Joint Design for Adhesive Joining of Sisal/Epoxy Composite Laminates

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1 Introduction

Natural fiber-based polymer composites have drawn the first-rate appeal due to the fact of low price, environment-friendship, and an opportunity of the alternate synthetic (artificial) fiber-reinforced plastic. Sisal woven mat epoxy composite is a family of natural fiber polymer-based composite; it has higher fiber content for the equivalent performance of artificial fibers, which reduces the amount of more contaminating base polymers [1, 2]. The assembly of structural construction from different components needs some means of joining. In this context, bonding with adhesives has many compensational compared to traditional joining methods, e.g., reduced the concentration of stresses on joined area, increased uniform distribution of stresses, minimized weight, and easy fabricating [3, 4]. Adhesive joining is used for most of the epoxy polymer composite material. Making holes and inserting small Teflon sheet in the adhesively joined area of sisal mat epoxy fibers, it increased the load-carrying capacity of the lap joining. Esteves and Romão [5] studied the joining behavior of adhesively joined sisal-epoxy composite. Sisal fiber was treated with sodium hydroxide (NaOH) solution (4 and 8% w:v) and for two different treatment times (1 and 2 h). Lap joint was made to characterize the joint strength. Treatment of fiber was reported an enhancement of joint strength. Gonzalez-Murillo et al. [6]

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studied lap shear strength of henequen and sisal fiber-reinforced epoxy composite with three different joint configurations, including single lap joints, intermingled fiber joints, and laminated fiber joints. Joint strength was determined for overlap length varying from 5 to 50 mm. Joint strength of single lap was reported lower than intermingled fiber joints and laminated fiber joints. In laminated fiber joints, joint strength was reached to 92% of plain composite strength. FEM analysis of single lap joints was reported high-value stress generation near the end of the lap joint. Analytical and numerical analyses were showed cohesive failure in adherends. The high quality bonded joint region is very important for the integrity of structures involving composites as unless all the parts are co-cured simultaneously [7, 8].

2 Experimental Investigations

2.1 Materials (Specimen Composition)

The composite specimens used as adherends were fabricated by using the hand layup technique. Hand layup is an open mold process where fiber reinforcements are placed by hand then wet with epoxy resin. Sisal fiber in the woven mat form was used to reinforcement, and the polymer-based epoxy material (Type: LY-556 with hardener HY-951 in the 10:1 ratio Make: Araldite) was used to matrix manufactured and marketed by Huntsman International (India) Pvt. Ltd, Mumbai, India. The matrix and fiber have a density of 1.16 and 1.45 g/cm^3, respectively, at room temperature. Sisal fiber in the form of woven fabric was supplied with the aid of the Women's Development Organization (WDO), Dehradun, Uttarakhand, India.

2.2 Mechanical Behavior of Developed Composites

From Table 1, it has shown that the mechanical characterization of pure sisal mat fiber, sisal/epoxy adherend, and the LY-556 pure epoxy adhesive with HY-951 hardener were chosen. The tensile and flexural properties of fiber, adhesive, and adherends tested on the INSTRON 5982 by ASTM D1683, D3039, and D7264, respectively.

2.3 Composite Fabrications

In the current study, as shown in Fig. 1, sisal-epoxy polymer composite material was fabricated by the hand layup method. Four consecutive sisal mat fiber layers had been prepared as per dimensions of mold plate size of 300 × 300 × 4 mm^3 was used to make the specimen. The composite specimen contains completely four layers of

Table 1 Tensile and flexural properties of adhesive and adherends

Material	Maximum load (N)	Stress at maximum load (MPa)	Stress at the yield point (MPa)	Modulus (E-modulus) (MPa)	Flexure stress at maximum load (MPa)	Young's modulus (MPa)	Flexure strain (extension) at maximum load (mm/min)
Epoxy LY-556 Hardener HY-951	1747.98	29.13	24.97	4713.69	56.55	4225.58	0.01
Pure Sisal Woven Fiber	2054.72	34.24	33.04	6840.86	–	–	–
Sisal/Epoxy	2197.82	36.63	39.877	8641.18	103.18	8298.71	0.015

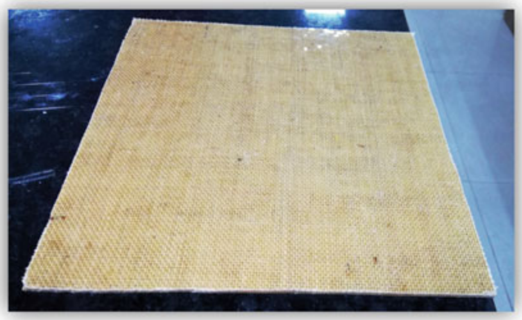

Fig. 1 Four layers sisal/epoxy polymer composite by a hand layup fabrication process

the sisal arrangement of fibers. The amount of epoxy is taken for a specific weight fraction of fiber and matrix with mixed the hardeners in the ratio of 10:1 after the woven fibers were wide-open to sunlight for two days.

Figures 2 and 3 show the mechanical properties of sisal-epoxy composite better than the pure epoxy polymer, indicated that making composite by the combination of sisal and epoxy is advantageous for further investigations such as joining.

2.4 *Preparation of Single Lap Joints*

Preparation of composite specimens as shown in Fig. 4, it is encouraged that a diamond-tipped circular saw wood cutting machine (Make: Dewalt Circular Saw Machine, Type: DW745-KR), that is capable of producing sharp cut edges as per

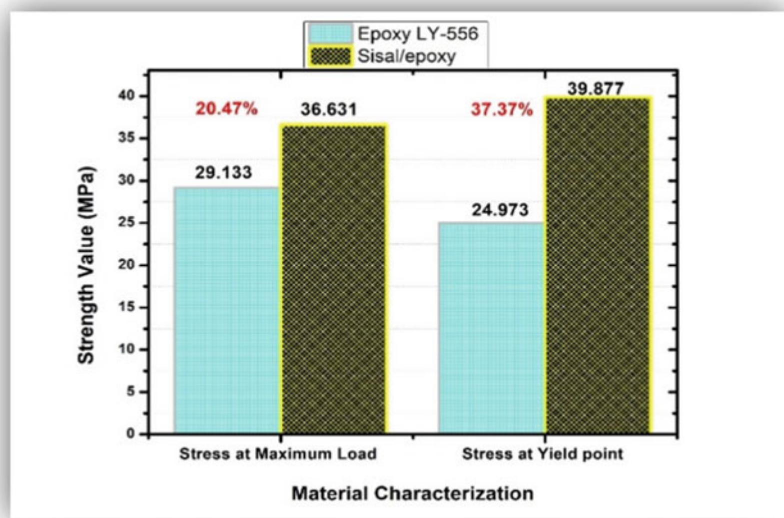

Fig. 2 Sisal/epoxy and pure epoxy stress at maximum load

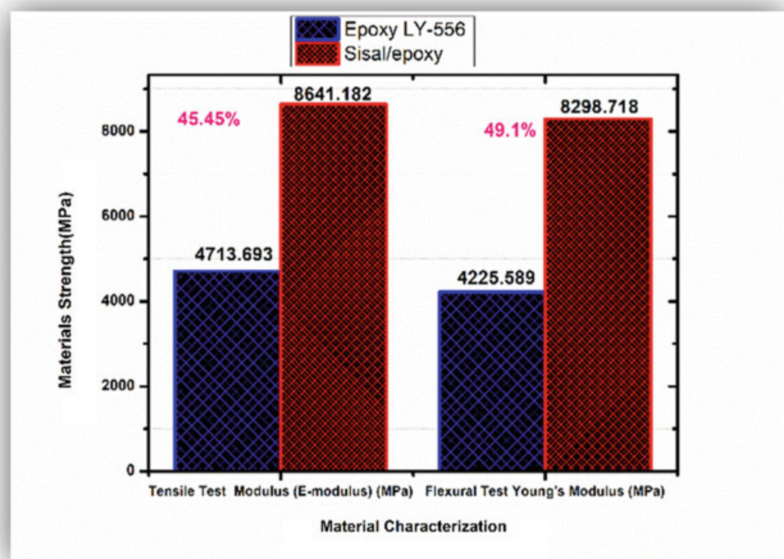

Fig. 3 Sisal/epoxy and pure epoxy tensile and flexural modulus

Fig. 4 Specimens cutting preparation by power circular saw machine

ASTM standard for different testing such as; D3039 for tensile, D7264 for flexural, D3410 compression and D5868 single-lap share testing.

The specimens to be used as adherends were cut from a fabricated composite laminate as per ASTM D5868-01 standard [9]. The ASTM standard dimensions of the composite test specimen are given in Fig. 5. The holes were drilled in the composite adherends as per different configurations at the spindle speed of 1087 rpm with a standard twist drill.

Four types of hole arrangements have been chosen, and the hole diameter used is 2 mm, and the depth of the hole is equal to the adherend thickness (through-hole), as shown in Fig. 5. The standard adhesive joint preparation protocol was adopted for joint preparation before applying the adhesive. All the testing specimens were tested after a curing period of 14 days under room temperature in order to gain the best joint performance [2, 10]. Four types of hole arrangements were drilled out in the joint overlap area in both the adherends. The holes were subsequently filled with adhesive and left for room temperature curing. The adhesive filled in the holes is expected to act as hinged support, capable of resisting forces acting in shear mode. Mechanical behavior of the adhesively joined test specimens was tested using the universal testing machine (UTM, Make: Instron, Type: 5982).

3 Results and Discussion

3.1 Mechanical Properties

As discussed earlier, holes were drilled in the adherends in different arrangements for investigating their influence on the tensile behavior of adhesively bonded composite joints. Figure 6 shows the load–displacement curves of sisal/epoxy with different hole

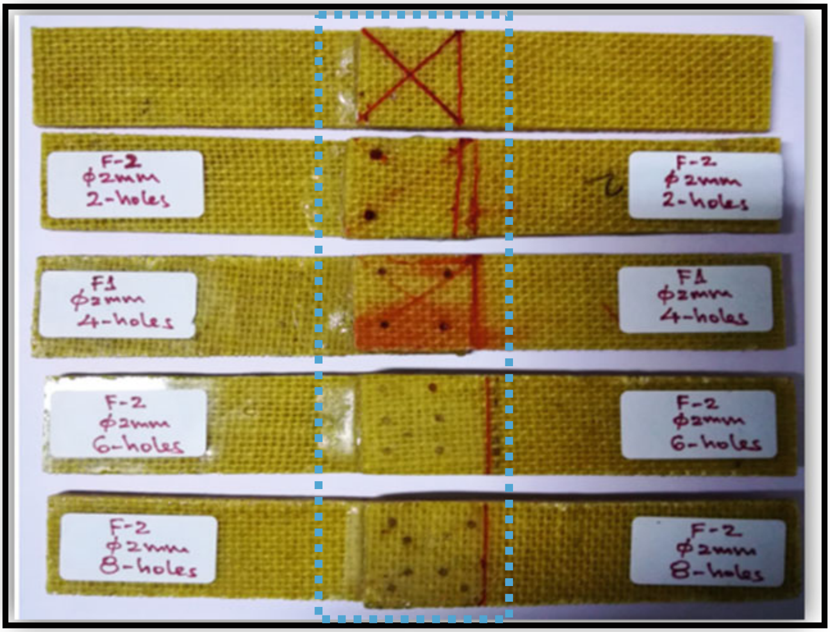

Fig. 5 Single lap adhesive joining of sisal-epoxy composite with four different hole arrangements

arrangements used in the current investigation. The adherends were tested without holes and with four different hole arrangements.

3.2 Sisal/Epoxy Single-Lap Holes Arrangement

The maximum displacement and failure load values after tensile testing are given in Fig. 6 at the load versus displacement curves of sisal-epoxy polymer composite, for eight-hole arrangement. Since the location of the eight holes on the cross diagonal of the joined area and all are symmetric at shown in Fig. 5 and the area percentage covered by the eight holes 10.78% of the total area of the lap joined it can affect the values of load and displacement on the given sisal-epoxy polymer composites, on the other hand, the minimum failure load of 1977 N and a 0.9 mm of elongation observed in six-hole arrangement. These types of holes location arrangements are very helpful for sisal fiber, and it is determined as a load of 2688.8 N and a 1.6 mm elongation. Lap shear strengths as a function of hole arrangement are shown in Fig. 7. This figure represents the result of the maximum shear stress for the different arrangements at different holes in composites. The shear stress in arrangements 2-holes and 6-holes (i.e., 10.90 MPa and 11.09 MPa, respectively) decreased related to pure lap

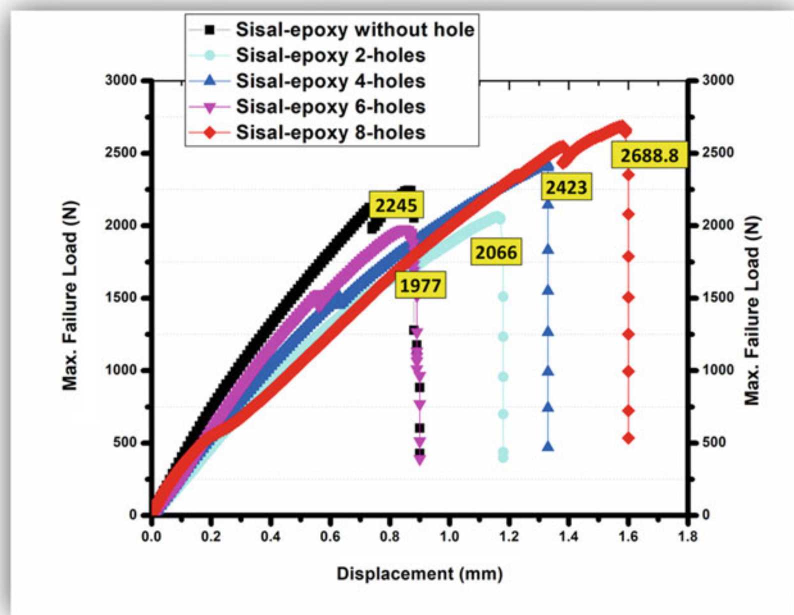

Fig. 6 Load–displacement curves for adhesively bonded joints with different hole arrangements

arrangement of the composite, but it increased at arrangements 4-holes and 8-holes (i.e., 12.06 MPa and 13.65 MPa, respectively). The lowest value of the shear stress of sisal mat composites was observed in the arrangement of 2-hole. The exact location of the four holes is on the parallel edge of the joint area, as shown in Fig. 5. Due to the symmetric arrangements of four and eight-hole, it is known that the failure occurred at the end of the overlapped area [1]. The outcomes of an experimental study making holes have little effect on the failure load of pure lap arrangement; however, there is a positive contribution at 4-holes and 8-holes arrangements.

The morphological structure of the sisal-epoxy mat composites is shown in Fig. 8. The composite samples after the tests have been cut to specified dimensions cleaned properly and mounted cross section-wise on the FE-SEM setup [11]. Among individual types of structural behavior, the matrix cracked without stretching on the surface of the composite, then again because of the applied tensile load, the sisal mat fibers are highly stretching and breakage.

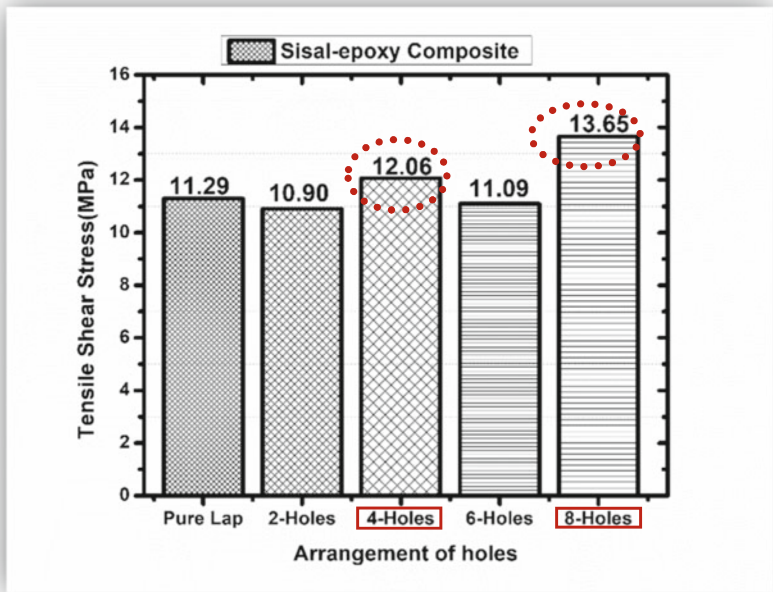

Fig. 7 Tensile shear strengths as a function of sisal-epoxy composite and arrangement of holes

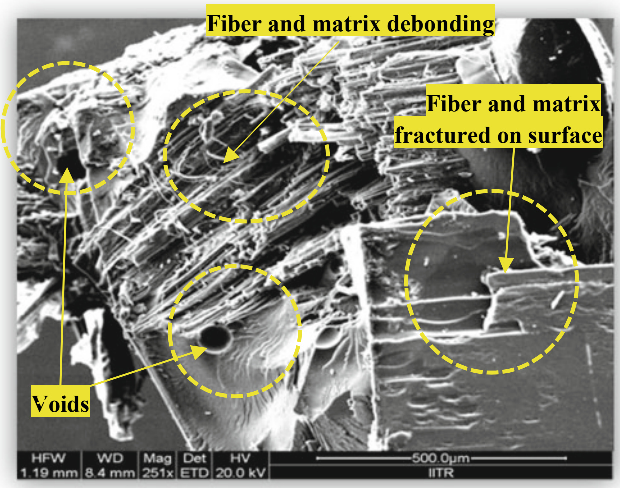

Fig. 8 FE-SEM images of woven sisal-epoxy composites under tensile failure mode methods

4 Conclusions

Based on the experimental investigation on the load-carrying capacity of a single-lap adhesive joint of woven sisal/epoxy composites having performed the tensile and morphological analysis.

The outcomes of this experimental study the following conclusions had been obtained:

- After tensile testing on UTM, it observed almost all a stock-break type of failure, because it created the strong adhesive bonding between the adherends.
- The maximum shear strength and failure load existed at four- and eight-hole arrangements.
- The increment of holes on the lap joint affected the smoothness of the bonded area.
- Symmetric hole arrangements of composite have a quite better adhesive bonding of a single lap joint.
- The FE-SEM images of the tensile fracture surface morphologies of sisal-epoxy composites reveal that relatively fewer fiber breakouts and de-bonding have been detected strong adhesion between matrix and fiber reinforcement.

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