Effect of temperature and filler concentration on the strength of adhesively bonded single lap joint.

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November 2021

Declaration

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MASTER THESIS WORK

We hereby recommend that the dissertation prepared under our supervision by: Yousaira Muqbool (318047), Titled: **"Effect of Temperature and Filler Concentration on Adhesively Bonded Single Lap joints"** be accepted in partial fulfillment of the requirements for the award of **MS Mechanical** degree

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Copyright Statement

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Abstract

Adhesively bonded joints are mostly commonly used joints for structure components in past few decades. The most common joints are single lap joints and epoxy resin is one of the most frequently used structural adhesives because of its mechanical and chemical properties. Numerous factors influence the strength of adhesive joints, and various researchers have discovered numerous methods for increasing the single lap joints strength. The cork powder is an effecting way for refining the strength of single lap adhesive joints. The cork act like a crack stopper but at different concentrations, it behaves differently. The strength of single lap adhesively bonded joints with two dissimilar adherends (composite carbon fibre and aluminium coupons) is investigated in this study at a variety of temperatures and cork filler concentrations. The single lap joints are tested under tensile testing at universal testing machine. The temperature ranges from 25 degrees, 50 degrees, 75 degrees and 100 degrees and the cork powder concentration for each temperature are 0.25wt.%, 0.5wt.%, 0.75wt.% and 1wt.%. It is observed that for different temperature and for each concentration, the strength of single lap joints shows similar behavior trend. The highest strength is observed at room temperature and at 0.75wt.% cork powder concentration and minimum strength is observed at 100 degrees and at 1wt.% concentration. The type of failure is changes from mix mode failure to cohesive failure as temperature and cork powder changes from low to high.

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Chapter 1: Introduction

1.1 Background

For a variety of subjective and objective reasons, adhesive joints are increasingly becoming the method of choice for attaching component parts[1]. Thousands of adhesives are available, each with subtle as well as significant differences. Adhesives are used to join the pieces together. Numerous materials can be bound together in a wide range of items and due to the wide variety of adhesives available, adhesives are used in a wide variety of applications, including mobile phones, personal care products, buildings, computers, and medical device as well as in automotive, marine, and aerospace industry [2].

Adhesively bonded joints are used because of high stiffness, low weight, low cost, and high strength properties as compared to other mechanical joining methods[3]. The efficiency of bonded joints is determined by numerous aspects, one of which is the sort of surface treatment used in the development of adherends' surfaces[4].Mechanical strength is one of the most essential characteristics of an adhesive junction, and it is linked to other characteristics and properties. The nature of material adhesion is a complicated subject which is complicated related to strength measurement. Several test procedures have been developed with the goal of determining a joint's 'strength'.

There is different type of adhesive joints such as single lap joints, double lap joints, stepped lap joints and scarf joints[5]. The most common joints on which most of experiments are being done is Single lap joints[6]. The strength of single lap joints depends on many parameters such as type of adhesives (brittle or ductile, strong, or weak), overlap length, type of adherends, thickness of adhesives/adherends, joint geometry, Temperature, weight age of different filler concentrations. Different types of experiments are being done with different adhesive and adherent to test the strength of the joints. Numerous reviews of the literature have been conducted with the goal of increasing the strength of single lap joints or decreasing the stress concentration. Different techniques are being adopted to increase the strength of single lap joints.

The effect of overlap length and adherend thickness on the strength and failure mode of an adhesively single lap carbon fibre reinforced epoxy composite is investigated. The phase angle declines as effective length grows for joints with smaller overlaps and rises for SLJs with larger overlaps[7]. The maximum load of the double-strap joints was also shown to be substantially dependent on overlap length. In fact, doubling the overlap length from 50 to 100 mm resulted in an almost 50% increase in maximum load[8]. It is observed that overlap length has a greater effect on shear strength than thickness. The strength of the carbon fiber reinforced plastic and aluminum single lap joints at different strain rates is being experimented. At high strain rate, brittle failures occur in the carbon fiber reinforced plastic single lap adhesive joints.

The strength of the bond at each contact, particle shape, and stress all influence failure modes. There are three types of failure modes adhesive failure, cohesive failure, and mixed failure[9] as shown in fig 1.1. Also, by increasing strain rate, the failure type of adhesive is transformed from adhesive and cohesive failure to cohesive failure and fiber tear failure mode Bonded joint failure is still difficult to anticipate since the failure modes varies based on the joining process, epoxy used, temperature, moisture, and other factors[10].

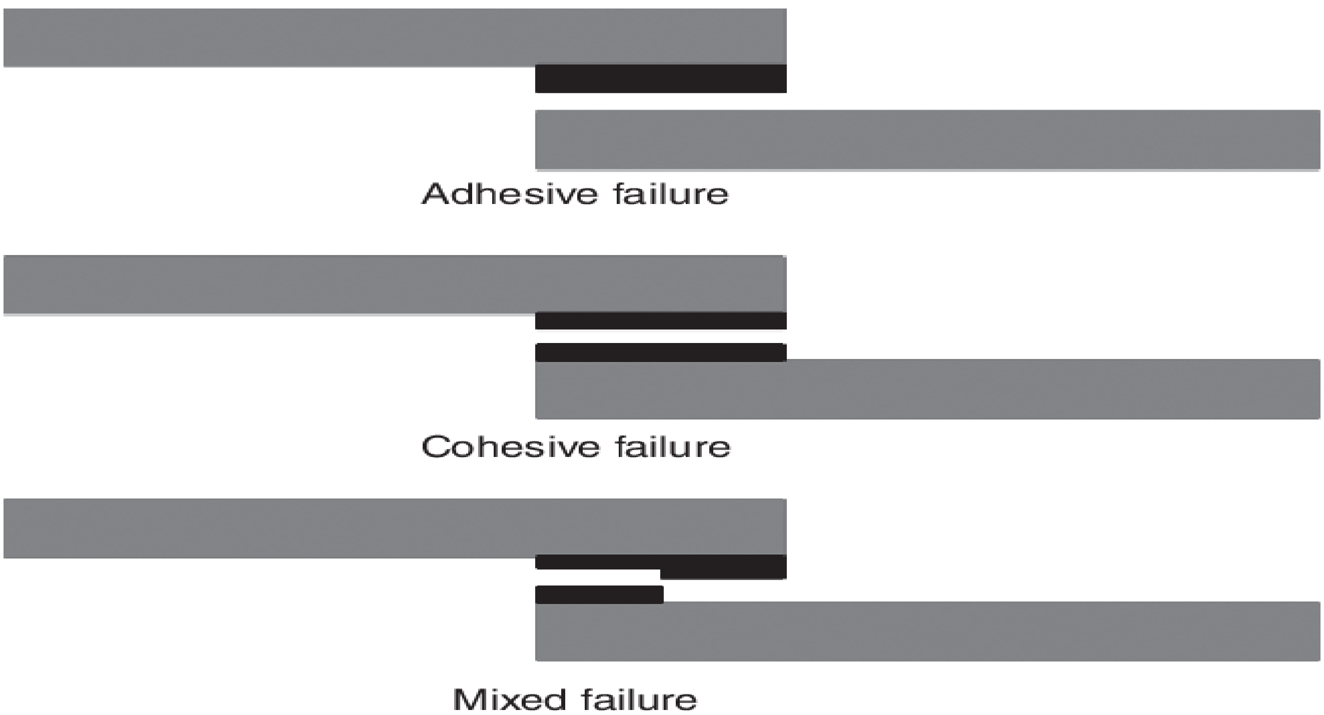


Fig1.1. Type of failure mode [9]

Experimental and theoretical evidence indicate that adhesive junctions between different materials create caused by thermal stresses, which increase with the high temperature coefficient mismatch and the curing temperature value[11]. A lot of experiment has been done in many research papers to see the effect of high and low temperature on the strength of adhesive joints. The characteristics of the adhesive and the composite influence the strength of the adhesively bonded BFRP-Al joints at various temperature. The failure strength of BJs, SJs, and TASJs diminishes as temperature rises, and the reduction is especially evident at high temperatures[12]. If the temperature is lower the glass transition temperature (Tg), the strength and modulus of adhesive joint is quite high, but their ductility is reduced. At the temperature beyond the glass transition temperature, adhesive is flexible and tough, but the strength will reduce. The temperature affects the bond properties of adhesive joints.

The type, shape, composition, size, and density of nanoparticles, as well as their specific surface area, cost, and accessibility, are critical aspects in selecting optimal nanoparticles to achieve the best qualities of epoxy adhesives[13]. To alleviate these adhesive limitations and improve the mechanical characteristics of adhesively bonded joints, introducing cork granules of various scales within the adhesive layer may be a simpler and less expensive solution[14]. When a nano-filled epoxy resin was used, the experimental results showed a significant improvement in the mechanical performance of the adhesive in terms of tensile resistance (+18%), length at break (+29%), and, as a result, strain energy at rupture (+53%) [15].

The single lap joints strength is increased by adding different concentration of cork particles. The effect of cork nanoparticles, molecular depending on the concentration of adhesives, and moisture condition were investigated in[16]. It is concluded that cork particle improves the toughness of the adhesives and cork particle with surface treatment has lower strain energy rate as compared to the adhesive with cork particle and without surface treatment in case of brittle epoxy adhesives. In this study, the effect of temperatures ranges from 25-100 degrees at different cork powder concentration is being experimented for single lap joints having two dissimilar adherends (aluminum and composite carbon) to evaluate the strength of single lap joints. Universal testing machine is being used to test the strength of single lap joints under tensile testing.

1.2. Research Gap

(a). Temperature rise in general affects the strength of adhesive joints, especially once a limiting temperature is reached.

(b). When nanoparticles, carbon nanotubes, and cork powder are added in a precise amount, they boost the strength of adhesive joints.

(c). The synergistic impact of temperature and cork powder addition on joint strength is mainly unknown.

1.3. Problem Statement

The strength of single lap joints is strengthened by introducing cork powder at room temperature. However, joints may experience temperature changes over their operational life. The durability of single joints at different temperatures and concentrations is unknown.

1.4. Aims and Objectives

The aim of this research is to investigate the strength and failure load of single lap joints at various filler concentration. The following objectives were identified to attain the aim.

(a). Prediction of strength at different cork powder and different temperature.

(b). To identify the failure load and comparison of the failure load for each parameter.

(c). To classify the type of failure in Single Lap joints

1.5. Research Scope

(a). The adherends used in my research consists of two different material that is Aluminum 5083 and composite carbon fiber coupons.

(b). The adhesive consists of epoxy that is Araldite LY-556 and hardener AD-22962 used in my research

(c). As a filler, Cork powder is used at concentration of 0.25wt.%, 0.5wt.%, 0.75wt.%, 1wt.%

(d). Universal testing machine is being used to test the Single lap joints.

Chapter 2: Literature Review

2.1. Introduction

Adhesive joints are intended to promote consistent load distribution while avoiding difficulties caused by stress concentrators such as bolts or rivet holes. Adhesive joints are cost effective and widely used due to their lighter weight, greater strength and resistant to fatigue alternatives. As a result of their potential applications, adhesives have become a focus of research. Adhesives are widely used in aerospace, industry, and medicine today. Reduced stress concentrations and maximization of the failure load are critical issues to solve in adhesively bonded joint applications. There are different types of adhesively bonded joints as shown in Fig.2.1 [17]. The single lap joints (SLJs) are the simplest form of adhesive joints in which two adherend can be joined easily and SLJs are used because of their simplicity and efficiency. The strength of adhesive joints is predicted by using various method. Different numerical and analytical techniques are used to evaluate the strength of adhesive joint at different overlap lengths and to calculate the maximum load. The strength of adhesive joints depends on the characteristics of adhesives, type of adherend, temperature, overlap length and the concentration of different nanoparticles. In many previous years, Different type of techniques has been experimented to increase the single lap joints strength.

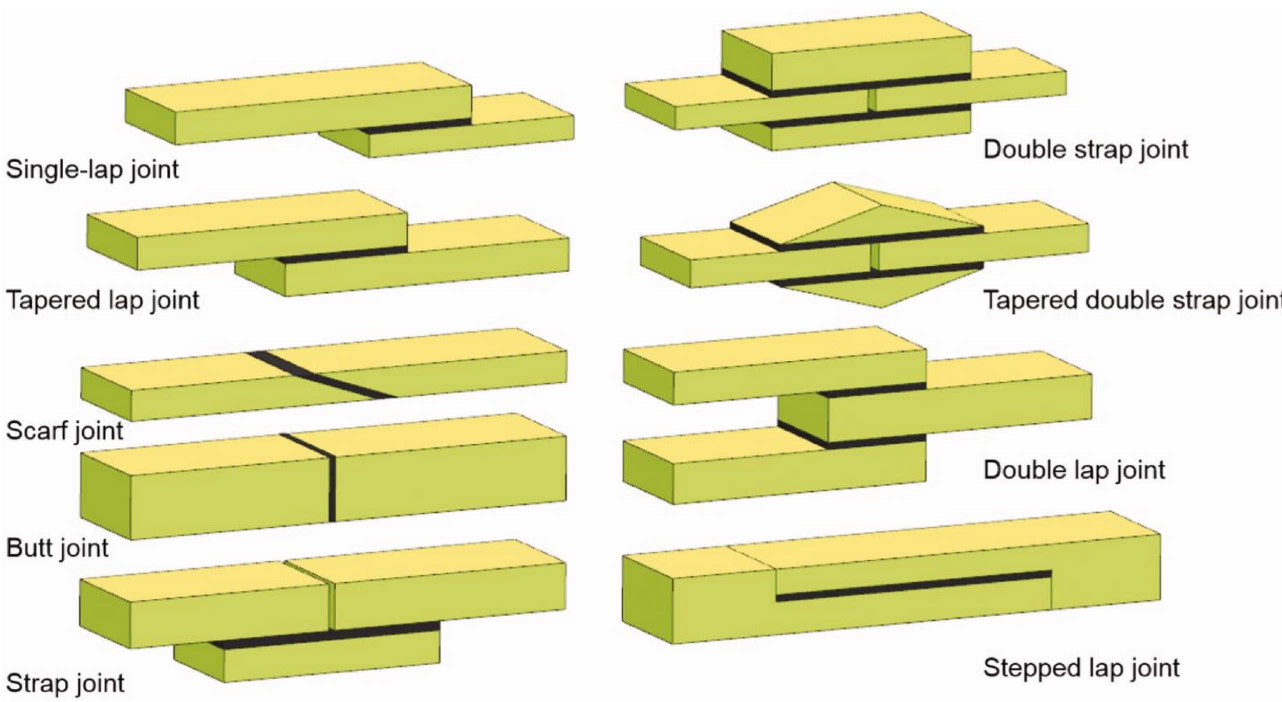


Fig.2.1 Types of Adhesive bonded joints [17]

2.2. Factors affecting the strength of joints

The error in bonding process will affect the single lap joints strength. Also, the effect of adherend misalignment on the single lap joints will be considered. FEA and MATLAB tool are used to correct the geometrical nonconformity of adherends. It is also concluded that for epoxy aluminum lap shear joints, the deviation from peak load in tensile test vary from 5% to 10%. It is investigated experimentally that misalignment in adherends cause the reduction in strength of single lap joints. Also, the strength of single lap joints increases by decreasing the adhesive thickness or volume. Additionally, it is demonstrated that the strength of single lap joints is dependent on the geometry of the component, the bonding process, and the equipment used to join the components. The reduction in strength is more prominent as compared to minimal case with same volume [18].

This is a review paper that discussed several procedures to increase the strength of adhesive joints and for decreasing the stress concentration with composite adherends. The material arrangement and geometry design are compared in different techniques. Different material-based techniques are graded adhesive, graded adherends, transverse adherend toughness which reduce the stress distribution in the adhesive and adherends and improve the surface roughness by using the rivets, bolts and help in improving the transverse strength of the adhesive joints. It is reviewed that the geometry should be selected carefully during design so that it does not cause any premature failure either in adhesive or adherends. Fabrication process in composites provide high strength, high delamination resistance and high surface roughness [19].

The bending effect of adhesively bonded single lap joints is reduced in this article by adding support patches at varying distances from the overlap region to increase the joint's strength. The liquid structured epoxy is used as adhesive, AA2024-T3 aluminum alloy as adherend and flat or curved aluminum alloy and steel of varying thickness are used as support patches. From experiments, it is observed that support patches increase the damage load of single lap joints between 16% and 94%. As the thickness of support patches increases, the rigidity in bending increase and will result in increasing the load bearing capacity of single lap joints. It is observed that when the overlap region section is equal to the outside the region, then maximum damage load is increased. The curved support patches increase the load bearing capacity of the joints [20].

The article discussed the tensile and compressive strengths of single lap adhesive joints made of green composite. Epoxy, polyurethane, and parent polymers are used to join the green composites (PLA). Overlap length and width of samples are the factor that effects the performance of adhesive joints. It is observed that single lap joints with a wider width and longer overlaps have a higher tensile and compressive strength. The greater bond strength area provides more energy for the adhesively joints to fail under load. It is concluded that the epoxy adhesive is most favorable bonding material due to its greater stiffness and rigidity in comparison to the other two bonding materials. The failure mode in green composites under tensile and compressive loading are failed due to adhesive, cohesive, and fibre tear failures, as well as structural failures [21].

In this paper, the bolted, bonded and hybrid single lap joint's strength is investigated experimentally and numerically three distinct adherend thicknesses and two distinct adherend materials with varying mechanical properties such as yield, tensile strength, and ductility were used. For bonded single lap joint, as the adherend thickness increases the maximum load increases while failure decreases with displacement. When hybrid joints are compared with bonded joints, then in both the joints, there is no considerable variation in maximum load. The energy absorbed by a hybrid joint is equal to the sum of the energy absorbed by both joints when aluminum adherend are used. Hybrid single lap joints are dependent on the adherend material and are stronger than the other two single lap joints [22].

By using molecular dynamic simulation, this article analyzed the performance of adhesive thickness on joint strength. The interfacial strength of the joint in terms of tensile, shear, or combined loading is determined by the strength between the adhesive and adherend, and failure occurs because of a weakness in the strength at the joint interface. The effect of thickness on the tensile stresses are shown in Fig 2.2. Cohesive failure occurs on different loading conditions when there is stronger interface of the joints. The bulk shear is difficult to recognize under mixed mode conditions. The yield strength does not depend only on interface but also depends on the thickness and improves as there is reduction in thickness. Strength also increase with increase in the density and polymer configuration [23].

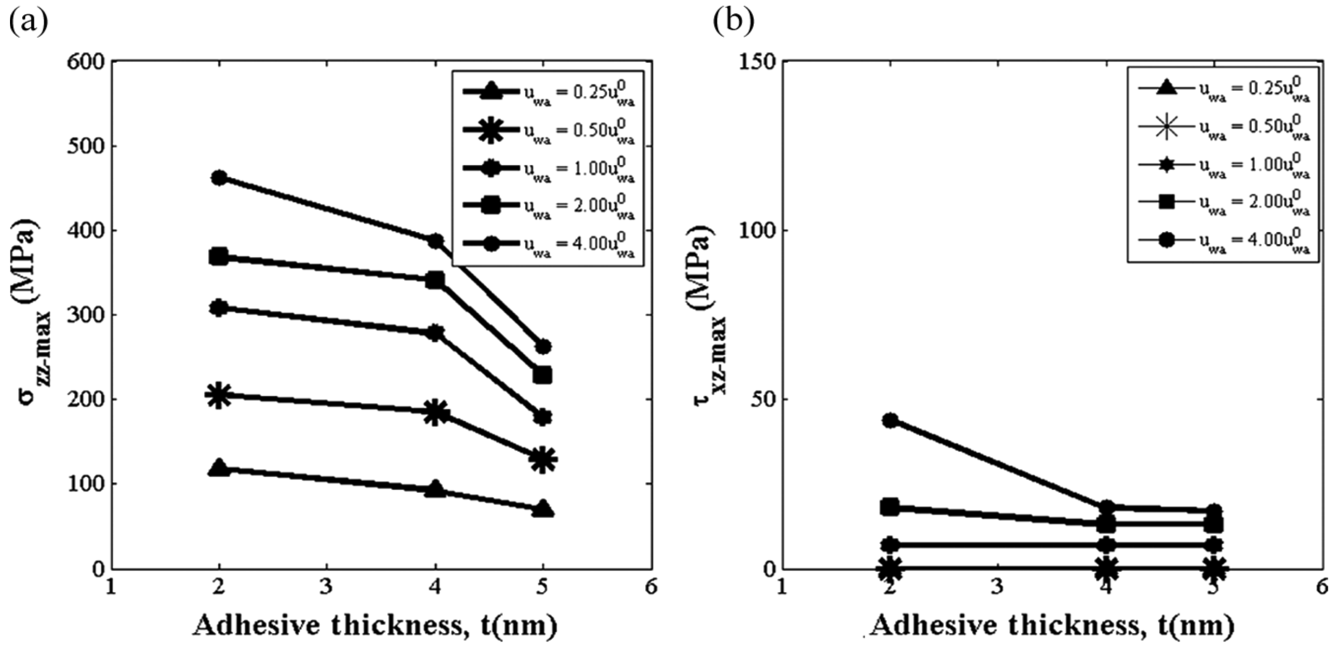


Fig 2.2. Effect of thickness and interface on (a) maximum Tensile stress, (b) Maximum shear stress [23]

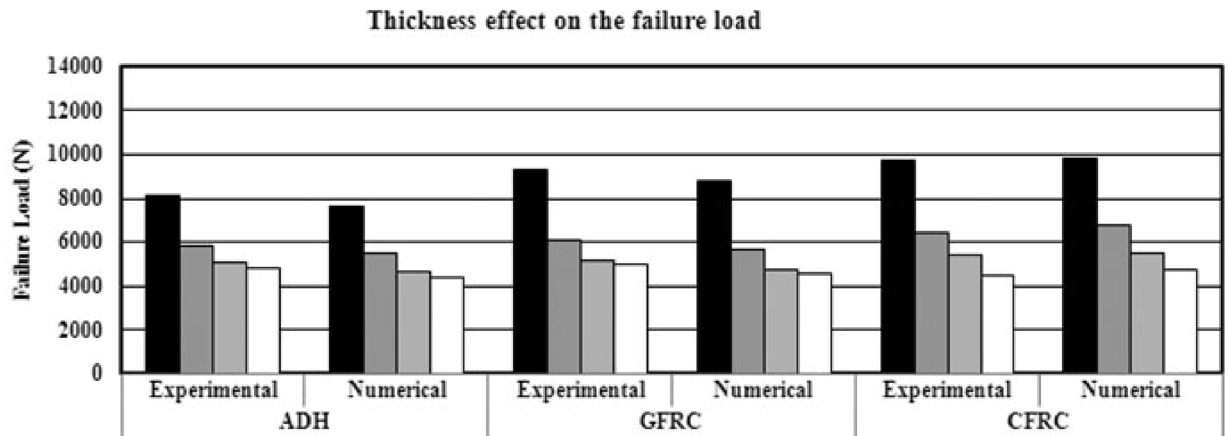
In this paper, the strength of single lap joint with two dissimilar adherend is analyzed by external bending moment. The stress distribution at interface is evaluated because of adherend thickness ratio, adherend length ratio between dissimilar adherend and young modulus ratio of adherend. It is noted that the intensity of stress distribution at interface increases as the adherend interface are smaller and intensity is greater at thinner adherend interface. It is detected from experiment that the joint strength increases as the young modulus and adherend thickness increases and the length ratio has very small impact on the single lap joints strength. Finite element analysis is carried out for dissimilar adherend of single lap joints and concluded that FEA has same results as observed from experiments [24].

This paper studied about the effect of the two different adhesives named as aluminum and carbon fiber reinforcement polymer on the glass sheet of double lap adhesive joints. In this paper five different types of adhesives (three epoxy and two acrylic) were tested at three different temperature conditions. It is observed that the acrylic adhesive show decrease in mechanical performance as the temperature increases as compared to epoxy adhesive. The epoxy adhesive shows highest load carrying capacity while acrylic adhesive has highest joint elongation capability. The failure mode in glass-aluminum samples is mainly the adhesive failure while the failure mode in glass- CFRP samples show cohesive failure or light-fiber-tear failure. At high temperatures, the epoxy and acrylic adhesive mostly show the adhesive failure in term of failure modes. The most suitable adhesive is considered as epoxy adhesive with large elongation capability [25].

In this paper, the influence of overlap length and adherend thickness on the strength and failure mode of the carbon fiber reinforced epoxy composite of adhesively single lap joint is experimented. It is observed that the shear strength is more effected by overlap length as compared to thickness. Multiple linear regression and algorithm- trained neutral network (NNs) are used for the evaluation of the strength and type of failure in the adhesively bonded single lap joints. Ten cases are experimented to check the error percent of both the techniques, and it is found that for multiple linear regression the error percent is 3.12% and for NNs the error percent is 2.27%. Both techniques give accurate results based on experiments rather than assumptions and both models can accurately improve the adhesively bonded single lap joints strength. These both model are used for bond joining process in industries [26].

2.3. Factors effecting the strength of carbon fiber and aluminum joints

This paper discussed about the effect of reinforcing adhesively bonded single lap joint on the failure of the joints. Three types of adhesive joints (unreinforced adhesive, adhesive with carbon fiber reinforced composites and adhesives with glass fiber reinforced composites) are used at different length and thickness of the joints. Finite element analysis is carried out to evaluate to failure progress and numerical techniques such as Hashin failure criteria and Tresca failure criteria are used to compare the experimental values with numerical results. When both results are compared it is observed that carbon fiber reinforced composites have highest failure load capacity for thin bond-lines as compared to the other two adhesive joints as shown in Fig.2.3. For thick bond-lines, the glass fiber reinforced composite is most favorable because it gives highest failure load for thick bond-lines. It is concluded that as the thickness of the adhesive joints decreases and the overlap length increases, the strength of adhesive joint will be increased [27].



	ADH Experimental	ADH Numerical	GFRC Experimental	GFRC Numerical	CFRC Experimental	CFRC Numerical
tha=0.4 mm	8136	7644	9290	8766	9775	9840
tha=0.8 mm	5850	5485	6128	5709	6415	6766
tha=1.2 mm	5056	4622	5125	4767	5446	5519
tha=1.6 mm	4790	4375	5025	4540	4487	4767

Fig.2.3. Failure loads variation as a function of the adhesive thickness [27]

The paper studied the single lap joint's strength for three different adhesives using critical longitudinal strain criteria (CLS) with rapid point interpolation method (RPIM). When critical longitudinal criteria are combined with the rapid point integration method, accurate results are obtained for all adhesives ranging from brittle to highly ductile and a maximum error of 17% is estimated for the toughness of a single lap joint. The critical longitudinal criteria are sensitive toward overlap length, so it is suitable to choose smallest and largest overlap length with first intersection point to fix this. The strength prediction of single lap joint is accurate when critical longitudinal criteria with rapid point integration method is used instead of finite element method [28].

The paper studied about the single lap joints strength for different material and dimension by means of critical longitudinal strain technique (CLS). Fracture mechanism is analyzed by using specific distance and longitudinal strain parameters for five different adhesives (epoxy, silicon, polyurethane, bismalemides and acrylic) and for two different substrates that is steel and aluminum alloys. Critical longitudinal strain technique can also predict failure mode for brittle and ductile adhesives. In this technique, 120 different configurations of single lap joints are used and short and long overlap length, thick to thin bond line and different substrate thickness is also taken. The CLS technique predicts the failure load accurately for intermediate and brittle adhesives for different configurations. For intermediate joints, CLS is a good approximation of the adhesive and stiffness ratios, the relation between stiffness ratio and CLS can easily be attained [29].

This paper studied the influence of tensile load on the adhesively bonded CFRP single lap joint. They take 7 different overlap length, 5 adherend width and 3 stacking sequences of joints to evaluate the experimental and numerical investigation. Finite element is an accurate method for analyzing the type of failure in single lap joint. It is observed that increasing the adherend width is most suitable for improving the load carrying capacity as compared to increasing the overlap length of the joints and by increasing the overlap length will decrease the cohesive failure and increasing the width is proportional in increasing the cohesive failure. Due to increase in stress concentration across the overlap edges, the stress level is higher and leads to premature failure. Both the cohesive and adhesive failure occur in [45/0/-45/90] composite single lap joints which shows less tensile strength while the adhesive failure occurs in [90/-45/45/0] composite single lap joints which shows a small load carrying capacity [30].

The paper evaluates the tensile shear strength of a single lap joint with various adhesion types. Carbon/epoxy composite, high flexural limit steel, and aluminium alloy are used as raw material. Adherend stiffness and high stiffness adherend material largely impacts the shear strength and by using high stiffness adherend material, shear strength will be highest. Also, the shear strength is affected by overlap length dependent on the various adherend material. From the numerical analysis it is observed that with increase the rigidity of the adhesive, the stress distribution will be uniform and by increasing in yield stress reduce the stress level and increase the single lap joints strength. From experimental results, it is concluded that for steel/steel joints the strength is higher as compared to composite/composite joints which has lower strength [31].

This paper investigates the strength of aluminum double lap joint with different adherend material for artificial aging condition and non-aging conditions to check the performance and mechanical properties of adhesive joints. It is concluded that for EXP1 adhesive, high stiffness is observed after 28 curing phases but EXP2 adhesive shoe high stiffness at all phases and EXP3 shoe irregular behavior. The failure mode in EXP1 and EXP3 are adhesive failure and EXP2 adhesives show mixture of both cohesive and adhesive failure. It is detected from experiment that EXP2 proves to be a most favorable adhesive in term of load bearing capacity and mechanical performance is also maintained under artificial aging [32].

Aluminum single lap adhesive joints is studied at different wt.% of the sphere- and rod-shaped Nano alumina under Quasi static shear strength. The maximum shear strength for both nano alumina is observed at 1.5 wt.%. Split Hopkinson pressure bar system is used for the prediction of dynamic shear strength at two different loading rates and at 1.5wt.% of both nano aluminas. Dynamic shear strength shows significant improvement that is three to seven times than the static shear strength. Sphere nano alumina increases the static and dynamic shear strength as compared to the nano rod alumina and neat adhesives. Sphere nano alumina show cohesive failure as compared to the neat adhesive or adhesive with nano rod [33].

The fatigue behavior of a carbon fibre reinforced plastic (CFRP) and aluminium single lap joint was studied under cyclical loading and quasi-static loading following an axial pre-impact. It is evaluated from experiments that with increase in the pre-impact energy, fatigue life of CFRP/Al decreased. Based on the fatigue testing, S-N curves are drawn to get the data and it is shown that by increasing the cyclical loading, fatigue life of joints decreases. It is observed that cohesive failure occurs during cyclical loading under quasi-static load because cohesive failure is highly dependent on the adhesive strength between adherend and adhesive, primarily in aluminium substrates, and interfacial failure occurs prior to adhesive reaching its static failure strength. Transverse pre-impact damages the adhesive and adhered material, resulting in adhesion strength as a result of the indentation in the aluminium adherend. By improving the surface texture on aluminum adherend, the bonding capacity will be highly improved thus increasing the fatigue properties of the joints [34].

At various strain rates, this article investigated the carbon fibre reinforced plastic and aluminium single lap joints experimentally. The microscopic and DIC analyses are used to evaluate the fracture mechanism and deformation process under different loadings. It is observed experimentally with the increase strain rate; joint strength demonstrates increasing trend. Additionally, joint strength and failure tensile strength are free of axial tensile velocity, and both decrease as the axial pre-impact velocity increases. The strain distribution of these joints is shown in Fig.2.4. At high strain rate, brittle failures occur in the carbon fiber reinforced plastic single lap adhesive joints. Also as strain rate increases, the failure mode of adhesive is changed from adhesive and cohesive failure to cohesive failure and fiber tear failure mode [35].

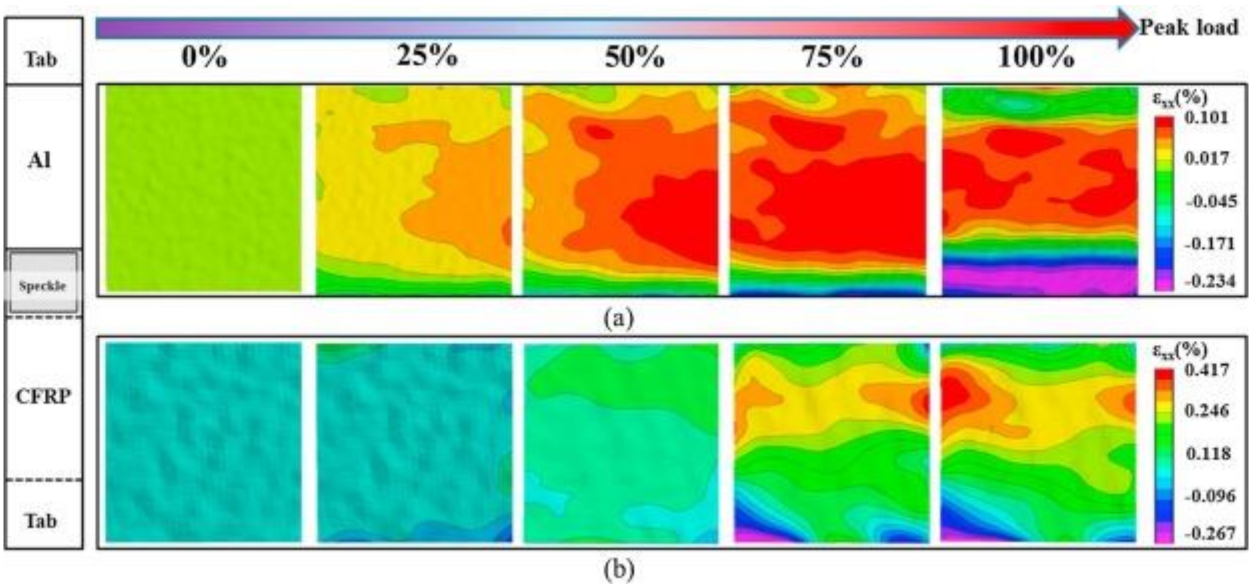


Fig.2.4. Strain distribution of joints after transverse pre-impact [35]

The impacts of various compressive strengths on the strength and failure of single lap joints made of carbon fibre reinforced plastic and aluminium alloys was investigated in this article. To calculate the strain rate at four different strengths from 2mm/min to 12 mm/min. It is observed that with increasing loading rate from 2 to 12 mm/min Digital image correlation (DIC) technique is used, the shear strength increases from 19.3 to 29.2 MPa. The cohesive failure and fiber tear failure occurs at the end of bonding areas and the middle of the bonding areas the failure is due to resin matrix failure of CFRP. In quasi static condition, larger failures in adhesives are due to cohesive failure. The plastic deformation in aluminum plate occur due to torque and lead the adhesive to fail early [36].

This paper studied about the failure analysis or strength of composite-aluminum adhesively bonded single lap joint with different overlap length using finite element method coupled with cohesive zone models. It is observed that stresses are peak at the overlap edges and these stresses are higher at adhesive adherend interface. The behavior of joints is numerically modeled, and it is observed numerically that the strength and failure mode of joints highly depends on the adhesives types. It is observed that maximum load in brittle adhesive with different overlap length is negligible and the maximum load in ductile adhesive shows a linear behavior with different overlap lengths as shown in Fig.2.4. The brittle adhesives show a quicker failure process and ductile adhesives show cohesive failure under global yielding conditions [37].

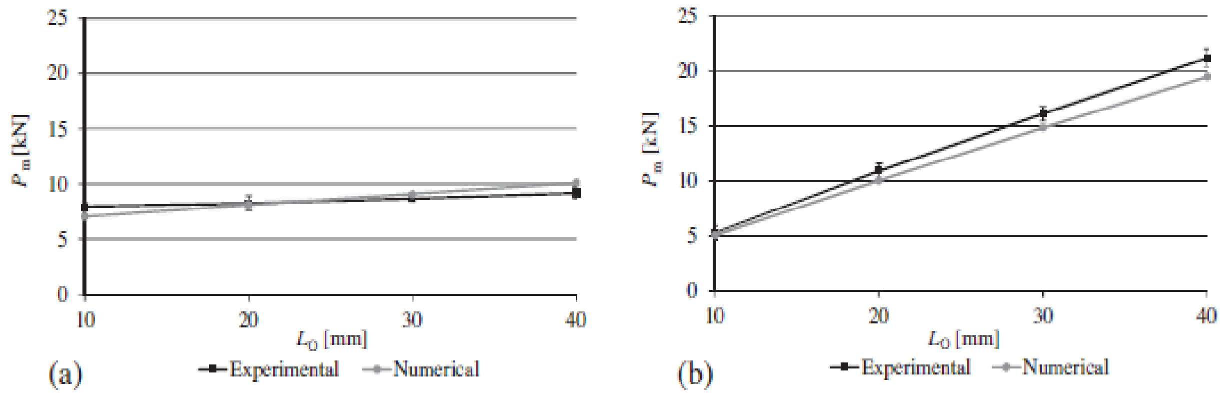


Fig.2.5. Experimental and Numerical Values maximum load and overlap length of joints (a)XNR6823 (b) and XNR6852 [37]

The paper investigates the toughness of adhesively bonded aluminium joints in a wet environment. Aluminum alloys are conquered to two distinct surface treatments with chromic sulfuric acid (FPL) and sulfuric acid ferric sulfate (P2). Both surface treatments give same results for strength of joints but the adherend treated with sulfuric acid ferric sulfate in humid condition have high durability. The amount of water consumed by epoxy adhesives has a significant effect on their glass transition temperature and joint strength. The good mechanical properties, high durability, high glass temperature and high lap shear strength is observed experimentally when new epoxy adhesives are treated with siloxanic hardener. When homopolymerized epoxy adhesives used as initiator, then strength of joint will be improved in wet environment but the strength of joints remains constant after aging [38].

The paper showed the effect of two-sided adhesive tape and rigid point connection made from two epoxy adhesive on the strength of single lap joint. TESA dual adhesive and Distal epoxy adhesive is used. Aluminum and GFRP are the composite materials that are joined and static tensile testing at room temperature for 25 samples is being analyzed. It is concluded that highest strength is achieved for 4-point connection model. Model 3 is most satisfactory for energy absorption. Deformation of double-sided adhesive tape and rigid point connections occurs when a two-component epoxy adhesive is used. Uniaxial tensile test is carried out on 5 type of mixed-adhesive lap joints and they showed high aesthetics with double sided tape and epoxy adhesives [39].

The paper discussed about strength and failure mode of double strap adhesive joint and single lap GFRP joints. It is also concluded the adhesive type, adhesive thickness and overlap length effect the strength of adhesive joints. The adhesive type has no effect on the joint strength or load displacement curve. Increase the adhesive thickness to decrease the joint strength and increase the overlap length to increase the joint strength. It is noted that joint strength is double strap adhesive joint increase with increase in overlap length, but the single joint does not show same behavior. It is also observed that double strap adhesive joint show greater load carrying capacity than the single lap joints. Peel stress and strain in single lap joints are greater than in double lap joints. Peel stresses are greater near the tip of double strap joints than in the middle[40].

In this paper, rapid point interpolation meshless method is used to analyze the stress distribution and strength of adhesively bonded composite single lap joints. To predict the strength, brittle adhesive with varying overlap length is being tested. The stress distribution results obtained from meshless method is then compared with finite element method results and both methods show similar trend. Similarly, the strength predicted from critical longitudinal strain criteria will matches with strength predicted experimentally. When rapid point interpolation meshless method is used with bi-material come up with a difficulty which is interface region between the material and this difficulty is solved with simplicity that restrict influence domain in that region [41].

The article analyzed the influence of adherend notching on the strength of single lap joints. Finite element method is used for different notch parameter to check the single lap joints strength. The notch parameter specifies the angle of the notch, the width of the notch, the depth of the notch, and the proximity from the overlap length. To check the failure mode of single lap joint, 90-degree notch angle is selected by numerical results and 3 different depths with two different adhesive curing method is considered. Adherend notching leads to plastic deformation of adherent based on the geometry and properties of adhesive and adherend thereby improving the joint toughness and give advantage of low energy absorption capability. A simple right-angle notch with a 20percent on average notch ratio affects the durability and bearing capacity of single lap joints by 55%. Adherend notching technique not dependent on the curing method [42].

In this paper the effect on adherend notching with one ductile and brittle adhesive are investigated to calculate the failure load in single lap joints. This paper includes two steps, in one step the finite element analysis technique is used to evaluate the effect of different notch parameter on the single lap joint strength and in second step, numerical values are taken to perform experiments. It is observed that failure load in single lap joints depend on the mechanical properties of adhesive material and the notch depth. Although adherend notching is an effective technique for increasing the strength of joints, the notch in the adherend renders it poor. The strength of single lap joint for brittle adhesives improved to 100% when the notch depth ratio is 20% while at same notch depth ratio, the strength single lap joint for ductile adhesives improves only 25% [43].

In this paper, single lap joint with brittle and tough adhesives is studied to check the fracture mechanism of the joints. It is observed experimentally that single lap joint joined with brittle adhesive show cohesive failure mode while single lap joints joined with rough adhesive show inter-laminar delamination in carbon fiber reinforcement plastics. To determine the damage in material and confirm the fracture mechanism, finite element method with cohesive zone is used. The failure load decreases as the mesh size decreases. The joints show cohesive failure whose surface is treated by acetone or plasma. The sandpaper treatment on adherend cause intralaminar delamination and leads to inaccurate fracture mechanism. The numerical values match with the experimental data when the current experimental parameters were used in term of failure mode. When different parameters are used then numerical results differ from experimental values in term of failure modes [44].

In this paper, the dual and single adhesive bond is recycled to check the shear and strength of the single lap joints. Between dissimilar adherend such as CFRP and aluminum, the Araldite and brittle adhesives are used separately. The ductile adhesive is used at the end because of their strength and brittle material is used at the middle of the bonded region. To check the relative displacement between dissimilar materials, digital image correlation method is used and for Finite element analysis, ABAQUS software is used. The peel shear and stresses values are calculated numerically and experimentally, and it is found that both values match closely to each other. In single adhesive, the failure happens at the edge between aluminum adherend and adhesive. In dual adhesive, the failure at bonded material is not easy at interface between adherend and adhesive and hence increases the bond strength. It is concluded that for better performance and for higher strength, dual adhesive should be most favorable option [45].

2.4. Effect of temperature on adhesive joint's Strength

This paper investigates the strength of epoxy adhesive, carbon fiber reinforced plastics (CFRP) and adhesively bonded aluminum alloy for scarf and butt joint exposed to high temperature and at high speed. Numerous types of analysis are used to determine the strength and mechanical properties of joints at elevated temperatures, including Fourier transform infrared spectroscopy (FTIR) and thermogravimetric analysis. For the analysis of fracture mechanism and failure strength of CFRP various surface treatment technique and scanning electron microscope are used after thermal exposure were tested. The post-curing behaviour of Araldite adhesive results in an increase in glass transition temperature, thermal stability, and tensile strength. It is observed that rupture surface of epoxy matric of unaged CFRP are irregular and coarse while for degraded CFRP, the surface was smoother and regular. The failure strength in degraded butt joint is greatly decreased due to increase in normal stress because larger area of fiber tear causes it to fail the joints early. It is observed that as shear stresses and light transmission increase, the adhesively bonded aluminium alloy's failure strength decreases more rapidly due to the thermal environment. [46].

In this paper, the time behavior of steel/CFRP double strap adhesive joints is analyzed at different loading rate and at constant temperature. Time behavior of joints is analyzed by the strength not only function of time but also the temperature. At same temperature close to glass transition temperature and the higher load leads to shorter time to failure. Under cyclic temperature, the strength of joint improved up to 47% as compared to the constant temperature under same loading levels. To avoid the strength degradation due to effect of temperature, it is suitable to keep the temperature at 7-10 ºC or below the glass transition temperature. The strength of joints decreases with time, when exposed to thermal temperature at 40, 45 or 50 ºC. When an adhesive is subjected to tensile load and maintained at a temperature closer or beyond the glass transition temperature, it is predicted that steel/CFRP double strap joints will fail over time. [47].

This paper review about high and low temperature effect on adhesive joints. As temperature changes the mechanical properties of adhesive joints so various component is being controlled. Also focus on improving the temperature resistant of the adhesive joint and their performances. It is reviewed that stresses generated due to shrinkage are very small and negligible as compared to the stresses generated by thermal expansion. The water expansion cure adhesive has almost no shrinkage as compared to hot cure adhesives. Selection of material and geometry should be careful to avoid the failure in adhesive joints. If the temperature is lower the glass transition temperature (Tg), the strength and modulus of adhesive joint is quite high, but their ductility is reduced. At the temperature beyond the glass transition temperature, adhesive is flexible and tough, but the strength will reduce. Composite substrate and stiffness adhesive bonding have fail early due to large thermal stresses generated in them [48].

The paper discussed about the effect of high temperature on the dynamic strength of single lap joints at different loading conditions. The joints are under dynamic loading are tested by split

Hopkinson pressure bar (SHPB). The temperatures range from 25 degrees to 100 degree and equilibrium loading condition is controlled by proper pulse shaping and shown in table 2.1. It is observed from failure joints that the failure is within the adhesive layers. It is concluded from experiment that the adhesive lap joints strength increases as loading rate increases and is more than the quasi-static strength at the same loading rate. The dynamic strength decrease with increasing the temperature and dynamic strength at 100º C is 25% less than at 25ºC but the dynamic strength at 100ºC is still 50% larger than the static strength at 25ºC [49].

Table.2.1. Lap Shear Strength as a function of loading rate and Temperature [49]

Temperature (°C)	Strength[a] (MPa)	Loading rate (MPa/µs)	Strength[a] (MPa)	Loading rate (MPa/µs)
25	50.5±1.3	1.33±0.08	75.9±3.4	4.74±0.22
50	46.3±2.1	1.29±0.05	68.2±2.6	4.54±0.24
75	38.0±2.9	1.26±0.16	61.3±0.6	4.38±0.05
100	33.7±0.5	1.10±0.08	54.6±1.5	3.86±0.20

This paper discussed and reviewed about the adhesive bonded joint composites and hybrid composites. Different factor is discussed such as temperature, surface treatment to show performance of adhesive joints. It is discussed that hybrid joint show high static strength and longer fatigue life. It is observed that in thin bond lines as bond thickness increase, failure load will also increase and in thick bond lines as thickness increase, failure load decrease. The SLJ of carbon-carbon substrate give the higher strength than the other substrates. The ductile adhesive bonded joint give better results as compared to brittle adhesive joints. The composite adhesive analysis is taken to show the failure of adhesive-adherend interface. It Is also reviewed that hybrid joint show greater strength that adhesive bonded joints [17].

This paper discussed about the effect of different temperature ranges and at different dynamic rates on the steel single lap adhesive joint’s strength under servo-hydraulic high-rate testing machine. Digital image correlation method is used for evaluating the strength and failure of the joints and the experimental result shown the strength, toughness, and strain distribution for different overlap length. It is observed that shear strength and bond strength increase by increasing the loading rate. It is also observed that at temperature ranges from -25 to 50ºC, the average bond strength increases, and strength decreases as the temperature ranges from 50 to 100ºC. At room temperature, failure mode is due to adhesive/steel interface but as the temperature increases at elevated rate, the failure modes changes to adhesive/BFRP interface. It is concluded that temperature effect the bond adhesives properties [50].

2.5. Filler concentration and temperature effect on the strength of Joints

This paper studied about the graphene-oxide nanoplatelet's effect on the nanocomposites at different temperature ranging from room temperature to glass transition temperature. The single lap adhesive joint with neat and with altered weight percentage of graphene-oxide nanoplatelet is experimented. It is observed that graphene improves the strength of joints at temperature near the room temperature. It is also observed experimentally that by increasing temperature, the effect of graphene-oxide nanoplatelet decreased. The nanoplatelet decreases the strength of joints if the temperature is increasing at a critical rate. The 0.1 wt.% of graphene-oxide nanoplatelet were added at the critical testing temperature of 60ºC and for 0.3 wt.% of nanoplatelet, the critical testing temperature was concentrated to 40ºC [51].

The paper discussed about cork and ceramic matrix composite joints (CMC) at high temperature and at in-situ polymerization of cork at the top of CMC. Shear strength and shear strain are tested at room temperature and at liquid nitrogen. It is observed that shear strength for alumina and graphite adhesive joint is closer to 0.53 MPa and is increased by 47% for Zr02-Zrsio4. At liquid nitrogen, the shear strength is increased up to 80% and shear strain is decreased up to 55%. In-situ polymerization of cork at the top of CMC, shear strength remains un effected but shear strain is increased because the cork itself is involved in the fracture. It is observed that overall Zro2-Zrsio4 adhesive joint show a greater shear strength and decreased shear strain as compared to alumina and graphite adhesive joint as shown in Fig.2.6. [52].

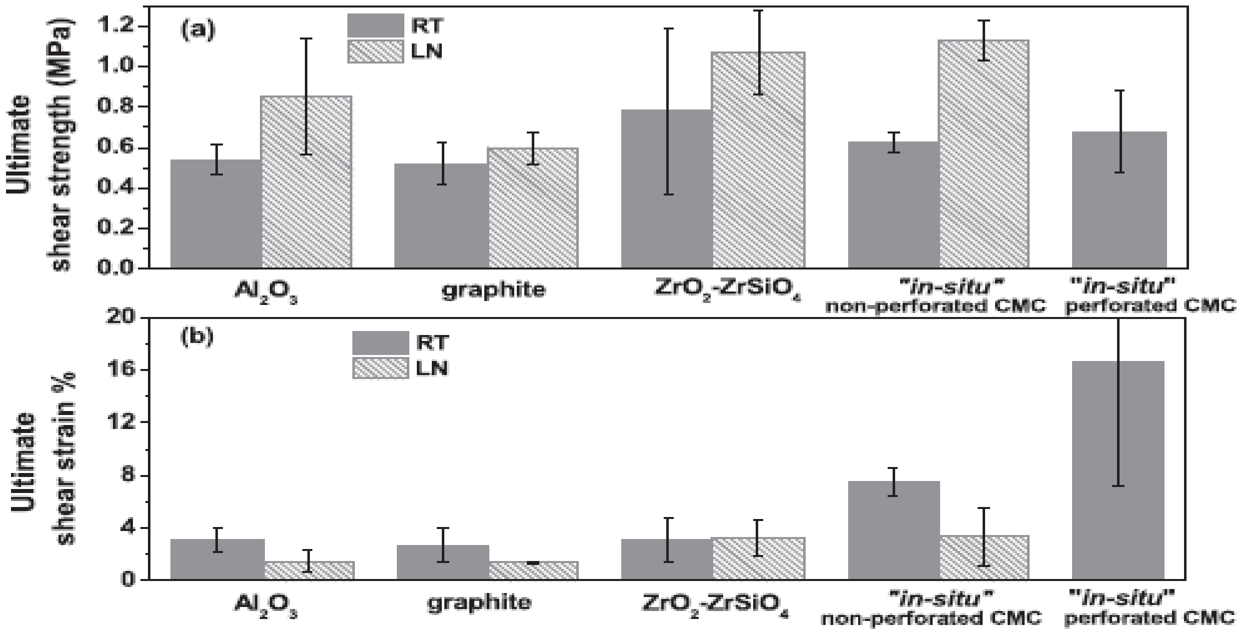


Fig.2.6. Comparative result of shear test [52]

This paper discussed about the strength and roughness of adhesive by use if different binder and cork particle. A direct correlation between the thermal conductivity and permeability of mortars, as well as between the compressive strength and stiffness of mortars, is established. It is observed that as the concrete density decreases, the thermal conductivity of concrete composite decreased. The strength of adhesive joint and mechanical properties depends upon the structure and roughness of mortars. It is observed that as cork particle increases in mortars, the mechanical properties such as strength and resistance decrease. The amount of cork and hydrated lime will result in increased the mortars absorptivity and decrease in mortars density [53].

The impact of nanoparticles on the strain rate of single lap adhesive joints was investigated in this article. Experiments are being done to compare the single lap joint's strength with and with-out nanoparticles. Steel plate adhesive joints are used, and the nanoparticles used in this paper are nano-Al_2O_3, nano-SiO_2 and nano-TiO_2. It is observed by reinforcing nanoparticles in adhesive joints the average damage load increases and at 4 wt.% nano-Al_2O_3 in epoxy adhesives maximum damage load is obtained. The failure mode is the mixture of interfacial and cohesive failure as the load increases. The strength of adhesive joint increases when nano-Al_2O_3 and nano-SiO_2 are reinforced and strength decreases when nano-TiO_2 is used. Since it is concluding that type of nanoparticles will affect the strength of adhesive joints and strength of joint will increase with the overlap length. At 20mm overlap length and 22.3% sample of nano-Al_2O_3, the highest fatigue strength is observed in single lap joint [54].

2.6. Effect of filler concentration on the single lap joint's strength

This paper discussed about the influence of stress rate on the aluminum single lap joint's shear strength that is bonded with nanoalumina adhesives. The nanoparticles used are Spherical- shaped and rod-shaped alumina. The static shear strength of aluminium alloy single alp joints under compression loading is determined using different percentage weights of nanoalumina particles. Dynamic shear strength is also investigated for neat adhesive and nanoalumina adhesive at weight of 1.5%. It is indicated that dynamic shear strength is three to five times greater than the static shear strength of joint. Dynamic shear strength of spherical shaped nanoadhesive is higher as compared to the rod shaped nanoadhesive because the spherical shaped nanoadhesive have better interfacial properties with epoxy [55].

This paper discussed about the impact of Nano alumina on the mechanical properties of aluminium single lap, double cantilever, and curved cantilever beam joints. Alumina nanocomposites are made from different percentage weight of alumina nanospheres and alumina nanorods. A remarkable improvement in strength and toughness of joints is observed when nanocomposites are used as compared neat epoxy adhesives. It is observed that the joints have maximum shear strength and maximum toughness of nanospheres and of nanorods adhesives is at 1.5 wt.% and 1 wt.%. It is also observed that fracture toughness of 1.5 wt.% of nanospheres is high as compared to fracture toughness of 1 wt.% of nanorods as shown in Table.2.2. It is concluded that by further increasing or adding the Nano alumina the shear strength and fracture toughness decreases. The average toughness observed from contoured cantilever beam is less than the average toughness observed from the double cantilever beam at all wt.% of Nano alumina [56].

Table.2.2. Comparative analysis of average toughness of joints [56]

S. No.	Wt.% of nano-alumina	Average fracture toughness (J/m^2) (±standard deviation)			
		Nanospheres		Nanorods	
		CDCB Joints	DCB Joints	CDCB Joints	DCB Joints
1	0.0	31.59 ± 01	33.87 ± 14	31.59 ± 01	33.87 ± 14
2	0.5	64.66 ± 05	82.7 ± 36	41.76 ± 01	67.08 ± 14
3	1.0	72.49 ± 09	96.18 ± 27	66.74 ± 04	86.78 ± 22
4	1.5	92.07 ± 09	171.61 ± 56	40.01 ± 04	74.43 ± 10
5	2.0	55.31 ± 05	66.73 ± 22	38.41 ± 02	52.57 ± 14

The paper studied the influence of SiC nanoparticles on the epoxy composite joint's strength combined with two acrylic adhesives. In situ polymerization technique is used and nanoparticles ranges from 25 to 40 nm are being used. The failure loads of SiC nanoparticles are higher as compared to the neat adhesives and for 1% SiC higher failure load is analyzed. Also, the shear's strength and failure load of single alp joint at 0.75% of nanoparticle is 38% higher as compared to neat adhesives. The adhesive joints without nanoparticles show adhesive failure but the adhesive joints with Sic nanoparticles show mixture of adhesive and cohesive failure. The load carrying capacity depends on the overlap length and as the overlap length increases, the load carrying capacity also increases. Distribution of different stress are investigated to analyze the nanoparticles effect on adhesive joints using finite element analysis techniques [57].

The paper discussed about the effect of two different nanoparticles that are multi-wall carbon nanotubes (MWCNTS) and silica nanoparticles (SNPs) on the single lap joints strength. It is observed that strength and failure modes are highly improved by adding the two nanoparticles on the adhesive joints. When MWCNTS added on the joints, and then by scanning electron microscope different mechanism such as shear yielding, crack growth deviation and plastic deformation were observed. It is concluded that by adding MWCNTS at low weight, shear strength is highly improved but by using larger weight of MWCNTS, shear strength is reduced. For SNPS, the phenomena were reversed that at larger weight of SNPs the shear strength is highly improved. The fracture surface of SLjs are shown in Fig.2.7.The cohesive failure modes are more prominent because of improvement in adhesion between adhesive and adherend, due to existence of MWCNTS and SNPs [58].

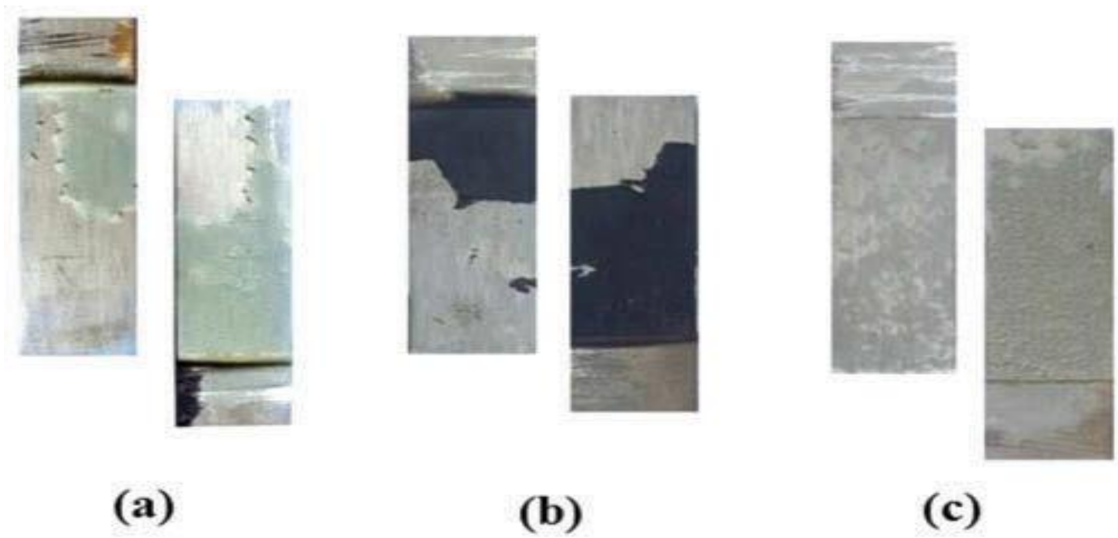


Fig 2.7. Fracture surface of Sljs (a) without nano-reinforcement, (b) reinforced with 0.5wt.% MWCNTs, (c) Reinforced with 0.8wt.% SNPs [57]

This paper reviewed about the epoxy adhesive and use of cork powder to enhance the toughness of adhesive. It is observed that toughness of particle depends on the size, distance, and volume fraction. To increase the toughness, micro particle with epoxy resin is used and has an advantage of reducing cost of component and give component a desired property. It is observed that shear yielding, and crazing phenomena is observed during the study of toughness of glassy polymer and metal plastics. The adhesion between filler and matrix effects the performance of composite materials. The toughness of adhesive joints is also improved by using brittle and ductile particles. It is also reviewed that low volume fraction of ductile material will enhance the adhesives toughness. The toughness of bulk adhesives increases as the size of particles increases. The effect of cork particle is also studied and it is observed that toughness of brittle is also improved by the use of cork particle [59].

2.7. Effect of cork particles on joint's strength

In this paper, a sandwich panel made of cork granule and green epoxy resin to determine the mechanical strength and viscoelastic response via static bending tests. Kohlrausch-william- watts model is used to collect experimental data and stress relaxation test proves that stress is reducing over time. The KWW model is most favorable for short prediction, and it predict the stress relaxation time accurately. To investigate and predict the strength for long term, the law of Findley powder is favorable one. it is concluded that fatigue increases as compared to the strength in sandwich with synthetic foam [60]

The paper discussed about the toughness of structural adhesives in the presence of cork particle. Cork act as crack stopper and particle ranging from 38-250 micrometers and amount is between 1 and 5%. Surface treatment is carried out to show the effect of adhesive-cork with several adhesions. By the pressure plasma treatment, it is shown that increase in surface energy will also increase the adhesion between cork particle and epoxy resins. With the plasma treatment, the density of cork powder reduces. Small amount of cork particle will result in better impact energy absorption that large number of particles. Plasma with a low density significantly reduces the contact angle and enhances moisture ability. The cork powder with different amount, size and with treated and untreated surface is shown in Fig.2.8. The percentage of cells in the cork/resin composite has an effect on its behavior[61].

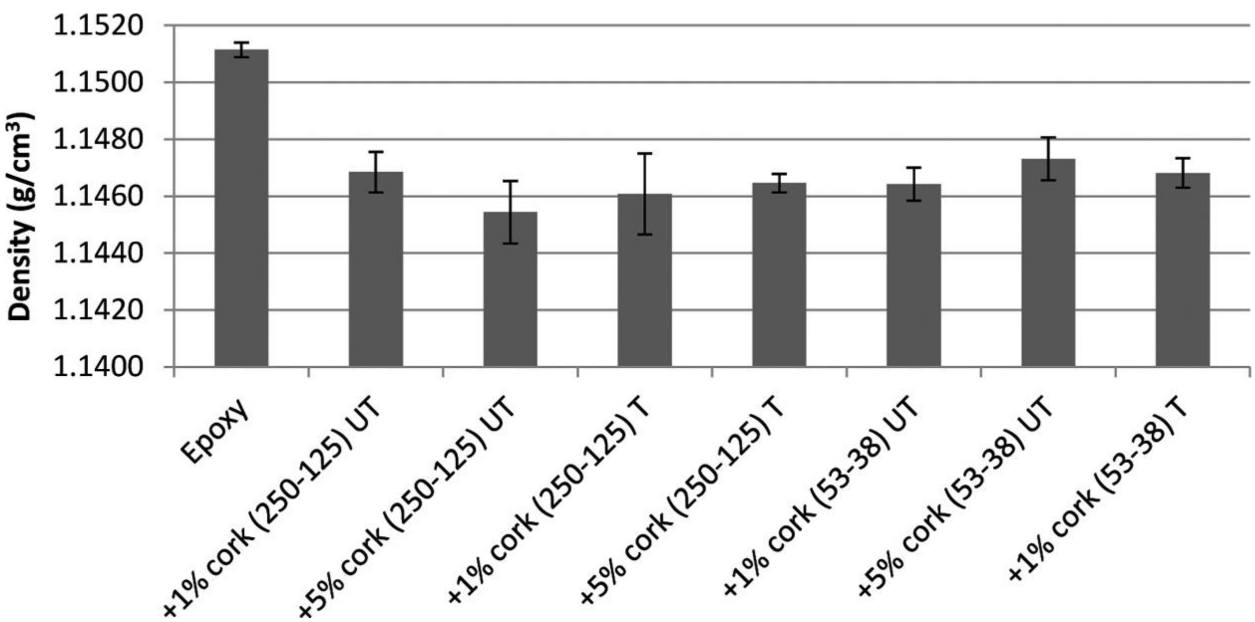


Fig.2.8. Density of composite specimens with different surface treatments, amount, and size of cork particles. T—treated; UT—untreated [61]

This paper discussed that the cork particle has an impact on the structural adhesive's strength. Cork particle ranging from 125-250 micrometers mixed with epoxy adhesive Araldite and amount of cork between 0.5-5 percent is used. Tensile test carried at room temperature and SLJ joint tested on same testing machines. It is concluded that large particle gives better results than the small particles. Tensile test carried with and without pre-heating and it is observed that the behavior of epoxy is not influence by the pre-heating. The adhesive with 1% cork particle shows more ductility behavior as compared to neat epoxy resins. SLJ joint at 1% cork particle show higher strength. 1% cork particle show lower glass transition temperature and resulted in more ductile behavior [62].

The paper discussed that the toughness of brittle epoxy adhesives is affected by the cork particles. Brittle resin is used with cork and without cork particles to analyze the kinetics of specimens. Tensile tests are used to correlate mechanical properties with thermal and chemical properties. It is observed that with increase of temperature of cure, the degree of conversion is also increases. The mechanical property of composite cork/resin does not depend on curing process. Specimen with cork particle show lower transition temperature than the specimen without cork particles. According to the DiBenedetto equation it is concluded that Cork particle has a compacting effect on resin, resulting in observed differences in mechanical properties. Brittle resin containing 1% cork particles and a structure composed of a limited number of cells exhibits greater ductility than resin containing the remaining 1% cork particles[63].

The paper studied about the moisture's effect on the decomposition of a cork particle-filled adhesive. It is observed that behavior remain similar for the specimen with and without cork particle and cork particle does not affect the movement of water, but the temperature has greatly effected this process. It is observed that will decrease in transition temperature; strain rate will increase. And increase in temperature will increase the diffusion rate. It is observed that in moisture uptake, mechanical property decay at higher temperature. It is also showed that the samples retain a similar value to those obtained during the initial stages in analysis of functional group after drying. The sample of moisture absorption will result in brittle failure and brittle fracture absorption specimen become more ductile surface [64].

This article investigated how cork particles could be used to increase the toughness of brittle epoxy adhesives. Additionally, this article discussed the effect of amount, size, and surface treatment on brittle epoxy adhesives. The cork particle varies from 38 to 53 and 125 to 250 micrometers and has a volume of 0.25 to 1 %. To check the toughness of brittle epoxy adhesives, plasma surface treatment is being tested with or without cork particle. It is concluded that cork particle improves the toughness of the adhesives and cork particle with surface treatment has lower strain energy rate as compared to the adhesive with cork particle and without surface treatment. Taguchi method study the effect of the variable and their interaction. It is concluded that amount of cork particle has less influence as compared to the interaction of presence of cork particle and surface treatment [65].

2.8. Conclusion

Different types of experimented are being done to improve or increase the single lap joints strength. It is being reviewed that various factor effect the adhesive joints strength e.g., temperature, nanoparticles, surface treatment, adhesive thickness, type of adherend etc. It is concluded from the review that strength is increased by increasing overlap length or by using different nanoparticles for different materials. Cork powder also increase the adhesive joints strength and adhesive with 1% cork particle show more ductility. Temperature's effect on the single lap joint's strength is also being studied. Temperature effects ranging from 25 to 100 degrees at various cork powder concentrations are investigated in this work for single lap joints with two dissimilar adherends (aluminium and composite carbon) to determine the single lap joint's strength.

Chapter 3: Experimentation

3.1. Research Methodology

Different experiments on single lap joints are being tested to check the strength based on different parameters. All the experiments are done on either different temperatures or cork powder concentration or on aluminum joints or carbon fiber reinforced plastic. So, there is need to check the strength of single lap adhesive joints on different temperature and concentration for two different adherends. In this study, the effect of temperatures ranges from 25-100 degrees at different cork powder concentration is being experimented for single lap joints having two dissimilar adherends (aluminum and composite carbon) to evaluate the strength of single lap joints. Universal testing machine is being used to test the strength of single lap joints under tensile testing. The Design of Experiment for present work is as shown.

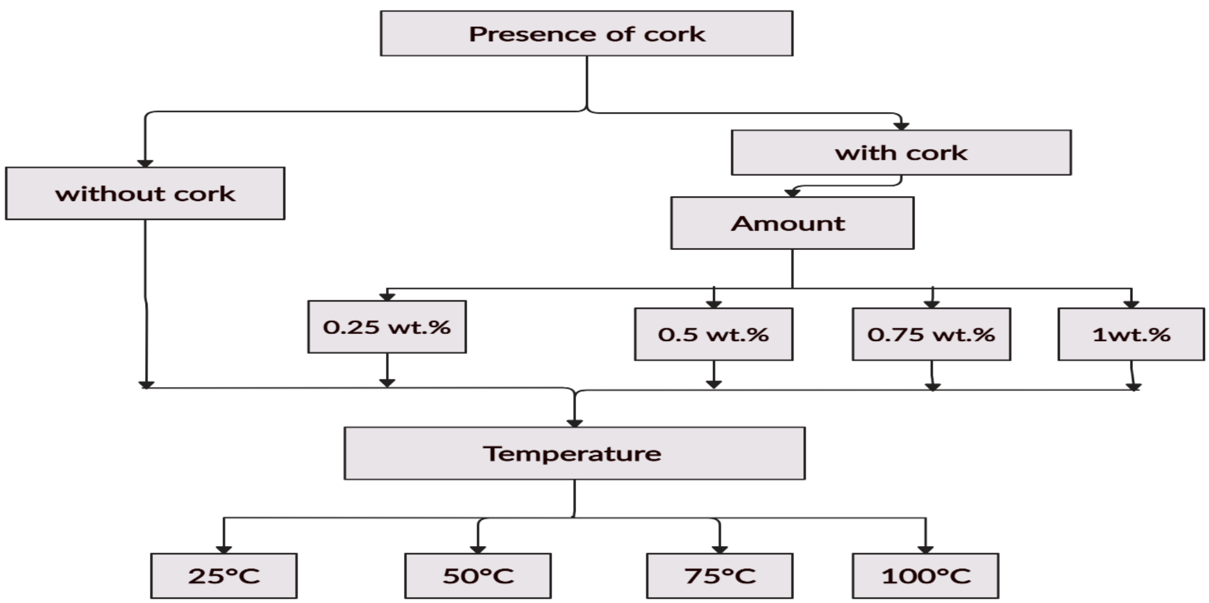


Fig3.1. Schematic diagram of cork specimens at different amount and different temperatures

3.2. Material

3.2.1. Adherend

Two types of adherends are used that is aluminum 5083 and composite carbon coupons

(a). Aluminum Coupons

(i). Aluminum Coupons Characteristics

Aluminum 5083 is well-known for its exceptional resistance to corrosion in extreme environments. Aluminum 5083 is highly resistant to seawater and industrial chemicals. Pressure vessels, tip truck bodies, rail cars, shipbuilding, vehicle bodies, and mine skips and cages are all made of this material.

(ii). Number of Coupons

Total numbers of Aluminum coupon samples required are 60 coupons as 3 coupons samples are used for every parameter

(iii). Properties

Table 3.1 properties of aluminum adherend

1	Young's modulus	76 GPa
2	Yield Strength	220 MPa
3	Ultimate Strength	332 MPa
4	Failure strain	18%

(iv). Dimensions

Width of aluminum coupons = 25.4 ± 0.2mm

Length of Aluminum coupons= 101.6 ± 0.2mm

Thickness of Aluminum coupons= 1.51 ± 0.1mm

(b). Composite Coupons

(i). Specification: composite carbon Fibers

(ii). Ply Configuration: Bi-directional

(ii). Dimensions

Width of composite coupons= 25.4 ± 0.2mm

Length of composite coupons= 101.6 ± 0.2mm

Thickness of composite coupons= 2.15 ± 0.15mm

(iv). Number of Coupons

Total number of composite coupons required is 60 coupons as 3 coupons samples are used for every parameter.

(v). Composite carbon Fiber Coupon Characteristics

Composite carbon fiber is used because of its high toughness, light weight and high corrosion resistance properties. It is used in automobile hood, aircraft brakes, textile machinery, road and marine transport etc.

3.2.2. Adhesive

Epoxy Araldite-LY-556 and hardener AD-22962 is both used as adhesive. Epoxy with greater strength has less ductility and more likely to be brittle. In mechanical field, we need that type of joints which can replace bolts and rivets so for that more strength is required that's why we use brittle epoxy because it has more strength. The brittle epoxy is more likely to fail easily that's why we add filler to prevent crack propagation because the filler fills the crack site.

(a). Epoxy resin

Any of a group of epoxide-polymer adhesives, plastics, or other materials. The family of essential parts or finished final product of epoxy resins is known as epoxy.

(i). Specification: Adralite-LY-556

(ii). Properties

Table 3.2 The properties of epoxy resin

1	Aspects (visual)	Clear Liquid
2	Viscosity at 25°C (ISO 12058-1)	10000 – 12000 [mPa's]
3	Density at 25°C (ISO 1675)	1.15 – 1.2 [g/cm^3]
4	Epoxies index (ISO 3001)	5.30-5.40 [Eq/kg]

(b). Hardener

A hardener is a substance that is added to specific sorts of compounds. A hardener is used in certain combinations merely to strengthen the robustness of the mixture once it has set. A hardener is employed as a curing component in other compositions. In the chemical reaction that happens during the mixing process, a hardener can be either a reactant or a catalyst. A hardener is sometimes referred to as an accelerator.

(i). Specification: AD-22962

(ii). Properties

Table 3.3 The properties of Hardener

1	Aspect (visual)	Colourless-little yellow liquid
2	Viscosity at 25°C (ISO 12058-1)	5-20 [mPa s]
3	Density at 25°C (ISO 1675)	0.89– 0.90 [g/cm3]

(c). Storage

Both the resin and hardener should be stored in a dry, well-ventilated area in a tightly sealed container. Containers that have been partially emptied should be closed immediately after use.

(d). Mix Ratio

Table 3.4 The mix ratio for the epoxy and hardener

Components	**Parts by weight**	**Parts by volume**
Araldite LY-556	100	100
AD-22962	23	30

It is preferred that each component be weighed with an associated accurate balance to avoid mixture inaccuracies that could affect the matrix system's properties. To ensure homogeneity, the components should be thoroughly mixed. It is necessary to incorporate the vessel's facet and bottom into the blending process. When processing large amounts of mixture, the pot life may be reduced due to the exothermic reaction. It is preferable to divide large mixtures into numerous smaller containers.

(e). Thickness: 0.1mm

(f). Curing Time of the epoxy and Hardener: Cure at 100ºC for 2 hours.

(i). 8g of solution is used for each configuration

(j). Application: Industrial and Structural composites

3.2.3. Filler

As a filler, cork powder is used. Due to its near-impermeability, cork's elasticity is ideal for bottle stoppers. Cork stoppers account for approximately 60% of all cork-based production. Cork has a nearly zero Poisson's ratio, which means that when squeezed or pulled, the radius of a cork does not change significantly. Cork granules can also be incorporated into concrete. Composites made from cork granules and concrete have a lower thermal conductivity, a thinner profile, and a high capacity for energy absorption. Density (400–1500 kg/m3), compressive strength (1–26 MPa), and flexural strength (0.5–4.0 MPa) are a few of the properties of composites.

(i). 0.25 wt.%,0.5 wt.%.0.75 wt.% and 1wt.% is used in experiment to check the single lap joints strength.

3.3. Equipment Utilized

The equipment's that are used in doing experiments are

1: magnetic stirrer with hot plate

2: Electronic balance

3: universal tensile machine.

3.3.1. Magnetic stirrer with hot plate

A magnetic stirrer is a device that is used to generate a rotating field. The magnetic stirrer generates a rotating field that is supported by a rotating magnet bar or plate. In fact, the plastic is coated over the magnet and the plate is magnetic. A rotating magnet can be used to create a rotating field. It is used for mixing the components and for heating purpose. In the experiment it is used to heat the sodium hydroxide and in the mixing of epoxy.

3.3.2. Electronic balance

Electronic balance is the instrument used for accurate measurement of the material. It is used in laborites for the accurate measurement of chemicals which is used in experiments. In the experiment, it is used for proper measurement of resin and hardener. This instrument used to measure the quantities up to 'one-milligram'.

3.3.3. Universal Testing machine

(i). Specification: HD-B607-S HAIDA INTERNATIONAL EQUIPMENT CO., LTD

(ii). Capacity: UTM of 100KN load cells.

(iii). Load accuracy: less than equal to ± 0.5%.

(iv). Test Conduct in UTM: Tensile room temperature test, tensile test at temperature of 50 degrees, 75 degrees, and 100 degrees in temperature chamber.

(v). Troubleshooting: Just in case of any condition with machine Press Red E Stop button on front of machine. Don't touch the machine & chamber once test is running. Once begin the check set limits for load.

(vi). Operation Mode: Computer tensile testing machine with PC control software "TESTER".

(vii). Test Speed: 1.3mm/min.

(viii). Display: After testing, it will display maximum failure load, length, time, and position. Data can be stored by manual operation in excel sheet.

(ix). User can set length, width, and thickness of product material according to the sample dimensions.

(x). Language: Chinese

3.4. Procedure for manufacturing and testing of single lap joints

The procedure consists of three main steps.

1: Degreasing of the Coupons.

2: Preparation of Single Lap joints.

3: Testing of the Single Lap joints.

These steps can be further divided into the small steps that can be explained in the methodology part.

3.4.1. Degreasing of coupons

Single-lap joints are a widely used method of joining two materials via an overlapping bond. They are relatively strong and simple. The widening use of composite materials in modern design processes usually requires the need to join materials that are becoming increasingly dissimilar. As a result, it is critical to understand the behavior of SLJs with dissimilar adherends. Prior to preparing the joints, it is essential to accurately clean the adherends of all particles to make sure that the strength of single lap joints is not impacted by other factors.

3.4.2. Degreasing of Aluminum Coupons

Degreasing is also referred to as grease removal or oil removal. The objective is to remove naturally occurring oxide film, process oil, rust-resistant oil, hand sweat, and dirt that adhere to oil. To ensure that alkali erosion surface is uniformly corroded.

Step 1. Washing of Aluminum coupons with Detergent

In degreasing, the first process is to wash all the aluminum coupons with the detergents. A detergent's primary function is to dissolve the surface tension that exists between grease and water. The term "surface active agents" or "surfactants" refers to them. Another purpose is to remove dirt (or SOIL) on to the surface of aluminum coupons. All the aluminum coupons are first washed with the washing powder (that is used as detergents). It is advisable to use the gloves during washing with detergents because the sharp edges of aluminum coupons will result into hand injury.

Step 2. Filling of Aluminum coupons

Before preparing the joints, it is necessary to remove the sharp edges because it can cause the hand injury. This process involves the taking the edge of 45º using a file. Basically, I take a file hold it at a 45 degree the coupons and then go across it in forward direction. Repeat the process until we get smooth edges and repeat the process for all other corners.

Step 3. Identify the Surface of Aluminum coupon

We identify the degreased surface with the help of the nail. First select the surface which is to be degreased and the surface is frictionless. Then hold the nail at the corner of the coupon and apply the force on the nail with the help of hammer so that the surface is pointed. A small dot is placed on the corner of the coupons that is used to identify the degreased surface of the aluminum coupons as shown in Fig3.1 (i).

Step 4. Clean the surface with Toluene

Toluene, also known as methylbenzene or phenyl methane, is a colourless, insoluble in water liquid with a characteristic paint thinner odour. Toluene is a thinner used in the manufacture of specialty paints and coatings. It is an excellent all-purpose cleaner and degreaser. It evaporates more slowly than acetone but more quickly than Xylene. First wear the gloves and then take a towel. Cover the towel on the finger and dip the towel in Toluene and then wipe that surface of coupon which is to be used for preparing joints. Two or three coupons can be wiped with that dip towel and then again dip the towel in Toluene and the coupons.

Step 4. Clean the surface with Acetone

Acetone is used for a variety of purposes including cleaning, degreasing, finishing, and paint removal. It can remove substantial amounts of grease and other undesirable substances from surfaces. When used for degreasing, acetone eliminates many of the concerns associated with heavy-duty equipment or products and processes for removing surface contaminants. After cleaning the surface with Toluene, we take the towel and dip one corner with acetone and close the acetone quickly as it evaporates more quickly. Then wipe the side of the coupon that is to be used for joining the joints. Wipe the 2 to 3 coupons and then again dip it in acetone and repeat for remaining coupons. Aluminum single lap shear (SLS) test coupons were degreased with acetone prior to immersion in the NaOH solution.

Step 5. Immersion of Aluminum coupons in NaOH Solution

For chemical etching process, the degreased Aluminum coupons were dipped in to the 6 wt.% of NaOH solution. First Take 1000ml beaker. Then pure the NaOH solution up to 400ml in beaker. Then heat the NaOH solution with the help of magnetic stirrer and heat until the temperature reaches the 50 degrees in Fig3.1 (ii). Note the temperature by soaking the temperature gauge into the NaOH solution. When temperature reaches the 50 degrees, turn off the magnetic stirrer and soak maximum 10 coupons into the solution and place the solution in open air because NaOH react with aluminum and form flammable and explosive hydrogen gas and can cause irritation to eyes, skin and in respiration and also generate fumes. When soaked the aluminum coupon in NaOH solution, turn on the timer for 6 minutes in Fig3.1 (iii). After six minutes of treatment, the surface appears much cleaner and possibly free of organic contaminants, in comparison to the black spots observed on the surface after wiped with acetone.

Step 6. immersion in water

As the time reaches the aluminum coupons will be removed from the NaOH solution and immersed into the water. For that, take 1000ml beaker and pore the 600ml pure water into the beaker. The etched samples were rinsed with ultra-pure water. The Coupons are immersed for 5 min into the water so that surface of coupon will be cleaned, and the remaining particles are removed that emerges by soaking the coupons in NaOH solution in Fig3.1 (iv).

Step 7. immersion of aluminum coupons in Acid cleaning solution

We take 9 wt.% of HNO_3. Take 1000ml beaker and pour HNO_3 up to 400ml. The aluminum coupon is then soaked in to HNO_3 solution for 3 minutes at ambient temperature in Fig3.1 (v). Acidic cleaning has been shown to effectively remove corrosion products formed on the aluminum surface as well as intermetallic particles following alkaline etching. After 3 minutes, the aluminum coupons are immersed into water as explained in step 6.

Step 8. wash the coupons with distilled water

After repeating the step 6, Pour 200 mL distilled water into a 250 mL beaker and then take a coupon and dip that side of coupon which is to be nailed for one second. Then wiped the back side of coupons with the tissue and put the coupon for drying. After the aluminum coupon is dried, cover them with clean tissue paper so that no dust particle accumulates on the degreased surface.

3.4.3. Degreasing of composite coupons

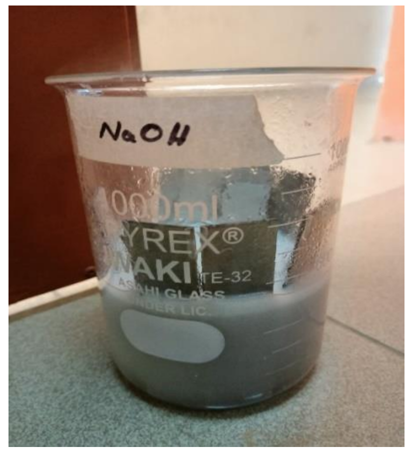
The degreasing of composite coupons required only three steps. We cannot do remaining etching steps because carbon fiber is non-metal, and the acid does not react with non-metal. Peel ply is used on carbon fiber parts that do not have mould on that side of the carbon fiber. It is a sheet of material like nylon cloth that allows resin to escape through small holes in the peel ply rather than travelling all the way to the end of the part through all the crevices in the carbon fiber itself, and perhaps most importantly. Peel ply is strong enough to withstand vacuuming. So, no extra surface treatment was performed on the carbon fiber coupons. The rough surface generated by the removal of peel ply during the manufacturing of carbon fiber coupons was used as a bond region.

(i). First, we identify the carbon fiber surface. We take that surface of carbon fiber that is less shinny and then degreased that surface.

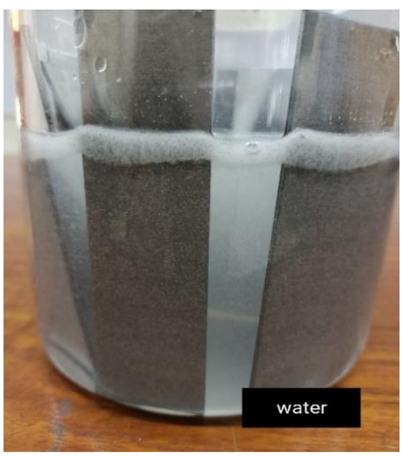
(ii). Then we degreased the surface with Toluene. The same process is repeated for carbon fiber as cleaning the aluminum coupon with Toluene.

(a)

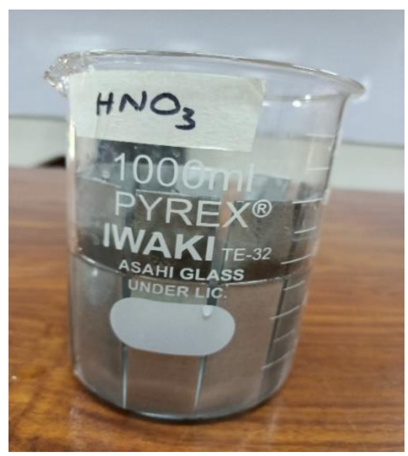
(b)



(c)



(d)



(e)

Fig.3.2. The degreasing steps for aluminum Adherends. (a): Degreasing with Toluene, (b): Heating and stirring of NaOH solution, (c): Coupons immersed in NaOH solution, (d): Immersed in water, (e): Immersed in nitric acid solution

3.4.4. Degreasing of End Tabs of single Lap joints

The end tabs were made of aluminum 5083 and is used for alignment of the single lap joints. Some joints automatically misalign before placing it in the testing machine, so bond tabs at the end joints for alignment purposes. The end tabs are also degreased so that they may not effected the strength of adhesive joints

(i). First step of degreasing the alignment tabs is to wash the end tabs coupons with detergents. The purpose of washing end tabs with detergents is to remove the dirt and soil particles from the end tabs. It is advisable to wear gloves, when washing the end tabs with detergents because the sharp edges of end taps result into hand injury.

(ii). The second steps in degreasing the end tabs are filling of aluminum end tabs joints. Take a file hold it at 45 degree of coupon and go across in forward direction. Do this again and again until the smooth edges obtained. Repeat the process for all other edges.

(iii). The third step in degreasing the end tabs is to identify the surface which is to be joints as end tabs. Take that side which is clean and has no bends and create no friction.

(iv). The fourth step in degreasing the end tabs is to clean the identified surface with Toluene. First wear gloves, then take a corner of the small hand towel and dip the corner in Toluene and then wipe the coupons with that dip corner.

(v). The fifth step and the last step is degreasing the aluminum end tabs is to clean the identified surface with acetone. First, we take a corner of hand towel, dip the corner in the acetone and close the lid of acetone because it evaporates quickly. Now take end tabs coupon wipe the coupons with that dip corner.

(vi). We cannot degrease the end tabs with acidic or alkanes etching steps because end tabs are only used for alignment purpose. Also, the thickness of end tabs is degreased by the alkane or acidic etching

(vii). Now place the degreased coupons on the tissue paper and cover with clean tissue paper.

3.4.5. Preparation of the Single Lap Joints

After the degreasing of the coupon, two types of epoxy adhesive are prepared that is for adhesive with and without cork powder.

3.4.6. Preparation of the neat Single lap Joints

In preparing neat single lap Joints consist of mixing of the epoxy and hardener without any filler concentration. The neat adhesive preparation requires less time as compared to preparation of adhesive with filler concentration. We prepare 12 neat joints, three samples for every temperature. The temperatures are 25, 50, 75, and 100 degrees. So, we take three samples for each temperature.

3.4.7. Mixing of Epoxy and Hardener

Epoxy resin is composed of two components: resin and hardener. By combining the resin and hardener, a chemical reaction occurs between them, converting them from a liquid to a solid. Accurate measurement and thorough mixing are critical to ensuring that your epoxy resin cures properly. Three simple steps must be followed when measuring and mixing epoxy resin:

1: Calculate the amount of epoxy resin required.

2: Measure resin and hardener precisely

3: Adequate Mixing.

Before mixing the epoxy and hardener, it is necessary to first to cover the binder clips with the help of masking tape so that during curing, joints will not stick to the inner side of binder clip (that is made of metal also). Also take a small scale and point 1-inch mark on the side of degreased aluminum coupons, so that epoxy should be applying to only that mark area.

Step 1. calculate the epoxy resin required

We have taken 100:23 portion of epoxy (E): hardener (H) means that for 100 parts of epoxy we take 23 parts of hardener. We have prepared 8 grams of solution for every configuration. So the amount of E:H is shown in equation 1

$$E:H = 100:23 \qquad \textbf{1}$$

$$Amount\ of\ epoxy\ in\ 8g\ solution\ =\ 8g\ *\left(\frac{100}{123}\right) =\ 6.504g \qquad \textbf{2}$$

$$Amount\ of\ hardener\ in\ 8g\ solution =\ 8g\ *\left(\frac{23}{123}\right) =\ 1.4965g \qquad \textbf{3}$$

$$OR$$

$$Amount\ of\ hardener\ in\ 8g\ solution =\ 8g - 6.504g\ =\ 1.4965g \qquad \textbf{4}$$

So, for 6.504g of epoxy as shown in equation 2, we take 1.4965g of hardener as shown in equation 3 or equation 4.

Step 2. Measure of epoxy and hardener

(i). First take 50ml beaker. For measuring accurate amount, we take weighting scale/Electronic compact scale. Now first we set the scale in grams. After setting into grams, measure the weight of 50ml beaker that is almost 29.98g as shown in fig (e).

(ii). Now first press the tare button on electronic compact scale, it will turn the weight of beaker into zero. Now take epoxy and slowly pour the epoxy into the beaker until 6.504 will pour into beaker. If bit large amount epoxy is poured into the beaker, we can remove the amount with the help of spatula.

(iii). Now third step is to add 1.4965g into the beaker. First press the tare button to put all values to zero. Then pour the hardener slowly and attentively because if a bit more amount is poured then it is difficult to remove the hardener because it is little liquidly and cannot removed by spatula.

Step 3. Adequate Mixing

Mixing of epoxy and hardener is most important steps.

(i). After putting the two parts in the right proportions, thoroughly combine them with a mixing stick for a full 2 - 3 minutes. Mix for a longer period when working with larger quantities.

(ii). During mixing scrape the container's sides, corners, and bottom several times. This includes full integration of the hardener into the epoxy-filler and should protect the resin from curing improperly.

(iii). Scrape both sides of the mixing cup as well. If the mixture does not reach a uniform consistency (streaks remain), continue mixing until the mixture is completely blended.

(iv). After mixing with the spatula, now mix the epoxy and hardener on magnetic stirrer for about 10 minutes to ensure the proper mixing and rpm will be bit high. After 10 minutes, mix the epoxy hardener with spatula again for about 2-3 minutes.

3.4.8. Joining the composite and aluminum coupon

(i). After the proper mixing of the epoxy with hardener, first cover the working table with the sheet so that epoxy does not stick on that table.

(ii). Now the mixture applied to form the joints. For that first take composite adherend apply the epoxy on the degreased side of the composite coupons approximately at a 1-inch. Similarly apply the epoxy on the 1-inch surface of degreased composite coupons.

(iii). After applying the epoxy on the composite coupon, take the aluminum coupons. Join side of composite on which epoxy is applied with the aluminum coupon till that marked point of aluminum. Now press with help fingers while keeping the two coupons align. Now pick one binder clip and bind the one side of coupon and check the alignment and then bind the other side of joints with the other binder clip. Again, checking the alignment that the coupons should be joining straight. Now repeat the process to joins the coupons.

3.4.9. Joining the end tabs on joint

(i). After joining the composite and aluminum coupons, mix again the epoxy with the help of spatula, then apply the epoxy on the degreased side of 1-inch end tabs with the help of spatula. Now apply the mixture on all the remaining end tabs.

(ii). Now take one end tabs on which epoxy is applied and joint the nailed side of aluminum coupons and align the end tabs on aluminum coupons and the press with help of finger and bind it with binder clip. Due to epoxy, the end tapes slip or misalign during its binding. Bind the end tabs carefully so that they may not misalign.

(iii). Now take another end tabs and place it on the opposite side of first end tabs on composite coupons. Apply the same procedure of binding as we apply first.

(iv). Now repeat the process for all other coupons. One joint required two end tabs. Similarly, for 12 joints, we need 24 end tabs.

3.4.10. Curing the joints in the oven

(i). The life of epoxy is 2 hours, after joining the joints we cured it immediately. We place all the 12 joints in over.

(ii). Before placing the joints in over, we first check the alignment. Then we place it in proper arrangement.

(iii). Then close the oven and turn its button ON. We set the oven at a curing temperature of 100 degrees.

(iv). After setting the oven at 100 degrees, Turn On the heat button and set the timer for about 2 hours. The curing temperature of epoxy is 100-150 so we cured it at 100 degrees for about 2 hours as shown in fig (g).

(v). After two hours turn off the oven and heat button. Wear the heat resistant gloves, then open the oven and take out the joint. Let the oven to cool down to room temperature and then close the oven.

(vi). Now as the joints cool down, remove the binder clips.

(vii). The single lap joints without any cork powder concentration are prepared.

3.4.11. Preparation of single lap joints with filler concentration

Cork powder behaves as a crack sealer. To determine the effect of cork powder on the strength of single lap joints, joints with varying concentrations of cork powder are prepared first. Cork powder concentration ranges from 0.25%, 0.5%. 0.75% to 1%. The method for preparing the filler concentrated joints is same for all concentration. Foe every concentration, we will prepare 12 joints, 3 joints for each temperature. All the steps in preparing the joints as explained earlier except one step that is mixing of the epoxy and hardener.

3.4.12. Mixing of Epoxy and Hardener

Epoxy resin is composed of two components: resin and hardener. By combining the resin and hardener, a chemical reaction occurs between them, converting them from a liquid to a solid. Accurate measurement and thorough mixing are critical to ensuring that your epoxy resin cures properly. The cork powder concentration taken is o.25%. Three simple steps must be followed when measuring and mixing epoxy resin:

1: Calculate the amount of epoxy resin required.

2: Measure resin and hardener precisely

3: Adequate Mixing.

Before mixing the epoxy and hardener, it is necessary to first to cover the binder clips with the help of masking tape so that during curing, joints will not stick to the inner side of binder clip (that is made of metal also). Also take a small scale and point 1-inch mark on the side of degreased aluminum coupons, so that epoxy should be applying to only that mark area.

Step 1. calculate the epoxy resin required

We have taken 100:23 portion of epoxy (E): hardener (H) means that for 100 parts of epoxy. We take 23 parts of hardener. We have prepared 8 grams of solution for every configuration. For the 0.25% cork powder the amount of E: H is as shown in equation 6

$$E:H = 100:23 \quad \text{———} \quad \mathbf{6}$$

$$Amount\ of\ epoxy\ in\ 8g\ solution\ = 8g * \left(\frac{100}{123}\right) = 6.504g \quad \text{———} \quad \mathbf{7}$$

$$Amount\ of\ hardener\ in\ 8g\ solution = 8g * \left(\frac{23}{123}\right) = 1.4965g \quad \text{———} \quad \mathbf{8}$$

$$OR$$

$$Amount\ of\ hardener\ in\ 8g\ solution = 8g - 6.504g = 1.4965g \quad \text{———} \quad 9$$

So, for 6.504g of epoxy as shown in equation 6, we take 1.4965g as shown in equation 8 or equation 9 of hardener and filler concentration is 0.25% or 0.0025

Step 2. Measure of epoxy and hardener

(i). First take 50ml beaker. For measuring accurate amount, we take weighting scale/Electronic compact scale. Now first we set the scale in grams. After setting into grams, measure the weight of 50ml beaker that is almost 29.98g as shown in Fig3.2 (i).

(ii). Now first press the tare button on electronic compact scale, it will turn the weight of beaker into zero. Now take epoxy and slowly pour the epoxy into the beaker until 6.504 will pour into beaker. If bit large amount epoxy is poured into the beaker, we can remove the amount with the help of spatula.

(iii). Now add filler to the epoxy system, according to the required proportion that is 0.25 wt. %.

(iv). Now for proper mixing and heating the epoxy and filler, magnetic stirrer is used.

(v). The filler and epoxy resin are magnetically stirring for 30 minutes and maintained at a temperature of 50 degrees as shown in Fig3.2 (ii).

(vi). It is difficult to maintain the temperature of 50 degrees on the magnetic stirrer, so when temperature reaches 32 degrees turn off the heat and stirrer the solution. The temperature continuously increasing because the plate on the magnetic stirrer is already hot, so it increases the temperature up to 50 degrees. The temperature is measured by the temperature gauge dipped into the epoxy and filler solution. The rpm should be bit higher than the earlier to ensure proper mixing. As the magnetic stirrer plate starting cool down, the temperature decreases below 50 degrees, now turn on the heat button for a while. Hence mixing of epoxy and filler required continuous assessment for 30 minutes.

(vii). After 30 minutes, turn off the magnetic stirrer. Cover the beaker with aluminum foil and let it be cool down to room temperature. It takes 8,9 minutes to cool down to temperature (viii). Now as the epoxy and filler solution cooled, add the hardener. First press the tare button, all the values go down to zero. Now pour the hardener slowly and attentively because if a bit more amount is poured then it is difficult to remove the hardener because it is little liquidly and cannot removed by spatula.

Step 3. Adequate Mixing

Mixing of epoxy-filler and hardener is most important steps.

(i). After putting the two parts in the right proportions, thoroughly combine them with a mixing stick for a full 2 - 3 minutes. Mix for a longer period when working with larger quantities.

(ii). During mixing scrape the container's sides, corners, and bottom several times. This includes full integration of the hardener into the epoxy-filler and should protect the resin from curing improperly.

(iii). Scrape both sides of the mixing cup as well. If the mixture does not reach a uniform consistency (streaks remain), continue mixing until the mixture is completely blended.

(iv). After mixing with the spatula, now mix the epoxy and hardener on magnetic stirrer for about 10 minutes to ensure the proper mixing and rpm will be bit high. After 10 minutes, mix the epoxy(filler)- hardener with spatula again for about 2-3 minutes.

(v). Joining of composite and aluminum adherend with the epoxy solution require the same procedure as explained earlier. Repeat the procedure as explained earlier for joining the composite and aluminum coupons.

(vi). Now the end tabs are joined to the joints and all the procedure is same as explained earlier.

(vii). Now cure the joints at 100 degrees for about 2 hours as shown in Fig3.2 (iii).

(viii). After 2 hours, joined is taken out from oven as shown in Fig3.2 (iv) and binder clips are removed.

(ix). Now label the joints as 0.25% concentration. So that 0.25% concentration may not mix with neat joints.

(x). Put all the joints in separate plastic bag to avoid from the moisture content.

(xi). The same procedure is repeated for 0.5%, 0.75% and 1% filler concentrated. All the steps are same except the filler concentration is changed.

(a)

(b)

(c)

(d)

Fig3.3: Preparation of single lap joint. (a): Weight of beaker on electronic scale, (b): Mixing of epoxy solution on magnetic stirrer, (c): Curing of Joints in Oven, (d) cool down the joints to room temperature

3.4.13. Testing of Single Lap Joints

When all the joints are prepared, then testing of joints is done on computerized ultimate testing machine (UTM) 100kN load cell. First, we test all the samples on 25 degrees then at 50, 75 and 100 degrees.

3.4.14. Testing of single lap joints on 25 degrees

Tensile test for 25 degrees is conducted on UTM. When a material is subjected to a tensile load, it resists the load by creating better resisting force. These resistances are a result of atomic bonding between the atoms of the material. The “stress" refers to the resisting force per unit area of a normal cross-section. Whereas the stress value in a material increases in proportion to the imposed tensile load, it also has an optimum (discrete) value. The ultimate tensile strength of a material is defined as the stress at which it fails. The yield point denotes the end of the elastic limit (load). As described later in the process, as loading is more than the elastic limit, the original cross-section area decreases until it reaches its minimum value at the point of failure.

(i). First, plug on the switch of the universal testing machine and the computer which is attached with UTM.

(ii). Turn on the software name “TESTER”. Then select the new file and give the dimensions of width, length, and thickness according to your specimen and click on the ‘OK’ button.

(iii). Then mount the specimen using suitable grips and edges. Load cell should be chosen according to the specimen length or grip. Here we are using 0-7mm grip load cell as shown in Fig3.3. (i).

(iv). It is advisable to mount the specimen very carefully because during tighten the grips, specimen may be break.

(v). The grip jaws can be move with the help of LCD display screen that can be used to operate the machine without the need for a computer connection.

(vi). The specimen should be mounted straight so that it may not break due to bending during tensile testing. So, after mounting the specimen, check whether the specimen is mounted straight

(vii). Now go to computer screen, check the load and length during mounting the specimen. We give preload of 110 N before testing and speed is kept at 1.3mm/min. If the force is going to 550 or more than 110N then we click on the down button and the load goes to drop down. As the load reaches 110 N then click on stop button on the computer screen. We want all values to start from zero then click on zero and start the testing by clicking on start button. If the force is less than

110N, we click on UP button and then stop the button when force reaches the 110N. Then zero all values and start the testing.

(viii). When the testing starts, a graph plotting show on the screen continuously until the specimen breaks. When the specimen breaks, maximum failure load is shown on the screen.

(ix). First save the data by click on the menu then save the file in the computer with the name of sample#1. It is advisable to first save the data because sometime the software stuck, and you cannot get any data.

(x). Now Go on the calculate data and the click on tensile test data and click on any value Control A, then click Control C and paste the value in excel sheet 1 for sample #1.

(xi). Remove the failed specimen from the grips after the data is saved.

(xii). Now same procedure is repeated for all specimens for 0.25%, 0.5%, 0.75%, 1% filler concentration at 25 degrees.

3.4.15. Testing of single lap joint on 50 degrees

To test the specimen at 50 degrees or above temperature, Temperature Chamber (oven) is used that is attached with ultimate testing machine during testing. Attached a stand with a track for connection to a universal testing machine. Attached a thermal discharge extend shaft to mitigate the effect of temperature on the tester. The temperature can be set manually, and maximum temperature of oven is 300 degrees. Additionally, environmental chambers include a slider rack that allows for additional space during room temperature testing and can be slid inside the machine space during high or low temperature testing.

(i). First, change the setup of ultimate testing machine to test at 50 degrees' temperature in the oven. Unload the load cells from the UTM. Slide the oven in a forward direction. Then load the new load cell that fits in the oven

(ii). First ON the TESTER software, Mount the specimen as explained earlier as in Fig.3.3. (ii).

(iii). The specimen should be kept straight. Now close the oven. Set temperature to 50 degrees in Fig3.3. (iii). and ON the power and heat button.

(iv). Now wait until the temperature reaches the 49.5. it takes much time to reach the 49.5 degrees, click on the UP button to retrieve the preload of 110N,

(v). As force reaches 110N, click the stop button and zero all the values.

(vi). Click on start and the testing start at 50 degrees.

(vii). As the specimen breaks, maximum failure load is obtained Fig3.3. (iv).

(viii). First save the data and then go to calculate data and copy the whole data and paste it into excel file

(ix). Then click on exist and open the new file for next specimen.

(x). The turn off the power and heat button of the oven. Open the oven and the failed specimen is removed

(xi). Wear heat resistant gloves before removing the specimen.

(xii). Repeat the process for testing the other specimen at 50-degree temperature.

3.4.16. Testing of joints at 75-degree and 100-degree

(i). For testing at 75- and 100-degrees' temperature, the process is followed except the temperature is set at 75 and 100 degrees manually

(ii). The specimen is mounted, close the oven, and turn on the power and heat button as shown in Fig3.3 (v).

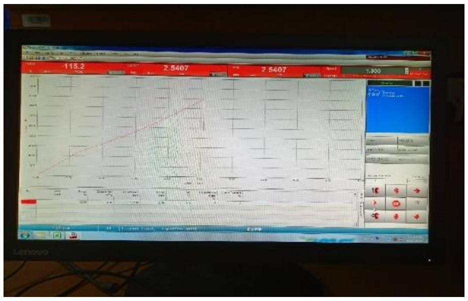
(iii). Wait until the specified temperature reaches, then start the testing in Fig3.3. (vi).

(iv). After testing, the graphs are plotted that is discussed in results section.

(a)

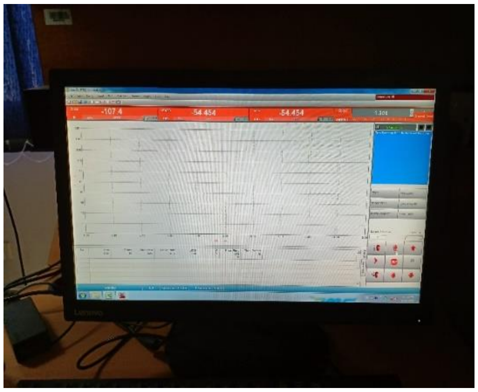
(b)

(c)



(d)

(e)



(f)

Fig3.4 The testing of single lap joints in UTM. (a): Testing at 25ºC, (b): Changing setup of UTM, (c): set Temperature at 50ºC, (d): Tester Software before Tensile Testing, (e): Temperature reaches desired temperature, (f): Data shown on screen during testing

Chapter 4: Results and Discussion

4.1. Effect of temperatures and cork powder on Failure load of Single lap joints:

Single lap joint (SLJs) with composite and aluminum adherend at four different temperatures that is 25, 50, 75 and 100 degrees is experimented to evaluate the average failure load with and without cork powder concentration. The cork powder concentration ranges from 0.25 wt.%, 0.50 wt.%, 0.75 wt.%, 100 wt.%. Three samples were tested under tensile testing at the displacement rate of 1.3mm/min for every combination. The average failure load values at every temperature and at each cork powder concentration are recorded after tensile testing.

Fig4.1. illustrate the graph of failure load and displacement with and without cork powder concentration (0.25wt.%,0.50wt.%,0.75wt.% and 1wt.%) at 25-degree temperature. It is shown that as the cork powder concentration increases the failure load increases from 0.25wt.% to 0.75wt.% and the failure load decrease at 1% cork powder concentration. The neat single lap joint shows a failure load of 7.35kN at a displacement of 1.57mm. The failure load at 0.25wt.% of cork powder is 6.42kN at a displacement of 2.29, while at 0.5wt.%, the failure load is 6.98kN at 3.12mm, at 0.75wt.% the failure load is 9.5kN at 2.92mm and at 1wt.%, it shows 7.64kN at 2.04mm. The strength of single lap joints increases as cork powder increases from 0.25wt.% to 0.75wt.% and then decreases at 1wt.% at 25-degree temperature.

Fig4.2 demonstrates the graph of failure load and displacement with and without cork powder concentration at 50-degree temperature. It is shown that neat adhesive shows a failure load of 6.28kN at a displacement of 2.41mm. The 0.25wt.% show a failure load of 6.00kN at a displacement of 3.48mm, while 0.5wt.% show a failure load of 10kN at a 5.338mm, 0.75wt.% show a failure of 8.95 at 6.217mm and 1wt.% show a failure load of 6.57kN at a displacement of 4.27mm. It is demonstrated that failure resistance increases from 0.25wt.% to 0.5wt.% and then begins to decrease. It is also observed that displacement has small impact on the single lap joints strength that is for higher load the displacement is small while for lower failure strength the displacement is large. The highest failure strength is at 0.5wt.% cork powder at 50-degree.

Fig4.3 demonstrates the graph of failure load and displacement with and without cork powder concentration (neat, 0.25wt.%,0.50wt.%,0.75wt.%,1wt.%) at 75-degree temperature. Failure load of 6.95kN at a displacement of 5.56mm is observed for neat adhesive. The failure load for 0.25wt.% is 5.95kN at 6.62mm, while at 0.5wt.% concentration the load carrying capacity is

7.43kN at a displacement of 6.01mm, at 0.75wt.% cork powder concentration the failure strength shows a value of 8.30kN at an elongation of 5.17mm and 1wt.% the failure load is 3.97kN at 5.05mm.the elongation increases from neat to 0.25wt.%. 0.5wt.% and then start decreases at 1wt.%. The failure strength shows same trend as it shows for 25-degree temperature that is the strength is higher at neat adhesive then at 0.25wt.% it shows lower strength as compared to neat adhesives. Then form 0.5wt.% to 0.75wt.%, the load carrying capacity increases and then decrease at 1wt.%. It is also observed that at 25-degree, the failure strength shows higher value and the displace show lower value than as compared to 75-degree. At both temperatures, the higher failure load shows at 0.75wt. % but the failure load at 0.75wt. % and 25-degree show higher strength as compared to the strength at 50-degree temperature.

Fig4.4 demonstrates the graph of failure load and displacement with and without cork powder concentration at a temperature of 100-degree. It shows that at a temperature of 100-degree, neat adhesive shows a failure strength of 4.68kN at 3.22mm, while at 0.25wt.% cork powder concentration the failure load is 4.67kN at 2.75mm, at 0.5wt.% the load carrying capacity is 5.06kN at 3.77mm, at 0.75wt.% the failure load is 5.99kN at an elongation of 3.555mm and at 1wt.% cork powder concentration the failure load shows a value of 4.67kN at a displacement of 3.22mm. the highest failure strength is at 0.75wt.%.

At all concentration, the single lap joints show same trend at all temperatures. The failure load is larger at neat adhesives as compared to 0.25wt.%. then failure load start increases from 0.5wt.% to 0.75wt.% and show a decreasing value at the concentration of 1wt.%.at the same concentrations (neat,0.25wt.%,0.5wt%,0.75wt.%, 1wt.%) and at different temperature (25,50,75 and 100-degree), the value of failure strength decreases. It means that at same concentration the failure strength decreases by increasing the temperature. The highest failure strength shows at room temperature as compared to other temperatures for same concentration.

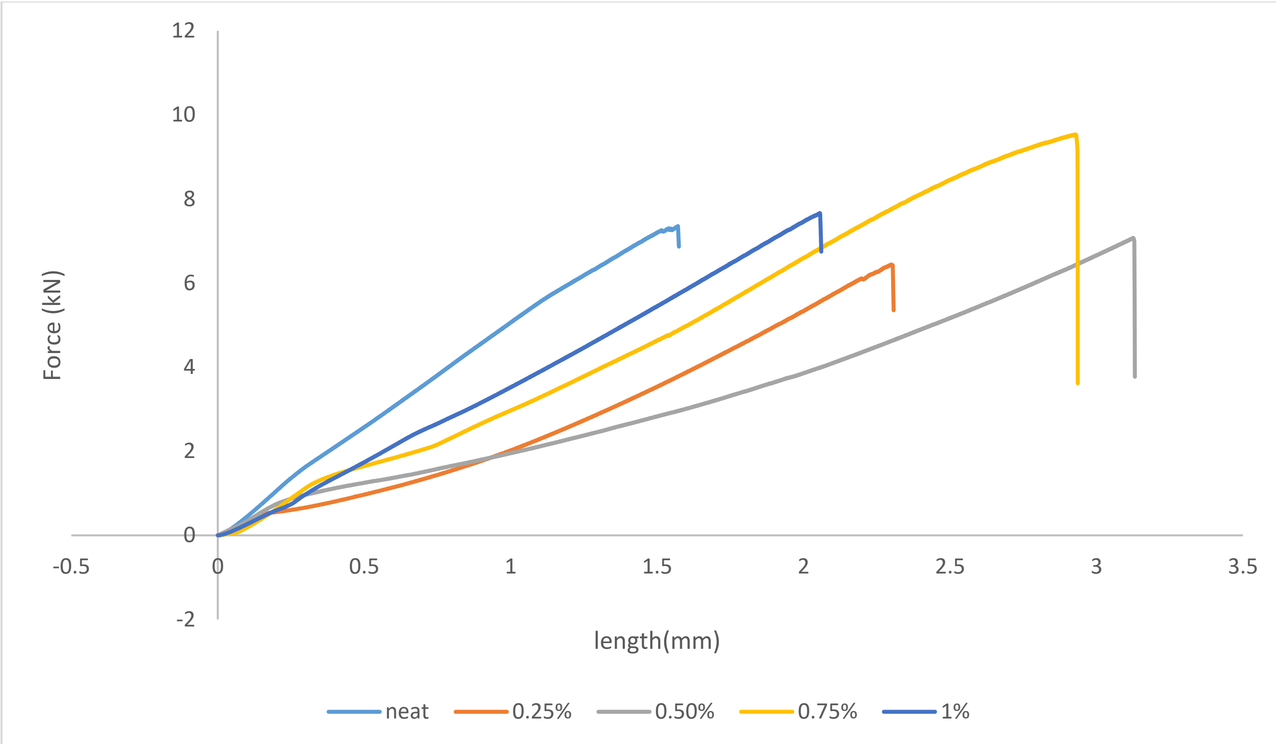


Fig 4.1. Force displacement curve at a temperature of 25-degree and at different concentration

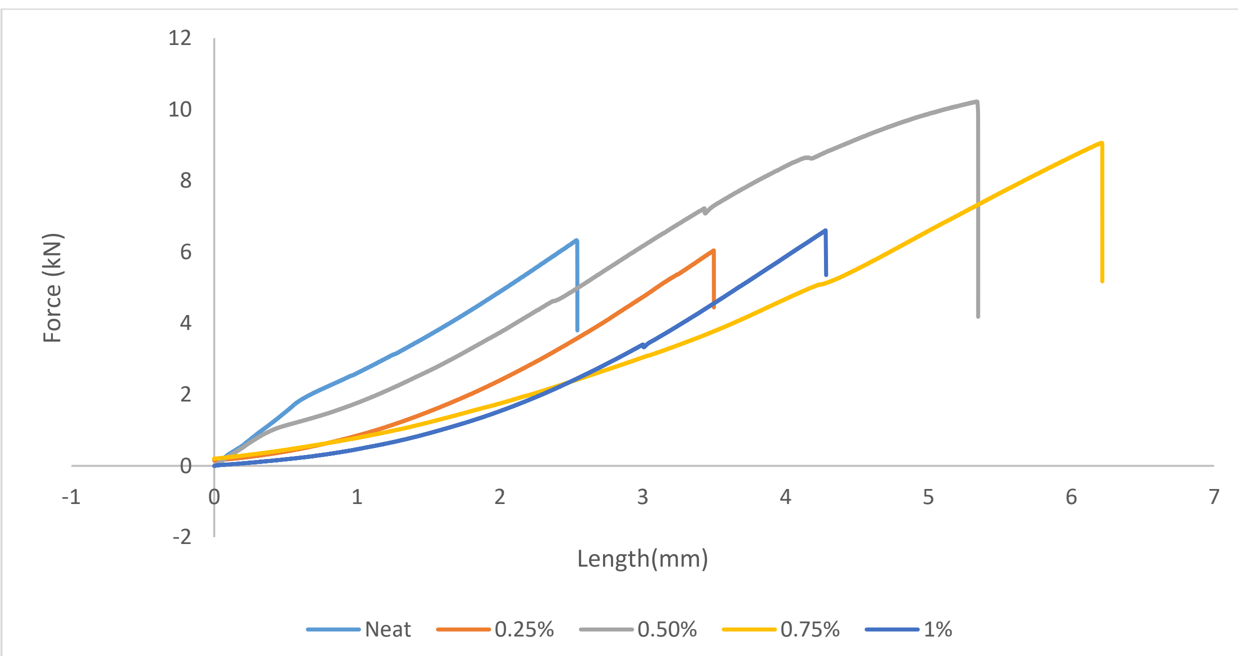


Fig 4.2. Force displacement curve at a temperature of 50-degree and at different concentration

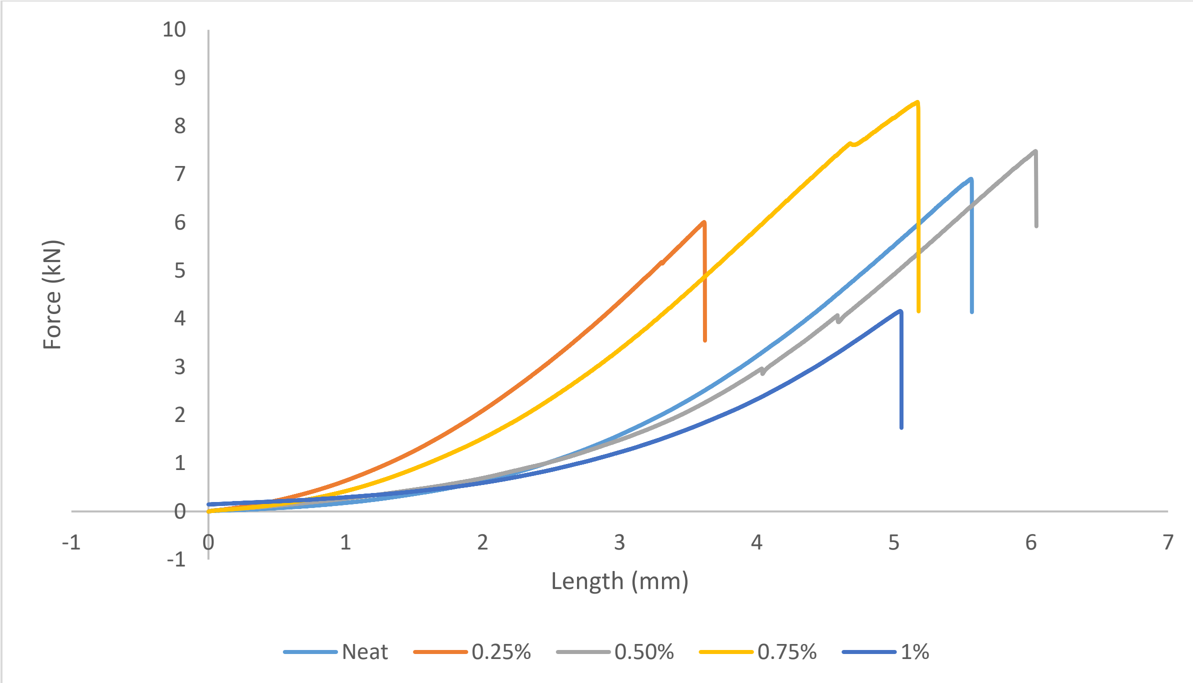


Fig 4.3. Force displacement curve at a temperature of 75-degree and at different concentration

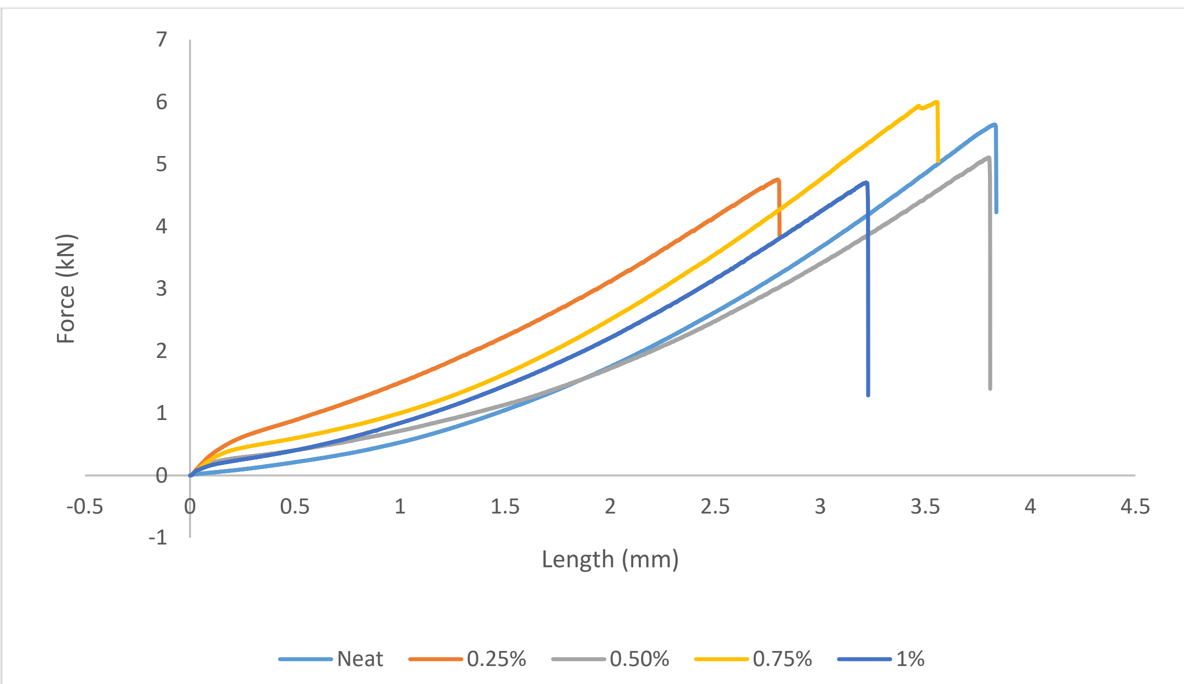


Fig 4.4. Force displacement curve at a temperature of 100-degree and at different concentration

Three samples were tested under tensile testing at a displacement rate of 1.3mm/min for every combination. The average failure load values at individual temperature and at each cork powder concentration are being calculated and plotted in graphs after tensile testing.

Fig 4.5. shows the graph of average failure load and cork powder concentration of single lap joints at 25-degree temperature. The average failure load for neat adhesives is 7.172kN, for 0.25wt.% the average failure strength is 6.617kN and for 0.5wt.% the average load carrying capacity is 7.272kN, for 0.75wt.% its value is 9.314kN and for 1wt.% the failure load is 7.674kN. The highest average failure load is at 0.75wt.% cork powder concentration for 25-degree temperature.

Fig 4.6. shows the average failure load and cork powder concentration of single lap joints at 50-degree temperature. The average failure load for neat adhesives is 6.588kN, for 0.25wt.% the average failure strength is 6.364kN and for 0.5wt.% the average load carrying capacity is 7.256kN, for 0.75wt.% its value is 8.449kN and for 1wt.% the failure load is 6.875kN. The highest average failure load is at 0.75wt.% cork powder concentration for 50-degree temperature.

Fig 4.7. shows the average failure load and cork powder concentration of single lap joints at 75-degree temperature. The average failure load for neat adhesives is 6.739kN, for 0.25wt.% the average failure strength is 6.668kN and for 0.5wt.% the average load carrying capacity is 7.114kN, for 0.75wt.% its value is 7.975kN and for 1wt.% the failure load is 4.879kN. The highest average failure load is at 0.75wt.% cork powder concentration for 75-degree temperature.

Fig 4.8. shows the average failure load and cork powder concentration of single lap joints at 100-degree temperature. The average failure load for neat adhesives is 5.678kN, for 0.25wt.% the average failure strength is 5.031kN and for 0.5wt.% the average load carrying capacity is 5.395kN, for 0.75wt.% its value is 6.056kN and for 1wt.% the failure load is 4.606kN. The highest average failure load is at 0.75wt.% cork powder concentration for 100-degree temperature.

All the figures show same trend at same concentration and at different temperatures. The failure load increases from 0.25wt.% to 0.75wt.% and then decreases at 1wt.% at 25,50,75 and 100-degree temperature. It is observed that by increasing the cork powder concentration, the failure load increases up to 0.75wt.% within same temperature. But the value of failure load decreases as we increase the temperature for same concentrations. The strength of adhesive decreases as the temperature rises, due to the weakening of bonding larger particles with a tiny bonding surface area and the increased difficulty of dismantling during testing. Along with temperature-induced stresses, changes must be considered in adhesive properties. Low temperatures make the adhesive more brittle (reduce the strain required to fail), while high temperatures make it more ductile but also prone to breakage and more highly susceptible to creep. As we apply force on SLJs as in tensile test. The crack begins to initiate because the epoxy become brittle after curing. So, when we add cork powder in epoxy, cord particle fills the cracks, and the crack propagation is late/delayed. So, value of failure load will be increased. As failure load increases, the value of maximum strain also increased and the strength of SLJs increases. As amount of cork particle increases, the values of F.L increases. Maximum strain values have less brittle structure. So, the strength of SLJs increases as amount of cork particles increases. For 1wt.% cork particles, the strength decreases because the particle begins to accumulate and act as impurity. For 1wt.% the particles of cork powder act as defect. A higher proportion of cork particles results in a higher strain value for samples, whereas a low proportion of particles results in reduction strain value than neat resin.

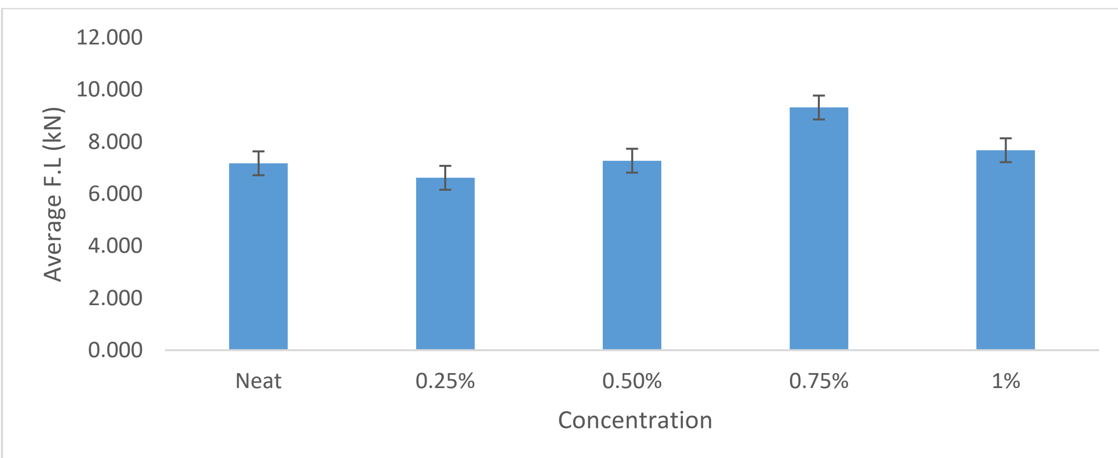


Fig4.5. Average failure load of SLJs at different concentration and at a temperature of 25-degree

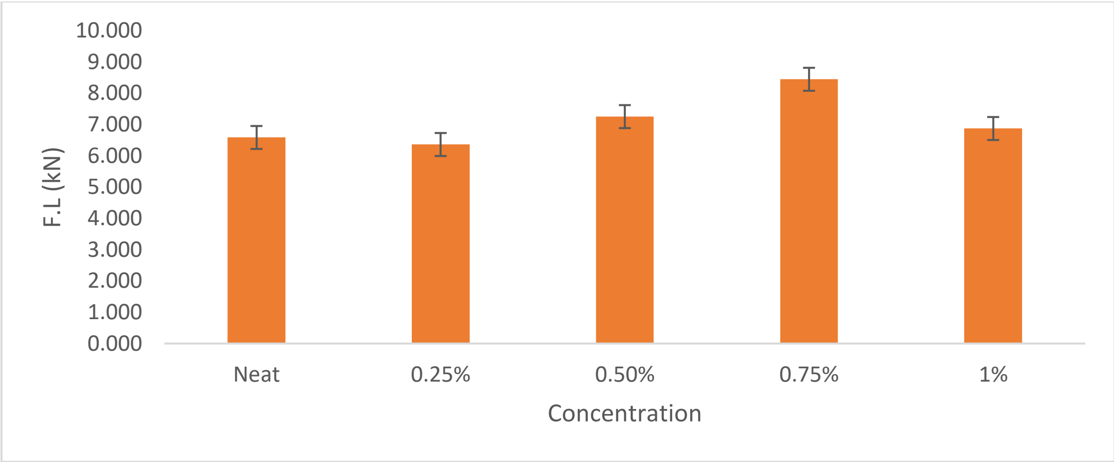


Fig4.6. Average failure load of SLJs at different concentration and at a temperature of 50-degree

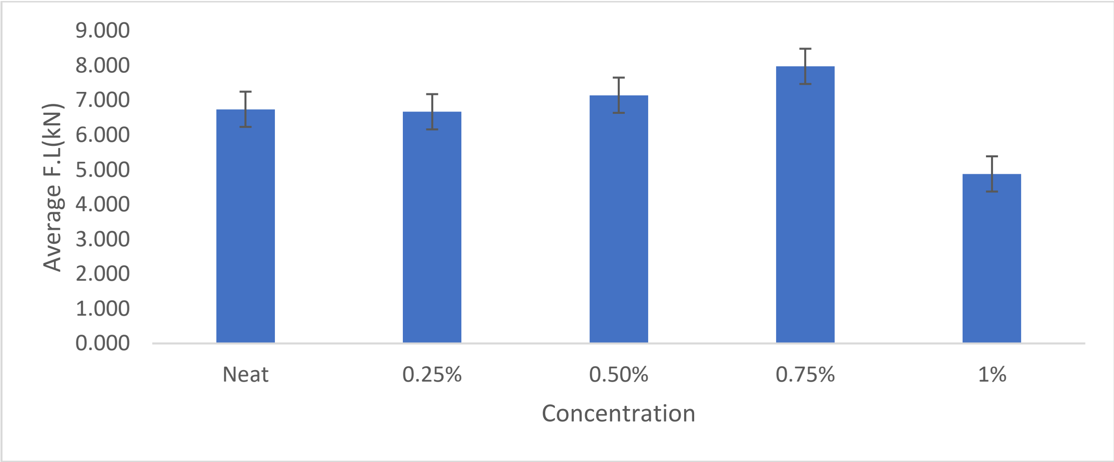


Fig4.7. Average failure load of SLJs at different concentration and at a temperature of 75-degree

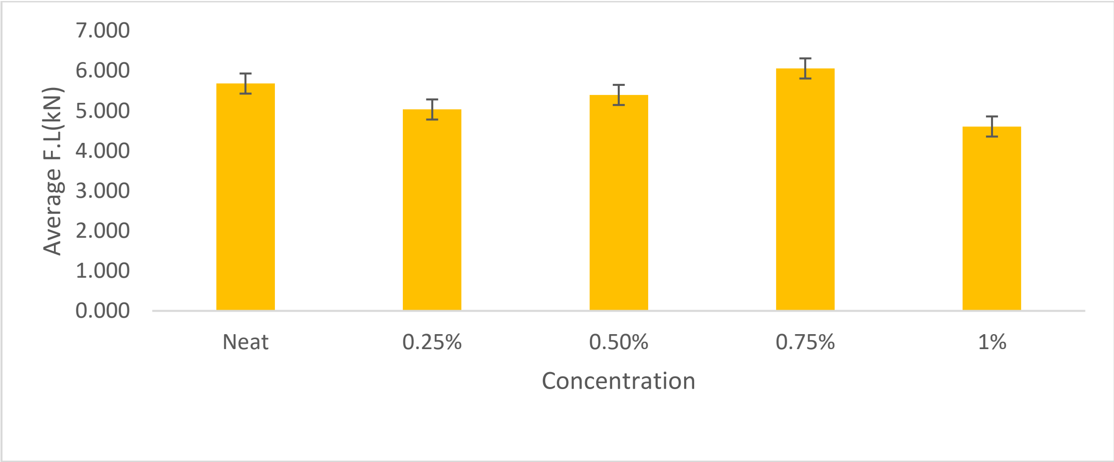


Fig4.8. Average failure load of SLJs at different concentration and at a temperature of 100-degre

Table 4.1.1 shows the average failure load at different cork powder concentration and at different temperature. It is noticed that average failure load decreases from neat adhesive to 0.25wt.% and then average failure start increases from0.25wt.% to 0.75wt.% and decreases at 1wt.%. We can say that by increasing cork powder concentration from 0.25wt.% to 0.75wt.% average failure load at different temperatures increases and the average failure load decreases at 1wt.%. It is also noticed that average failure at 25-degree temperature is has higher values as compared to the other failure load at other temperatures for 0.5wt.%, 0.75wt.% and 1wt.% concentration. As we increase the temperature the average failure load start decreases because the strength of adhesive decreases as the temperature rises, due to the weakening of bonding larger particles with a tiny bonding surface area and the increased difficulty of dismantling during testing. For neat and 0.25wt.% adhesives, it is shown that average failure load has highest vales at 25 and 75 degrees and has decreasing values at 50 and 100 degrees. At 100- degree, the failure load has lowest vales because mechanical properties change at high temperature and make it weaker and more likely to creep. Hence single lap joints strength decreases with increasing temperature. Table 4.1.2 demonstrates the failure load evaluation of adhesive joints at different temperature. The room temperature is taken as reference temperature and the other temperature value of average F.L is compared with that room temperature in term of percentage.

The negative value shows that percentage decrease for every temperature difference from the room temperature/ reference temperature. At 0.25wt.% and at temperature difference between 75 degrees and 25-degree there is an error which is shown as positive value percentage. Similarly, same formula is used for the failure load comparison for neat and with cork filler concentration to see the percentage improvement by taking neat adhesives as a reference at that same temperature as shown in table 4.1.3.

Fig 4.1.3 shows the comparison of average load at various temperature and various cork powder concentration. It is observed that the maximum failure load is observed at 0.75wt.% cork powder concentration and at 25- degree. The failure load is maximum at 0.75wt.% for all temperatures but the value of failure load at 0.75wt.% and at 25 degrees is 9.314kN that is large as compared to value of o.75wt.% joints at other temperatures. It is also observed that at 0.75wt.% the values of average failure load start decrease as temperature increases from 25-degree to 100-degree. Hence from the experiments we can observed that composite and aluminum adherend with 0.75wt.% at 25-degree temperature show highest strength and the strength is decreases as we increase the temperature for 0.75wt.%. It is also observed that neat adhesive shows slightly higher strength as compared to 0.25wt.% and the strength is increases from 0.5wt.% to 0.75wt.% and decreases at 1wt.%. The maximum strength is observed at 0.75wt.% at 25-degree that is 9.314KN and minimum strength is observed at 1wt.% at 100-degree temperature that is 4.606KN.

Table4.1. Average Failure load at different concentration and temperatures

Serial #	**Concentration**	**Average F.L at 25-degree**	**Average F.L at 50-degree**	**Average F.L at 75-degree**	**Average F.L at 100-degree**
1	Neat	7.172	6.588	6.739	5.678
2	0.25wt.%	6.617	6.364	6.668	5.031
3	0.50wt.%	7.272	7.256	7.144	5.395
4	0.75wt.%	9.314	8.449	7.975	6.056
5	1wt.%	7.674	6.875	4.879	4.606

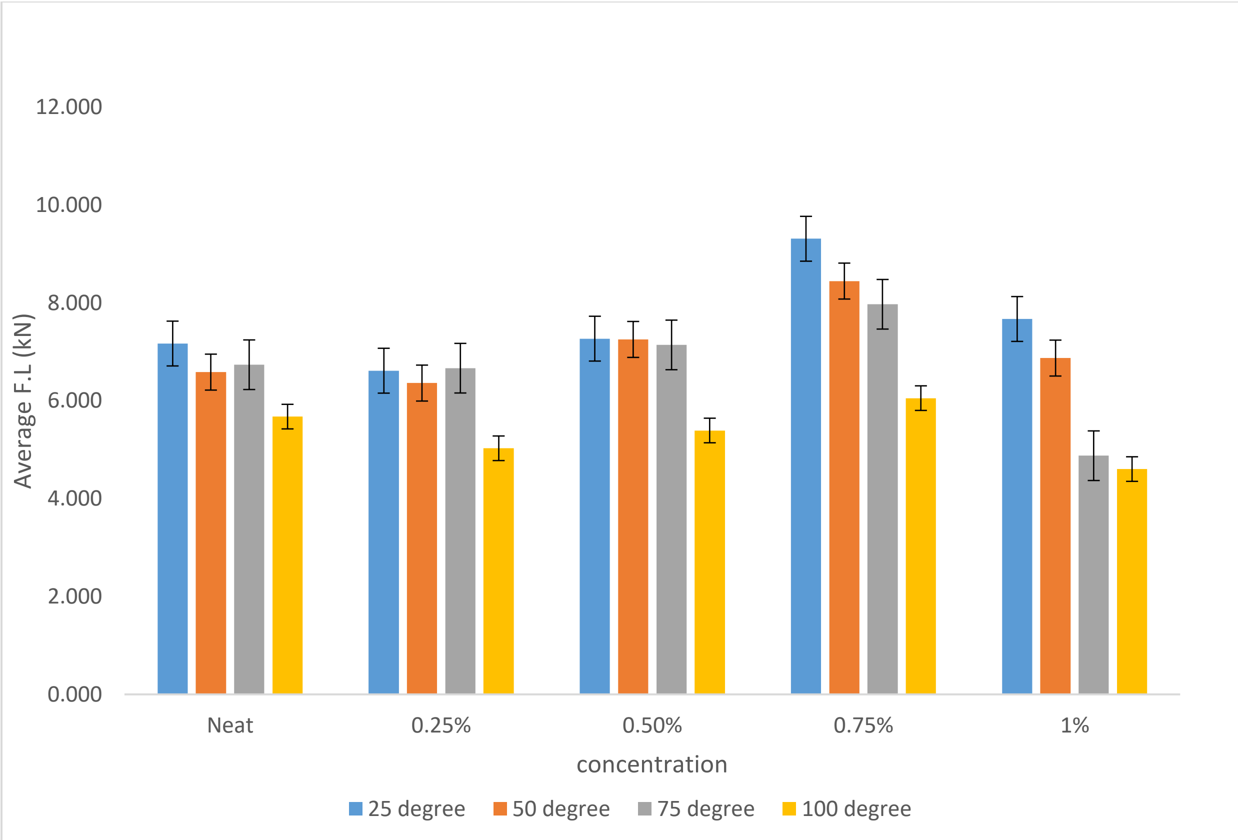


Fig 4.9. comparison of average F.L at different concentration and at different temperature

Table4.2. Failure load comparison at different temperature with the reference to room temperature

Concentration	**Temperature**	**Effect(%)**
Neat	25°C 50°C 75°C 100°C	-8.14278 -6.03737 -20.831
0.25wt.%	25°C 50°C 75°C 100°C	-3.82348 0.770742 -23.9686
0.5wt.%	25°C 50°C 75°C 100°C	-0.22002 -1.76018 -25.8113
0.75wt.%	25°C 50°C 75°C 100°C	-9.28709 -14.3762 -34.9796
1wt.%	25°C 50°C 75°C 100°C	-10.4118 -36.4217 -39.9792

Table4.3. Failure Load comparison of neat and with cork filler adhesive joints

Temperature	Concentration (wt.%)	%age
25-degree	0	
	0.25	-7.738472
	0.50	1.394311
	0.75	29.866146
	1	6.999442
50-degree	0	
	0.25	-3.400121
	0.50	10.139647
	0.75	28.248330
	1	4.356405
75-degree	0	
	0.25	-1.053568
	0.50	6.009793
	0.75	18.341000
	1	-27.60053
100-degree	0	
	0.25	-11.394857
	0.50	-4.984149
	0.75	6.657273
	1	-18.87988

A surface graph is plotted to show that maximum strength is obtained at 0.75wt.% as shown below in fig4.1.4. The inputs are taken as concentration and temperature as x and z axis and the output is the failure load as z axis.

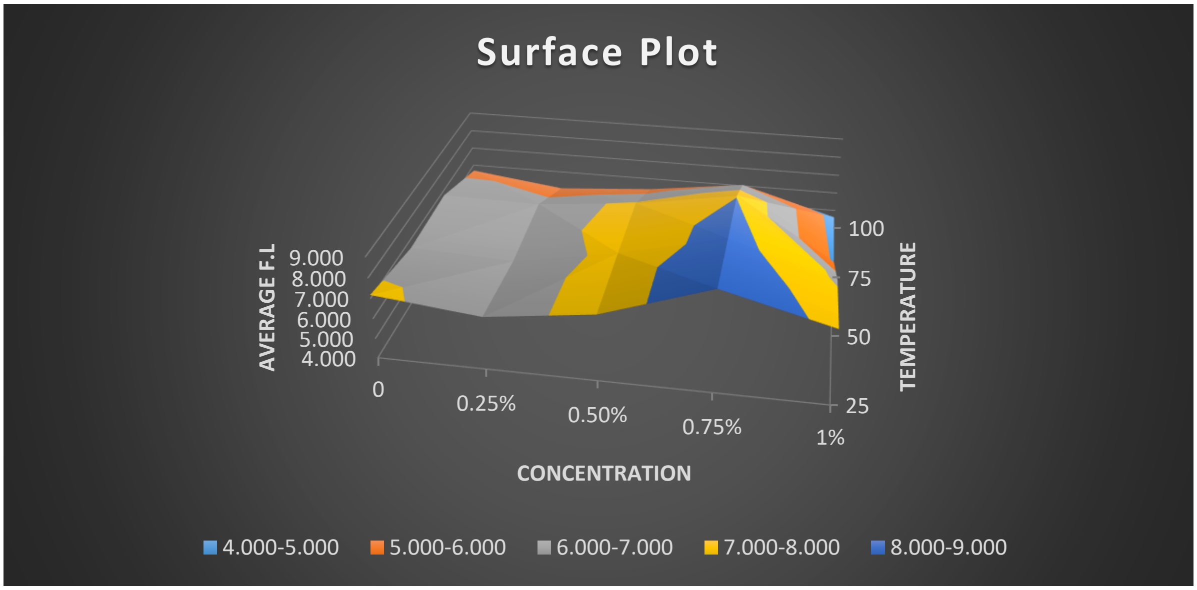


Fig 4.10. Surface Plot of temperature, concentration and Average F.L

4.2. Type of failure in Single Lap Joints

To analyze the type of failure in single lap joints having composite carbon coupons and aluminum adherend at different temperature and at different filler concentration, Optical Microscope DSX-1000 is used at a magnification of 20X. Type of failure in single lap joints can also be analyzed visually as shown in figures below Fig4.11. From Fig 4.11 (a-t) shows the mixed mode failure changes to cohesive failure as the temperature change. The mixed mode failure shows three type of layer arises from coupons. First is the metal surface, second is the bubbles form and the third layer is the adhesive layer. But in cohesive failure, the surface is mainly due to adhesive layer. Also at higher concentration, the cork powder particles are shown in the adhesive and at high temperature, the cork powder particles accumulate as shown in the microscope images as in s and t image in fig 4.11. The table4. 2.1 show the type of failure as the temperature and concentration changes. From the table it is observed that as temperature and filler concentration changes, the type of failure from mix mode failure are shifted toward the cohesive failure. At higher temperature and filler concentration, cohesive failure is experimented because at higher temperature, the adhesive become ductile and less durable. The cohesive failure rate is inversely proportional to the durability. The greater the cohesive failure. Lower will be the durability. Also, at high temperature the adhesive shows plastic deformation more as compared to neat adhesives. It is observed that carbon composites and aluminum adherend with brittle adhesives show cohesive failure at high temperatures. It is also observed that the mode of failure becomes more cohesive when the amount of cork powder in the SLJs is increased**.**

Table4.4. The type of failure mode of SLJs

Type of Failure in SLJs					
Temperature	**Concentration**				
	Neat	**0.25%**	**0.5%**	**0.75%**	**1%**
25 degrees	Mix mode failure	Mix mode Failure	Mix mode Failure	Cohesive Failure	Mix mode Failure
50 degrees	Mix mode Failure	Mix mode Failure	Cohesive Failure	Cohesive Failure	Cohesive Failure
75 degrees	Cohesive failure	Cohesive Failure	Cohesive Failure	Cohesive Failure	Cohesive Failure
100 degrees	Cohesive Failure	Cohesive Failure	Mix mode Failure	Cohesive Failure	Cohesive Failure

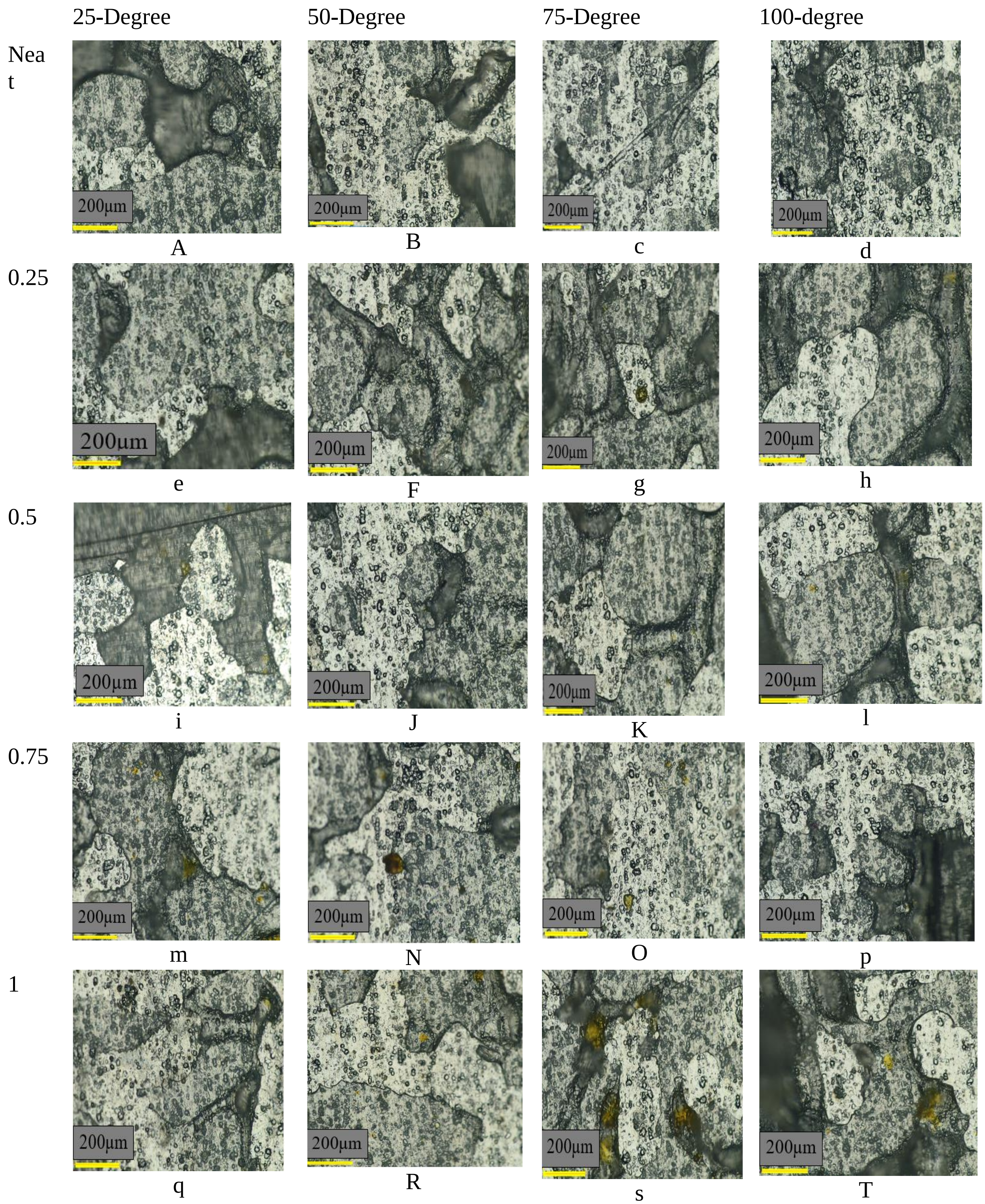


Fig4.11 (a-t) The type of failure mode for neat and different filler adhesives at 25-degree, 50-degree, 75-degree, 100-degree on optical microscope. (a-d) failure mode for neat adhesive and at different temperatures, (e-h) Failure mode for 0.25 wt.% and at different temperature, (i-l) Failure mode for 0.5wt.%, (m-p) Failure mode for 0.75 wt.% and at different temperatures, (q-t) Failure mode for 1 wt.% and Different temperatures

Chapter 5: Conclusion

Tensile tests on a Universal tensile machine are being performed to determine the strength and type of failure of single lap joints made of composite carbon fibre and aluminium adherends with brittle epoxy. The test was performed for neat samples and with the cork powder concentration ranges from 0.25wt.%- 1wt.% and at the temperature ranges from 25 degrees, 50 degrees, 75 degrees and 100 degrees.

(i). Epoxy with greater strength has less ductility and more likely to be brittle. In mechanical field, we need that type of joints which can replace bolts and rivets so for that more strength is required that's why we use brittle epoxy because it has more strength. The brittle epoxy is more likely to easily fail that's why we add filler to prevent crack propagation because the filler fills the crack site.

(ii). From failure load- displacement curves, it is concluded that all the samples shown same behavior/trend at different temperature and concentration. The failure load increases from o.25wt.% to 0.50wt.% and 0.75wt.% and them start decreases from 0.75wt.% to 1wt.% for all temperatures ranges from 25 degrees, 50 degrees, 75 degrees to 100 degrees. The failure mode for neat samples also noted on graphs.

(iii). The average failure load can also be analyzed, and it is concluded that average failure load decreases from neat adhesive to 0.25wt.% and then average failure start increases from0.25wt.% to 0.75wt.% and decreases at 1wt.%. We can say that by increasing cork powder concentration from 0.25wt.% to 0.75wt.% average failure load at different temperatures increases and the average failure load decreases at 1wt.%.

(iv). At 100- degree, the failure load has lowest vales because mechanical properties change at high temperature (plasticity flow at higher temperature) and make it weaker and more likely to creep. Hence single lap joints strength decreases with increasing temperature.

(v). It is concluded that strength of SLJs increases by adding cork powder at any given temperature compared to neat.

(vi). It is also concluded that the strength at 75-degree and 0.75wt.% is large as compared to neat adhesive at 25- degree. So, by adding cork powder and at different temperature, the strength will increase up to certain extent and the decrease at 100-degree temperature. So, Temperature stability is shown as well.

(vii). It is observed that composite and aluminum adherend with 0.75wt.% at 25-degree temperature show highest strength and the SLJs at 1wt.% and 100 degree show minimum strength. From the surface plot, it is also concluded that maximum strength is at 0.75wt. %.

(viii). It is concluded that the best adhesive ductility can be obtained by using significant amount of cork particles. The less amount of cork cause inaccurate results and the cork particles begins to act as defects at 1% as the adhesive becomes less ductile.

(ix). The failure mode in SLJs is analyzed through optical microscope and visually. It is concluded that the failure mode for neat adhesive shows mix mode failure and as the temperature increases with concentration the failure mode from mix mode failure is shifted towards cohesive failure.

(x). It is concluded that carbon composites and aluminum adherend with brittle adhesives show cohesive failure at high temperatures.

Recommendations

(i). The future research will carry out to investigate the strength for different type joint such as double lap joint at same temperature and concentrations.

(ii). It is recommended to change the material of adherends or to take same adherend materials for same temperatures and filler concentrations to evaluate the strength of the single lap joints.

(iii). The filler concentration can be taken for 1wt.% to 5wt.% in future work to show the effect of higher cork powder concentration at the same temperature ranges.

(iv). The future work may be carried out at different temperature from 100ºC onward up to 300ºC to show the effect of temperature on strength of single lap joints.

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