Tensile Shear Testing of Double Strap Adhesive joints Using Cork Particles

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I am thankful to my Creator Allah Subhana-Watala to have guided me throughout this work at every step and for every new thought which You setup in my mind to improve it. Indeed I could have done nothing without Your priceless help and guidance. Whosoever helped me throughout the course of my thesis, whether my parents or any other individual was Your will, so indeed none be worthy of praise but You.

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Abstract

The main objective of this research is to investigate the strength of Aluminum Alloy **(5083)** based **double strap** adhesive joints with and without the inclusion of reinforcements. These adhesive joints are exposed to tensile shear test and the results are compared with and without added reinforcement. Double strap adhesive joints configuration using Araldite 2011 epoxy is used and samples are tested under Universal Testing Machine at atmospheric conditions.

Various reinforcements are being used but in this research, Cork powder is used as reinforcements. 80-mesh size cork powder with 10:1 specifications is used. The powder was extracted from Amur tree, which is environmental friendly.

The mixture prepared contained Huntsman Araldite 2011 Adhesive and 80-mesh size cork powder. The mixture is prepared carefully in different steps. Firstly, Adhesive and cork powder is mixed thoroughly in mechanical stirrer for 20 minutes and then in sonicator afterwards hardener is added and again mixed for 20 minutes under mechanical stirrer. At the end, specimens are prepared using this mixture.

The tensile shear strength is measured using bonded Aluminium Alloy (5083) Double Strap joints, and it is observed that the strength of these joints increases in a specific range of cork powder inclusion. Different trends are seen; above that specific range the strength of these joints decreases. The specimens as well as mixture of adhesive and cork powder is observed under optical microscope hence there structure and type of failure were studied.

In this research, following variations are chosen:

1. With and without inclusion of cork powder
2. Cork powder with different ratios.

Different Cork Powder ratio chosen was 0.25%, 0.5% and 0.75% by weight. With each ratio, specimens are prepared and the strength, which they can withstand, is studied.

Experimentally it was proven that Aluminium Double strap Adhesive joints Tensile Shear strength increases up to 0.25% then decreases at 0.5% and more at 0.75%.

Keywords

Shear strength, Double strap joints, Aluminium, Adhesive

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CHAPTER 1: INTRODUCTION

1.1 Background

Different types of joints exists and designers are using them to produce complex structures. Types of joints such as rivets, fasteners, bolts etc are known as mechanically fastened joints. With the development of technology and research in polymer materials another type of joint came into existence that is known as **adhesively bonded joint.** The term "adhesive" is defined as a substance that is capable of holding or resisting the separation of pre-treated materials after the applied adhesive is cured and the materials that are bonded together are called adherends. Initially, these joints found their application in aeronautics but due to new developments and further enhancement in research and techniques they are implemented in automotive and marine industries as well.

The advantages of Adhesively bonded joints are numerous. The important ones are:

- Decrease in stress concentration
- Good fatigue life
- High strength to weight ratio
- Ability to join different adherends
- As no holes or welds are included so the chances of corrosion are decreased.

1.2 Aim of the research

The aim of this research is to determine the effect of inclusion of cork powder in an epoxy based adhesive. The strength of joint was main parameter of interest.

Different cork powder ratio chosen was 0.25%, 0.5% and 0.75% by weight. With each ratio, specimens were prepared and the strength, of double strap adhesive joints was determined.

1.3 Objectives of the research

The objectives of this research included

- Preparation of double strap adhesive joints
- Preparation of adhesive and cork powder mixture with various cork powder %ages.
- Testing of adhesive joints to determine strength
- Analysis of failure surfaces to determine type of failure.

1.4 Outline of thesis

Chapter 1 Introduction of Research work.

Chapter 2 is about the review and historical development of research in adhesive joints and identification of research gap

Chapter 3 includes the methodology used to prepare the joints and adhesives. It also includes the details of experimental procedure.

Chapter 4 deals with the detailing of results and discussion based on experiments.

Chapter 5 provides the main conclusion of this research.

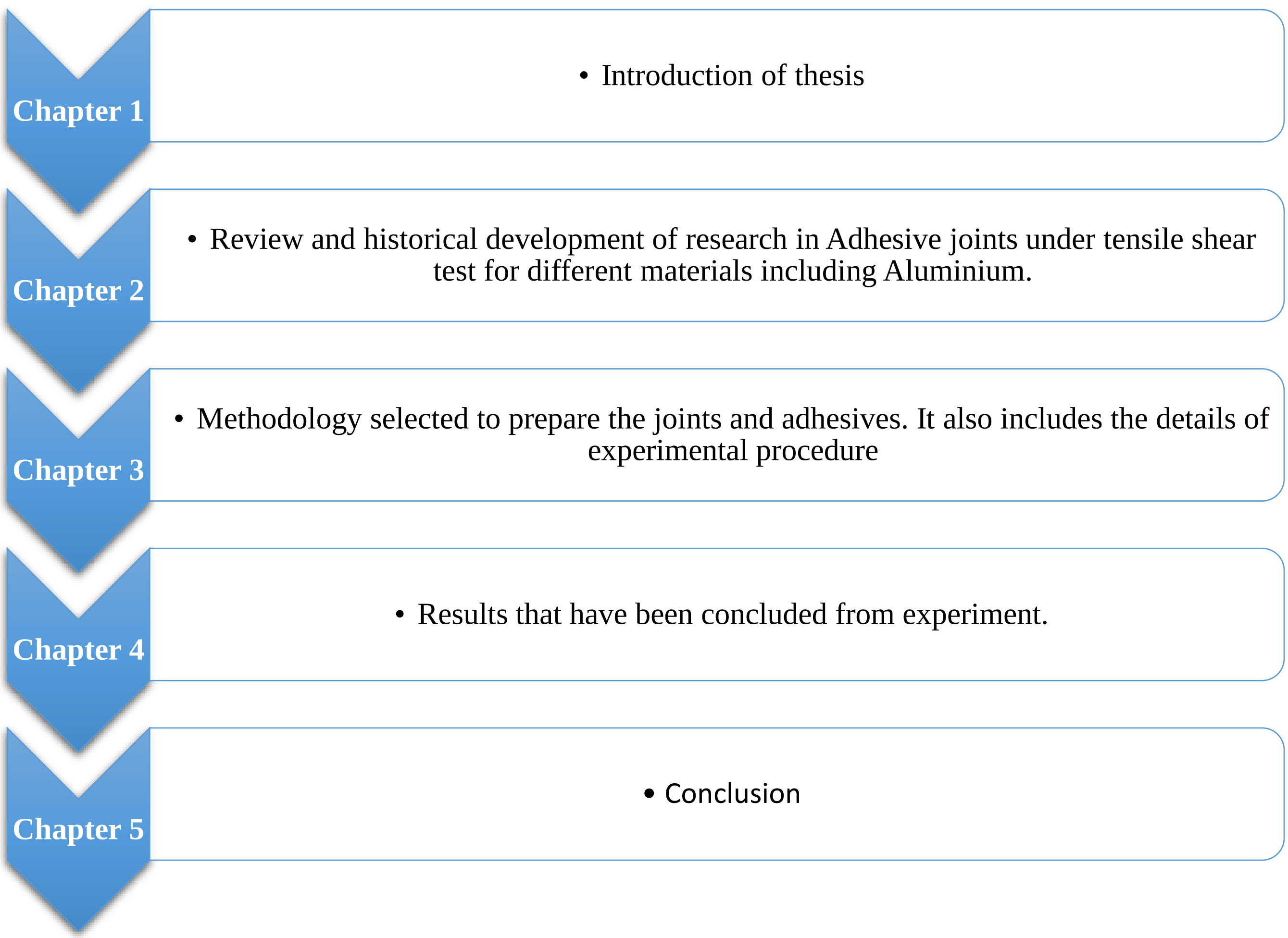


Figure 1-1: Outline of thesis

CHAPTER 2: LITERATURE REVIEW

2.1 Adhesive and Adhesive Joint

An adhesive is material applied on two surfaces to join them by adhesive bonding process. An adhesive is a substance capable enough of forming bonds between two surfaces after a specific period, called curing time. Adhesion is a state and excellently defined by [1]

"Adhesion refers to the state in which two dissimilar bodies are held together by intimate interfacial contact such that mechanical force or work can be transferred across the interface. The interfacial forces holding the two phases together may arise from van der Waals forces, chemical bonding, or electrostatic attraction. Mechanical strength of the system is determined not only by the interfacial forces, but also by the mechanical properties of the interfacial zone and the two bulk phases"

The joint made with the help of adhesive and applying on the surfaces is called adhesive joint

2.2 Failure Modes

Suppose that a hypothetical bond is prepared [2] as shown in the Fig 2.1. Let us consider further that the prepared specimen is tested using tensile testing machine. The possibilities of different types of failures may occur.

2.2.1 Adhesive Failure

If the failure of the bond take place between the adhesive layer and one of the adherend then this type of failure is called adhesive failure, As shown in Fig 2.1 (a)

2.2.2 Cohesive Failure in Adhesive layer

The type of failure in which there is little bit of adhesive left on the adherends surfaces or adherends covered with adhesive layer then this is termed as cohesive failure in adhesive layer, as shown in Fig 2.1 (b)

2.2.3 Cohesive Failure in Adherend Layer

The type of failure in which the specimen break apart without damaging the adhesive bond. This is termed as cohesive failure in adherend layer, and is shown in Fig 2.1 (c)

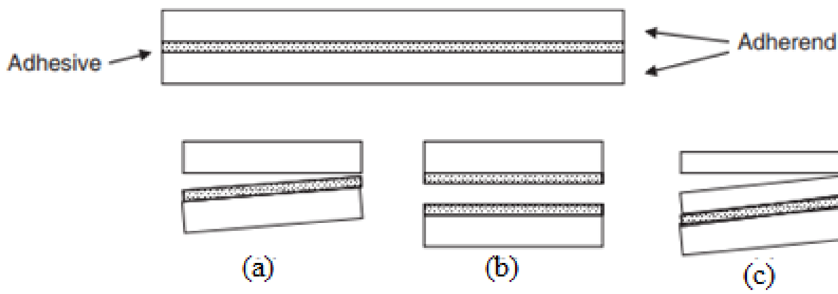


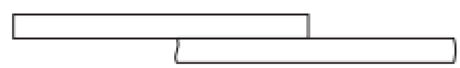
Figure 2-1: Failure modes

2.3 Types of Adhesive joints

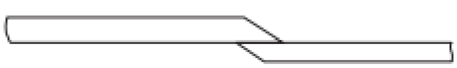
There are numerous types of adhesive joints that are now implemented in different industries according to application. Types of adhesive joints are shown in Fig 2.2.

Plain butt joint

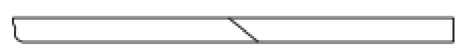
Single Lap Joint



Beveled lap joint



Scarf butt



Joggle lap

Single strap

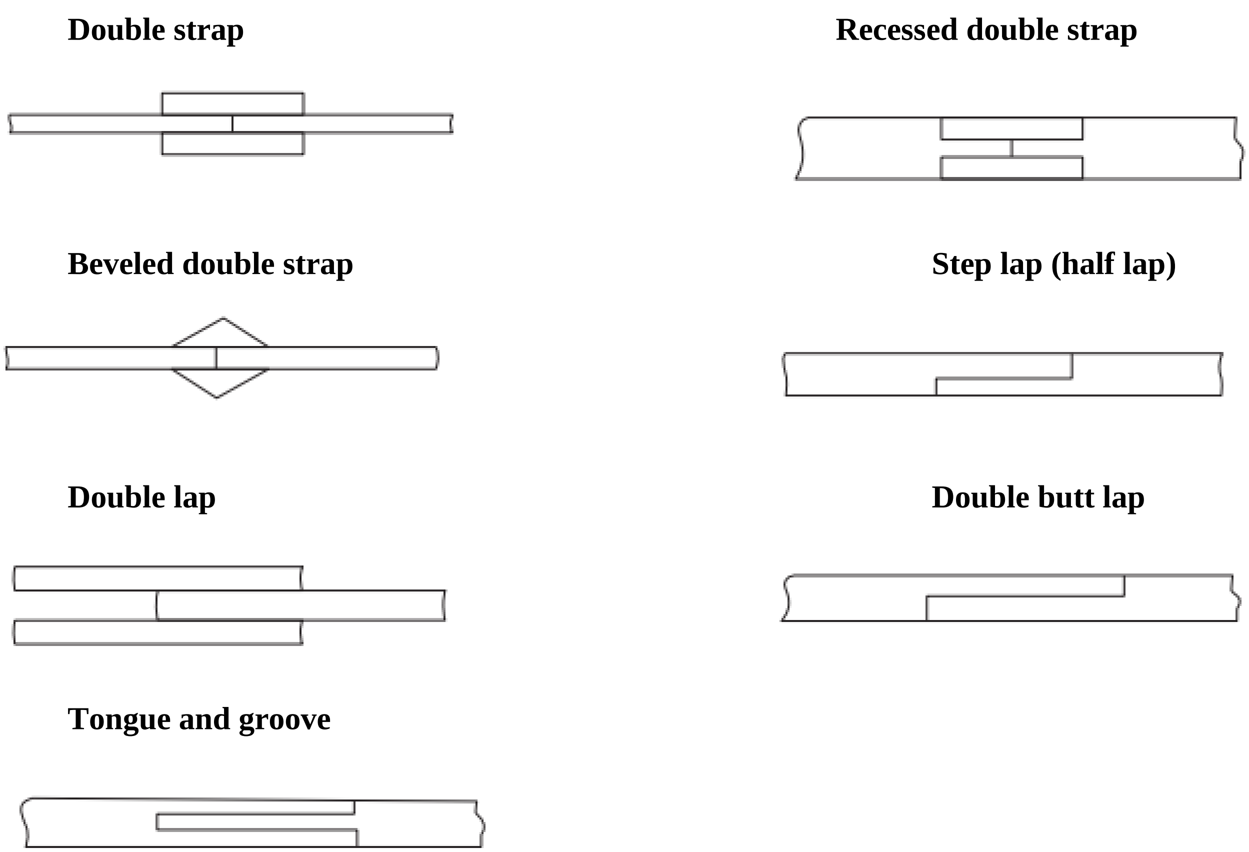


Figure 2-2: Types of joints

2.4 Types of Stresses in Adhesive joints

Five types of stresses are discussed below. Any combination of stresses may occur in adhesive application.

2.4.1 Compression

The chances of failure are very less when compressive stresses are induced in adhesively bonded joint. Applications of compressive loaded joints are less.

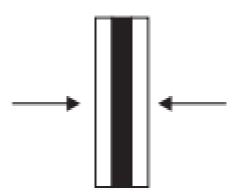


Figure 2-3: Compressive Loading

2.4.2 Shear

In this type of joint stress is evenly distributed over the entire bonded area. It is an economical joint and is more resistant to joint failure.

Figure 2-4: Shear Loading

2.4.3 Tensile

Tensile stress occur when forces act perpendicular to the plane of joint.

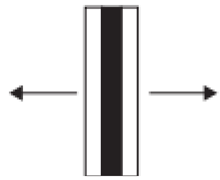


Figure 2-5: Tensile Loading

2.4.4 Peel

In this type of stress, one of the adherend must be flexible. Increasingly high stress is applied to induce these type of stresses. Unless the load is small or there is wide joint, failure will occur.

Figure 2-6: Peel Loading

2.4.5 Cleavage

This is similar to peel but in this type, forces act at one end of the adherend and try to split apart the adherends. A situation in which offset tensile force or moment is applied.

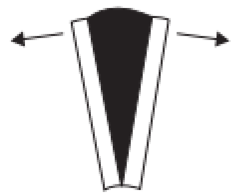


Figure 2-7: Cleavage Loading

2.5 Strength Determination of Adhesive Joints

Performance prediction of various structures and components under real life loading conditions can be based on models. These models are validated by experimental testing of specimens using relevant types of loading.

Experimental research has been carried out on adhesive joints for long. Researchers considered different types of mechanical loading, different types of materials or adhesives. Furthermore, adding secondary particles, silicates and carbon nanotubes have also been considered for the enhancement of strength of adhesive joints.

Researchers used different adhesives in order to study the mechanical behavior of adhesive joints. Adhesive curing time is a critical parameter in joint preparation. [3] carried out a study of the curing process of Araldite (2014). It had been concluded that increase in curing temperature leads to more complete curing in shorter period of time. It was experimentally observed that 28 days were needed for complete curing of adhesive at room temperature while only 4h at 64^{o}C. Furthermore, ageing test (40^{o}C in water vapors) was also conducted and the properties were measured over a period of 36 days. It was reported that water worked as a plasticizer leading to the softening of the adhesive. Due to the ageing, the elastic modulus decreased while deformation and plastic contribution to total deformation were increased. This is shown in Fig 2.8

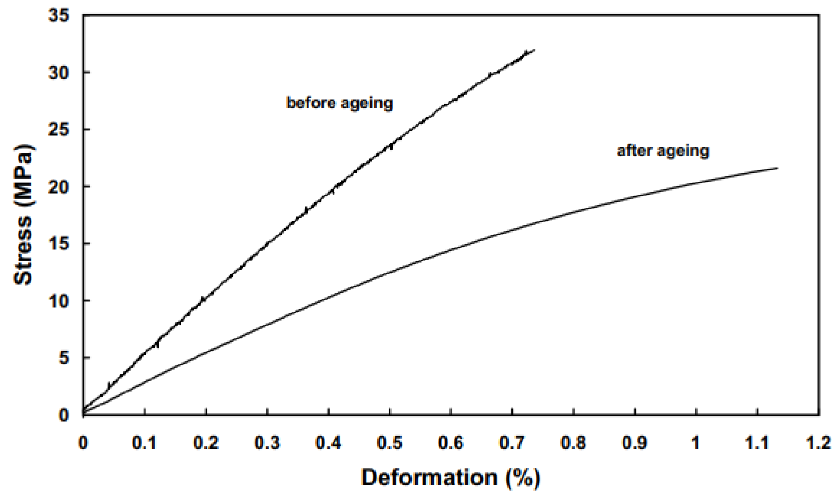


Figure 2-8: Stress-deformation curves before and after ageing test

Enhancement of fracture toughness of unsaturated polyester resin was studied by [4], adding aluminium particles as reinforcements. Various aluminium particles sizes (20 μm, 3.5 μm, 100 nm) were used. It was observed that fracture toughness increased monotonically with volume fraction of aluminium particles. Moreover, smaller particles led to greater increase in fracture toughness of given particle volume fraction.

[5] showed that the inclusion of low concentration of Nano silica particles to rubber-toughened adhesive increased the toughness of adhesive and also led to increase in glass transition temperature and single lap shear strength. Moreover, they found out that addition of 1% to 8% by mass of these types of Nano particles helped in improvement of mechanical and thermal performance of rubber toughened two-part epoxy adhesive.

Number of test had been performed on double strap joint between pultruded GFRP profiles with variation in geometry. [6] showed that failure began at the material layer situated in the outer part of the adherends. In addition, there was no cohesive as well as adhesive failure in the adhesive and between adherend and adhesive respectively. For every specimen ultimate failure load, stress-strain curve and mechanism of failure was observed. It was also observed that the behavior of these joints typically was elastic-brittle. The ultimate failure load is basically influenced by the thickness -length ratio of the outer adherents. Parameters on which ultimate failure load depends are the ratio between the inner and the outer thickness and stiffness of the adherends, as well as the adhesive stiffness.

[7] discussed the properties, capabilities and applications cork. Cork is strong resilient and have excellent sealing ability. It is in use in many technological industries. Furthermore, because of its properties of naturally occurrence, renewable, sustainable and highly adaptable material, cork is playing an important role in developing new products.

[8] reported that almost all failures of double strap adhesive joints begin at overlap area due to stress concentrations occurring at the ends. Hence, in this study researchers used two different adhesives one stiff and the other flexible with different mechanical behaviors adhesives were subjected to bending moment. Application area of the stiff adhesive was in the overlap area while flexible adhesive was applied at the edges. Hence the results showed that, that the specimens with bi adhesives carry more load and had more strength as compared to specimens with single adhesive.

[9] studied the addition of nano-silica particles in epoxy polymer which were 20 nm in diameter. It was observed that modulus and toughness of epoxy increased, and fracture toughness increased from 100 J/m^2 to 460 J/m^2 with 13-vol% of nano-silica. Hence, significant toughening effect of epoxy polymer was observed by using nano-silica particles

Lap shear strength of single lap adhesive joints was measured by **[10]** and it was concluded that lap shear strength increased with the overlap length increase but as adhesive thickness increased, lap shear strength decreased. Moreover, lap shear strength increases with decrease in adherend thickness.

[11] studied effects of both the substrate surface and adhesive properties using single lap aluminium (AA6082) joints using ASTM D1002 standards. Roughness was induced into the aluminium specimens by treating it with abrasive surfaces

[12] studied that adhesive joint strength using different hybrid assemblies. Single lap joints of titanium sheet (CP1) composites and aluminium sheet (2024PLT0) composites were prepared and experimentally as well as numerically (ABAQUS) studied. The study included five type of joints.

Experimentally it was observed that greatest strength was obtained for Titanium titanium sheets and then decreases in composite ones while in aluminium the greatest strength was observed in aramid/epoxy composite–aramid/epoxy composite assembly.

[13] studied the thickness of adhesive joints for butt joints and single lap joints. Tensile and shear strength of joints was investigated. Material used was AA 5052-H34 and polyimide (Skybond 703). Hence, it was concluded that there was decline in the tensile strength of butt joints with increasing adhesive thickness. On the other hand, shear strength for single lap joint remained constant regardless of adhesive thickness. In addition, the specimens failed in interfacial manner.

[14] examined the effects of curing conditions on the performance of steel/CFRP double strap joints exposed t combined loading, cyclic loading and humidity. CFRP specimens were prepared and tested according to ASTM D3039-08 to determine the tensile strength of CFRP. By using carbon fiber and steel plates double strap adhesive joints were prepared as shown in Fig 2.9. Prepared specimens were cured at two different temperatures; room temperature and an elevated temperature of 120°C. Specimens kept at room temperature were cured for 14 days and the ones at 120°C were cured for 1 hr only based upon manufacturer’s recommendations.

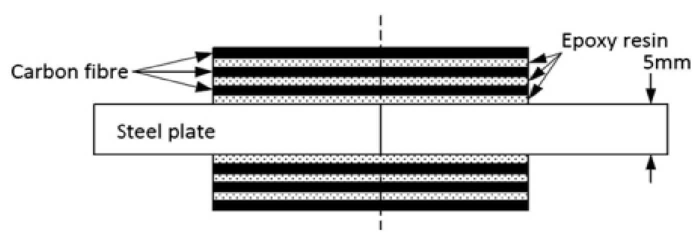


Figure 2-9: Schematic view of specimen

The study concluded that the specimens cured at elevated temperature did not improve the ultimate strength of double strap adhesive joints. Furthermore, when the joints were tested at temperature of 50°C, specimen cured at elevated temperature showed 100% strength as compared to other specimens which maintained only 50%. Moreover, mechanical loading caused significant strength degradation under combined cyclic temperature (between 20°C and 50°C) and a constant 90% relative humidity. In addition it was concluded that lower loads or higher curing temperature resulted in longer time to failure.

[15] used single lap joints. Four different types of joints were prepared comprising of composites-composites, aluminium-aluminim and aluminium-composite combination with different stacking positions. The results they got are shown in Fig 2.10 and 2.11 below:

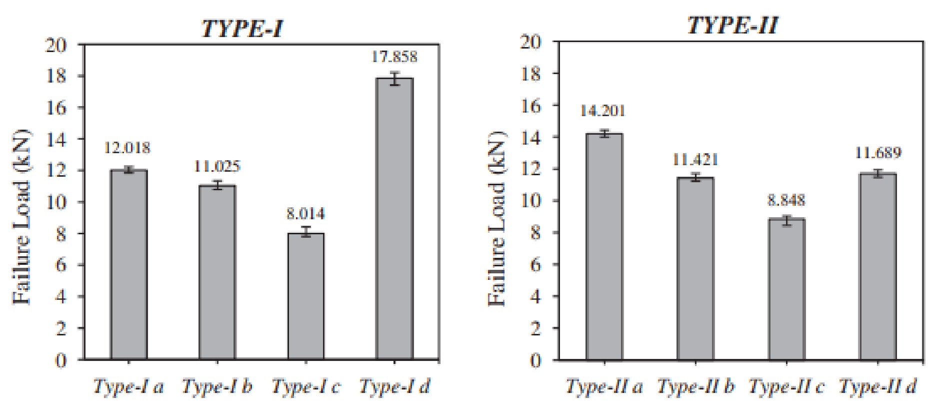


Figure 2-10: Maximum failure loads obtained for four different stacking sequences of the composite

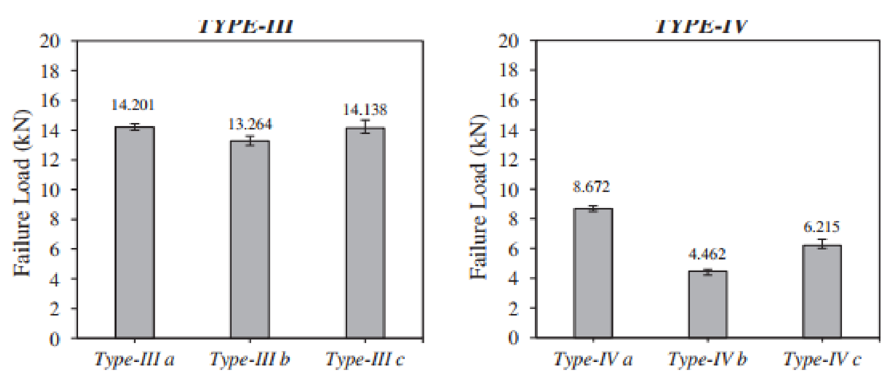


Figure 2-11: Maximum failure loads obtained according to three different aluminum thicknesses

The above results showed us that stacking sequence of adherend affects the failure load.

Adhesively bonded CFRP joint strength was measured by [16] applying tensile loads. The study parameters chosen were overlap length, adherend thickness, adherend width and scarf angle. Single lap joints and double lap joints were prepared. It was concluded that for single lap joints load-displacement curves behaved non linearly as the adherend thickness increases because of bending caused by eccentric loading in SLJs. For double lap joints, load-displacement curves were linear. Same is the case for the scarf joints, their load-displacement curves were linear also. Comparing the three joints collectively it was concluded that double lap joints had highest ultimate failure load and scarf joints had highest lap shear strength.

In the search of increasing the strength of adhesive joints different techniques were implemented and still being researched. One of them is adding reinforcements (micro particles) into the adhesive to increase the strength of adhesive ultimately increasing adhesive joints.

Adding Micro into the adhesive increases the toughness of adhesive and this was employed because of 2 main reasons.

1. To reduce the cost of component
2. To attain desired properties of adhesive joint

Hence in the quest of increasing the toughness of adhesives, [17, 18] were the first to add rubber spheres reinforcements into adhesives. Their initial idea of this led to many other experiments also.

[19] reported that If brittle particle reinforcements have to be used then the size of the particles must be between 4 and 100 micro m. Use of biological particles as reinforcements is very beneficial, because of their environmental friendly affects. One of the biological reinforcement is cork. Macroscopically, cork is light, elastic and also impermeable to gas and liquid. While microscopically cork have honey comb structure. Cork is implemented in number of ways. Cork/rubber Composites were prepared and employed in automobile industries. NASA have been using this biological reinforcements for more than 50 years for making joints and vibration insulations. It has also been employed to control oil spills [19]. Now moving towards the size of cork particles, it was shown that the particles size must be above 30 microns. Below this value the cork have no effect on increasing the toughness because of its structure.

General conclusions that were drawn by experimentally testing specimens of SLJs, Impact test and dog bone specimen with Araldite 2020 mixed with Cork powder by [20], [21], [22] were

1. Inclusion of cork powder changed the mechanical properties of adhesive. Further suggested that mechanical properties could be optimized by varying the size and ratio of cork powder.
2. Cork powder was found to increase the toughness of epoxy. Particle size and amount had impact on the toughness of adhesive
3. Surface treatments were not effective in cork particles.
4. Cork particles as reinforcements are excellent and beneficial application of natural product.

Influence of the size and amount of cork particles on the impact toughness of a structural adhesive

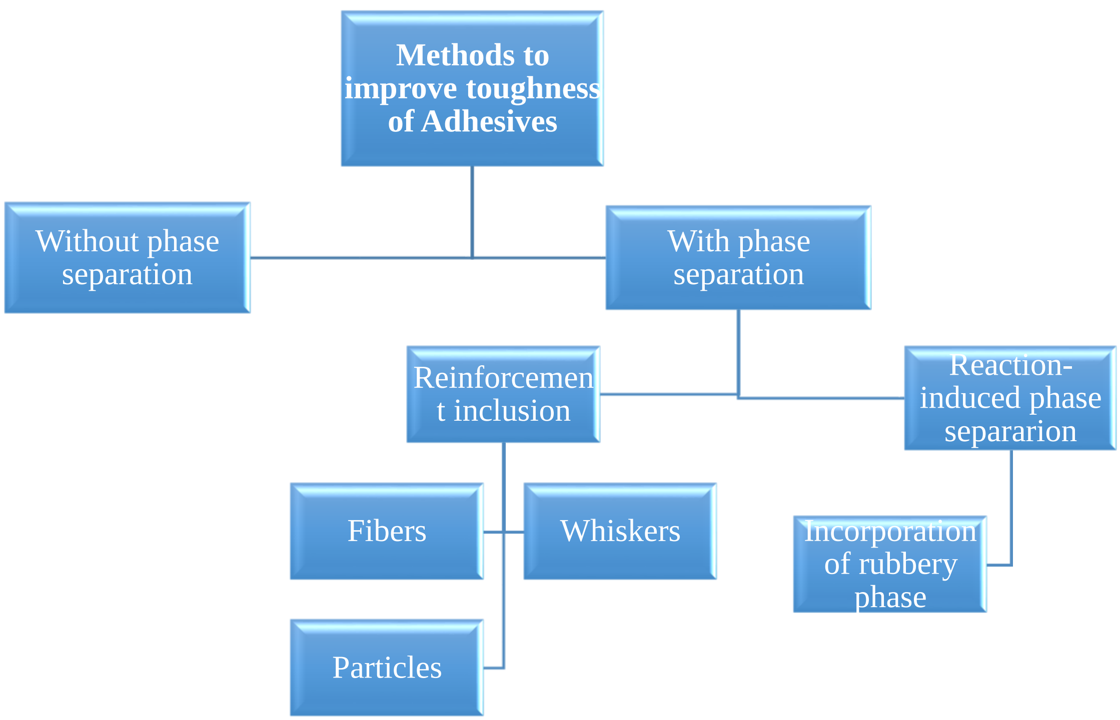


Figure 2-12: Methods to improve toughness of Adhesives

2.6 My Thesis work

It is shown that addition of secondary particles provides improvements in joint strength. However, many factors play an important role in the decision to add secondary particles. These includes the type of particles, percentages of particles, loading type and joint geometry among others cork powder, and due to its nature friendliness has shown a lot of potential for increasing joint strength. Studies exploring the effect of cork powder on double strap joints made from metal adherends and epoxy are few and much more investigation is required to completely understand the interaction between cork powder and adhesive under such loading conditions. This investigation is thus the main area of research for this thesis.

CHAPTER 03: MATERIALS AND EXPERIMENTAL METHODS

3.1 Introduction

The main aim of this chapter is to explain the material type, joint configuration, reinforcement added and experimental technique used to carry on the project:

- Description of materials used that includes the properties of adherend, adhesive and reinforcement.
- Description of joint configuration used.
- Description of proper mixing of adhesive and reinforcement
- Description of machine used for measuring tensile shear strength.

3.2 Material

The adherend selected was Aluminium Alloy (AA) 5083 because of its wide spread application in shipbuilding, pressure vessels and drilling rigs. Adhesive was Araldite 2011 and reinforcement used was cork powder. They are individually discussed as below.

3.2.1 Aluminum Adherends

The adherends used in this study was Aluminium Alloy 5083. Aluminium Alloy is highly resistant to seawater as well as industrial chemical environments. Four (4) aluminium strips was used to make 1 sample, containing 2 strips of 4 inches in length and 2 strips of 2 inches length, thickness of all the strips were same which was 1.5 mm as shown in **figure 3.1**. The composition and properties of AA 5083 are shown in Table 3.1 and 3.2 respectively.

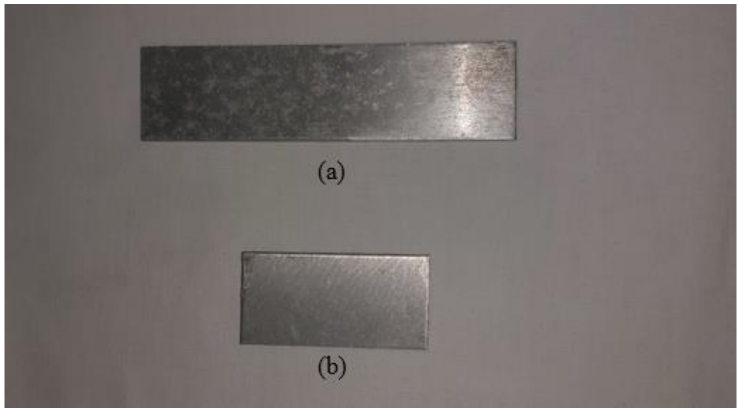


Figure 3-1: Aluminium Adherends, a) 4in long strip, b) 2in long strip

Table 3.1: Composition of AA 5083 [23-25]

Component	**Wt %**
Al	92.4-95.6 (Balance)
Cr	Max 0.05-0.25
Cu	Max 0.1
Fe	Max 0.4
Mg	4 - 4.9
Mn	0.4 – 1
Si	Max 0.4
Ti	Max 0.15
Zn	Max 0.25

Table 3.2: Mechanical and Physical Properties of AA 5083 [25]

Mechanical Properties	**Value**
Tensile Strength	300 MPa
Proof Strength	145 MPa
Elongation	23%
Shear Strength	175 MPa
Physical Properties	**Value**
Density	2.65 Kg/m^3
Melting Point	570 ^oC

3.2.2 Adhesive

The type of adhesive used in this study was Araldite 2011 from Huntsman Corporation imported from USA. It is two part structural adhesive of high strength and toughness. It is suitable for metal-to-metal binding, ceramics, rubber, glass and other materials used commonly. Properties of adhesive are shown in table 3.3.

Figure 3-2: Araldite 2011 (Huntsman)

Table 3.3: Properties of Adhesive (Araldite 2011)[25] [3]

Property	Araldite 2011 A	Araldite 2011 B
Appearance	Neutral	Pale Yellow
Density, g/cm^3	~1.15	~0.96
Viscosity at 25 ^oC, cP	30, 000 – 50,000	20, 000 – 35, 000

3.2.3 Reinforcement

Cork powder was used as reinforcement in this study. The size of a single particle was 80 (mesh size). It is environmental friendly and was obtained from the bark of tree (Amur**). Figure 3.3** shows cork powder used in this study.

Figure 3-3: Cork powder (Reinforcement)

3.3 Surface Preparation

In order to improve the adhesion the surfaces of adherends were cleaned from unwanted particles and grease subjected and subjected to surface treatment called Anodizing. Anodizing was selected because it is the best surface treatment in case of aluminium alloy 5083.

Anodizing is an electrochemical process in which a metal specifically aluminium is coated with protective oxide layer when immersed into an acid electrolyte bath. In this study, the acid used was phosphoric acid hence it is called as Phosphoric acid anodizing.

Table 3.4: Multi-stage cleaning of specimens for Phosphoric acid Anodizing

Stage of cleaning	Solution	Temperature / ºC	Time / min
Degreasing	Toluene	Room temperature	As required
Rinsing	50% DI water and 50 % Acetone	Room temperature	5
Alkaline Etching	NaOH	50	10
Cleaning	HNO3	Room temperature	3
Rinsing	Tap water	Room temperature	As required
Rinsing	DI water	Room temperature	5-10

3.3.1 Specimen cleaning for Phosphoric acid anodizing

Prior to anodizing, there were few steps that had to be followed which are as follows:

1. Firstly, all the strips of aluminium were cleaned with Toluene solution in order to remove dust and unwanted grease from the metal. Toluene is an aromatic hydrocarbon and colorless water insoluble liquid.
2. Afterwards the strips were dipped into the deionized water (50%) and acetone (50%) mixture in beaker to further clean the surfaces.
3. These acetone water cleaned strips were immersed into NaOH for alkaline etching for 10 mins at 50^{o}C temperature maintained. Sodium Hydroxide etch the surface of metal that was exposed to environment and bought the fresh underlying layer of aluminium metal. Because of this, the metal surface and NaOH itself becomes black and release ***hydrogen gas hence this step had to be carried out carefully in open atmosphere.*** Also, filtration of Sodium Hydroxide is required to remove black particles from NaOH.
4. For the removal of black surface the strips were immersed into HNO_3 to make the surface free from blackness.
5. The metal was then again dipped into deionized water for about 5-10 mins to further clean the surface and remove any black particles left on metal surface.
6. After that, a fresh layer was prepared for Phosphoric Anodizing.

3.3.2 Phosphoric Acid Anodizing

For structural adhesive bonding of aluminium phosphoric acid anodizing is recommended.

After the pre-treatment of metal surface, aluminium metal was given positive connection (anode) and the steel plate was given negative charge (cathode) the voltage was kept at 15 V. Afterwards the aluminum metal strips were immersed into the phosphoric acid up to the length at which adhesive bonding was required. The temperature of phosphoric acid was kept at 30^{o}C. As a result, the acid act as a path and hence the transfer of oxide layer started to deposit on anode (aluminium).

After Phosphoric acid anodizing the specimens were rinsed thoroughly with tap water as well as deionized water and then left for drying. The surface that is anodized must not be touched else, it will be contaminated. The anodized specimen , shown in **figure 3.4**, then wrapped in wax paper and stored for adhesive bonding.

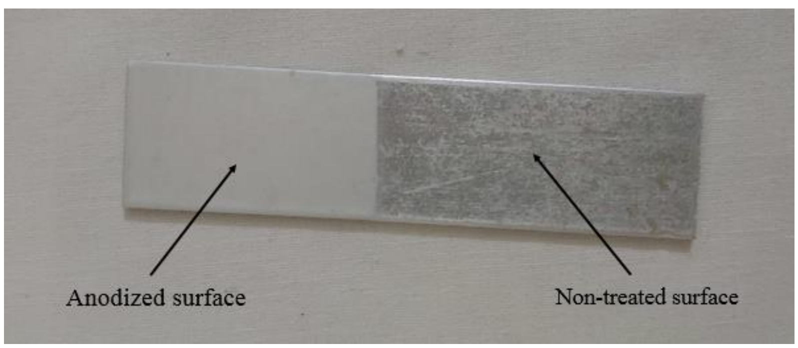


Figure 3-4: Phosphoric acid anodized surface (4in long strip)

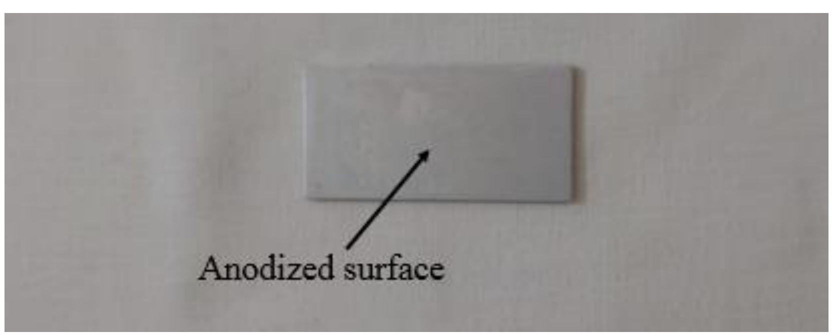


Figure 3-5: Phosphoric acid anodized surface (2in long strip)

3.4 Adhesive – Reinforcement Solution Preparation

Following were the adhesive and reinforcement used to prepare mixture

- Adhesive : Araldite 2011 (Huntsman)
- Reinforcement: Cork Powder

Steps involved for the preparation of mixture are as follows:

- Resin was taken in a beaker according to the requirement and cork powder as a reinforcement was added (by weight 0.25%, 0.5%, 0.75%). The mixture was placed under mechanical stirrer (shown in figure 3.6) for about 20 mins for thoroughly mixing of resin and adhesive under optimum speed.
- After thoroughly mixing of resin and cork powder, hardener was added. The hardener added was 80% by weight of the resin. Furthermore, the mixture (resin + hardener + cork powder) was placed in sonicator for 20 mins. **Sonication** is a process of applying sound energy to the particles for homogenous mixing, the frequency kept is usually >20 Hz

Figure 3-6: Mechanical stirrer

3.5 Adhesive Joint Configuration

The type of joints used were Double Strap Joint (DSJ). Two types of DSJ specimes were prepared

- Double Strap Joints (DSJs) without reinforcements
- Double Strap Joints (DSJs) with reinforcements

3.5.1 Double Strap Joints

Double strap joints were used in this research to investigate the strength of adhesive joints with and without reinforcements, added in different ratio. Specimens were manufactured using Aluminium Alloy 5083 as adherends. **ASTM D3528 standards were taken in manufacturing of specimens.** The dimensions of Double strap joints are shown in **figure 3.7** and the arrangement of Aluminium metal strips for double strap adhesive joints are shown in **figure 3.8**

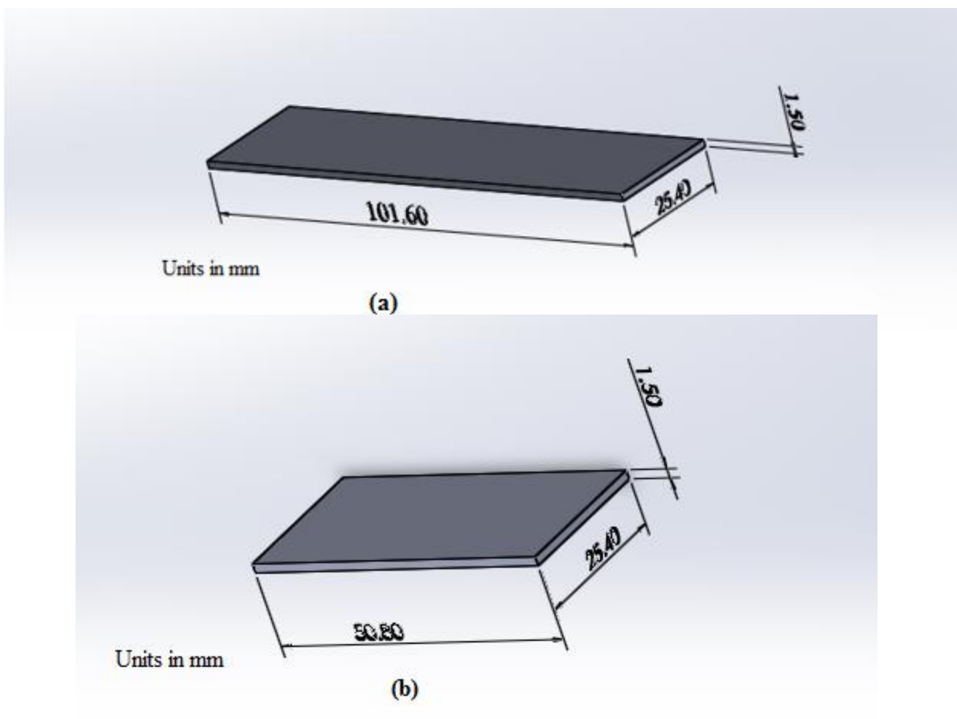


Figure 3-7: Aluminium adherends dimensions, a) 4in Long strip, b) 2in long strip

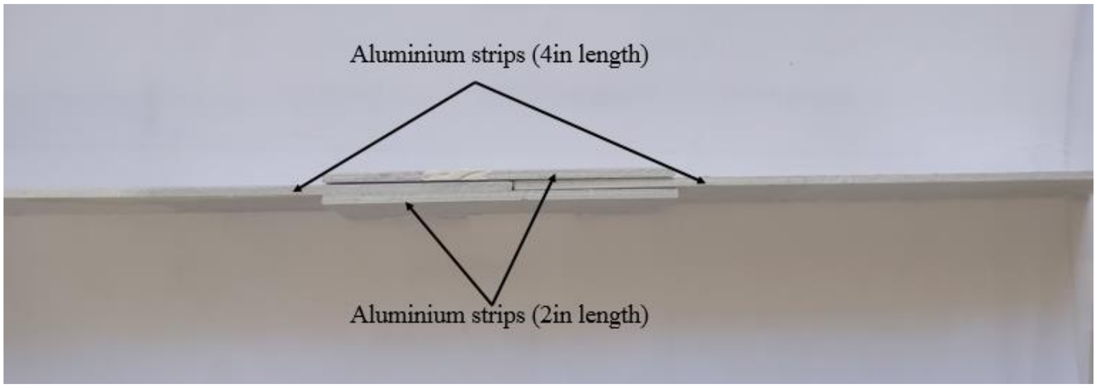
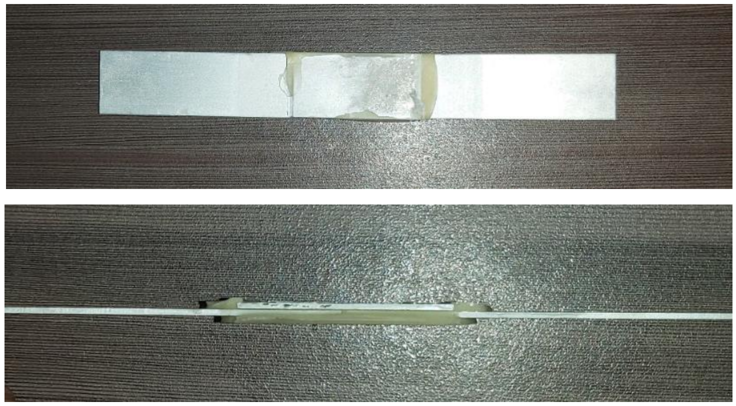


Figure 3-8: Arrangement of strips in Double strap adhesive joints

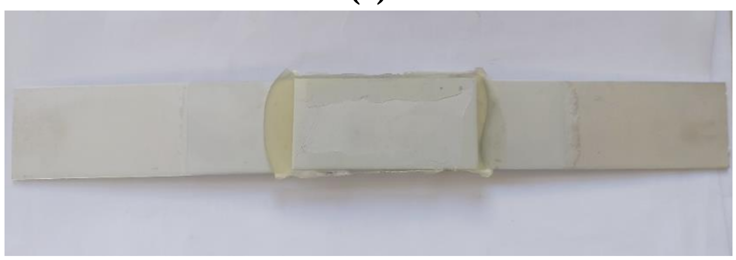
After the preparation of mixture, it was applied to the specimens very carefully. A mold was prepared as shown in **figure 3.9** in order to make the joint stay in its place. Three specimens of same ratio were prepared at one time and then kept for curing for 24 hrs. at room temperature to each specimen. After 24 hrs, tensile shear test was performed on these specimens to investigate their shear strength.

Figure 3-9: Mold design for curing Double strap adhesive joints

Double strap adhesive joints, with and without reinforcement are shown in **figure 3.10** respectively



(a)



(b)

Figure 3-10: Double strap adhesive joints, a) with reinforcement, b) without reinforcement

Figure 3-11: Overall Thickness of specimen (0.5mm adhesive thickness)

3.6 Experimental Method

The mechanical test conducted on double strap bonded joints was Tensile shear test.

3.6.1 Tensile shear testing

A universal testing machine, **figure 3.11**, with digital control and computer data logging was used in tensile shear testing. The strength of joints was calculated by maximum force it can withstand at strain rate of about 1.5mm/m. The load cell was of 100kN.

Figure 3-12: Universal Testing Machine (SHIMADZU) with 20 kN Load cell

In figure 3-13 specimen under tensile shear testing is showed with 100kN load cell and strain rate of 1.5mm/min.

Figure 3-13: Specimen under Tensile shear testing (UTM, 100 kN load cell)

3.6.2 Microscopy

Specimens with and without reinforcements were observed under optical microscope shown in figure 3-14 to study microscopically how material and adhesive behaved under tensile shear testing.

Figure 3-14: Optical Microscope

CHAPTER 04: RESULTS AND CONCLUSION

4.1 Introduction

The aim of this chapter is to understand and measure the shear strength of double strap adhesive joints when exposed to tensile shear testing. The research is focused on the following objectives:

- Detailed analysis of double strap adhesive joints (DSJs) loaded in tensile shear conditions.
- To study the shear life of double strap adhesive joints.
- To compare the tensile shear strength of DSJs.
- To perform microscopic study of tested specimens.

4.2 Tensile Shear Testing of Double Strap Adhesive Joints

Different specimens of DSJs were prepared with details of dimensions discussed in previous chapter. This chapter will provide the experimental data of tensile shear test on DSJs, analyzing the surface of adherends microscopically and comparison of specimens.

4.2.1 Test Results

After collecting experimental data, a plot of force against % age of cork powder is presented in Figure 4.1. Average is taken to minimize the error. It is shown in the graph that shear strength of DSJs increases from 0% to 0.25% of cork powder inclusion and afterwards it decreases at 0.5% and more at 0.75% by weight of cork powder. After 0.25% the specimen showed an almost decreasing linear behavior. This abrupt decrease in strength of joints is associated with cork powder acting as an impurity and as reinforcement in the adhesive.

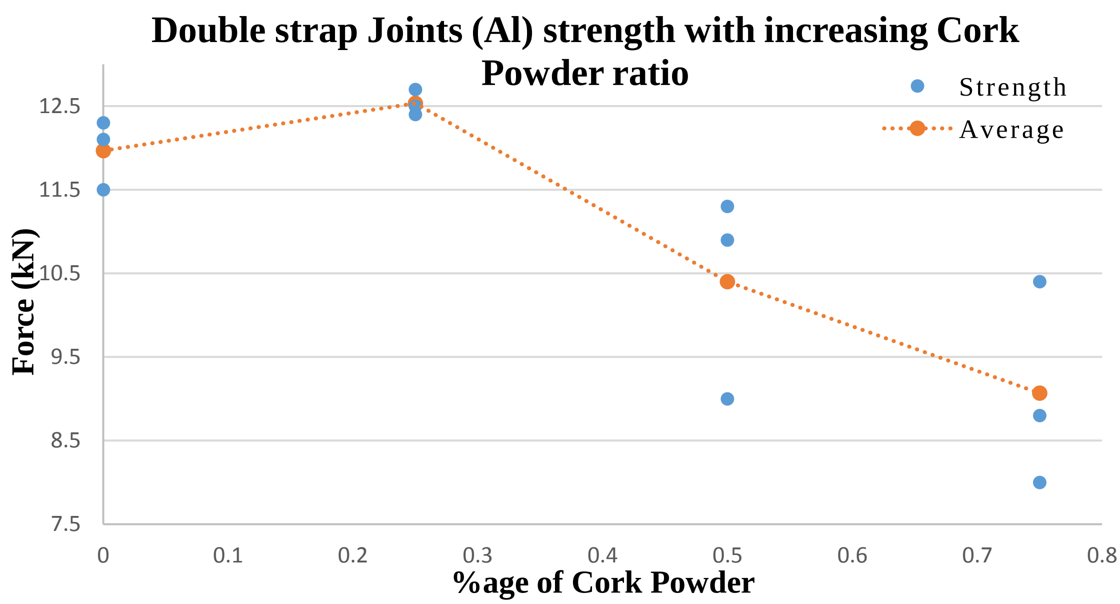


Figure 4-1: Force and cork powder % age plot for Aluminium Double Strap Joints

4.2.2 Conclusion

By studying the graph, it has been concluded that Double strap adhesive joint show maximum shear strength at 0.25% of cork powder ratio when tested under UTM machine and at room temperature. Hence maximum shear strength of double strap adhesive joint is 12.58kN at 0.25% by weight of cork powder.

4.2.3 Test Results

Displacement of failure is a critical value because it helps us find whether the adhesive joint is behaving as ductile or brittle material before and after inclusion of particles. Regarding this, a plot of displacement of failure against % age of cork powder is presented in Figure 4.2.

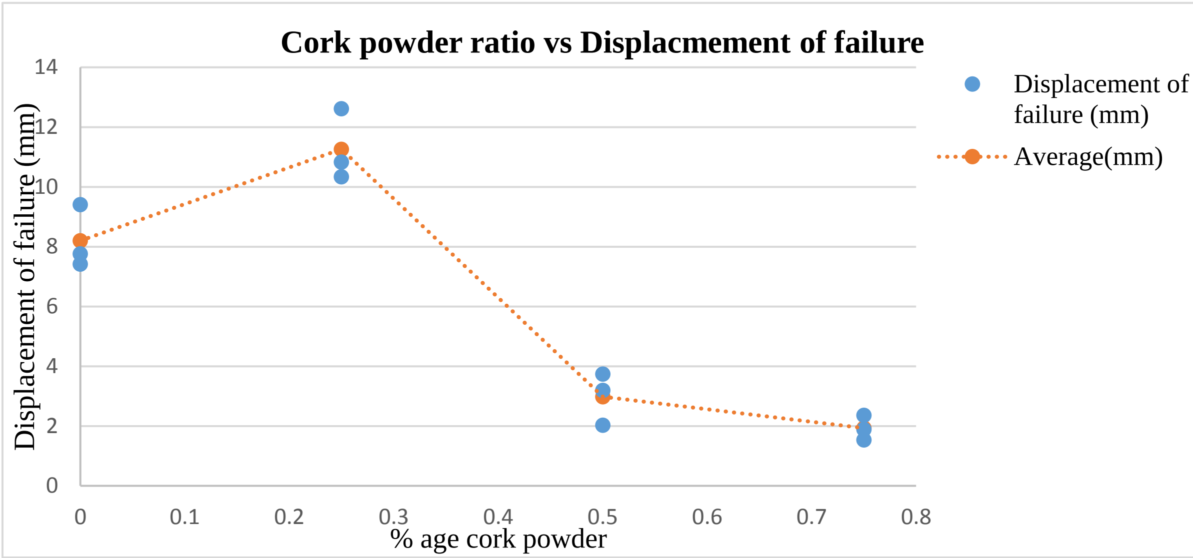


Figure 4-2: Displacement of failure in DSJs

4.2.4 Test Results

Type of failure, studied in literature section, of Double strap adhesive joints was observed. Table 4.1 shows the type of failure, average strength and displacement of failure of double strap adhesive joints. Cohesive failure is preferred type of failure because in this type of failure maximum strength of material in joint reaches[26].

The table shows us that Joint have maximum strength and displacement of failure at 0.25%. The type of failure occurred in 0.25% ratio is 50% adhesive and 50% cohesive failure while in the rest of cork powder ratio mostly adhesive failure happened.

Table 4.2: Types of failure in Double Strap Adhesive Joints

% age Powder	Type of failure		Strength (Avg.) (kN)	Displacement of failure (Avg.) (mm)
	Adhesive Failure (AF)	Cohesive Failure (CF)		
0	S1(50%AF & CF) S2 (100%AF) S3(100%AF)		12.01	8.1936
0.25	S1 (50% both) S2 (100%CF) S3(100 %AF)		12.58	11.261
0.5	S1 (100%CF) S2(100%AF) S3 (100%AF)		10.46	2.9863
0.75	S1(100%AF) S2(100%AF)S3(100%AF)		9.12	1.931

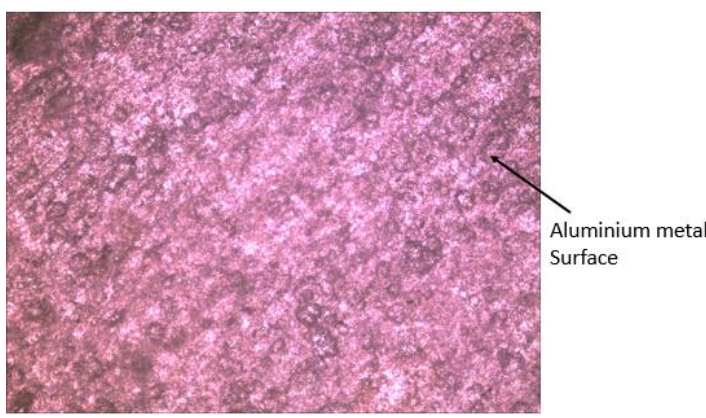
4.2.5 Conclusion

The results in this section have shown that adhesive joint behaved as a ductile when 0.25% of cork powder is added in adhesive. The graph and table show that at 0.25% joint have maximum strength and displacement from mean position as compare to other. As the displacement of failure increases, the ductility of adhesive increases. Furthermore, the brittleness of adhesive increases as we add more percentage of cork power into adhesive because the displacement of failure decreases. In addition, at 0.25% Cohesive and Adhesive failure occur while at other ratio most of the joints failed under adhesive failure.

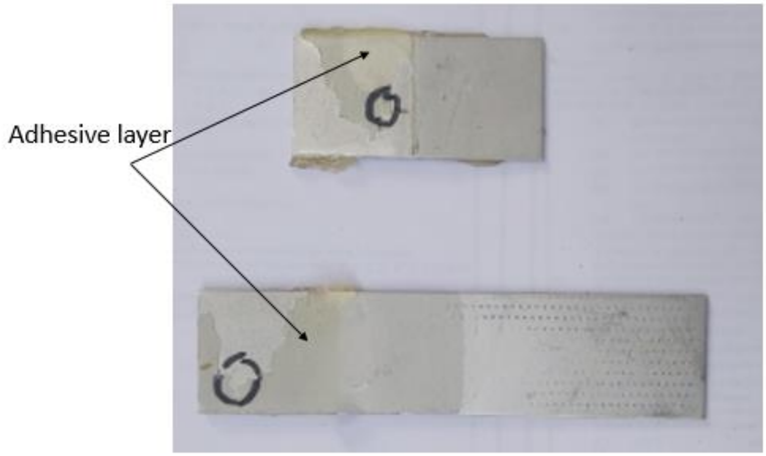
4.3 Digital Microscopy

Optical microscope was used to study the adhesive layer, dispersion of cork particles in adhesive and metal surface. In Figure 4.3(a), aluminium metal strip is shown under optical microscope. These are the samples without reinforcement so no cork powder is seen in the following images. In Figure 4.3(b), optical image of aluminium surface is shown without any adhesive layer. In figure 4.3(c), both cohesive and adhesive failures are observed.

(a)



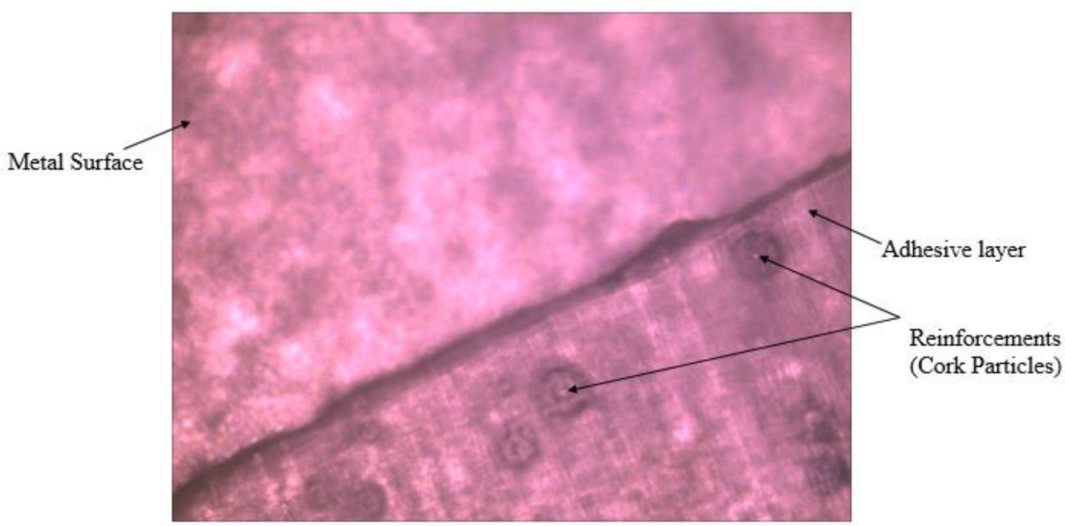
(b)



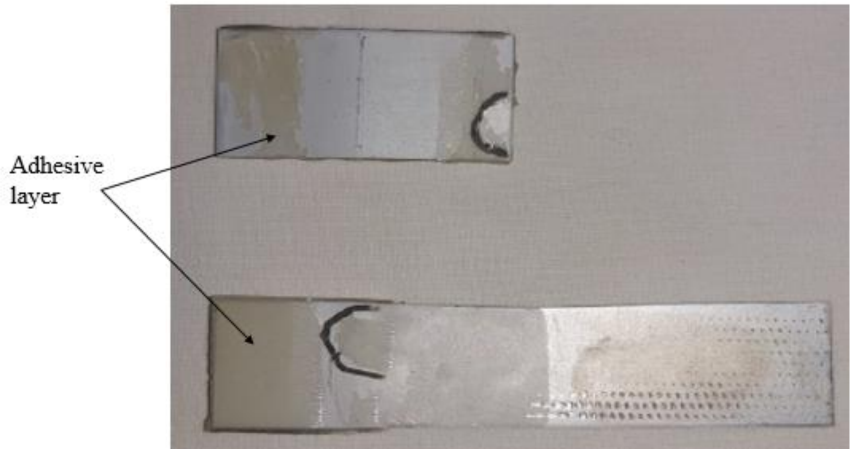
(c)

Figure 4-3: Optical micrographs of aluminium in Double strap joints tested in shear loading: (a) aluminium metal Strip under Optical Microscope (50x); (b) aluminium metal surface; (c) marked areas represents observation under optical microscope

Sample prepared with 0.25% of cork powder, which is shown in **figure 4.4(b),** showed both adhesive and cohesive failure. Because at some regions there is thin layer of adhesive bonded to substrate surface.



(a)



(b)

Figure 4-4: Tested samples under optical microscope with 0.25% cork powder ratio: (a) Reinforcements (cork powder) seen clearly at 200 times magnification; (b) Double strap joints after shear load testing.

In figure 4.5, 0.75% of cork powder was added into adhesive. The image is 100 times magnified than original and cork particles are clearly seen in the adhesive dispersed uniformly. The increased concentration of particles acted in increase of the brittleness of adhesive hence reducing strength of joint and leading to adhesive failure.

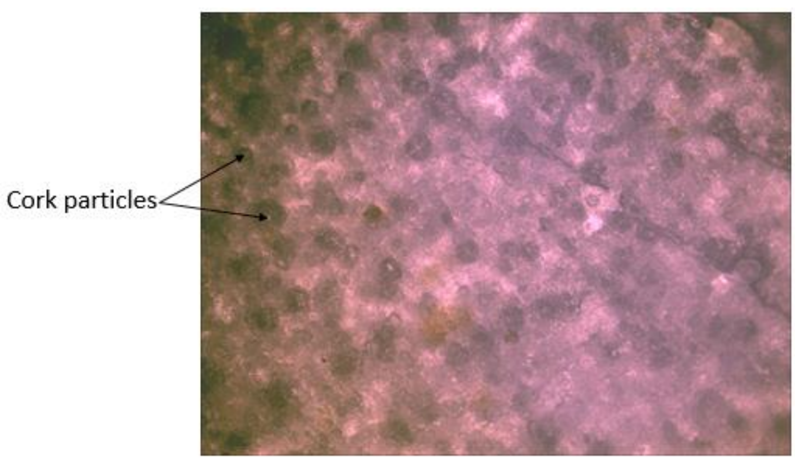


Figure 4-5: 0.75% of cork powder in adhesive

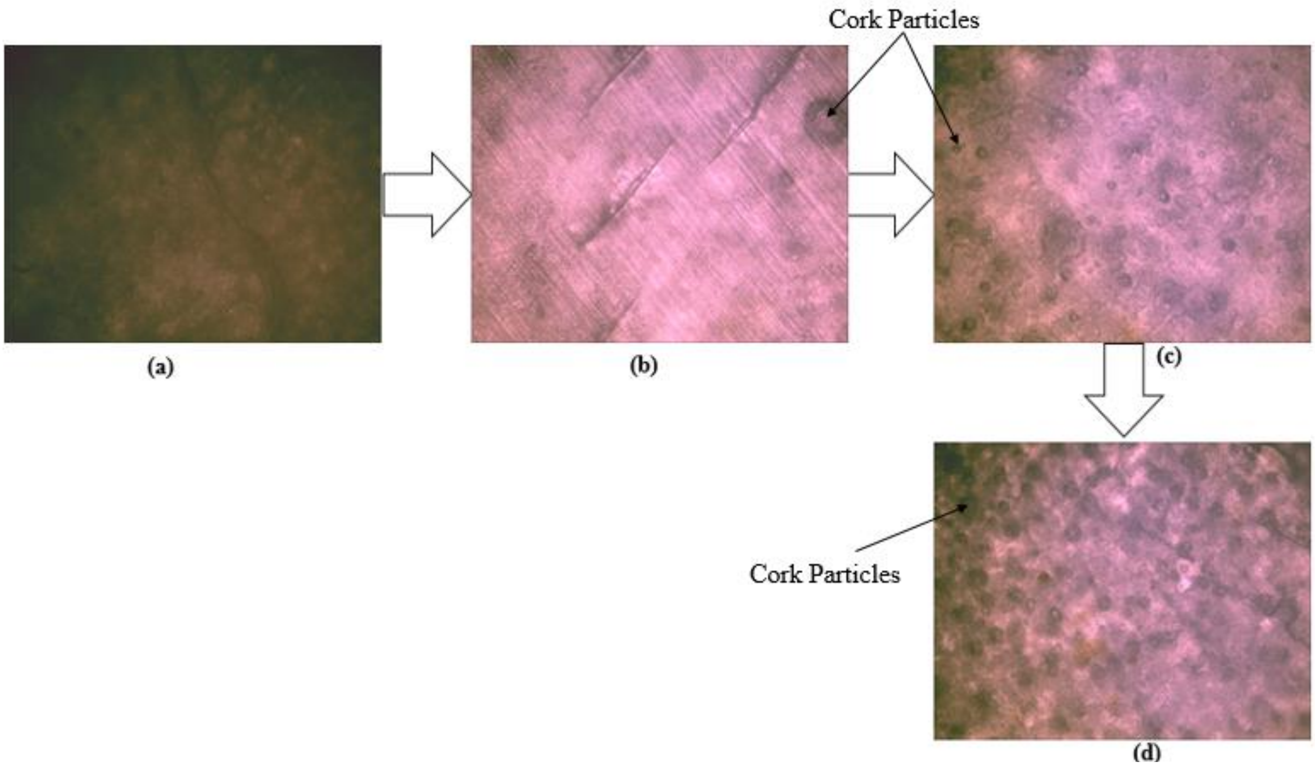


Figure 4-6: Optical micrographs of cork particles mixed in adhesive: **(a)** 0%; **(b)** 0.25%; **(c)** 0.5%; **(d)** 0.75%

4.4 Conclusions

- Double strap adhesive joints shows maximum shear strength of 12.58kN at 0.25% of cork powder under shear loading. This is because at 0.25% cork particles acted as reinforcement which increased the shear strength of joint. Hence, more energy was required to break the specimen.
- Cork particles acted as impurity at 0.50% and 0.75%. And as impurities decreases the strength of joint hence less energy was required for the failure of specimen.
- Double strap adhesive joints shows maximum displacement of failure from mean position at 0.25% of cork particles it is because at 0.25% adhesive started to act as ductile.
- Mostly cohesive failure in adhesive layer is observed in samples prepared from 0.25% of cork powder. Because in this type of failure maximum strength of material in joint reaches and at 0.25% maximum strength was observed.
- As the concentration of cork particles increased from 0.25%, adhesive started to act as brittle. Hence, more the cork particles more will be the brittle behavior.

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