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Experimental investigation on strain behavior of jute/polyester composite with an open hole under axial loading

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Abstract

Mechanical assembly requires joint mechanism involving fasteners and holes. Deformation of the holes will greatly affect the integrity of the mechanical joins. This research objective is to reveal the strain behavior of jute/polyester composite containing open hole under axial loading. It is very important to know the behavior of the strain surrounding the hole under loading. Experiments were carried out by preparing jute/polyester composites. The composites were manufactured by using a vacuum infusion method. There are two configurations of the number of laminations, i.e., 3 and 5 sheets and of hole sizes, i.e., 5 and 10mm holes. An axial load is applied to the specimen through a tensile test. Strain gauges are attached near the holes, axially and laterally. Strain in axial and lateral directions in the vicinity of a hole is recorded and presented. The research result shows that the strain gauges located parallel to the loading axis indicate a positive-strain value. On the other hand, the strain gauges located lateral to the loading axis indicate a negative value. Furthermore, the strain gauges located beside the hole in the direction parallel to the loading axis indicate the highest strain value in all types of specimens.

Keywords: hole deformation, natural fiber composite, simultaneous strain measurement

1 Introduction

The anisotropic, even orthotropic, nature of natural fiber-reinforced composites requires a more comprehensive study of their mechanical properties. Fiber materials derived from plants are more complicated with non-uniform properties [1]–[3]. References are mentioned related to this point, which proves jute fiber (jute, corchorus capsularis) as one of the natural or plant fibers that can be relied upon to become a reinforcement for polymer composites [1]–[7]. In these studies, the mechanical properties of the composite have been tested, including tensile strength, bending strength, and impact. In most cases, jute fiber has an average strength compared to other natural fibers. However, jute has a good ratio in strength to weight among natural fibers.

An object which has a discontinuity of shape which gives rise to a high-stress concentration has a high potential for premature failure. Before it is damaged in the stress concentration section, a plastic stretching phenomenon will occur. So that the integrity of the object will also be affected by the plastic stretching, as well as the composite [8]–[10].

Regarding the anisotropic nature of the composite, Ahmed [3] has investigated the occurrence of greater strain in the lateral (transverse) direction. This is in sharp contrast to an isotropic material such as a metal, which is more predictable that it will strain in different directions. The existence of strains with different magnitudes, in this case in the direction of the 2 axial and lateral axes, will also affect the magnitude of the strain that occurs in the geometry of objects that have discontinuities, for example, holes or other shapes. Strain concentration, also known as stress concentration, can occur in the lateral direction.

The prediction of stress concentration in composites using numerical methods was carried out by Zappalorto and Carraro [11] which is very useful for estimating the stress concentration factor of orthotropic curved bodies, orthotropic composite laminae, orthotropic unidirectional laminations, and homogeneous orthotropic composite laminations. Liu and Tang [9], found a relationship between the notch and stress/strain concentration, where the support at the crack tip can affect the stress distribution that occurs. An experiment explaining the importance of considering the distribution of stress and strain was carried out by Zhao [12] and Othman [13] by analyzing hollow composite joints using the bolt connection method.

Salleh [14] conducted experiments with composites that were given holes subjected to tensile loading. The occurrence of fractures in the specimens indicates the influence of the distribution of strain that occurs around the holes. The stress concentration factor with variations in hole size is also an important aspect in considering product design [10].

A forecited study examines the strain behavior of jute/polyester composite containing an open hole under axial loading. Based on the study, the measured strain in composites reinforced with natural fiber, specially woven jute fiber, will be useful for considering hole deformation in structural design.

2 Materials and Methods

Composite specimens were manufactured by vacuum infusion process with 3 and 5 plies of woven jute fiber. In addition, the pile configuration of the jute fiber plies combined between the weave directions of the jute fiber 0°/90° and 45°/45° in some specimens.

The stack configuration is shown in Fig. 1. In Fig. 1, the direction of the jute fiber weaves 0°/90° is symbolized by "A" and 45°/45° by "B". The configuration of stack of specimens is arranged as:

- 3 plies: AAA, BBB
- 5 plies: AAAAA, BBBBB

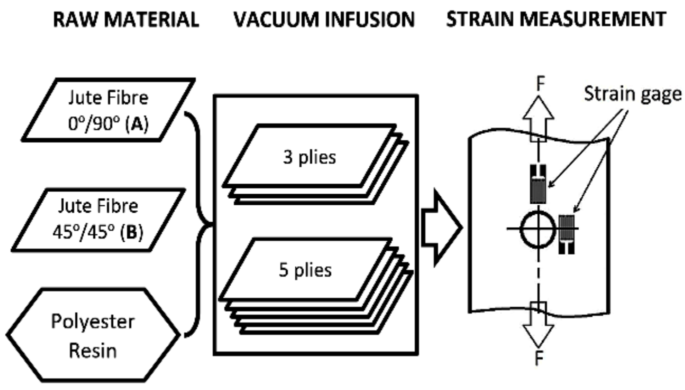


Fig. 1. Specimen preparation outline

The composite sheet is cut to the size of the specimen. Holes with a diameter of 5 and 10 mm were made at the center of the specimen. In each specimen, a strain gauge was installed above the hole and beside the hole. On the front side of the specimen, the strain gauge is in the direction of the axial axis, while on the rear side of the specimen, the strain gauge is perpendicular to the axial axis, in other words, in the direction of the lateral axis. So that there are 4 strain gauges in each specimen. The strain gauge used in this study is general-purpose foil strain gauges with a gauge resistance of 120 ohms and a gauge factor of 2.1. The grid size of the strain gauges is 3mm in length and 1.3mm in width. Specimens that have been given a strain gauge, tested with a tensile testing machine, and connected to the data acquisition system. The data obtained is in the form of stress data from each strain gauge mounted on the specimen.

The polymer material used for composites is polyester produced by PT. Justus Kimia Raya with type 157 BTQN-EX, brand Yucalac which is licensed by Showa Highpolymer Co., Ltd (Japan) and Polynt SpA (Italy). According to the information PT. Justus Kimia Raya on its official website, this type of resin is resistant to water (normal temperature) and weak acids and is very popular in shipbuilding in Indonesia apart from other applications including tanks, sanitary ware, and FRP pipes. This resin is BKI (Indonesian Classification Bureau) certified.

The fiber reinforcement used is jute fiber (jute, *corchorus capsularis*) obtained from local providers with good quality. This jute fiber is already in woven form with plain weave type. The jute fiber obtained from the provider is dried before being used for composites. The weight of the dried jute fiber woven was 25 g/m^2. Drying is carried out using an electric heater with a temperature of 50^{o}C until the weight of the jute fiber obtained from the provider is no longer reduced, meaning that the water content in the jute fiber has been maximally reduced.

Consumable materials used are the materials used for the manufacture of this composite, namely consumables for the vacuum infusion process, catalysts, and other additional materials for research operations such as alcohol, acetone, strain gauges, wires, and paper cups.

A tensile testing machine Tarno Grocki GmbH UPH 100KN is used to give the specimen tensile loading to obtain strain data. Strain amplifiers and data acquisition systems are used for the experiment instrumentation. The data acquisition system is supported by very reliable sensors to detect the response of composite materials during loading. The data acquisition system includes dynamic strain amplifiers NEC AVIO AS-1803, Analog-to-Digital Converters Interface Corp. PCI-3126, and personal computers. This data acquisition system is used to retrieve and record data from the transducer used.

Manufacturing composites using the vacuum infusion system method is shown in Fig. 2. The same method is used in [2], [15], [16]. The vacuum infusion system is very efficient in the use of resin and the process is cleaner. The resulting composite is also very homogeneous in quality. The main components of the vacuum infusion system are a vacuum pump, resin trap, molding, vacuum hose, and clamping. The vacuum pump used in this study is a 2-stage vacuum pump with a flow rate of 283 liters/minute and an ultimate vacuum of 2x10^{-1} Pa (partial pressure) or 15 microns (total pressure).

The specimen is prepared according to ASTM D-5766, similar to the study in [17]–[22]. The specimen geometry shown in Fig. 3 is also a geometrical approach so that the strain that occurs due to deformation in the testing process can be concentrated in the hole vicinity of the specimen. The shape of the specimen used in this study is shown in Fig. 3. The specimen measures 150 mm long, 30 mm wide and *t* thick. The thickness of the specimen depends on the number of sheets of jute fiber used. For the gripping part of the specimen on the tensile testing machine, each end of the specimen, 30 mm long, is covered with a 1 mm thick aluminum sheet bonded with epoxy glue. With the aluminum sheet, the specimen is not damaged by the grips of the tensile testing machine (Fig. 4).

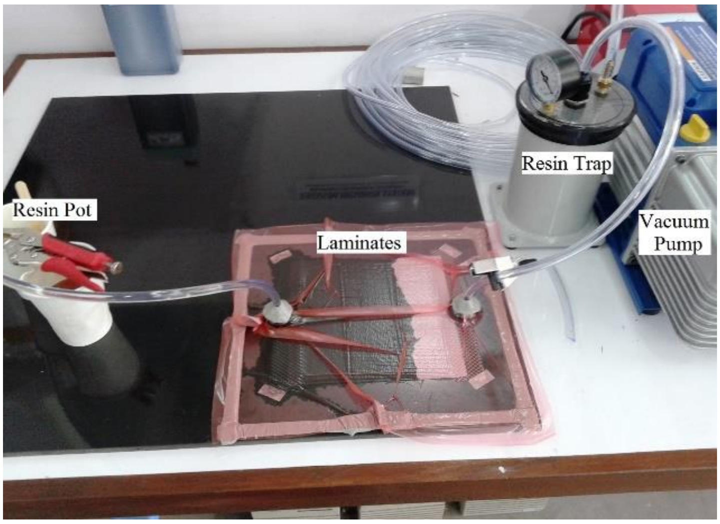


Fig. 2. Vacuum infusion system

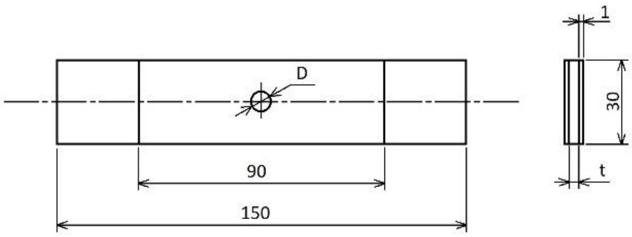


Fig. 3. Specimen geometry

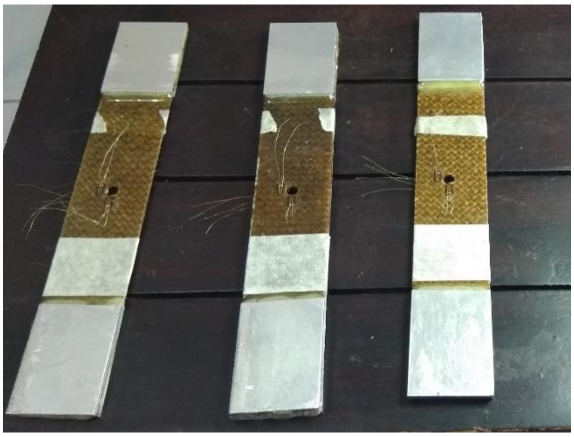


Fig. 4. Examples of specimen

The strain gauge configuration on the specimen is shown in Fig. 5. The installation of strain gauge is located on the top and side of the hole made. At each location, strain gauges were installed in axial and lateral directions with one strain gauge on the front surface and one on the rear surface of the specimen. SG1 and SG2 are strain gauges for measurement in the axial direction (in the direction of the loading axis) and at the edge of the hole. While SG3 and SG4 are strain gauges for measuring the lateral direction (perpendicular to the loading axis) which are installed on other surfaces to facilitate installation (Fig. 6). Strain gauges are located approximately 2mm, measured from the hole edge to the center of the gauges.

This configuration aims to determine the distribution of strain at that location both for the axial and lateral directions. The strain gauge used has a resistance value of 120 ohms with a sensor size of 2 mm. The strain gauge installed on the specimen already has a connecting wire to make it easier to connect to the bridge boxes.

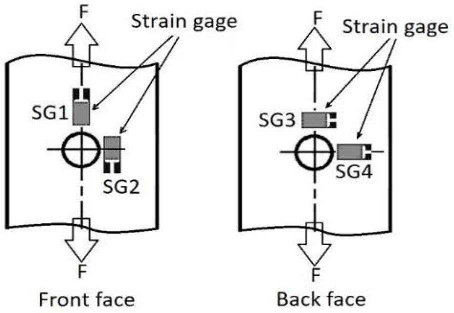
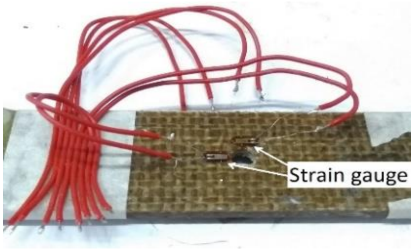
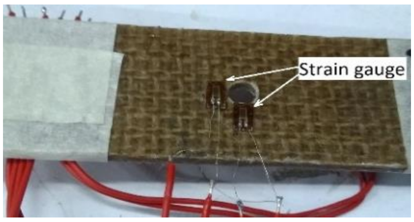


Fig. 5. Strain gauge configuration



(a)



(b)

Fig. 6. Strain gauges wiring; (a) front face and (b) rear face

Data acquisition was carried out using a data acquisition system that processes analog data from strain gauges into numerical data recorded by a computer. The data acquisition system is illustrated in Fig. 7. In Fig. 7, changes in the strain on the specimen cause changes in the resistance of the strain gauges. Changes in the resistance of the strain gauge produce changes in the voltage that will be output by the strain amplifier. The signal from the strain amplifier is still in analog form. Furthermore, the analog signal is converted into a digital signal by the ADC (Analog to Digital Converter). The digital signal will be recorded by the computer as numerical data which will then be processed into a strain value. This strain value will be analyzed through the resulting graphs.

The configuration of the equipment on the tensile testing machine can be seen in Fig. 8. The load sensor (loadcell), displacement sensor, and strain gauge are connected to digital devices so that the data obtained can be directly read and recorded by a computer (Fig. 9).

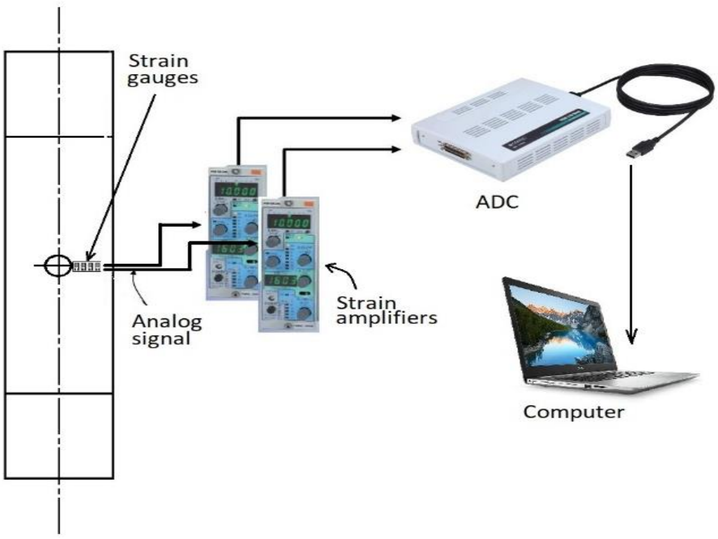


Fig. 7. Data acquisition system

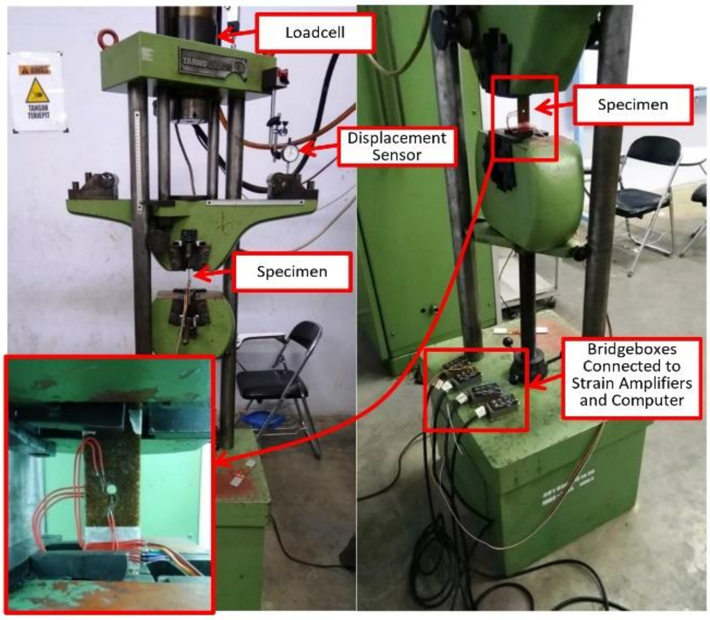


Fig. 8. Tensile testing setup

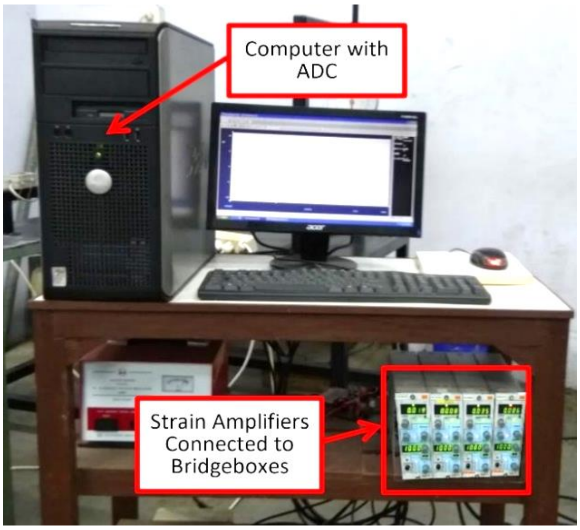


Fig. 9. Data acquisition setup

3 Results and Discussion

Fig. 10-19 presents the strain data obtained from experiments with axial loading on specimens with strain gauges attached. The configuration of the composite plies of the jute fiber woven is made according to the design in Fig. 1. The location of the strain gauges has been marked with the notations SG1 and SG2 in the axial direction and SG3 and SG4 in the lateral direction. The strain graphs in Fig. 10-19 are displayed in the form of the output voltage of the strain amplifier in volts (V) on the vertical axis and the number of data samples on the horizontal axis.

Fig. 10 shows the results of strain measurements for the AAA specimen, with a hole diameter of 5mm. In Fig. 10, it is shown that the value of measured strain on SG1 and SG2 is positive and on SG3 and SG4 is negative. The positive strain value represents positive deformation and the negative strain value represents negative deformation in the direction of the strain gauges axis, respectively. The positive deformation changes the hole size in the direction of the loading axis. The result of this study is in very good agreement with the study of [23]. In the study of [23] strain gauges are also attached in several positions around a hole of the CFRP laminates. However, in the study of [23] the hole size is quite large compared to the specimen width. Theoretically, the Von Mises static stress fields in the vicinity of the hole for tensile loads presented as “butterfly” stress distribution [24].

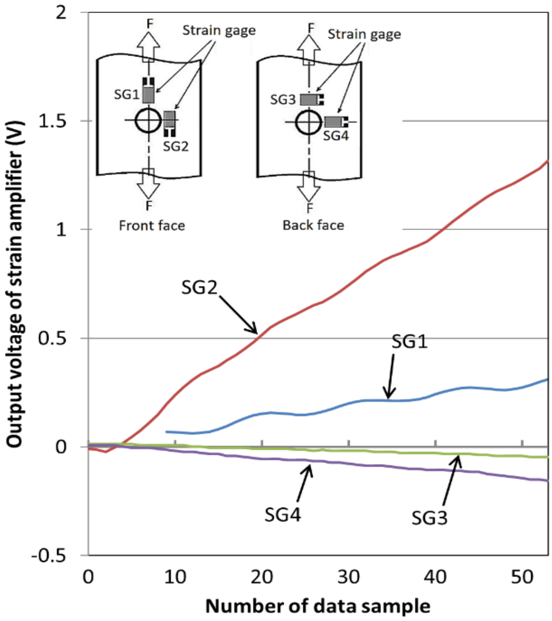


Fig. 10. Strain graphs of Type AAA specimen with a hole diameter of 5mm

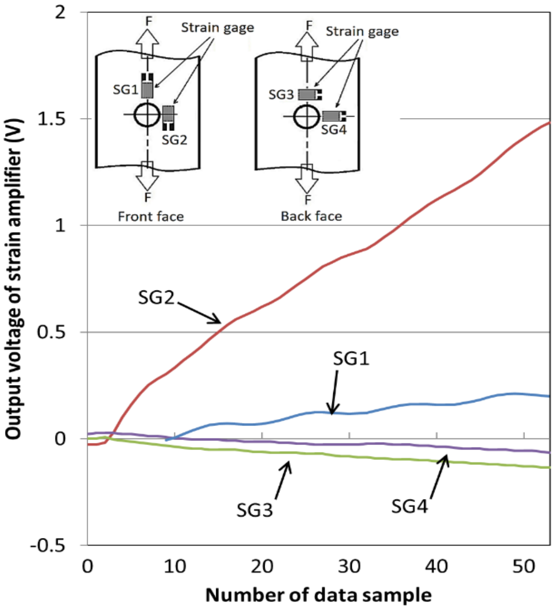


Fig. 11. Strain graphs of Type AAAAA specimen with a hole diameter of 5mm

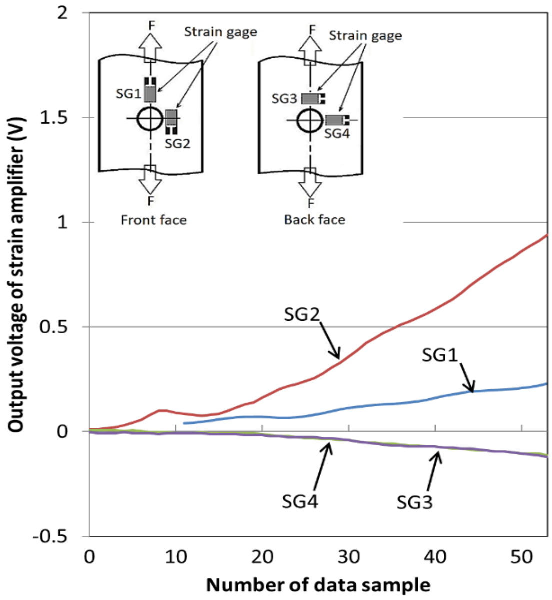


Fig. 12. Strain graphs of Type BBB specimen with a hole diameter of 5mm

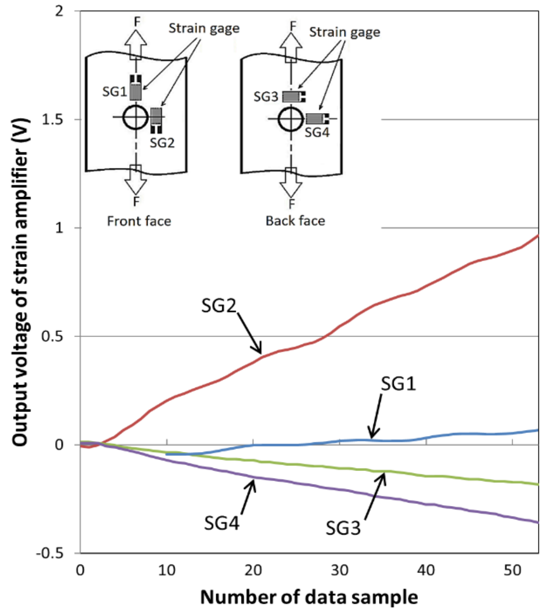


Fig. 13. Strain graphs of Type BBBBB specimen with a hole diameter of 5mm

In the cases of AAA and AAAAA specimens with 5mm hole diameter (Fig. 10 and Fig. 11), the strain value of strain gauges SG2 are higher than those of BBB and BBBBB specimens with 5mm hole diameter (Fig. 12 and Fig. 13). The type B specimens, i.e., with the direction of the jute fiber weaves 45º/45º gives higher resistance to deformation at the hole vicinity than the type A specimens, i.e., with the direction of the jute fiber weaves 0º/90º. In the other words, fiber reinforced composites with fiber weaves direction of 45º/45º resulted in higher strength than that of 0º/90º. The similar studies have been conducted by [25]. In the study of [25] is reported that open-hole properties of hybrid structure were more sensitive to lateral direction than axial direction. Furthermore, in the study of [26], the fiber stress around the hole shows that 0º plies are loaded more than 45º plies. Fig. 14 and 15 shows the results of strain measurements for AAA specimen, with a hole diameter of 10mm. Fig.s 14 and 15 reveals the result trend like those in Fig. 10-13.

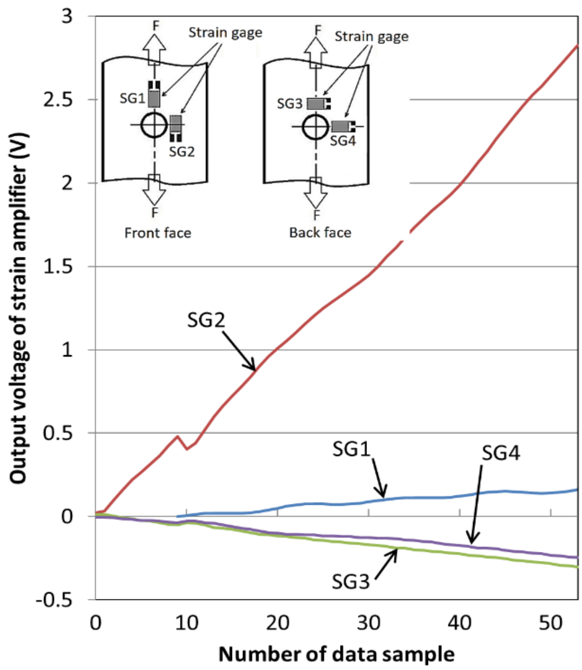


Fig. 14. Strain graphs of Type AAA specimen with a hole diameter of 10mm

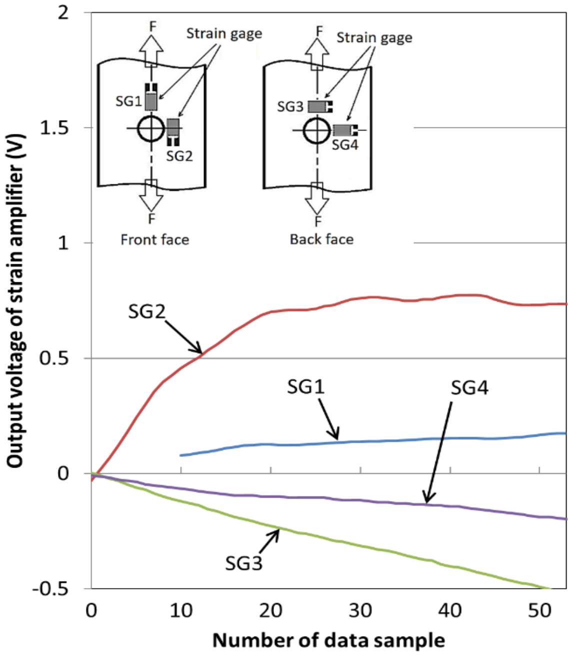


Fig. 15. Strain graphs of Type BBB specimen with a hole diameter of 10mm

Fig. 16-19 summarizes the results presented in Fig. 10-15. Fig. 16 and 17 show the results of the recorded signal from the strain gauge SG2, i.e., the strain gauge located beside the hole parallel to the loading direction of the specimen with a hole diameter of 5mm and 10mm. Fig. 16 shows AAA and AAAAA stack configurations and Fig. 17 shows BBB and BBBBB stack configurations. Fig. 18 and 19 show the results of the recorded signal from the strain gauge SG3, i.e., the strain gauge at the location above the hole in a lateral direction on a specimen with a hole diameter of 5mm and 10mm. Fig. 18 shows AAA and AAAAA stack configurations and Fig. 19 shows BBB and BBBBB stack configurations.

It can be noted from Fig. 16-19 that specimens with a hole diameter of 10mm indicate higher strain value of strain gauges SG2 than specimens with a hole diameter of 5mm, in both specimen type A and B. This higher value can be recognized as a result of a smaller specimen cross-section with the same loading. The smaller specimen cross-sectional area resulted in the higher stress at the hole vicinity. This is very important in considering the critical size of composite plates containing holes to avoid catastrophic failure as suggested in [13].

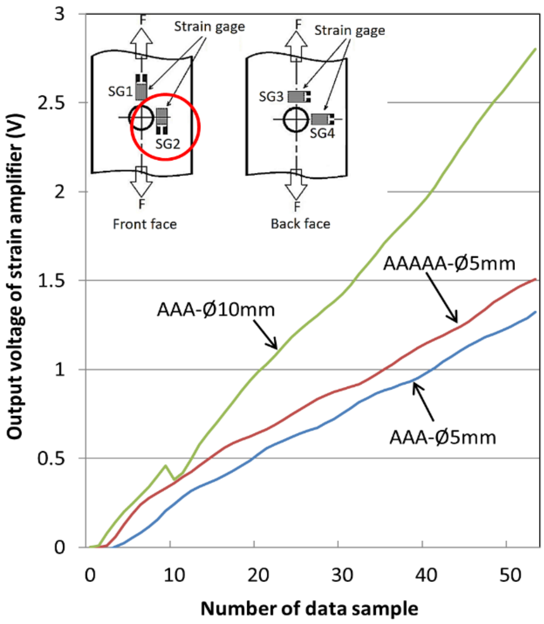


Fig. 16. Strain graphs of strain gauge SG2 on Type A specimens with hole diameters 5 and 10mm

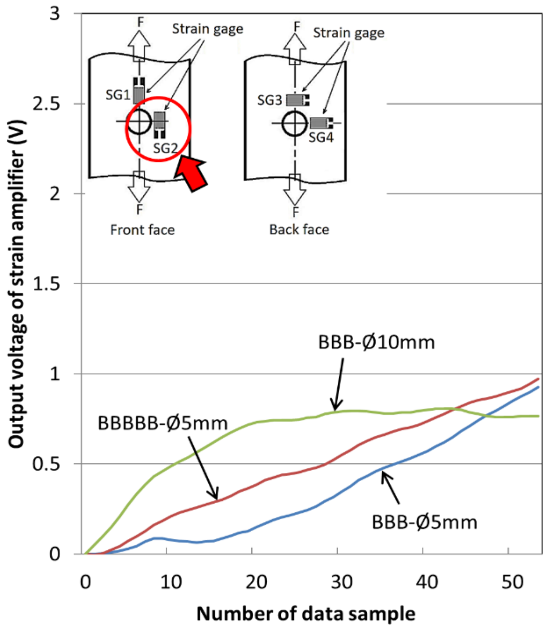


Fig. 17. Strain graphs of strain gauge SG2 on Type B specimens with hole diameters 5 and 10mm

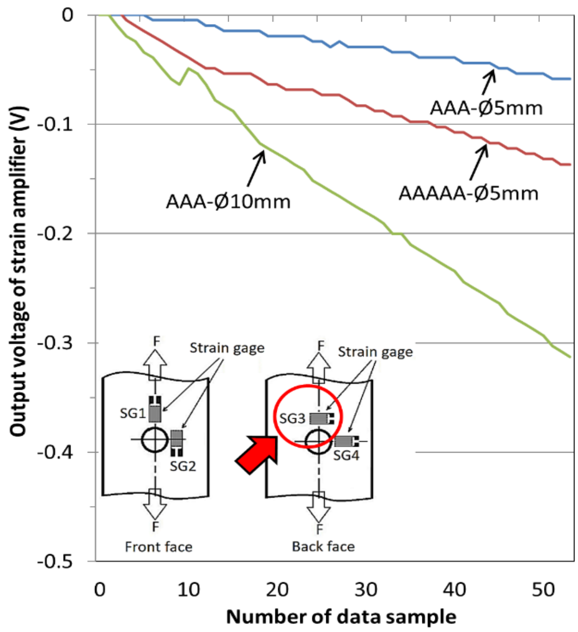


Fig. 18. Strain graphs of strain gauge SG3 on Type A specimens with hole diameters 5 and 10mm

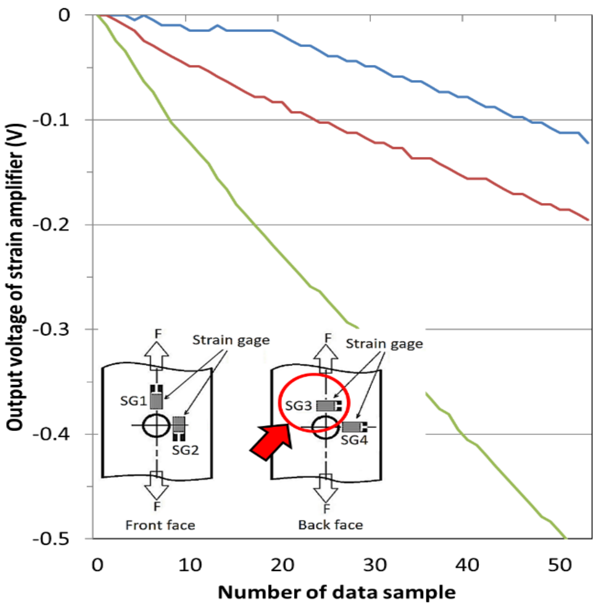


Fig. 19. Strain graphs of strain gauge SG3 on Type B specimens with hole diameters 5 and 10mm

In addition, Fig. 16 and 17 also show that the strain value of strain gauges SG2 of type A specimens are higher than that of type B specimens. Contrarily, Fig. 18 and 19 show that the strain value of strain gauges SG3 of type B specimens are higher than that of type A specimens. However, this result is also in good agreement with [26] that shows stress distribution around the hole in 360°.

4 Conclusions.

The strain behavior surrounding the hole in jute fiber-reinforced polyester composite under axial loading have been investigated. The result shows that the strain gauges located parallel to the loading axis indicate a positive strain value. On the other hand, the strain gauges located lateral to the loading axis indicate a negative strain value. measured strain at the hole side in the direction parallel to the loading axis reveals considerably higher strain value than the lateral strain at hole's upper side, i.e., larger deformation occurs on the hole in the direction parallel to the loading axis. It is very important for considering hole deformation in structural design with natural fiber-reinforced composites, especially woven jute fiber.

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