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Influence of Joint Parameters on Adhesively Bonded Single Lap Joints in Hemp Fiber Composites

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***Abstract*— The use of adhesive bonding in structures made from composite materials has increased in recent years due to their various advantages such as uniform load distribution, ease of fabrication, lightweight design, good strength etc. In this paper, adhesively bonded joint in hemp fiber and epoxy laminate was investigated experimentally. Influence of adhesive thickness, overlap length and curing temperature on bond strength has been discussed. Additionally, failure analysis of the adhesively bonded joints under uniaxial quasi-static loading for different parameter ranges was investigated. It was observed that joint strength is mainly affected by curing temperature followed by overlap length. It was observed that adhesive failure is predominant over adherend failure in bondline area.**

***Index Terms*— Composites, Adhesively Bonded Joints, Natural Fiber**

I. Introduction

THE composite laminates are rapidly being used in the aircraft, automobile industries as substitute material. They provide higher strength to weight ratio. One of the major disadvantage of composite laminate is that it's difficult to join them. Thus new joining techniques are being researched. One such technique is adhesive bonding, which can result in decreased weight, improved strength of components. Robust strength and failure analysis methods are required to assess new design. It is generally recognized that bond strength variation at the fibre–matrix interfaces greatly affects the mechanical properties of composite materials. On the other hand, bond strength depends strongly on the chemical/molecular features, atomic composition and topographical nature of fibre surface layers, which is strongly influenced by modification of fibre surfaces sizing. Synthetic material based fiber reinforced polymer composites are widely used in engineering applications. But their non-degradability and non-recyclable nature puts limitation on their use [1]. This concern driven many scientist to investigate use of natural fiber in composite material for low mechanical strength application. Moreover, natural fiber composites can be used in automotive body parts without compromising to strength and durability. The dashboards, door panels, parcel shelves, cabin linings, seat cushions, backrests are few application of natural fiber composites. These composites were produced in simple shapes and easy design structures by positioning the structural elements on top of each other to create the desired design [2]. Every component cannot be fabricated as whole due to manufacturing limitations such as space required, complex shapes etc., and hence joining two parts plays vital role in field of composite application. The core joining processes are: adhesive bonding, mechanical fastening, welding. The joint strength is important part of in designing a structure. Hence joint strength is primary criteria while designing joints in composites. For light weight structures adhesive bonding is gaining more importance for joining similar or dissimilar structural components. Adhesively bonded joints are also acting as replacement for fasteners and rivets [3]. Hence studying behavior of adhesively bonded joints in different loading as well as operating condition has great importance in order to conclude application area of composites. Materials experts from various automakers estimate that an all-advanced-composite auto-body could be 50–67% lighter than a current similarly sized steel auto-body as compared with a 40–55% mass reduction for an aluminum auto-body and a 25–30% mass reduction for an optimized steel auto-body. For the widespread use of adhesive joints a solid understanding of the failure process as well as a precise prediction of the failure load are vital. Therefore a strength and failure mechanism of bonded joints between these materials needs to be explored in detail.

S.M.R. Khalili [4] investigated strength of adhesively bonded single lap joint subjected to tensile, bending, impact and fatigue loads. They used glass reinforced composites as adherend and epoxy reinforced with micro glass powder, unidirectional and chopped glass fiber, as adhesive. They varied volume fraction of glass fiber in adhesive region. Taib [5] reported that increasing adhesive thickness beyond 1 mm induce increased stress up to certain limit. But for larger thickness, voids decreases the joint strength. The FEA study also predicts the joint strength and failure location similar to

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the experimental results. The FEA should be carried by developing nonlinear material model for adherends and cohesive zone modelling for the adhesive region. The nonlinearity in response should be considered because the results obtained by FEA deviates from experimental ones if static linear analysis is performed. Hence MFSF De Moura [6] projected feasibility of cohesive and continuum damage model for analysis of bonded joints in composites. R.D.S.G. Campilho [7] studied tensile fracture toughness of adhesive joints in natural fibre composites. They had used ductile polyurethane adhesive. However tensile behaviour of joints were not studied.

In this work the parameters which govern the joint strength were varied. The results were gathered and studied. These parameters include overlap length, bondline (adhesive layer) thickness and curing temperature of adhesive.

II. Materials and Manufacturing

A. Fibers

Hemp fibers are found in the stem of the plant which makes them strong and stiff, a primary requirement for the reinforcement of composite materials. Its important applications include manufacturing of agricultural twines, cloths and sacks. The hemp fibers used was in woven form as shown in fig 1. The hemp woven mat used was of 400 GSM. The density of hemp was 1.28 g/cc which was taken from manufacturer's handbook. The modulus of hemp fiber was 70 GPa.

Fig. 1 Hemp Woven Mat

B. Matrix

The matrix material keeps fibers in place, transfers stresses between the fibers, provides barrier against chemical and moisture and protects surface of fiber from mechanical degradation. The matrix material used here was epoxy system (epoxy + hardener) thermoset polymers. The matrix component is based on Tuff-Tite Resin and Tuff-Tite Hardener. The density of epoxy was 1.08 gm/cc with tensile strength of 15 MPa.

C. Adhesive

Structural adhesives are materials of high strength and performance. Their primary function is to hold structures together and to be capable of resisting (bearing) high loads. The Fevitite Standard is two-component structural paste adhesive used to join laminates. It has density of 1.15 gm/cc and achieves bond strength up to 15 MPa at room temperature. The Fevitite adhesive has excellent resistance to water, salt spray, and most organic fluids and also presents high mechanical performance up to 120^0C.

D. Laminate fabrication

The laminates were prepared using hemp with [$0^0/90^0$] orientation was used as fibre with the matrix based on Tuff-Tite Resin and Tuff-Tite Hardener. This orientation is selected to obtain best strength laminate. The laminate is manufactured using 6 layers of hemp mat. The matrix was formed by mixing hardener and resin in ratio of 1:0.8. This epoxy system is well recognized for its good performance in structural and industrial composite applications. Hand lay-up technique was used to manufacture the laminate. After manufacturing the laminate it is allowed to cure for 24 hrs. under compression in compression moulding machine as shown in figure 2. It was done to evenly spread the matrix, remove any air bubble and wrinkles from the laminate. This also ensures good adhesion between the layers. The spacers of 3.5 mm were used to maintain thickness of the laminate. The two-component structural paste adhesive Fevitite Standard was selected to bond the composite adherends together. The Fevitite adhesive has excellent resistance to water, salt spray, and most organic fluids and also presents high mechanical performance up to 120^0C. Its lap shear strength at room temperature is 15 MPa as per manufacturer's catalogue.

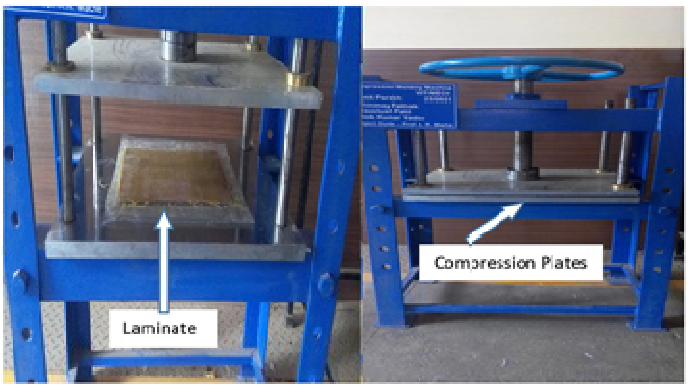

Fig. 2 Compression Moulding Machine

E. Adhesive Joint Prerequisites

For adhesion to take place, it is necessary for wetting to occur between the adhesive and the adherend. Wetting, which relates to the spreading out of a liquid on a solid surface. It is achieved by proper surface preparation described in adhesive technology handbook. Quality of the adhesively bonded joints is greatly influenced by surface preparation of the adherends. To prepare good bond strength and durability, production of a

roughened surface, cleaned of contaminants (particularly any chemicals, grease and dust resulting due to exposure or after the composite fabrication process), is required. The surface was neatly cleaned with acetone. The roughened was obtained by grinding the surface with 240-grit water paper.

III. Experimental Details

A. Pilot Experimentation

For the finalization of operating parameters pilot experiments were performed. Firstly, the experiment was carried out for 25 mm overlap length, 0.5 bondline thickness and epoxy based Araldite Standard as adhesive. The result obtained showed good load bearing capacity as shown in table 1. The failure mode observed was adherend failure. This failure mode does not depicts actual joint strength as adherend failed before joint fails. This was due to adhesive seemed to be stiffer than the adherend.

Another trial was carried out using polyurethane based Paracol D4 single part adhesive. The overlap length and adhesive thickness was maintained at 25 mm and 0.5 mm respectively. The joint strength obtained was low. From the Fig. 3 it can be clearly seen that the porous nature of the adhesive gives lower strength. The expected adhesive failure mode was observed after the ultimate joint strength was reached.

For obtaining intermediate results such as good joint strength and adhesive failure mode, third trail was carried out using epoxy based two part adhesive, designated as Fevitite Standard. The overlap length of 25 mm and adhesive layer thickness of 0.5 mm gave better results as compared to previous trials. The adhesive failure observed in the experiment gave satisfactory results. Hence Fevitite Standar adhesive was selected for carrying out this work.

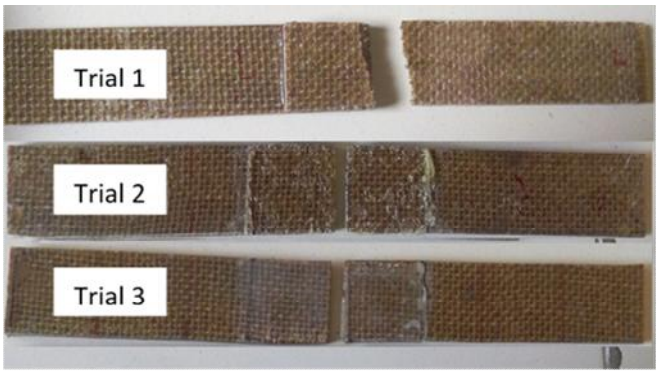

Fig. 3 Failure modes in pilot experimenting

TABLE 1
Trial Experiment Results

Experiment No	Adhesive Type	Joint Strength (Mpa)	Failure Mode
1	Araldite Standard	5.12	Adherend
2	Paracol D4	1.92	Adhesive
3	Fevitite Standard	5.01	Adhesive

B. Joint Configuration

Specimens were made according to ASTM D5868-01 as shown in fig 4. For manufacturing single lap joint configuration, strips of laminate were cut by water jet cutting and then bonded with adhesive. The strips are of dimension 100 mm × 25 mm. To improve the mechanical properties of the adhesively bonded joints, a post curing is required to ensure the polymerization cycle of the matrix and adhesive. The post curing consisted of keeping the specimens at room temperature for 3-4 days. The average thickness of adherend was 3.5 mm. From the literature it can be seen that overlap length of 20 mm to 30 mm is optimum [4, 9, and 10]. The bondline thickness ranging from 0.2 mm to 0.8 mm will give better joint strength [11, 12, and 13]. The curing temperature was varied from 30^0C to 70^0C. The parameter ranges selected were shown in table 2.

Fig. 4 Single Lap Joint

TABLE 2
Adhesive Joint Parameters

Sr. No.	Parameter	Parameter Ranges Values		
1	Overlap Length (mm)	20	25	30
2	Bondline Thickness (mm)	0.3	0.5	0.7
3	Cure Temperature (0C)	30	50	70

C. Test Procedure

The tensile shear tests are carried out on servo hydraulic universal testing machine of 600 Ton capacity. The test setup was as shown in fig 5. The incremental static loading and elongation was recorded by automated recording system. The loading rate was controlled at 3 mm/min as mentioned in ASTM D5868-01. For each configuration of specimen, two tests were conducted and system shear stress vs. strain was plotted. The shear strength are calculated as:

$$\sigma = F/A$$

Where σ is shear stress, F = Load applied and A = Shear area.

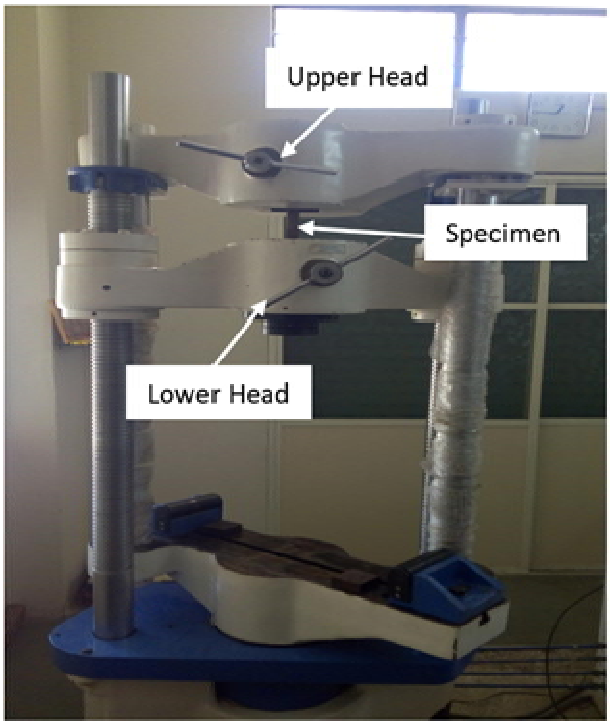

Fig. 5 Lap Shear Test Setup

D. *Taguchi L9 Orthogonal Array*

Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The overall objective of the using this method was to carry out optimum experiments to derive effect of overlap length, adhesive thickness and cure temperature on strength of joint. For this study with 3 variables and 3 states would have required $3^3 = 27$ number of experiments but orthogonal L9 array reduced the number of experiments to 9. The table 3 shows design of experiments used here.

TABLE 3
DESIGN OF EXPERIMENTS

Experiment No.	Overlap Length (mm)	Adhesive Thickness (mm)	Cure Temp. (^{0}C)
1	20	0.3	30
2	20	0.5	50
3	20	0.7	70
4	25	0.3	50
5	25	0.5	70
6	25	0.7	30
7	30	0.3	70
8	30	0.5	30
9	30	0.7	50

IV. RESULTS AND DISCUSSION

The effect of overlap length, adhesive thickness and joint curing temperature on joint strength is enlisted in table 4. The table shows that highest strength was achieved for overlap length of 25 mm, bond line thickness of 0.5 mm and curing temperature of 70^{0}C. The adhesive failure was observed for various joint configurations in which adhesive thickness, overlap length and cure temperature are varied. Joints designated from 7 to 9 are failed in adherend due to lower strength of adherend. This was due to adherend unable to mitigate increased overlap length. The experiments show that the variation in curing temperature strongly affects joint strength as increase the curing temperature increases the joint strength.

TABLE 4
EXPERIMENTAL RESULTS

Experiment No.	Joint strength MPa
1	3.66
2	4.44
3	5
4	4.82
5	5.07
6	3.43
7	3.58
8	4.46
9	4.62

The graphical representation shown in fig 6, depicts behavioral response between load and extension of joint. It can be seen that the adhesive behaves like a brittle material. The linear nature of the graph indicates good adhesion between surfaces as there is no sudden hiccups in graph line. The adhesive failure was governed by the ultimate point in graph representation.

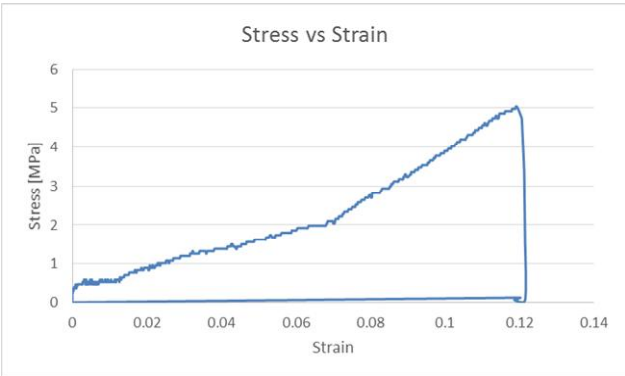

Fig. 6 Stress vs. Strain Graph for experiment No. 5

V. CONCLUSION

In this work hemp fiber composites was fabricated using hand layup technique. The composite material was machined according to the dimension. In the material joining process component gave the good tensile shear strength when compared with same dimensions of single plate. An experimental investigation on the mechanical properties of adhesive single lap joints was carried out.

The effect of variation in overlap length, adhesive thickness and curing temperature of adhesive were studied. The experiments shows that for overlap length of 25 mm, bondline thickness of 0.7 mm and curing temperature of 70^0C the joint strength was 5.07 MPa which is maximum.

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