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STRENGTH PROPERTIES ANALYSIS OF BIOMIMETIC NATURAL WIRE WEED FIBER REINFORCED POLYMER COMPOSITE HONEYCOMB PLATES

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***ABSTRACT**: In the present study, the compressive strength analysis of bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates manufactured was studied. The findings were that bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates were primarily characterized by compression failure of the non-perforated surface when bearing compressive load. Bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates clearly exhibited the features of plasticity. Buckling failure mode of the upper or lower laminates were not observed in the bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates, and it possess the ideal integrity. Additionally, the bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates produced with 50-mm-long fibers have the greater shearing modulus of elasticity and good plastic deformation ability. These results were of significance for disaster prevention and safety in quakeproof applications. The failure features, strength property parameters, and simple calculation model for compression of bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates obtained in this research provide a foundation for the prediction of compression and the design of bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates in future engineering applications.*

KEYWORDS**: **Strength properties analysis, Compressive strengths and modulii, Bio-mimetic composite plates, Sandwich-structured composites, wire weed fiber

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I. INTRODUCTION

In recent years, honeycomb structures have gained increasing importance in emergency projects, such as emergency bridges and temporary housing for victims after natural disasters (e.g. earthquakes and floods). Nearly 20 years ago, Chen et al. observed the three-dimensional microstructure ((Allen, 1969), (Lira et al, 2010), (Smith et al, 2010), (Cheng et al, 2016), (Gunes et al, 2016), (Vitale et al, 2016), (Zhou, 2001), (Herrmann et al, 2005), (Long et al, 2002), (Chen et al, 2003), (Xu et al, 2004), (Li et al, 2005)) of beetle forewings and creatively developed a structural model of bio-mimetic fully integrated honeycomb plates (FIHPs) with honeycomb-trabecula features ((Gu et al, 2012), (Tuo et al, 2016)). Furthermore, he succeeded in producing a FIHP using short basalt fiber (SBF) and epoxy resin and then performed a series of experiments to measure its out-of-plane strength properties, such as its compressive and flexural properties ((Tuo et al, 2016), (Xie et al, 2015)). Honeycomb structures are commonly used in the design of lightweight, high strength composites ((Allen, 1969), (Lira et al, 2010), (Smith et al, 2010), (Cheng et al, 2016), (Gunes et al, 2016), (Vitale et al, 2016)), with many applications in the fields of aerospace ((Zhou, 2001), (Herrmann et al, 2005)), transportation, and architecture (Long et al, 2002). Currently, basalt fiber, which is a type of inorfil, has gained popularity in the world. In comparison to fiberglass, carbon fiber, and aramid fiber, it has the advantages of wide availability, excellent strength properties, and good resistance to temperature, acids and alkalis, and ultraviolet radiation ((Jia et al, 2005), (Ha et al, 2007)). More importantly, there are no emissions of harmful materials throughout the manufacturing process of basalt fiber. Because of its ecological safety (Wang et al, 2004), it is an environmentally friendly material that can avoid pollution from the source, thus promoting the sustainable development of a social economy (Shang et al, 2004). Due to its reputation as a ‘‘new material of the 21st century’’ (Liu et al, 2006), it has attracted much attention from researchers ((Cao et al, 2007), (Bicher, 1993)). Over the past 20 years, as a new type of sealing material, short fiber reinforcement polymer (SFRP) has been widely applied in pressure vessels and pipelines as a substitute for asbestos ((Wang et al, 2011), (Chen et al, 2007)). Composite industries listed the key special-execution solution of ‘‘green structures and industrial structures’’ in the industry’s key research project, named ‘‘thirteen five,’’ in 2016 (Li, 2011).

This research aims to achieve the international advanced level in the field of technical systems, products, and equipment in several crucial aspects, such as building energy-savings, environmental quality improvement, efficiency-increments and quality control safety, etc. Furthermore, this work aims to provide technical support for the development of green buildings and building industrialization for now and in the future. Thus, wire weed fiber will have more applications in the future. In addition to their use in components subjected to loads perpendicular to the surface layer, honeycomb plates can also be employed in compression components (parallel to the surface layer, namely, in-plane compression) (Li, 2011). To investigate the strength characteristics and failure mechanism of in-plane compression in bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates, the compressive test of bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates was conducted in this research. The results indicated that bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates have the potential to be used in a wide range of engineering applications.

the past few decades there is a rapid increase in the demand of the fiber reinforced polymer (FRP) composites because of the unique combination of high performance, great versatility and processing advantages at favorable costs by permutation and combination of different fibers and polymers (Zaman et al, 2010). FRP composites possesses interesting properties like high specific strength and stiffness, good fatigue performance and damage tolerances, low thermal expansion, non-magnetic properties, corrosion resistance and low energy consumption during fabrication (Jawaid et al, 2011). Fiber reinforced composites made up of carbon, boron, glass and kevlar fibers have been accepted widely as the materials for structural and non-structural applications (Gowda et al, 1999).

Environmental concerns are increasing day by day and the demand of replacing the existing synthetic fibers with the biodegradable, renewable and low cost natural fibers for fabrication of composite materials increases (Sandhyarani et al, 203). In comparison to the traditional reinforcing materials natural fiber such as sisal, jute, abaca, pineapple and coir has acceptable specific strength properties, low density, low abrasion multi-functionality, good thermal properties, enhanced energy recovery and cause less skin and respiratory irritation ((Dey et al, 2011), (Chin et al, 2009)). Pervaiz and Sain (2003) examined the energy consumption of glass and natural fibers, and they found that by using vegetal fibers in place of glass fibers, energy could be saved at a rate of 60% per ton of product. The insulating characteristics of jute may find applications in automotive door/ceiling panels and panel separating the engine and passenger compartments (Hamada et al, 2005).

Finger root, a natural fiber in polymer composites would be suitable for the primary structural applications, such as indoor elements in housing, temporary outdoor applications like low-cost housing for defense, rehabilitation and transportation. The use of natural fiber like finger root not only help us in ecological balance but can also provide employment to the rural people in countries like Nigeria, India and Bangladesh where finger root is abundantly available.

In this study bi-directional finger root fiber has been used for the preparation of the composites. The purpose of this study was to investigate the potential utilization of finger root fiber as reinforcement in polymer matrix composites. Also, the effect of finger root fiber content on the physical and strength behavior of the composites were investigated.

II. MATERIALS AND METHOD

The experimental materials and research methods embarked upon in this investigative work are as depicted in the following headings and sub-headings below.

A. SAMPLE PREPARATION

Natural wire weed fiber obtained from southern Nigeria, after treatment with silane, length: 10 mm, 30 mm, and 50 mm, diameter: 13 mm), obtained by retting process, were used as reinforcement material. Bisphenol A-E51 epoxy resin, produced by nycil Nigerian Chemicals Ltd., but supplied by GeoMela CCRD was used as the matrix material ((Zhang, 1997), (Zhang, 2002)). Curing Agent 593, produced by nycil Nigerian Chemicals Ltd., was used as the curing agent. The reactive diluent 501, produced by produced by nycil Nigerian Chemicals Ltd., was used as the diluent. Based on our extensive research results, samples with fiber volume content (V_f) of 30% have a more even fiber distribution than those with V_f of 10% or50%. Thus, 30% was selected as the $V_f$in this investigation.

The bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plate samples were designed and produced according to the Standard Test Method for Compressive Strength of Sandwich-structured composite Constructions(ASTM C364/C364M-07) (ASTM C364/C364 M-07, 2012) and the Test Method for Compressive Properties of Sandwich-structured composite Constructions (GB/T 1454-2005) (Yoji et al, 2017). Its geometric dimensions and the actual object are noted.

The bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plate samples were manufactured and shaped in the form of a hexagon (Yoji et al, 2017). The whole processes were divided into two stages: the preparation of molds and manufacturing processes.

B. PREPARING THE MOLDS.

The surfaces of the female mold were cleaned with industrial alcohol before usage. For easy separation of the samples and molds after formation, a layer of oil was spread onto the inner surfaces of the female molds and then wiped with cotton gauze to create a thin homogeneous layer of oil. Before assembling the female mold, a layer of high-vacuum grease of a certain thickness was applied on the contact surface of its parts to ensure that each contact surface was well-sealed. Countersunk head bolts were used to assemble all of the parts, and the positioning panel was then placed at the bottom of the cavity of the female mold. Finally, small columns were inserted into the holes of the positioning panel.

C. LAYING OF FIBERS AT THE BOTTOM.

Weighted fibers were uniformly applied to the assembled female mold, and the fiber layers were compacted by the press panel. Finally, the press panel was removed, and the small columns were removed.

D. ASSEMBLING THE MALE MOLDS AND PACKING OF THE FIBERS.

All male molds were carefully and orderly placed into the holes of the positioning panel, following which the weighted fibers were packed into the voids. Weighted fibers were uniformly applied to the surface of the male mold and then compacted by the press panel.

E. PREPARING THE ADHESIVE SOLUTION.

The adhesive solution was prepared by mixing the epoxy, curing agent, and diluent at a ratio of 10:3:1 (mass ratio) (Yoji et al, 2017), and 0.5 – 1 wt. % of the internal release agent was added to this mixture.

F. POURING AND VACUUM PUMPING THE ADHESIVE SOLUTION.

The adhesive solution was poured into the assembled mold. A vacuum pump was then used to precipitate bubbles from the adhesive solution. To ensure that all of the bubbles had precipitated, this step was repeated three times. The entire process took approximately 20 min.

G. CURING, DEMOLDING, AND POURING OUT THE PARAFFIN WAX SOLUTION.

A thin and even layer of oil was spread onto the interface of the cover plate and the wall plate to facilitate demolding. The cover plate was fixed together with the wall plate with the help of screws. The entire assembly, consisting of all of the molds, was placed in an air-drying oven and successively pre-heated for 2 h at 60 ^oC before being post-heated for 1 h at 150 ^oC. During this process, paraffin wax was heated to melting and then flowed along the holes of the positioning panel, forming the inner voids. The sample was immediately demolded, and the liquid paraffin wax was poured out. A bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plate sample was thus obtained. The corresponding locations connected to the positioning holes formed the technical holes. Thus, an arc with a radius of 2mm was designed for the natural wire weed fiber reinforced polymer composite honeycomb plate in order to simulate the real bio-mimetic prototype structure.

H. COMPRESSIVE TEST

Compressive test were conducted on bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plate samples using a universal testing machine with a load capacity of 1000kN and a load measurement precision of ± 0.5% in an American Instron Company, Instrument Model: 1000HDX).The upper and lower ends of the sample were installed in the supporting clamps. The screw was slowly rotated to prevent dropping of the sample. The assembly, consisting of the sample and supporting clamps, was placed on the tabletop. The spherical support, located in the movable upper pressing head, was adjusted so as to provide uniform pressure on the two sides of the sample plate. When the compressive test started, the upper pressing head was moved downwards. The pressurized mode was used to apply automatic and continuous loading at a speed of 0.5 mm/min. The number of samples in each sample group was 3. The strain was directly measured using the displacement meter included in the test system. Following test standard (Wei et al, 2017), the experimental data were analyzed, and the compressive strength and compressive modulus of elasticity (MOE) of the samples were obtained. The environmental temperature, T, during testing was 25 ± 2 ^oC, and the relative humidity (RH) was 60 ± 5%.

III. RESULTS AND DISCUSSIONS

Failure mode of compression of bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates shows the failure mode of compression of the sample. As observed, failure occurred first and primarily on the nonporous side of the sample plate, for all fiber lengths of 10 mm, 30 mm, 50 mm and fiber loadings of 10 wt. %, 30 wt. %, 50 wt. %. The locations of failures were close to the center lines and exhibited horizontal fissures. Only the plate with a fiber length of 30mm showed a local uplift on the nonporous side during the later stage of loading. On the porous side, an inclined crack appeared along the end of the hole, only at the end of the middle part. For the plate with the 30mm fibers, an inclined crack appeared at the end of the hole, with an angle of 45^o to the horizontal line. The remaining samples were well-preserved. The inclined crack with an angle of nearly 45^o, occurring on one side of the sample, is a feature of shear failure. Based on the experimental observations, all of the cracks were found to extend obliquely downward from the middle part of the porous side to the nonporous side. This phenomenon occurred because the angle at the end of the hole was nearly 90^{o}and stress concentration was very obvious. Therefore, this region failed first, following which the damage cracks, extended obliquely downward to the porous side along the 45^o direction. However, the inclined crack described above did not appear on the other side. Only horizontal cracks appeared in the middle part of the samples with 30mm and 50 mm fibers. Analysis of the above failure shows that although the failure of the bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates initiated on the porous side, it led to the appearance of cracks and failure on the nonporous side. In other words, the local observations (up and down cracks) indicate that the whole failure possessed the features of bending failure only after the occurrence of primary failure. The entire honeycomb plate still did not show an obvious convex appearance, caused by buckling failure of the surface layer. Thus, the failure was primarily caused by compression failure, and there was no obvious buckling failure of the plate. In fact, in the compression of the bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plate, the surface layer was not separated from the core layer of the honeycomb plate, proving that no buckling failure occurred. Therefore, this finding also verified that the bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plate had good integrity.

Compressive stress–strain curve and mechanical performance parameters of bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates. Figure 1 – 6 shows the stress–strain relationship for compression of the bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates. As shown in all figures, for the samples with all fiber lengths of 10, 30, 50 mm and fiber volume fractions of 10%, 30% and 50%, the stress–strain curves were be divided into two phases (Phases I and II).

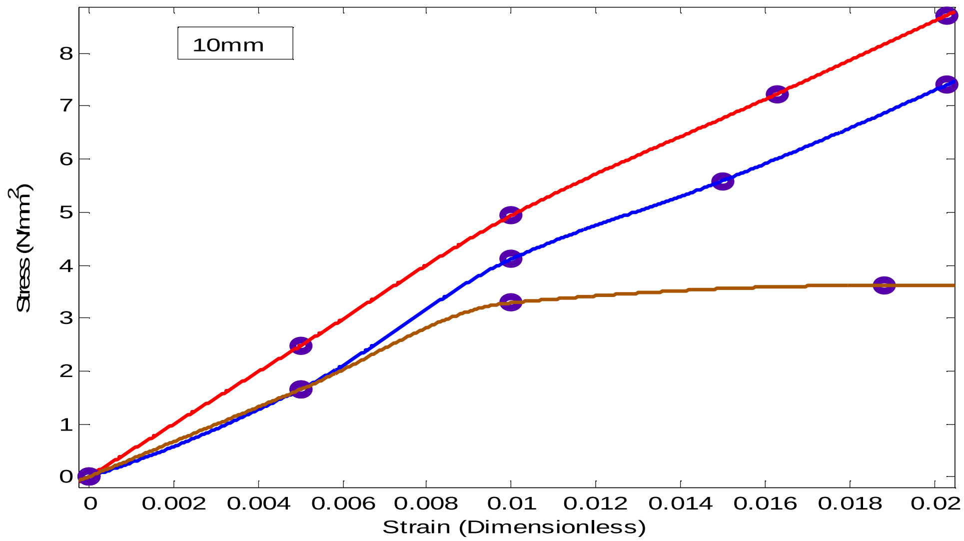

Fig. 1. Stress–strain curve during compression testing of biomimetic natural wire weed fiber reinforced polymer composite honeycomb plates with a fiber length of 10 mm.

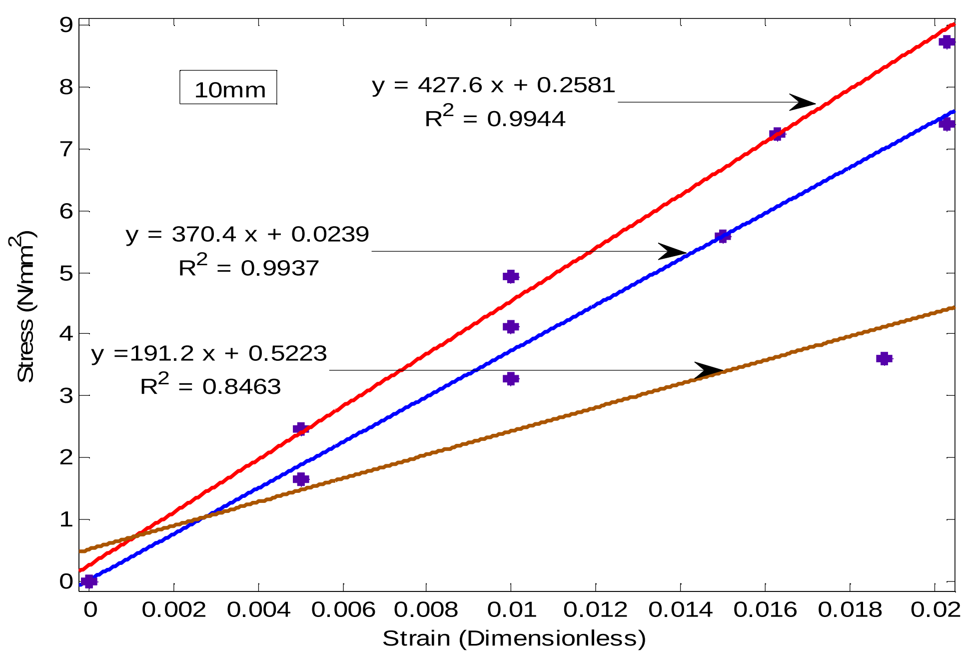

Fig.2. Linearized Stress–strain curve during compression testing of biomimetic natural wire weed fiber reinforced polymer composite honeycomb plates with a fiber length of 10 mm.

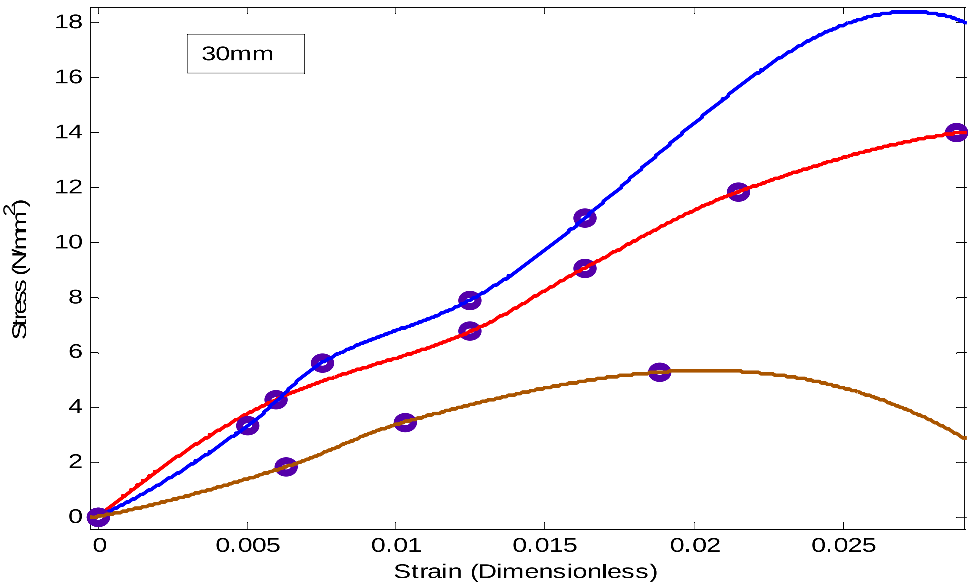

Fig.3. Stress–strain curve during compression testing of biomimetic natural wire weed fiber reinforced polymer composite honeycomb plates with a fiber length of 30 mm

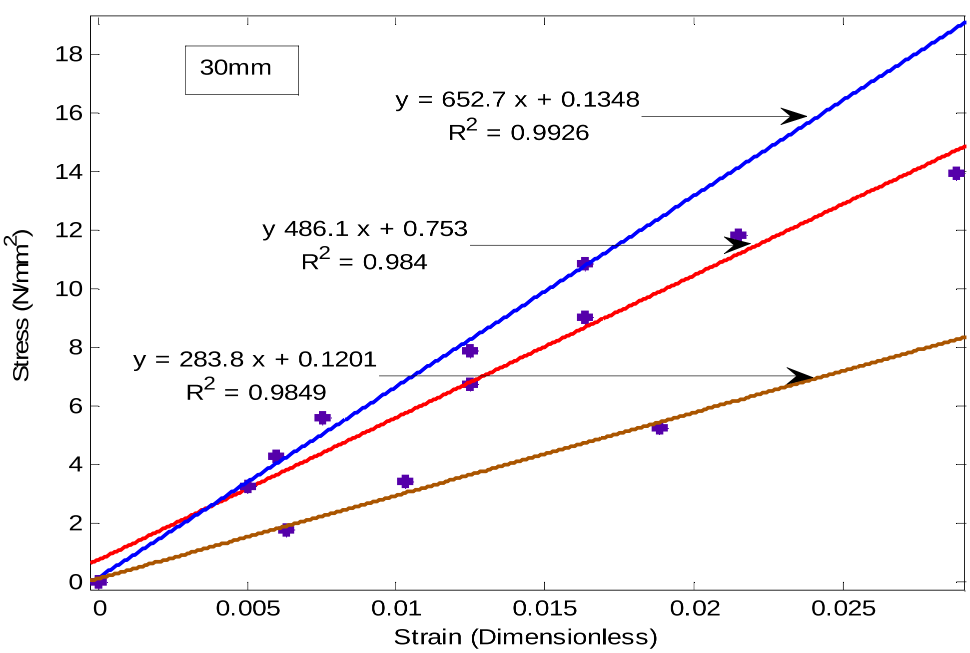

Fig.4. Linearized Stress–strain curve during compression testing of biomimetic natural wire weed fiber reinforced polymer composite honeycomb plates with a fiber length of 30 mm

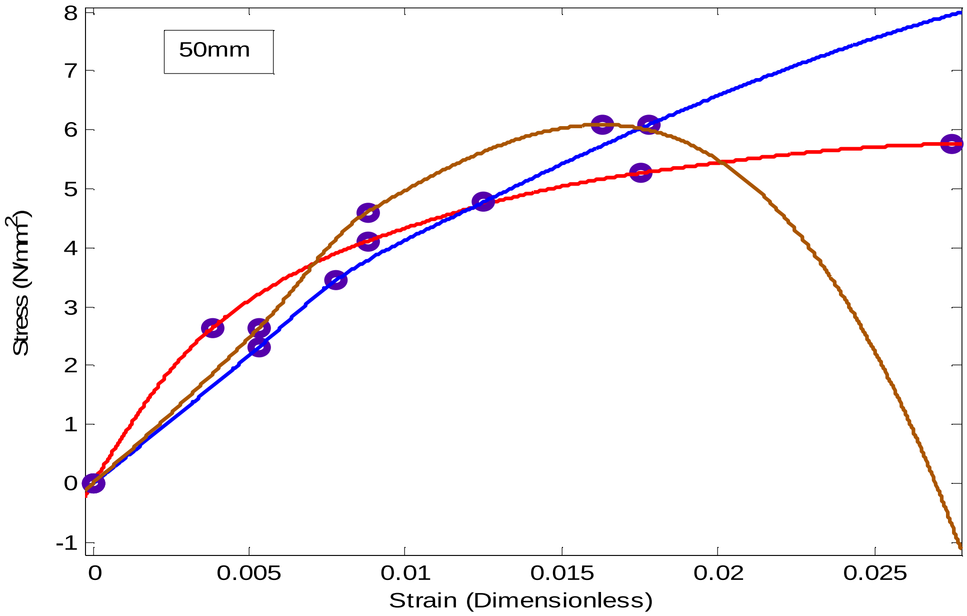

Fig.5. Stress–strain curve during compression testing of biomimetic natural wire weed fiber reinforced polymer composite honeycomb plates with a fiber length of 50 mm

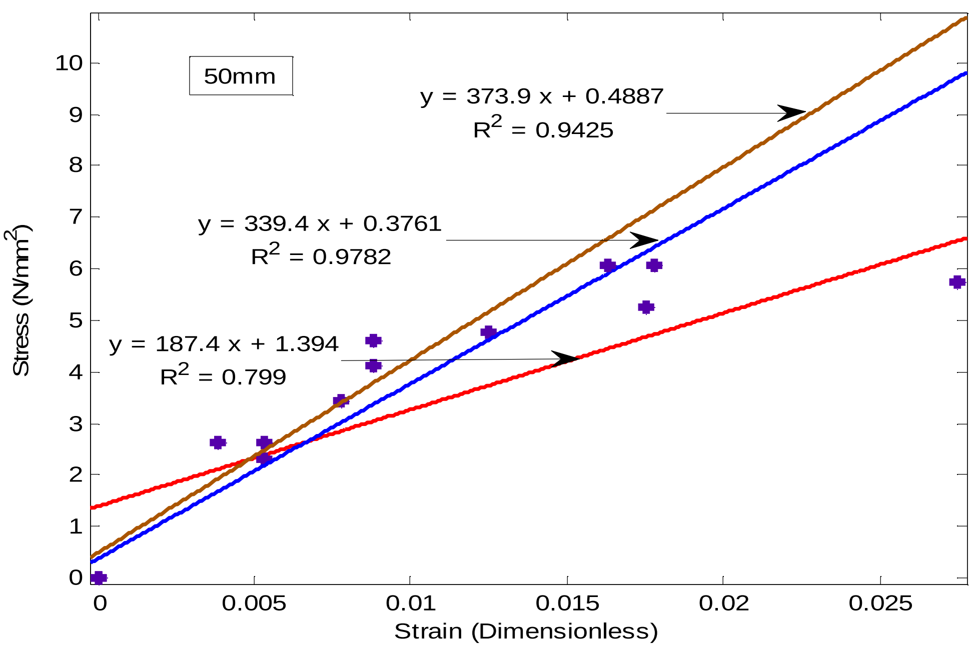

Fig.6. Linearized Stress–strain curve during compression testing of biomimetic natural wire weed fiber reinforced polymer composite honeycomb plates with a fiber length of 50 mm

Phase I was the elastic stage, in which the stress and strain of compression exhibited a nearly linear relationship with small variations. At the point of ultimate strength of the material, compression failure occurred on the nonporous side of the plate, as discussed in the previous section. Upon entering the plastic Phase II, there were large variations in the stress–strain relationship. While achieving their ultimate strengths, most curves oscillated horizontally as the strain increases. The samples maintained a high-stress state and underwent significant plastic deformation, with the exception of a few curves that showed a rapid decline in compression stress. These results showed that bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates exhibited obvious plastic characteristics during compression. Furthermore, the plastic phase of the 50-mm bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates was evidently longer than that of the other two samples (10- and 30-mm bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates). In other words, the 50-mm bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates exhibited better compression performance. This result essentially agrees with the relationship between the length and volume content of short fibers and the shear mechanical properties of SBF-reinforced polymer (SBFRP) composite, studied in a recent report (Li, 2011). The failure phenomenon occurred in Phase II because the bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates in this research consisted of short wire weed fiber reinforced polymer, and tilt (slip) failure generally occurs in short-fiber reinforced polymers. In the failure, partial fibers maintained a tensile state and played a bridging role, bearing a certain amount of load through the shear force between the fiber and the matrix (Xu et al, 2004). Although the ultimate strength of bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates was exceeded, the compressive bearing capacity did not drop significantly, i.e. the bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates was not compressed to paralysis, taking the macro-strength properties into consideration. In particular, the bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates with 50-mm fibers had very good plastic deformation ability, because its actual plastic strain, strain energy (unit volume) and ductility all are greatest (figure 5). This result is significant for disaster prevention and safety in quakeproof applications.
The compressive strengths of the samples, calculated according to the standard (Zhuang, 1997), are listed in figures 1 to 6. Obviously, the compressive strengths of bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates manufactured from WWFRP did not change significantly with the fiber lengths but was maintained in the range of 3.6184 – 13.9803 N/mm^2. In other words, the compressive strengths of the bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates was not sensitive to fiber length for V_f = 30%. More importantly, this material exhibited good elasto-plasticity. Thus, the properties of bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates discussed above provide potentials for preserving the strength stability of various structures and products. The compression moduli of elasticity of the samples, calculated from the relationship between the stress and strain values in the linear phase, are listed in figures 1 to 6. The compressive strengths and moduli of elasticity are shown in figures7 and 8. Figures7 and 8 indicated that as the fiber length (Lf) is increased from 10mm to 30mm and 50 mm, the curve of the compressive strength increased to a maximum before decreasing. However, the MOE increases to a maximum before decreasing as well.

The compressive strength and MOE exhibited same trends with changes in fiber length. Due to the local micro-features revealed by the compressive strength, the fiber and matrix have basically the same failure mode, namely, compression failure. Thus, the strength was influenced by the fiber length. However, the MOE is a macro-feature of the material. The stiffness and compressive strength of the material increases with increasing fiber length up to a maximum and decreases with decreasing fiber length. Based on the combined results of plastic deformation and energy dissipation abilities discussed above, reinforced epoxy with 50-mm-long WWFs is recommended for use in the fabrication of bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates.

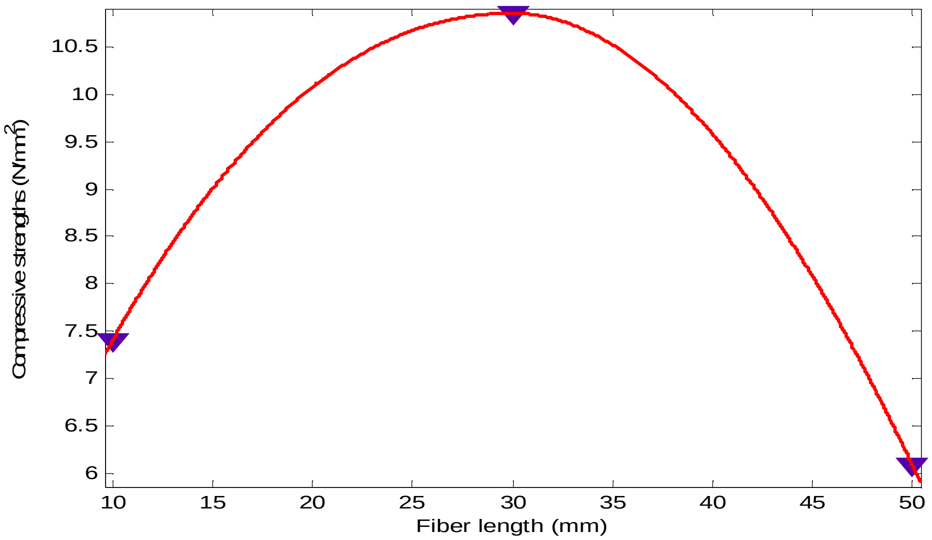

Fig.7. Compressive strengths of FIHPs (V_f = 30%). The number of samples in each sample group was 3.

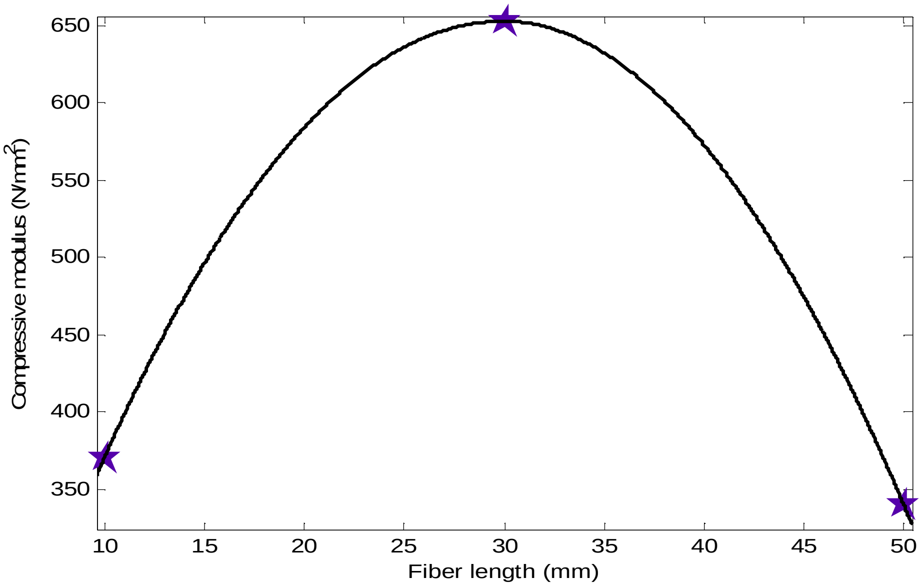

Fig.8. Compressive modulus of FIHPs (V_f = 30%). The number of samples in each sample group was 3.

A. DERIVATION OF MODEL FOR COMPRESSION BEARING CAPACITY OF BIOMIMETIC NATURAL WIRE WEED FIBER REINFORCED POLYMER COMPOSITE HONEYCOMB PLATES

According to the analysis presented in the previous two sections, the bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates in this research exhibited obvious features of compression failure in compression tests conducted. To reduce the number of experiments required for applying this material in engineering practice and for improved, prompt, and accurate theoretical prediction of its strength properties, an equation for the compression bearing capacity is derived in this section. By comparing the theoretical predictions and experimental values, a simple formula was obtained, which provides a foundation for the prediction of compression and design of bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates for future engineering applications.

The end face of the bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates bore a uniform load, while its side was free and without restriction. As shown in Figures 1b, the ultimate elastic strains at the ultimate strength of the bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates with 10-mm, 30-mm, and 50-mm-long fibers were 2.03%, 1.63%, and 1.78%, respectively. Thus, in this research, only the parameters for the linear-elastic phase of the constitutive relationships of the material were adopted during the process of derivation.

Incomplete centering of the sample during the process of compression inevitably led to initial off-centering. Thus, there was additional eccentricity in the axial pressure during the process of compression, resulting in additional bending effects. According to the ''Code for design of concrete structures'' (2015 edition) ( ), 1/30th of the thickness of the bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plate was used as the value of additional eccentricity (ea). The effects of both compression and bending were considered in the following derivation of the compression bearing capacity of bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates.

The sample with a fiber length of 30mm ($V_f = 30\,\%$) was selected as an examplefor the derivation; the elastic modulus of WWFRP, E, was 652.7 N/mm^2, and its compressive strength, σ, was 10.8553 N/mm^2. The maximum load that the bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates could bear, F_{max}, was 66 kN, and the corresponding displacement, v, was 2:12 mm. When failure occurs, the axial pressure of bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates N can be calculated as follows:

$$N = \sigma A = \varepsilon E A = \varepsilon E(A_{s1} + A_{s2} + A_c) \qquad (3.1)$$

$$= \frac{1.6250mm}{100mm} * 652.7\ {}^{N}/_{mm^2} * (1{,}900 * 320 * 60.8)mm^2 = 24.3\ kN$$

where N is the axial pressure of bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates (kN); σ is the average compressive stressof the cross section (N/mm^2); A is the cross-sectional area (mm^2); ε is the average compressive strain; other variables are the same as the above. The additional bending moment M resulting from N can be calculated by

$$M = Ne_a \qquad (3.2)$$

$$= 24.3kN * 3.2mm * (1/30) = 2.6\ kNmm$$

The maximum compression stress resulting from N can be calculated by

$$\sigma_{COm} = E\varepsilon \qquad (3.3)$$

$$= 652{,}7\ {}^{N}/_{mm^2} * \frac{1.6250mm}{100mm} = 7.5876\ {}^{N}/_{mm^2}$$

The maximum compression stress resulting from M can be calculated by

$$\sigma_{bm1} = \frac{M}{H\,A_{s1}} \qquad (3.4)$$

$$= \frac{2.6kNmm}{3.2mm * 1{,}900mm^2} = 0.4276\ {}^{N}/_{mm^2}$$

The maximum tensile stress resulting from M can be calculated by

$$\sigma_{bm2} = \frac{M}{H\,A_{s2}} \qquad (3.5)$$

$$= \frac{2.6kNmm}{3.2mm * 320mm^2} = 2.5391\ {}^{N}/_{mm^2}$$

where $\sigma_{bm1(2)}$ is the maximum compression or tensile stress resulting from M (N/mm^2); H is the thickness of bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates (mm); other variables are the same as the above.

Based on the stress yield criterion, the total stress can be calculated from a superposition of the compression stress (σ_{com}) and the bending stress (σ_{bm}).
For plate A,

$$\sigma_A = \sigma_{com} + \sigma_{bm1} \qquad (3.6)$$

$$= 7.5876\ {}^{N}/_{mm^2} + 0.4276\ {}^{N}/_{mm^2} = 8.0152\ {}^{N}/_{mm^2} < \sigma_A = 10.8553\ {}^{N}/_{mm^2}$$

$$F_A = \sigma_A A_{s1} \qquad (3.7)$$

$$= 8.0152\ {}^{N}/_{mm^2} * 1{,}900mm^2 = 15.228\ kN$$

For plate B,

$$\sigma_B = \sigma_{com} - \sigma_{bm2} \tag{3.8}$$

$$= 7.5876\ {}^{N}/_{mm^2} - 2.5391\ {}^{N}/_{mm^2} = 5.0485\ {}^{N}/_{mm^2}$$

$$F_B = \sigma_B A_{s2} \tag{3.9}$$

$$= 5.0485\ {}^{N}/_{mm^2} * 320mm^2 = 1.619\ kN$$

For the core layer,

$$\sigma_C = E\varepsilon \tag{3.10}$$

$$= 652.7\ {}^{N}/_{mm^2} * \frac{1.6250mm}{100mm} = 10.6064\ {}^{N}/_{mm^2}$$

$$F_C = \sigma_C A_C \tag{3.11}$$

$$= 10.6064\ {}^{N}/_{mm^2} * 60.8\ mm^2 = 0.645\ kN$$

$$F = F_A + F_B + F_C \tag{3.12}$$

$$= 15.228\ kN + 1.619\ kN + 0.645\ kN = 17.492\ kN$$

$$\left|\frac{F_{max} - F}{F_{max}}\right| \tag{3.13}$$

$$= \left|\frac{66\ \text{kN} - 17.492\ kN}{66\ \text{kN}}\right| * 100\% = 73.5\ \%$$

In fact, for plate A, the following can be obtained on the basis of the above analysis:
Because

$$\sigma_A = \sigma_{com} + \sigma_{bm1} \tag{3.14}$$

$$= 7.5876\ {}^{N}/_{mm^2} + 0.4276\ {}^{N}/_{mm^2} = 8.0152\ {}^{N}/_{mm^2} < \sigma_A = 10.8553\ {}^{N}/_{mm^2}$$

Therefore, even when plate A failed, the material was still in the elastic range. Thus, a simple formula can be used to calculate the bearing capacity of the bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates, as follows:

$$F = \sigma A = \varepsilon E A \tag{3.15}$$

Similarly, the theoretical values of the compression bearing capacity of the bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates with fiber lengths of 10 mm and 50 mm were 19.749 kN and 13.858 kN, respectively, and the corresponding measured values were 53.000 kN and 37.000 kN, respectively. The deviations between the theoretically predicted and the measured values were 62.7 % and 62.6 %, respectively, which clearly demonstrates that the theoretical predictions agree well with the measured values. The results also prove that it is feasible to calculate the compression bearing capacity from this simple formula, allowing one to meet the requirements of engineering design, which has only been verified with internal experiments. Although we did not verify whether or not this is valid for other experiments using other natural fibres, we speculate that it is suitable for other natural fibres.

IV. CONCLUSION

In this research, the compression strength analysis of bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates manufactured from natural wire weed fiber were studied. The specific conclusions are as follows:

1. The basic material properties of bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates consisting of fibers with lengths of 10 mm, 30 mm, and 50 mm were proposed, including the compressive strength and MOE. This material exhibited good plasticity while bearing compression. Due to these properties, bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates have ideal utility for preserving the strength stability of structures and products.

2. The bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates did not exhibit buckling failure and accordingly possess the good integrity. Additionally, the bio-mimetic natural wire weed

fiber reinforced polymer composite honeycomb plates with 50-mm-long fibers had good plastic deformation ability. Thus, the use of reinforced epoxy with 50-mm-long wire weed fibers is recommended for the fabrication of biomimetic natural wire weed fiber reinforced polymer composite honeycomb plates. This result is of significance for disaster prevention and safety in quakeproof applications.

3. The failure features, strength property parameters, and simple calculation formula for compression of bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates obtained in this research provide a foundation for the prediction of compression and the design of bio-mimetic natural wire weed fiber reinforced polymer composite honeycomb plates in future engineering applications.

DECLARATION OF CONFLICTING INTERESTS

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