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Mechanical Characteristics of Bio-Composite Materials Reinforced by Pandanus Tectorius Natural Fibers

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Abstract:- The wastes of naturally non-biodegradable materials, both solid and liquid forms, are a crucial issue that has led to the issuance of government regulations regarding the use of those kinds of materials for industrial processing. In order to face this problem, bio-composite materials are developed to protect the environment from acute pollution while still being able to develop the industry. Bio-composites consist of two elements; natural fiber and reinforcement, which are friendly to the environment. In this research, new materials based on the bio-composite reinforced by Pandanus Tectorius natural fibers were observed by mechanical testing deeply. The results show that the mechanical properties of such kinds of bio-composite material are varied depending on their compositions. The ultimate tensile strength (UTS) of each kind of specimen was 24.85, 35.52, and 37.01 N/mm^2, respectively. These results were also confirmed to mechanical based-simulation results using finite element method.

Keywords:- *Bio-composite properties; natural fiber; Pandanus Tectorius; mechanical testing; chemical evaluation; morphology observation.*

I. INTRODUCTION

The waste management of naturally non-biodegradable materials, both solid and liquid, is a crucial issue that has led to the issuance of government regulations regarding the use of those kinds of materials in several countries, including Indonesia [1]–[3]. On the other hand, in the development of an increasingly better relationship between human life and its environment, humans need friendly various types of materials used for various purposes in their life. The type of material continues to experience development along with technological developments which increasingly encourage the number of inventions in certain fields such as the manufacturing, automotive, and construction industries. The materials needed must be of high quality and environmentally friendly [4], [5]. Therefore, researchers continue to develop their innovations to find the materials in order to address that problem and at the same time protect the earth from acute pollution while still being able to develop industry. One alternative of materials that provides those thigh requirements is bio-composite materials. These kinds of materials are the mixing of two or more constituents of base material and then becoming a new material that has different characteristics from the properties of the base material [6], [7]. Natural fibers which are playing a primary role usually serve as reinforcement and other responsible as the matrix [8], [9].

Madhu, P. et al. [10] chemically extracted Agave Americana-C (GAC) leaf fiber, then investigated its mechanical properties and examined the uniqueness of the fiber through a scanning electron microscope (SEM). After modifying the fibers through chemical treatment and applying a variety of other test parameters, they concluded that GAC natural fibers may be used to form new composite materials for lightweight applications. Edy Syafri et al. [11] extracted Agave Gigantea leaf fiber using various concentrations of NaOH. They concluded that 5% NaOH concentration was the best condition to produce pure cellulose (76.7%) with an average fiber diameter of 147 µm. In contrast to the two research groups above, Bezazi et al. [12] extracted the leaves of Agave Americana-L (GAL) naturally. They extracted the fiber in two ways, the first was by soaking the GAL leaves in water for several days, and the second was by burying them in the ground for three months. Then tested 120 GAL fiber samples to determine the tensile strength and elastic modulus (Young's modulus). GAL fiber obtained by burying showed a higher Young's modulus and tensile strength than the fiber extraction method with water immersion.

After extracting natural fibers and analyzing their mechanical strength according to the method described above, generally, researchers will produce bio-composite materials and analyse them. In this case, natural fibers will play an important role as reinforcement (reinforced) and added a few percent of the binding matrix. Sathiamurthi, et al. [13] and Arumugam, et al. [14] investigated the mechanical properties of Agave Americana fibrous bio-composite through tensile and bending tests with several matrix variations. Binoj and Bibin [15] explained the thermo-mechanical properties of Agave Tequilana waste fibrous bio-composite materials through tensile, flexural, impact, and hardness tests. While the thermal strength was tested through thermogravimetric analysis with a flow rate of 20 ml/minute. While Mancino et al. [16] and Kumar et al. [17] investigated the mechanical properties of Agave Sisalana and Himalayan Agave fibrous bio-composites with polyester variations. According to them, the tensile and impact strength increased with increasing fiber length, and for a fiber size of 7 mm it had a tensile strength of 25.43 MPa, an impact strength of 45.55 J/m^2, and a hardness of up to 48.01 HV.

Indonesia has the potential to become the largest natural fiber producer in the world because it has thousands of plant species that can be processed into natural fibers, both from leaves, seeds, fruits, roots, stems, and plant bark [18]. These natural fibers can then be supplied to meet domestic market demand which reaches 1,982 tons/year and the international market which requires 319,000 tons as raw material for various human needs, including the bio-composite industry, namely materials consisting of natural fiber as reinforcement and matrix as a binder [6], [19]. Furthermore, this bio-composite material can be used to support the rapid development of the current railroad and automotive manufacturing industry.

Pandanus Tectorius widely live in many areas of Indonesia. The leaves of this plant are often used by people around the coast to make mats. Utilization of this leaf is still very limited. If further studies are carried out, another potential of this plant will be known, namely as a reinforcement in the manufacture of bio-composite materials. So that it can increase the functional value of the fiber. In an effort to utilize the Pandanus Tectorius plant as an alternative to natural materials used as reinforcement in the manufacture of composite materials, this research was carried out.

This work aims to provide information regarding the mechanical properties of fibers and bio-composite materials made from natural fibers of Pandanus Tectorius which are associated with chemical properties and morphology observed under an electron microscope. The mechanical properties were evaluated using tensile tests, the chemical properties of materials were examined through Fourier-transform infrared (FTIR), and the morphological investigation was analyzed by employing a scanning electron microscope (SEM).

II. PROPOSED DEFECT DETECTION METHOD

You Several methods were applied to conduct the research. The natural fibers of Pandanus Tectorius were first hand-extracted from the leaves, then the bio-composite based on these fibers was produced. Extracted natural fibers were examined for their chemical properties by Fourier Transform Infrared (FTIR). On the other hand, bio-composite materials were tested for their mechanical properties by tensile tests which are related to their morphological form that was observed under Scanning Electron Microscope (SEM). Those methods are explained by following description.

A. Extraction of Pandanus Tectorius Fibers

The method of extracting Pandanus Tectorius fibers is shown in Figure 1. The figure provides four ways to extract the fibers. Figures 1(a), 1(b), 1(c), and 1(d) are the way of cleaning and boiling the leaves, brushing, alkalization process, and drying, respectively. As can be seen from Figure 1(a), Pandanus Tectorius leaves with dark green are cleaned from the dirt substance and then boiled in water at a temperature of 95°C for 3 hours. Then, removed the leaves from the boiling process and soaked them in fresh water for 10 days in order to get a soft form of the leaves. After these processes, the boiled leaves were then brushed using a brush in order to obtain the proto fibers and dried them under direct sunlight as shown in Figure 1(b). The alkalization process was then applied for reducing cellulose which adhere to the proto fibers as shown in Figure 1(c). In this case, the proto fibers were then soaked in an alkaline solution of Potassium Hydroxide (KOH) with a concentration of 5% and soaked for 4 hours. Those Pandanus Tectorius fibers were then neutralized by immersing the fibers in fresh water for two days. Every 6 hours, the fiber was rinsed and replaced with soaking water. Then, the fiber is aerated to dry slowly so that there is a balanced drying between the inside and the outside. The extracted fibers are shown in Figure 1(d).

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(a) Cleaning and boiling the Pandanus Tectorius leaves

(b) Brushing the boiled leaves

(c) Alkalization process

(d) drying Pandanus Tectorius fibers

Fig. 1: Hand-extraction method for obtaining Pandanus Tectorius Fibers

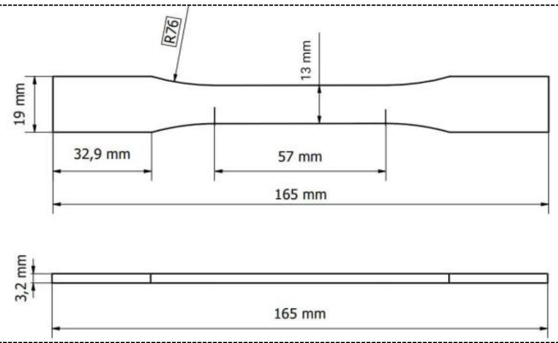


Fig. 2: Dimensions of tensile test specimen according to standard ASTM D638 type 1 [20]

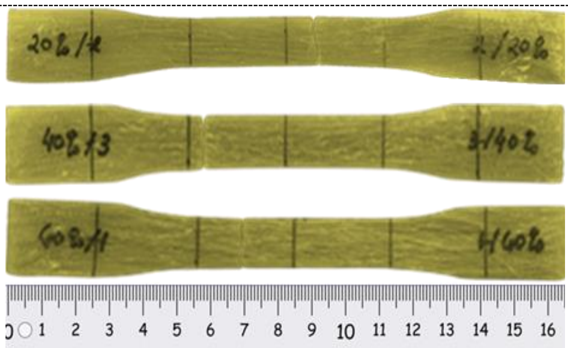


Fig. 3: Finished composite results

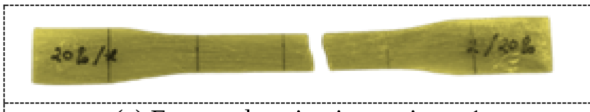
B. *Producing Specimens*

The next step is producing bio-composite specimens using based on the obtained fibers. The specimens are produced following the ASTM D638 TYPE 1 standard. The form and dimension of the specimen are shown in Figure 2. As can be seen from the figure, the specimen has a total length, width, and thickness of 165, 19, and 3.2 mm, respectively. The length of the handling test, gauge length, and radius are 32,9, 27, and 75 mm. These kinds of testing specimens were prepared by the hand lay-up method with the percentage of Pandanus Tectorius fibers were 20%, 40%, and 60% compared to the matrix. The matrix was a mixing of resin and catalyst which were determined by their volume ratio, namely 2 : 1 (resin : catalyst). These kinds of bio-composite material testing were then referred to as specimens 1, 2, and specimen 3, respectively. The three kinds of specimens are shown in Figure 3.

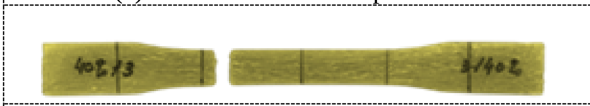
III. RESEARCH METHODS

A. Mechanical Properties Bio-composite Material Reinforced by Pandanus Tectorius

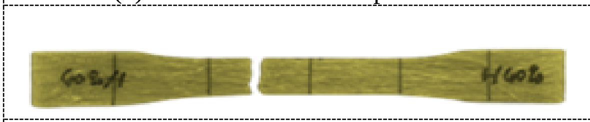
In order to determine the mechanical properties of bio-composite materials, tensile tests were conducted by providing an axial force load subjected to the specimens. The fracture specimens obtained from the tests are provided in Figure 4. As can be seen from the figure, the tensile fracture occurs at the gauge length of the specimen. It means that the testing was in the correct procedure. Each specimen is fractured without experiencing necking. Therefore, these materials seem to be brittle material. Besides, a more detailed fracture mechanism is going to be seen microscopically by scanning electron microscope (SEM) to explain these phenomena.



(a) Fracture location in specimen 1



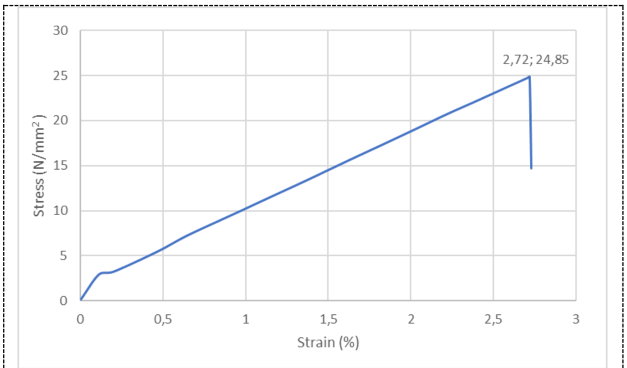
(b) Fracture location in specimen 2



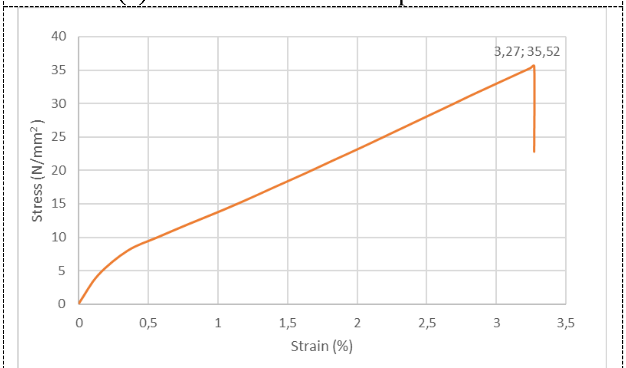
(c) Fracture location in specimen 3

Fig. 4: Form of fracture of bio-composite specimen after tensile test.

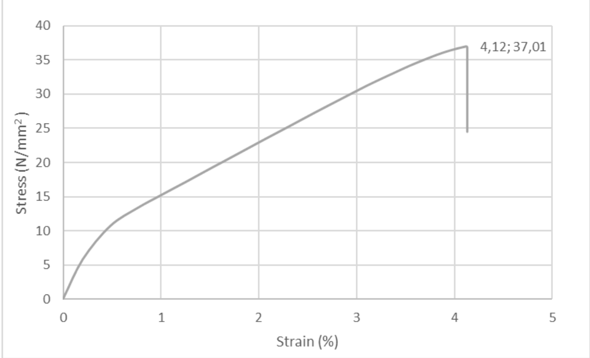
The mechanical properties of the testing materials including ultimate tensile test (UTS), strain, and modulus elastic were examined by strain-stress curves obtained from the tests. The curves for each specimen are shown in Figure 5. Overall, the curves show that the specimens experience the elastic phase, no necking can be seen from the graphs. The line on the curve has a shape that tends to be straight or linear up to the yield point and directly fractures. This causes the resulting yield point value to be the same as the UTS. From each curve, the UTS point of specimen 1, 2, and specimen 3 are 24,85; 35,52; and 37,01 N/mm^2, respectively. Those UTS appropriate to the strain points, namely are 2,72; 3,27; and 4,12%, respectively.



(a) Strain-stress curve of Specimen 1



(b) Strain-stress curve of Specimen 2

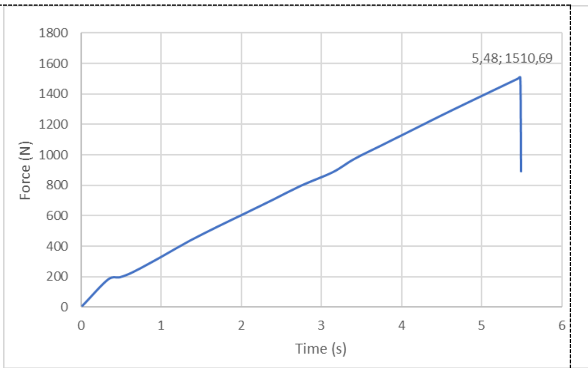


(c) Strain-stress curve of Specimen 3

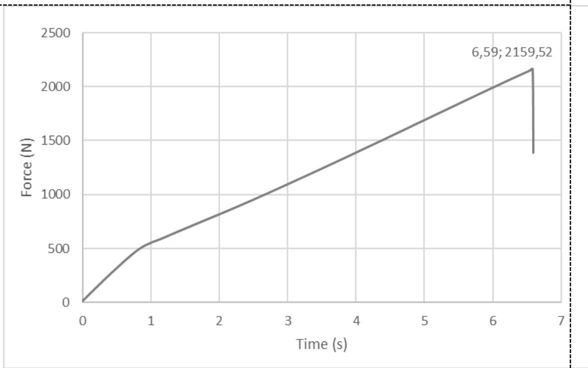
Fig. 5: Strain-stress curves obtained from tensile tests for each specimen

For understanding the time and force when the fracture was coming, the time-force curves are provided as shown in Figure 6. From the curves, it can be seen that the amount of force that can be accepted and the time needed until the specimen experience fracture are varied for each specimen. When the force received by the specimen during testing reached its maximum, the specimen was fractured. It can be seen in Figure 5(a); the specimen is able to withstand a force of 1.510,69 N until it finally fractures and takes 5,48 seconds. This event was also experienced in specimens 2 and 3. In specimen 2, the specimen was able to withstand a force of 2.159,52 N until it finally broke, and took 6,59 seconds. While, for specimen 3, the specimen is able to withstand a force of 2.252,3 N until it finally breaks, which takes 8,27 seconds.

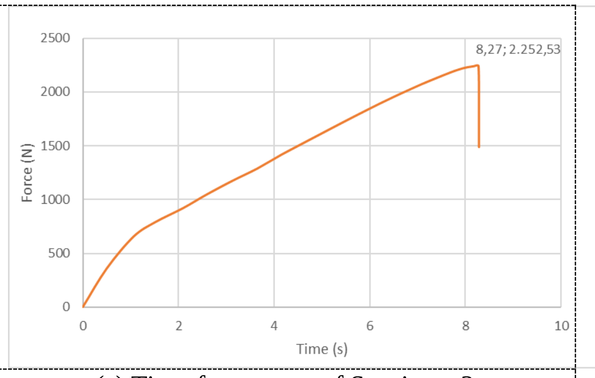
Figure 7 shows the linear regression method for determining the elastic modulus. The modulus of elasticity measures the resistance of a material to elastic deformation. Modulus is defined as the slope of the straight-line portion of the stress and strain curve. It can be seen from the curves; a linear regression line is shown with a straight upward sloping shape. The shape of the slope obtained is steeper and the modulus value is higher than ductile materials such as rubber. The elastic modulus of each specimen is 868.18; 982.29; and 802.96 N/mm^2, respectively.



(a) Time-force curve of Specimen 1

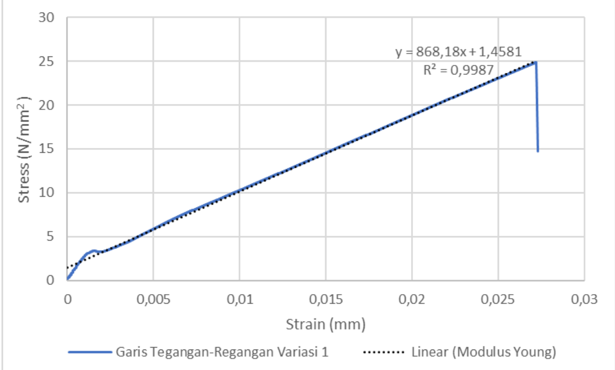


(b) Time-force curve of Specimen 2

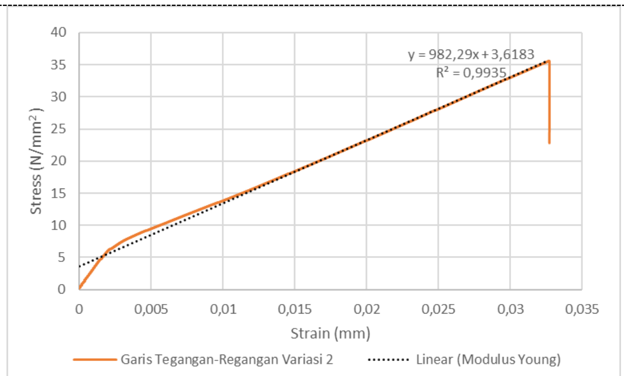


(c) Time-force curve of Specimen 3

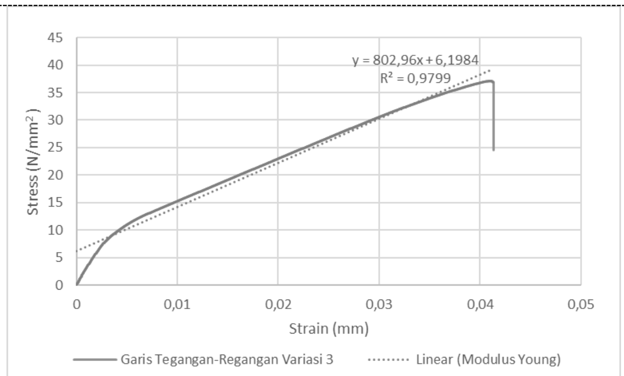
Fig. 6: Time-force curves obtained from tensile tests for each specimen



(a) Linear regression curve of Specimen 1



(b) Linear regression curve of Specimen 2



(c) Linear regression curve of Specimen 3

Fig. 7: Linear regression for determining elastic modulus of each specimen

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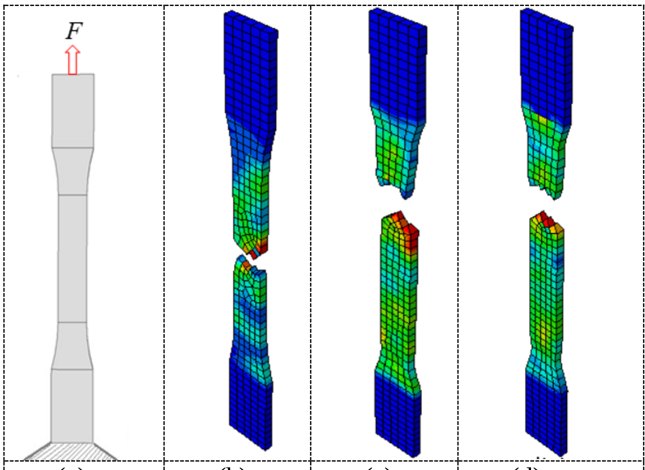
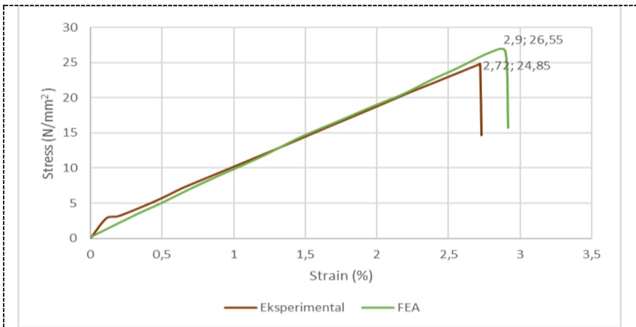
In order to confirm the result of the test, the simulation based on the Finite Element Method (FEM) was conducted as shown in Figure 8. From the figures, it can be seen that the fractures of the material seem to be similar to the testing specimens shown in Figure 4. Besides, the stain-stress curves are provided in Figure 8, which are compared to the curves obtained by tensile tests. From the figures, it can be seen that the experimental testing and simulation have good agreement.

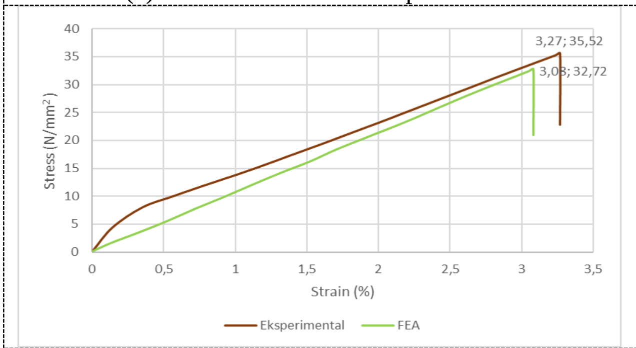


(a) (b) (c) (d)

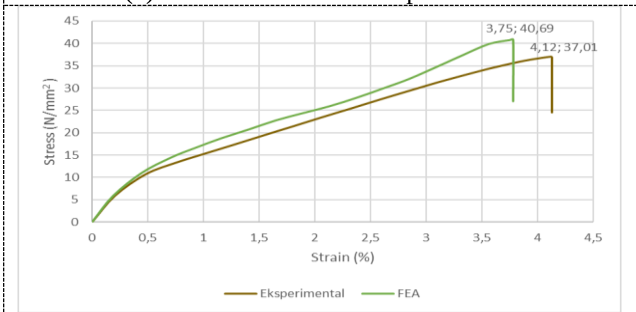
Fig. 8: Simulation result based on FEM; (a) model; (b) fracture results in the simulation for specimen 1; (c) specimen 2; (d) specimen 3.



(a) Strain-stress curve of Specimen 1



(b) Strain-stress curve of Specimen 2



(c) Strain-stress curve of Specimen 3

Fig. 9: Comparing strain-stress curves between tensile tests and simulation for each specimen

IV. CONCLUSION

This article studied about characteristics of bio-composite material reinforced by the natural fiber of Pandanus Tectorius. The characteristics were inspected by mechanical tests, morphological observation, and chemical evaluation. Based on the tensile tests, there was no necking and yield phenomenon observed, so no plastic deformation occurs for each specimen. The crack occurred quickly before finally fracturing. Therefore, the bio-composite material was typically brittle. The ultimate tensile strength (UTS) values of specimens 1, 2, and 3 were 24.85, 35.52, and 37.01 N/mm2, respectively. While, the strain values were 2.72, 3.27, and 4.12% for each specimen. These results have been confirmed by simulation using the finite element method (FEM).

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