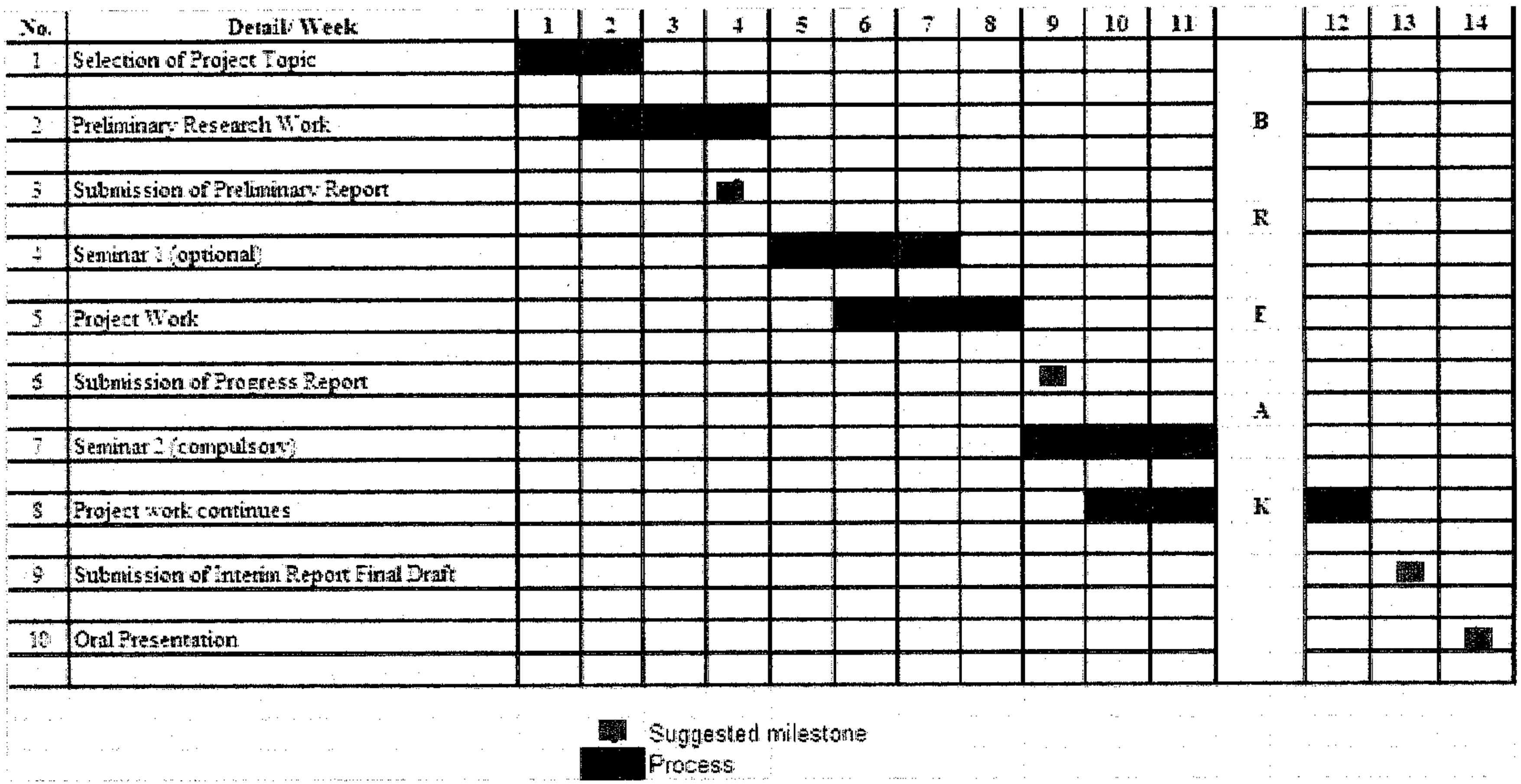


Figure A1: Gantt chart for FYP1

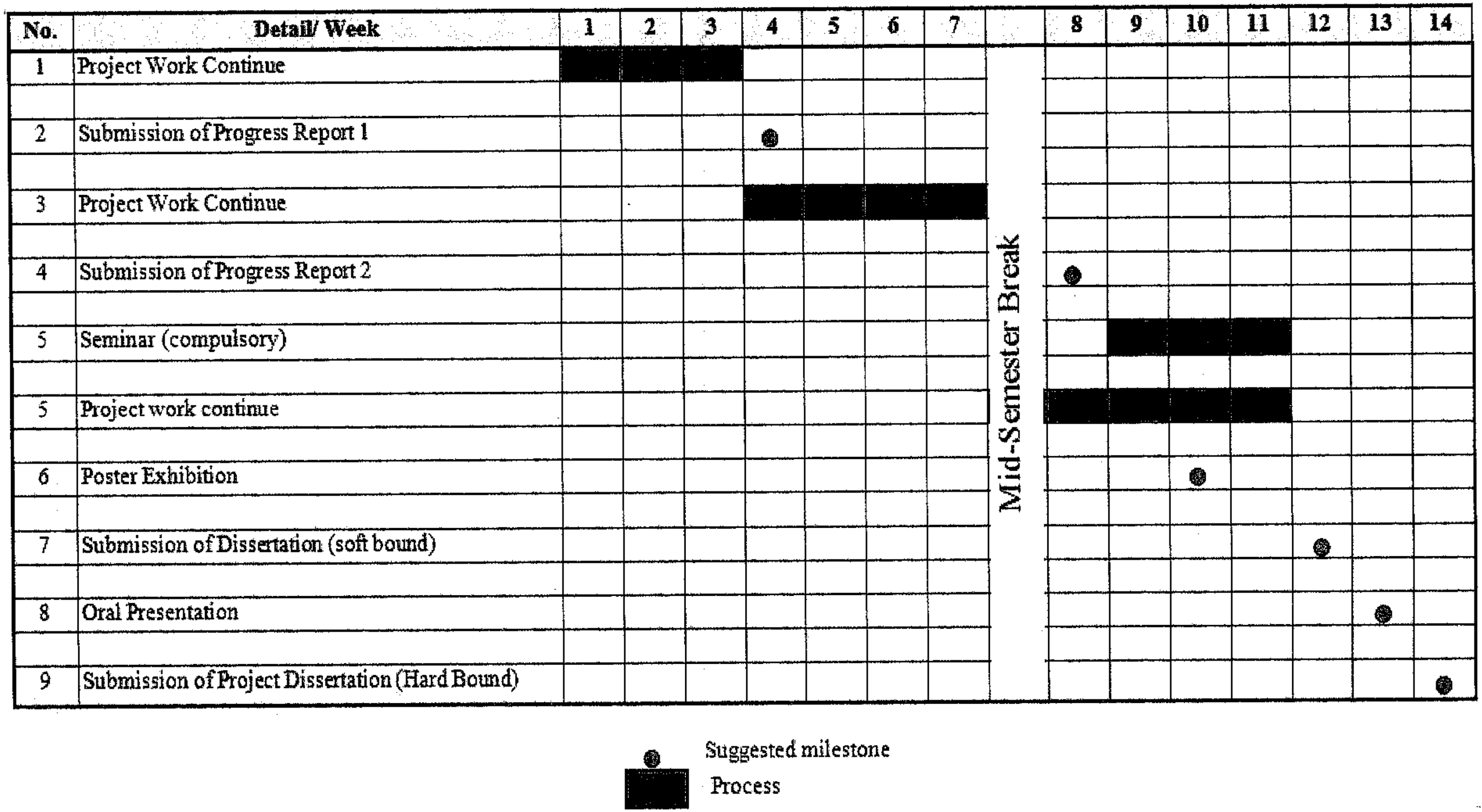


Figure A2: Gantt chart for FYP2

APPENDIX B

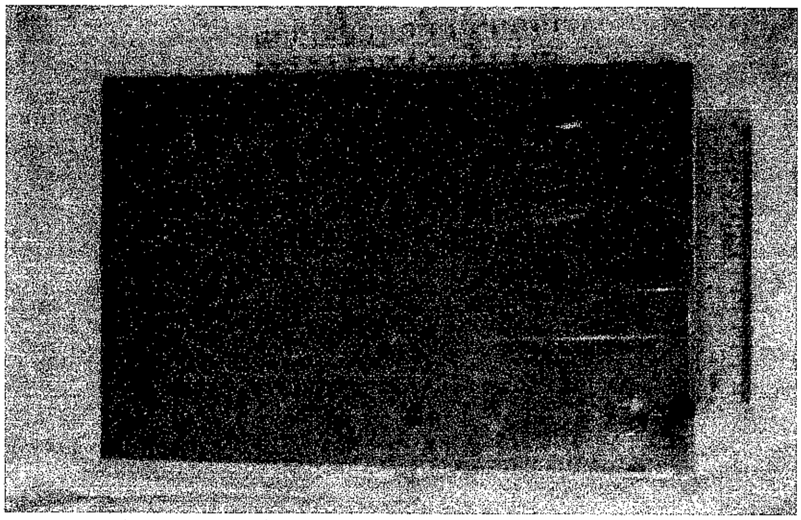


Figure B1: Row plate

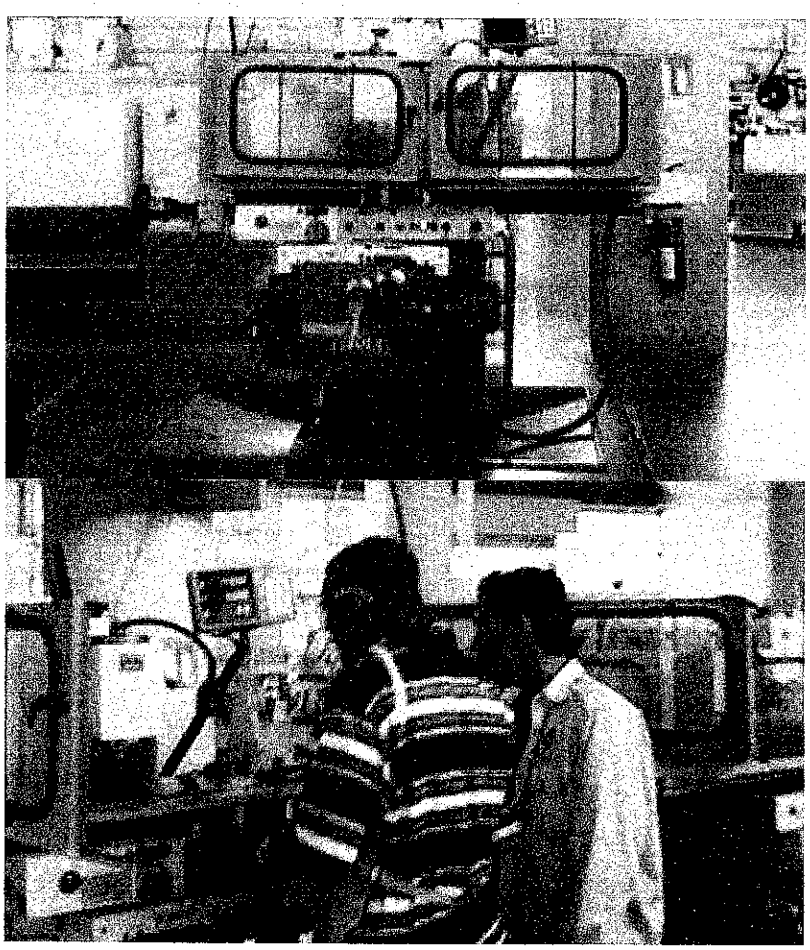


Figure B2: Milling Machine

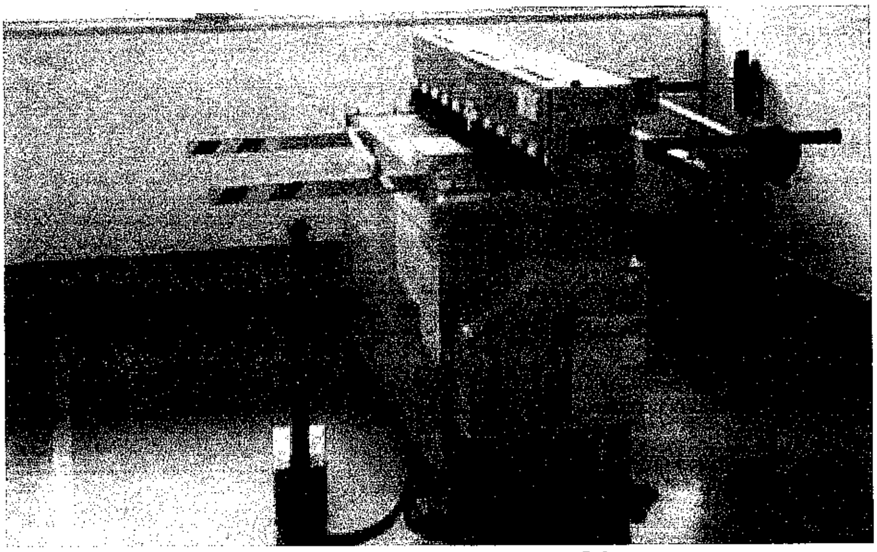


Figure B3: Shearing Machine

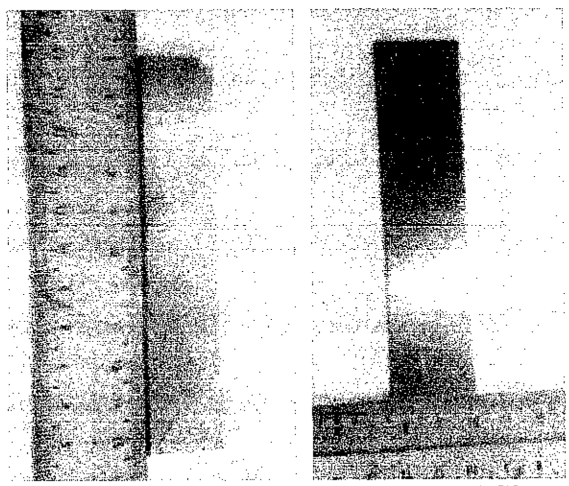


Figure B4 & B5: Aluminum & Steel Sheets

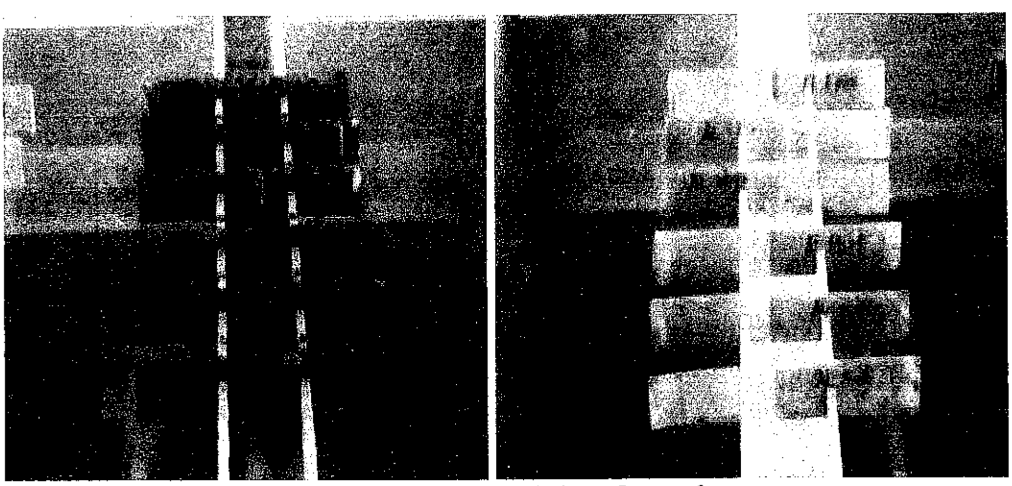


Figure B6: Corroded jointed specimens

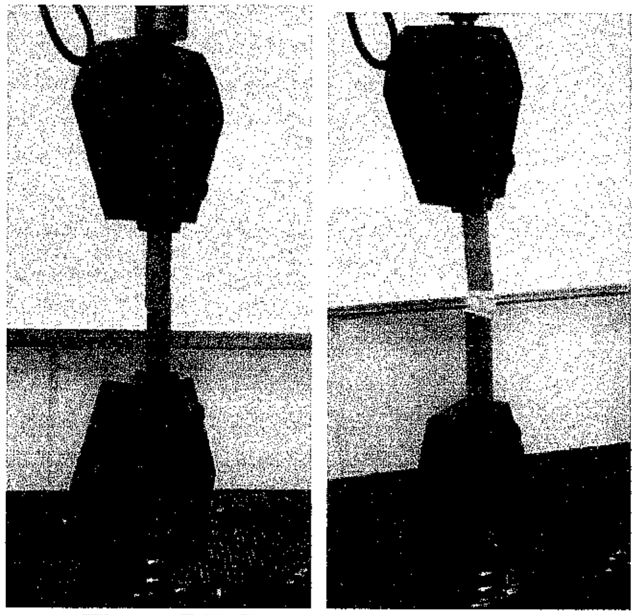


Figure B7: Shear Strength Testing

Brunel Close, Park Farm
Wellingborough
Northants
NN8 6QX
01933 675299
01933 670800
12/05/08

APPENDIX C

2 TON EPOXY

PRODUCT DATA SHEET

A high strength, non-shrinking, adhesive/potting compound specially formulated for high clarity, good impact strength, and water resistance. The adhesive bond is resistant to weathering, solvents, and wide variations in temperature.

FEATURES

- Formulated for clarity
- 100% reactive, no solvents
- Good water and chemical resistance
- *Fills gaps and voids*
- Room temperature curing
- Non corrosive

RECOMMENDED APPLICATIONS:

- Bonding or potting electronic components and assemblies
- Creating moisture-resistant seals
- Fast-curing, thin set, bonding above 4°C
- Suitable for bonding ceramics, ferrous and non-ferrous, ferrites, wood, glass and concrete

PRODUCT DATA

Physical Properties - (uncured)

Colour	Clear
Mix ratio by volume	1:1
Mixed viscosity	5,000 cps
Working time 28 grams @ 24°C	10 mins
Functional cure @ 24°C	2 hours
Coverage 0.25mm thickness	15.18 cm^2/Kg
Specific Volume	907cm^3/kg
% Solids by Volume	100

Performance Characteristics - (7 days cured @ 24°°C)

Adhesive tensile shear, ASTM D1002	15.5N/mm^2
Operating temperature, dry	-40°C to 93°C
Cured Density ASTM D792	1.10 gm/cm^3
Cured hardness, ASTM D2240	83D
Dielectric strength ASTM D149 (volts/mil)	600
Compression strength ASTM D695	75.86 N/mm^2
Coefficient of thermal conductivity ASTM D696	83

Chemical Resistance: 7 days room temperature cure (30 days immersion @ 24°C)

Kerosene	Very Good	Methanol	Fair
Hydrochloric Acid	Fair	Toluene	Very Good
Chlorinated Solvent	Very Good	Ammonia	Very Good
Sulphuric Acid 10%	Fair	Sodium Hydroxide 10%	Very Good

Please consult ITW Devcon for other chemicals.

Brunel Close, Park Farm
Wellingborough
Northants
NN8 6QX
01933 675299
01933 670800
12/05/08

Epoxies are very good in water, saturated salt solutions, leaded gasoline, mineral spirits, ASTM#3 oil and propylene glycol. Epoxies are not recommended for long-term exposure to concentrated acids and organic solvents.

APPLICATION INFORMATION

General Surface Preparation:

2 Ton Epoxy works best on clean surfaces. If surface is oily or greasy, use Devcon Fast Cleaner 2000 Spray/Cleaner Blend 300 to degrease the surface. Surfaces should be free of heavy deposits of grease, oil, dirt or other contaminants or cleaned with industrial cleaning equipment such as vapour degreasers or hot aqueous baths. Abrading or roughing the surfaces of metals will increase the microscopic bond area significantly and optimise the bond strength.

Mixing:

This product is available in cartridge and 28g Devtube form only.
The cartridge should be used with the appropriate manual Applicator Gun and Static Mixer Nozzle.
The Static Mixer Nozzle enables the epoxy to be dispensed, metered and directly applied to the surfaces to be bonded.
Please note: Once the product cures in the nozzle it has to be thrown away and a new nozzle used.
For small amounts use Devcon's 28g Devtube, which comes with it's own plunger to extrude the two components at an equal rate.

Application:

Apply mixed epoxy directly to one surface in an even film or as a bead. Assemble with the mating part within the recommended working time. Obtain firm contact between the parts to minimise any gap and ensure good contact of the epoxy with the mating part. A small fillet of epoxy should flow out the edges to show there is adequate gap filling. For very large gaps, apply epoxy to both surfaces and spread to cover the entire area, or make a bead pattern, which will allow flow throughout the joint.
Let bonded assemblies stand for the recommended functional cure time before handling. They are capable of withstanding processing forces at this point, but should not be dropped, shock loaded or heavily loaded.

Cure:

Full bond strength is reached in 16 hours.

STORAGE AND SHELF LIFE

Devcon Epoxy Adhesives should be stored in a cool dry place when not used for a long period of time. A shelf life of 3 years from date of manufacture can be expected when stored at room temperature (22°C) in their original containers.

PRECAUTION

For complete safety and handling information, please refer to the appropriate Material Safety Data Sheets prior to using this product.

ORDERING INFORMATION:

Stock No	Unit size	Stock No	Unit size
14311	28g Devtube	20015	50ml Manual Applicator Gun
14260	50ml Cartridge	14281	200ml Manual Applicator Gun
20222	200ml Cartridge	20020	400ml Manual Applicator Gun
20242	400ml Cartridge	29991	50ml Static Mixer Nozzle
19550	Fast Cleaner 2000 Spray	29999	200/400ml Static Mixer Nozzle
19510	Cleaner Blend 300 250ml		

Brunel Close, Park Farm
Wellingborough
Northants
NN8 6QX
01933 675299
01933 670800
12/05/08

Warranty: Devcon will replace any material found to be defective. Because the storage, handling and application of this material is beyond our control we can accept no liability for the results obtained.

Disclaimer: All information on this data sheet is based on laboratory testing and is not intended for design purposes. ITW Devcon makes no representations or warranties of any kind concerning this data.

For technical assistance please call 01933 675299

LOCTITE

1001 Trout Brook Crossing
Rocky Hill, CT 06067-3910
Telephone: (860) 571-5100
FAX: (860) 571-5465

Product Description Sheet

Product 404

Industrial Products, February 2000

›RODUCT DESCRIPTION

.OCTITE® Product 404 is a single component fast curing ethyl ;yanoacrylate adhesive. Product 404 is particularly suited for ›onding O-rings as well as other rubber and plastic :omponents.

ΓYPICAL APPLICATIONS

:abricating O-rings from a variety of rubber materials. Bonding ubber belts, pads, and bumpers. Useful for tacking rubber jaskets and weatherstripping, mounting plastic labels and ıameplates.

›ROPERTIES OF UNCURED MATERIAL

	Typical Value	Range
Chemical Type	Ethyl cyanoacrylate	
Appearance	Water-White to Straw-Colored Liquid	
Specific Gravity @ 25°C	1.09	
Viscosity @ 25°C, mPa.s (cP)		
Brookfield LVF		
Spindle #1 @ 30 rpm	90	70 to 110
Flash Point (TCC), °C	>80	

ΓYPICAL CURING PERFORMANCE

Jnder normal conditions, the surface moisture initiates the ıardening process. Although full functional strength is leveloped in a relatively short time, curing continues for at least !4 hours before full chemical/solvent resistance is developed.

:ure speed vs. substrate

'he rate of cure will depend on substrate used. The table ›elow shows the fixture time achieved on different materials at !2°C , 50% relative humidity. This is defined as the time to levelop a shear strength of 0.1 N/mm² (14.5 psi) tested on ;pecimens according to ASTM D1002.

Substrate	Fixture Time, seconds
Steel (degreased)	15 to 30
Aluminum	2 to 10
Neoprene	<5
Nitrile rubber	<5
ABS	2 to 10
PVC	2 to 10
Polycarbonate	15 to 50
Phenolic materials	5 to 15

:ure speed vs. bond gap

'he rate of cure will depend on the bondline gap. High cure ;peed is favored by thin bond lines. Increasing the bond gap vill slow down the rate of cure.

:ure speed vs. activator

Vhere cure speed is unacceptably long due to large gaps, ıpplying activator to the surface will improve cure speed. łowever, this can reduce the ultimate strength of the bond, herefore testing is recommended to confirm acceptable ›erformance.

TYPICAL PROPERTIES OF CURED MATERIAL

Physical Properties

Coefficient of thermal expansion, ASTM D696, K^{-1}	$80x10^{-6}$
Coefficient of thermal conductivity, ASTM C177, $W.m^{-1} K^{-1}$	0.1
Glass Transition temperature, ASTM E228, °C	120

Electrical Properties

Dielectric constant & loss, 25°C, ASTM D150:

	Constant	Loss
measured at 50Hz:	2.3	<0.02
1kHz:	2.3	<0.02
1mHz:	2.3	<0.02
Volume resistivity, ASTM D257,Ω.cm:		1×10^{16}
Dielectric strength, ASTM D149, kV/mm		25

PERFORMANCE OF CURED MATERIAL

(After 24 hr at 22°C)

	Typical Value	Range
Shear Strength, ASTM D1002, DIN 53283		
Grit Blasted Steel, N/mm²	24	18 to 26
(psi)	(3500)	(2610 to 3770)
Etched Aluminum, N/mm²	17	11 to 19
(psi)	(2500)	(1595 to 2755)
ABS, N/mm²	>6	
(psi)	(>870)	
PVC, N/mm²	>4*	
(psi)	(>580)	
Polycarbonate, N/mm²	>5*	
(psi)	(>750)	
Phenolic, N/mm²	10*	5 to 15
(psi)	(1450)	(700 to 2200)
Neoprene rubber, N/mm²	>10*	
(psi)	(>1450)	
Nitrile rubber, N/mm²	>10*	
(psi)	(>1450)	

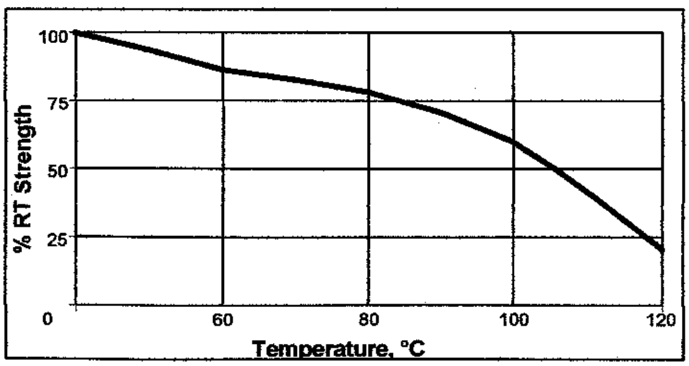
* Adhesive exceeds strength of bonded material

TYPICAL ENVIRONMENTAL RESISTANCE

Test Procedure :	Shear Strength ASTM-D1002/DIN 53283
Substrate:	Grit blasted mild steel laps
Cure procedure:	1 week at 22°C

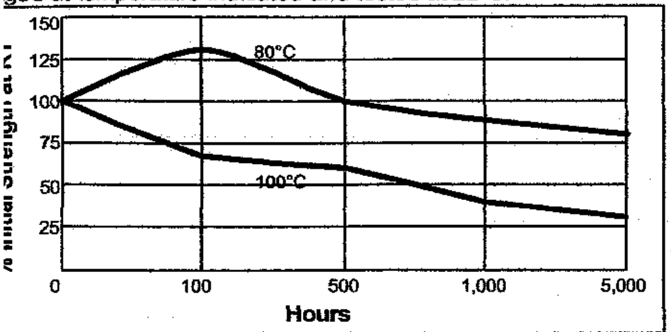
Hot Strength

Tested at temperature.



leat Aging

ged at temperature indicated and tested at 22°C.



:hemical / Solvent Resistance

ged under conditions indicated and tested at 22°C.

Solvent	Temp.	%Initial strength retained at 100 hr	500 hr	1000 hr
lotor Oil	40°C	100	100	95
iasoline	22°C	100	100	100
opropanol	22°C	100	100	100
umidity 95% RH	40°C	80	75	65

iENERAL INFORMATION

his product is not recommended for use in pure oxygen nd/or oxygen rich systems and should not be selected as sealant for chlorine or other strong oxidizing materials.

or safe handling information on this product, consult the **laterial Safety Data Sheet, (MSDS).**

lirections for use

or best performance surfaces should be clean and free of rease. This product performs best in thin bond gaps,).05mm). Excess adhesive can be dissolved with Loctite clean p solvents, nitromethane or acetone.

Storage

Products shall be ideally stored in a cool, dry location in unopened containers at a temperature between 8° to 21°C (46° to 70°F) unless otherwise labeled. Optimal storage conditions of cyanoacrylate products are achieved with refrigeration: 2° to 8°C (36° to 46°F). Refrigerated packages shall be allowed to return to room temperature prior to use. **Once opened do not return packages to refrigerated storage.** To prevent contamination of unused product, do not return any material to its original container. For specific shelf-life information, contact your local Technical Service Center.

Data Ranges

The data contained herein may be reported as a typical value and/or range Values are based on actual test data and are verified on a periodic basis.

Note

The data contained herein are furnished for information only and are believed to be reliable. We cannot assume responsibility for the results obtained by others over whose methods we have no control. It is the user's responsibility to determine suitability for the user's purpose of any production methods mentioned herein and to adopt such precautions as may be advisable for the protection of property and of persons against any hazards that may be involved in the handling and use thereof. In light of the foregoing, **Loctite Corporation specifically disclaims all warranties expressed or implied, including warranties of merchantability or fitness for a particular purpose, arising from sale or use of Loctite Corporation's products. Loctite Corporation specifically disclaims any liability for consequential or incidental damages of any kind, including lost profits.** The discussion herein of various processes or compositions is not to be interpreted as representation that they are free from domination of patents owned by others or as a license under any Loctite Corporation patents that may cover such processes or compositions. We recommend that each prospective user test his proposed application before repetitive use, using this data as a guide. This product may be covered by one or more United States or foreign patents or patent applications.

APPENDIX D

Table D1: Full table of results of aluminum sheets bonded with Devcon Epoxy

	Young's Modulus (MPa)					Load at offset yield (N)					Shear Strength (MPa)				
	1	2	3	4	mean	1	2	3	4	mean	1	2	3	4	mean
Non corroded	11152.2	15083.1	14210.2	12126.5	**13143.01**	5133.1	4792.7	5010.4	4778.04	**4928.56**	14.87	17.68	15.9	17.27	**16.43**
Corroded	9102.6	8764.2	7789.5	7074.7	**8182.76**	3610.5	2967.8	3274.6	2800.86	**3163.44**	8.97	12.14	9.78	11.27	**10.54**

Table D2: Full table of results of aluminum sheets bonded with Rill super glue

	Young's Modulus (MPa)					Load at offset yield (N)					Shear Strength (MPa)				
	1	2	3	4	mean	1	2	3	4	mean	1	2	3	4	mean
Non corroded	14015.1	11242.05	11843.3	13.149.65	**12562.5**	3909.4	3678.61	3562.23	3853.8	**3751**	13.15	11.86	12.04	12.95	**12.50**
Corroded	2488.33	2565.4	2802.6	2885.67	**2685.5**	1022.14	1297.56	1349.05	1779.8	**1362.14**	5.04	4.09	4.61	4.42	**4.54**

Table D3: Full table of results of aluminum sheets bonded with the mixture of adhesives

	Young's Modulus (MPa)					Load at offset yield (N)					Shear Strength (MPa)				
	1	2	3	4	mean	1	2	3	4	mean	1	2	3	4	mean
Non corroded	2413.7	2108.5	2117.2	2274.48	**2228.47**	2121.3	2108.4	1952.3	1918.44	**2025.11**	5.96	8.12	6.08	6.84	**6.75**
Corroded	1708.8	1552.4	1692.3	1747.38	**1675.22**	1214.13	1095.7	1109.8	1278.97	**1174.65**	4.49	4.01	3.24	3.86	**3.90**

Table D4: Full table of results of steel sheets bonded with Devcon Epoxy

	Young's Modulus (MPa)					Load at offset yield (N)					Shear Strength (MPa)				
	1	2	3	4	mean	1	2	3	4	mean	1	2	3	4	mean
Non corroded	8422.3	7388.4	8009.8	6848.2	**7667.18**	4848.7	3742.25	4195.02	4806.15	**4398.03**	14.47	14.73	14.64	14.8	**14.66**
Corroded	4023.1	3652.4	2523.6	2765.02	**3241.03**	2019.4	1698.75	1809.7	1908.87	**1859.18**	7.25	6.04	5.58	5.89	**6.19**

Table D5: Full table of results of steel sheets bonded with Rill super glue

	Young's Modulus (MPa)					Load at offset yield (N)					Shear Strength (MPa)				
	1	2	3	4	mean	1	2	3	4	mean	1	2	3	4	mean
Non corroded	5210.7	5876.21	5605.3	5640.2	**5583.10**	5543.06	6003.2	4985.8	5080.06	**5403.03**	19.05	17.85	16.98	18.16	**18.01**
Corroded	3289.69	3501.4	3396.10	3192.81	**3345**	4115.32	3895.57	3907.7	4140.45	**4014.76**	14.05	13.68	12.66	13.13	**13.38**

Table D6: Full table of results of steel sheets bonded with the mixture of adhesives

	Young's Modulus (MPa)					Load at offset yield (N)					Shear Strength (MPa)				
	1	2	3	4	mean	1	2	3	4	mean	1	2	3	4	mean
Non corroded	1314.15	1142.75	1202.65	1417.97	**1269.38**	3195.86	3097.54	3315.76	3109.72	**3179.72**	11.4	9.8	10.1	11.14	**10.61**
Corroded	502.4	387.49	407.32	552.75	**462.49**	1012.07	884.9	904.86	1061.73	**965.89**	4.04	3.05	3.01	2.82	**3.22**