

A Study into the Mechanical Behavior of Adhesively-Bonded Jute Fiber-Reinforced Composite

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ABSTRACT

Rapid progress in the interdisciplinary field of automotive engineering and the pressing need for an environmental friendly alternative to metal and synthetic fiber-reinforced composites for vehicle structure have triggered recent research in the field of natural fiber-based composites. Their potential advantages are attributed to their light weight, low cost and biodegradability. However, their usage in present day automotive systems is restricted due a lower magnitude range of mechanical properties and limited study in this area. In contrast to mechanical joints, the adhesively bonded joints aid in reducing stress concentration, joining of dissimilar materials, corrosion prevention, weight reduction and a smoother finish. Thus, in the present study, failure load, and mean shear stress of single lap shear and double lap shear joints as a function of joint overlap length, are evaluated using a two part epoxy adhesive made by Huntsman. Initially, the specimens are tested according to the reference test methods specified in ASTM D5868 and ASTM D3528 standards, and the overlap length is then varied to determine the failure load and the mean shear strength at failure in respective conditions. It has been observed that higher curing temperatures give rise to only marginally high failure load and mean shear stress at failure compared to curing at room temperature. It has been found that with increasing overlap length, failure load increases and mean shear stress at failure decreases, in both single lap and double lap joints. It is further noticed that delamination is the dominant type of failure observed in both single lap as well as double lap joints.

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INTRODUCTION

It has been a trend in today's automotive world to move towards newer materials which are functionally superior compared to the existing materials and yet are cost-effective. For example, researchers are making regular efforts to explore lightweight materials which can provide good specific properties to structures. To fulfill the needs of strict safety standards, improved emission norms, reduced weight, improved fuel economy, and higher performance, industries have been constantly taking steps towards the development and characterization of newer materials like aluminum alloys, different grades of high strength steel, fiber reinforced plastics, ceramics, etc.

Composite materials, in the form of fiber reinforced plastics as mentioned above, are available today as good alternatives to metals for achieving weight reduction and improved specific properties. Composite materials such as carbon fiber-reinforced composites (CFRCs) and glass fiber-reinforced composites (GFRCs) are widely used in consumer products, and, aerospace, navel and automotive structures and components. However, CFRCs are expensive and more common GFRCs tend to be hazardous to human health in terms of

handling and exposure to glass fibers. In general, recyclability is a concern for all synthetic fiber-reinforced composites. An increasing need for eco-friendly and sustainable materials necessitates detailed studies in the field of natural fiber-reinforced composites. In addition to being lightweight as other polymer composites, bio-composites offer the additional benefits of low cost and biodegradability. Keeping the latter attributes in mind, the current study is centered around jute-polyester composite. Although the deployment of a synthetic resin (due to the requirements of viable mechanical properties and ready availability) does not make the considered composite truly biodegradable, it may still be considered as more environment-friendly as compared to the common glass fiber-reinforced composite.

In practical applications of composites such as automotive body structures, joints between laminates and components will play a key role. A commonly used joining method for composite materials is usage of mechanical fasteners such as bolts and rivets. Although this method of joining is relatively easy to implement, it suffers from the twin drawbacks of adding weight to a structure and leading to stress concentration at the fasteners thereby making the same vulnerable to

failure in the long run. An alternative technique for joining composite materials is adhesive bonding which appears to circumvent the afore-mentioned shortcomings of mechanical fasteners; however, it also carries its own challenges associated with maintaining uniform adhesive thickness in joints, extra time involved in curing, and doubts on adequacy of joint strength.

Extensive investigations have been done on joining of metals with adhesives, but studies in adhesively bonded joints using composite adherends and considering failure are relatively limited. A number of researchers have explored and characterized various behaviors and mechanical properties of jute-fiber based composites [1, 2, 3, 4, 5, 6]. However, it appears that a study on adhesively bonded joints with jute-composite substrates is yet to be reported. A review of surface treatment for fiber reinforced composites for adhesive bonding has given by Wingfield [7]. Mazumdar and Mallick [8] studied the static and fatigue behaviors of adhesive joints with sheet molding compound composite adherends. The joint failure load was shown to increase as the overlap length or adhesive thickness increased. Kairouz and Matthews [9] examined single-lap bonded joints with cross-ply adherends. They showed that the surface layer orientation has a large effect on the failure mode and strength of these joints. A few studies [10, 11, 12] have been reported on the behavior of adhesive joints for moderate strain rate conditions resulting from impact loading. Zgoul and Crocombe [13] tested single lap joints at three different controlled strain rates. Stewart, Chambers and Gordon [14] studied experimentally the effects of temperature and after cure duration on cohesive performance of an epoxy adhesive. Studies on failure of adhesively bonded joints have been done considering the loading to be static (monotonically increasing till failure) and cyclic initiating fatigue failure [15-16]. Li, Lee-Sullivan and Thring [17] studied the stress and strain distributions across the adhesive thickness in composite single-lap joints. Kim et al. [18] investigated the effect of different bonding methods on the failure mode and strength of composite single-lap bonded joints. Owens and Lee-Sullivan [19] studied stiffness loss due to crack growth in composite-aluminum joints by testing single lap joints at room temperature and at 40°C under quasi-static conditions.

EXPERIMENTAL STUDY

Materials

In the present study, composite laminates are fabricated using woven mats of jute fiber and a general purpose polyester as matrix. Laminates, as shown in Figure 1, are manufactured using the simple hand lay-up technique and compression molding where 6 layers of woven mat of jute fiber are placed one above the other keeping same orientation of all layers with resin between every layer to obtain an approximate thickness of 3 mm. A set of three specimens, each from longitudinal and transverse directions of a laminate, are tested, and the average value of a material property has been obtained for each test condition. The basic properties obtained in this manner are given in Table 1. It is noted that a tensile coupon test specimen had dimensions of 200 mm (length) by 25.4 mm (width). The free length between grips was 110 mm. An electronic extensometer was employed to measure displacement for a gage length of 25 mm.

Table 1. Basic mechanical properties of jute-fiber reinforced polyester composite laminates

Property	Longitudinal Direction	Transverse Direction
Peak Tensile Stress	70.5 MPa	44.4 MPa
Peak Tensile Load	5.2 kN	3.5 kN
Stiffness Modulus	6.1 GPa	4.6 GPa
Failure Strain (%)	2.3	2.9



Figure 1. A jute fiber-reinforced composite laminate

The adhesive used for joining the substrates is a two component epoxy adhesive (viz. Araldite AV 138M and Hardener HV 998) made by 'Huntsman Advanced Materials'. According to the data supplied by the latter, the adhesive mentioned when cured at 40°C for 16 hours will have a tensile modulus of 4.7 GPa, a shear modulus of around 2.4 GPa, a tensile strength of 43 MPa and a tensile failure strain of 1.2%.

Preparation of Adhesively Bonded Specimens

The typical dimensions used for single and double lap joints are shown in Figure 2. The dimensions used for a single lap joint are according to the ASTM D5868 standard which extends the application of conventional joint tests to composite-composite single lap joints; similarly, the dimensions of a specimen for a double lap joint in Figure 2 are in conformity with the ASTM D3528 standard.

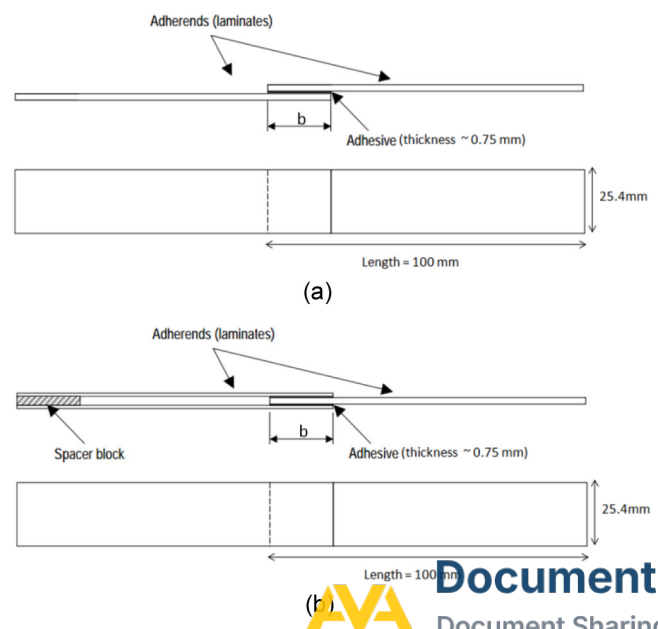


Figure 2. Typical dimensions of (a) a single lap joint and (b) a double lap joint

Substrates for preparation of joint specimens are deliberately cut from different laminates to cater to variations in material, manufacturing, etc. Surface preparation of the substrates has been done prior to the use of adhesive for joining. Surfaces to be joined are initially marked with three different overlap lengths viz. 6.35 mm (1/4 inch), 12.7 mm (1/2 inch) and 25.4 mm (1 inch), and then the respective area is abraded with the help of sand (emery) paper followed by cleaning of the roughened surface with soft cotton cloth soaked in acetone to remove dirt, grease and any loose particles from the joint surface (see Figure 3). Finally, the substrates are dried at room temperature.

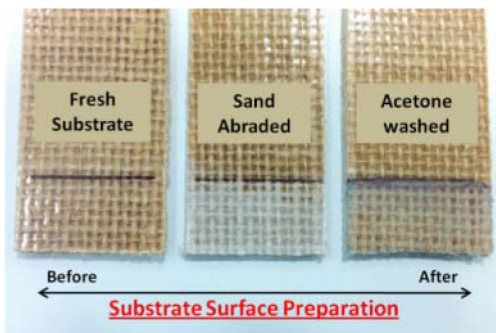


Figure3. Sequence of surface preparation before joint fabrication

Adhesive is prepared in the proportion of 'Adhesive:Hardener = 1:0.4' by weight (as per manufacturer's recommendation). Wooden fixtures are used to fabricate the specimens which are capable of holding and precisely maintaining the overlap length of the joint. Bond line thickness of ~ 0.75 mm is used and controlled by incorporating glass beads at the time of application of adhesive over the substrates. Since the pot life of mixed adhesive is 30-35 minutes, approximately 8-10 specimens could be made at a time, which are then cured at three different temperatures viz. 100°C, 80°C and 23°C for the durations of 10-15 minutes, 15-20 minutes and 24 hours respectively as recommended by the adhesive manufacturer.

Test Procedure

A 100 kN capacity universal material testing machine (UTM) of make BiSS is used to perform tensile lap shear tests. In the present study, only quasi-static type of loading is considered with a low actuator speed of 1 mm/min. The experimental test set-up is shown in Figure 4.



Figure 4. A servo-hydraulic UTM (on the left) with mounted specimen in close-up view (on the right)

RESULTS AND DISCUSSIONS

Effect of Curing Temperature

Fast manufacturing is an integral aspect of today's industry where demand for various products is rising day by day. If adhesively bonded joints are employed in a product, curing temperature/time will play an important role in reducing any potential lag between demand and supply. In the current study therefore, the effect of curing temperature on the strength of single lap shear joints in tensile tests is investigated.

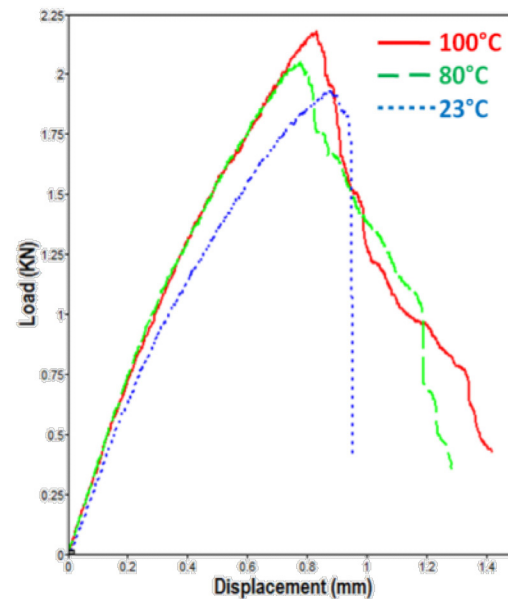


Figure 5. Load versus displacement curves for single lap joints of 12.7 mm overlap length cured at different temperatures

A set of load-displacement curves for single lap joints tested at three different curing temperatures mentioned above with a joint overlap length of 12.7 mm is shown in Figure 5. These load-displacement behaviors are typical of composite materials. The displacement of the joint is generally a superposition of the shear deformation in the adhesive and tensile stretching of substrates. The total displacement of the joint compared to the free length of the specimen between grips in Figure 4 is minimal and the failure is of brittle nature. In the case of higher curing temperatures, progressive failure of layers of substrate material in the joint could have taken place, which is implied by a gradual drop in the pertinent load curve, while in the case of curing at room temperature (23°C), a sudden drop in load is observed on reaching the peak load.

A summary of results obtained for three curing temperatures considered i.e. 100°C, 80°C and 23°C is given in Figure 6 for single lap joints. Three specimens were tested for each case. The average failure load and the mean shear stress (i.e. failure load divided by the total surface area of joint overlap) are shown in the form of bar charts in Figure 6. It appears from the latter figure that failure load increased at 80°C by about 4% with respect to 23°C, and again by about 4% at 100°C with respect to 80°C. It can thus be concluded that curing at a higher temperature for a significantly lower duration as compared to room temperature imparts higher strength to the adhesively bonded joint, and is beneficial from the viewpoint of manufacturing.