Mechanical Behaviour of Ferrocement Lightweight Banana Fibre Concrete under Uniaxial Bending

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Mechanical Behaviour of Ferrocement Lightweight Banana Fibre Concrete under Uniaxial Bending

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ABSTRACT: To obtain lightweight and environmentally friendly building materials that can be produced quickly at low cost, among others, can be obtained through the use of natural fiber based ferrocement concrete technology. The use of light weight building materials combined with natural fibers to form structural components is intended to reduce the weight of the building mass but also to protect the environment and benefit banana farmers' income. Ferrocement lightweight concrete (FLWC) can be obtained by partially substituting fine aggregate with pumice sand and by adding banana stem fiber to form a ferrocement lightweight fiber concrete (FLWFC) composition. Compressive and tensile tests on ferrocement lightweight concrete and ferrocement light fiber concrete were carried out at 7, 14, 21 and 28 days, respectively. The test results showed that the optimal composition of FLWC and FLWFC occurred in the substitution of pumice sand by 40% and banana stem fibers with a length of 3 cm by 0.05% of the weight of cement and obtained a concrete mass density of 1437 kg. The compressive strength and tensile strength of FLWC without fiber at 28 days were 8.4 MPa and 2.15 MPa respectively, while FLWC with fiber added increased by about 6%, namely 8.9 MPa for compressive strength and 83% for tensile strength is 3.94 MPa. Flexural tensile strength of Sandwich Wall Panels (SWP) at 28 days of prism-shaped specimens with dimensions of 60 x 30 x 5 cm, 45 x 15 x 4 cm and 30 x 10 x 3 cm respectively 1.60 MPa, 1.86 MPa and 2.4 MPa for FLWC without banana stem fiber. The increase in the flexural tensile strength of the SWP was 40.63% (2.25 MPa), 21.51% (2.26 MPa) and 18.75% (2.85 MPa) respectively in the SWP-FLWC using Banana Fibers (BF) or an average of 26% increase. The size effect of the SWP test object looks significant, that is, there is a tendency that the larger the dimensions of the test object, the smaller the flexural tensile strength value, but on the contrary, the role of banana stem fiber in contributing to the increase in flexural tensile strength is seen to be more significant.

KEYWORDS: Mechanical Behavior, Banana Fiber, Ferrocement Lightweight Concrete, Tensile Strength

1. INTRODUCTION

1.1 Background

Damage to buildings caused by the earthquake or tsunami generally requires relatively large repair or rehabilitation costs. To overcome this relatively large cost, one can do it through the use of natural fiber-based ferrocement concrete technology.

According to ACI Committee 549:

"*Ferrocement is a type of thin wall reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small size wire mesh. The mesh may be made of metallic or other suitable materials."* (ACI Code, 1997)[1].

Various efforts have been and are being made to develop various environmentally friendly technologies through the exploration of new materials with various variations, innovation and creativity as well as certain types of design concepts while still paying attention to aspects of engineering, economy, environment and availability of raw materials. The development of material engineering technology has led to the use of natural fiber materials as an environmentally friendly sustainable material technology application which so far has not been utilized optimally, efficiently and economically as secondary reinforcement in concrete materials[2]. Alignment with environmental issues and the development of environmentally friendly materials is a challenge to produce alternative materials that can simultaneously reduce the amount of CO_2 gas emissions and other toxic gases released into the surrounding natural environment.

Concrete is a construction material that has the advantage of receiving compressive loads but is weak against tensile loads. The tensile strength of the concrete material is about one-tenth of its compressive strength so that the fracture mechanisms of the concrete material generally originate from tensile cracks. This condition makes the concrete building structure system require regular assessment of the health status of the concrete structure itself and thus the concrete material is no longer included in the category of maintenance free materials[3][4][5][6]. In connection with the planning of reinforced concrete structural systems, generally the concrete material is not taken into account to carry the tensile load. The tensile load is always transferred to the reinforcement system through the contact surface of the concrete material and the reinforcement material[2][7]. However, cracks are often found in concrete mainly caused by changes in temperature, humidity and tensile loading. Efforts to increase the tensile strength of concrete include adding fiber to the concrete mix. The type of fiber used can vary in terms of the type of material, length, diameter, fiber shape and amount. The addition of fiber that is optimal and evenly dispersed in the concrete material in addition to increasing the tensile strength of concrete, is also useful in preventing the occurrence of tensile cracking and will substantially improve its static and dynamic properties[8]. Historically, the use of fiber in concrete mixes began with the use of horsehair in mortar and mud brick mixtures. In the 1900s asbestos fibers began to be used as a material for forming fiber concrete, followed in the 1960s through the use of steel fibers, glass fibers, synthetic fibers and other natural fibers in the composition of the concrete mix[9].

Utilization of natural fiber, especially banana stem fiber as a component in producing fiber concrete material is expected to reduce environmental pollution from banana stems which are often left lying around to rot by banana farmers and provide added value to increase income and quality of life of farmers. The natural fiber used in this study was produced from the trunk of the banana tree (Musa paradisiaca Var. Forma Typica) which grows fast and is easy to obtain in the tropics, so it is hoped that the need for this fiber can be easily met. As a raw material for industry, natural fiber from banana stems has been used to replace synthetic fibers in the automotive industry and the concrete industry because it has economic and ecological advantages.

In earthquake-prone areas, the use of building materials to form a structural system is more directed to the selection of building materials that are light in weight. This is intended in addition to reducing the mass weight of the building and the seismic forces acting on the building's structural system, as well as making construction costs more economical and efficient. This condition has motivated to study the behavior of FLWC with natural fibers of banana shoe stems.

1.2 Formulation of the Problem

Efforts to increase the tensile strength of concrete include adding fiber to the composition of the concrete mixture. The type of fiber used is banana tree trunk fiber. Several considerations in determining the type of natural fiber to be studied were mainly based on the availability of the banana tree, easy to find in the tropics, has fast growth, and the banana tree only bears fruit once and then it is cut down. In addition, the use of banana stem fiber besides helping to reduce environmental pollution due to rotting banana tree trunks which are generally left scattered after being cut down in the surrounding environment, can also improve the standard and quality of life for banana farmers through increased income which at the same time has a positive impact on conservation. environment. However, the challenge of using banana stem fiber is related to quality standards and manufacturing techniques to ensure continuity of supply of banana stem fiber in the market. Requirements in the field of civil engineering, especially regarding processing, decomposition behavior and mechanical behavior of composite materials which can be known through comparisons between the results of testing concrete specimens with and without fiber. Optimum conditions for fiber content in the composition of the concrete mix are mainly influenced by the type, dimensions and variations in fiber length. The study on the utilization of banana shoe fiber stems as one of the basic ingredients in the manufacture of natural fiber-based ferrocement lightweight concrete is directed at producing thin ferrocement sandwich wall panel prototypes which, apart from being more economical, also function to improve the mechanical characteristics of lightweight concrete materials and can prevent cracking of structural components at lower levels. specific loading and reduce structural failure due to corrosion of reinforcing steel. The amount of economic added value that can be obtained is very dependent on the magnitude of the influence of banana shoe fiber on the improvement of the behavior of the mechanical characteristics of ferrocement lightweight concrete materials. This condition is also illustrated by the high added value of the utilization of natural fiber from the stem of the banana shoe (Musa paradisiaca Var. Forma Typica) in the manufacture of thin panel partition walls using Ferro Split-Bamboo Mesh[10].

1.3 Problem Statement

This study was focused on the utilization of natural banana stem fiber with a length of 3 cm and a concentration of 0.05% by weight of the cement content.

1. Basic Concrete Material Compositions: (a). cement: Portland cement type I (brand Tonasa). (b). Fine Aggregate: The natural sand comes from the village of Girian. (c) Water: From the drilling wells of the Faculty of Engineering Sam Ratulangi University (UNSRAT). (d). Additives: Banana stem fiber (*Musa paradisiaca Var Forma Typical*) derived from old or fruiting banana stems (age approximately 10-12 months), dried in sunlight where the fiber characteristics are golden brown, and clean with variations of percentage and length. (e). Slump value (set): 80 - 100 mm.
2. Mechanical properties of concrete tested: (a). Compressive strength. (b). Split tensile strength and (c). Flexural strength.
3. Concrete Age Tested: 7, 14, 21 and 28 days.
4. Concrete test specimens. (a). Cylinder size 10/20 cm. (b). Cube size 15 x 15 x 15 cm. (c). Sandwich Wall Panel sizes: 60 X 30 X 5 cm, 45 X 15 X 4 cm and 30 X 10 X 3 cm

1.4 Scope and Goals of the Research

The aim of this research is to get the relationship and description of the basic mechanical properties of banana stem fiber concrete and its application as follows:

1. Compressive strength, tensile strength, and flexural tensile strength
2. To determine the relationship between uniaxial flexural tensile strength of SWP-FLWC and banana stem fiber.

1.5 Research Significance

This experiment is to try to understand the basic behavior of SWP-FLWC_BF due to uniaxial loading and to find out the benefits that banana stem fiber can provide to changes in the basic behavior of FLWC.

1.6 Definitions

Concrete is a composite material formed by the hardening of a mixture of cement, water, fine aggregate, coarse aggregate, and sometimes other admixture materials[11][12]. Fiber Reinforced Concrete (FRC) could be defined as A composite materials made of portland cement, aggregates and incorporating discrete discontinuous fibers[9][13][14][15] [16]. According to ACI Committee, fiber concrete is a concrete compose with cement, fine aggregate, coarse aggregate and a small amount of fiber. FRC is essentially a material made by adding pieces of fiber into a certain amount of concrete mixture[9][14][15] [16]. In principle, the basic materials of concrete forming can essentially be grouped as active ingredients consisting of cement and water which will serve as adhesives / binders, and a group of passive materials ie fine aggregates and coarse aggregates with function as fillers. The strength of concrete are depends on many factors, including the proportion of the mixture with the quality of the stacking material, the method of casting, the temperature and humidity in place where the mixture is placed and hardened[14][11]. Research activities in many countries such as Europe, which utilize natural fiber based composite, have utilized natural plant fibers to produce traditional building materials. The weak tensile strength response by the concrete could be overcome with fiber applications. Fibers with different dimensions and geometries can act as a mechanism that bridges resistance to cracks with different crack widths. The efficiency to hold the crack is dependent on the interface properties of thefiber surface. Fiber composites have greater tensilestrength, both in first crack and in ultimate crack of concrete structures subjected to flexible loading[9][14][15] [16]. Why do we want to add fiber to the concrete?. Plain concrete is a brittle material, with low tensile strength and low strain capacity. The role of randomly distributed fibers is to retain (to bridge across) the developed crack so as to provide post cracking ductility[11][13][16][17][18]. The addition of fiber can reduce the plastic shrinkage cracking because the fibers will stop the crack propagation and increase the tensile strength of the concrete[17][18][19]. Physically, fiber has the same role as aggregateinclusions. However, fiber cannot be considered as a direct replacement of longitudinal reinforcement in reinforced concrete structural elements and prestressed. Characteristics of fiber reinforced system: the fibers are spread over the entire cross section, whereas the reinforcing steel is only placedin the required area. The fiber is short (discrete) andtightly squeezed, while the reinforcing steel is continuous (long). Fiber has a small reinforcement ratio whereas reinforcing steel has a large reinforcement ratio. The advantages of fiber reinforced concrete, some of which are easy to be placed (cast, sprayed, and labor-saving), fiber concrete can be made into thin sheets and certain forms that do not regular and can be used when the placement of reinforcing steel is difficult. The presence of fibers in the concrete material will contribute to increasing the binding strength of the concrete matrix so as to reduce and prevent cracking at certain loading levels while simultaneously making the fiber material more ductile than the non-fiber concrete material. Improvements in the behavior of these concrete materials have motivated the development of diversified types of fibers that can be used as additives to form fiber concrete. These fibers are dispersed randomly and vary fromfiber type, dimensions (length and diameter), shape and concentration, where all of which will have different effects on the behavior of the concrete material. Each type of fiber has different characteristics and effects on concrete behavior.The main purpose of adding fiber in a mixture of concrete is to improve the mechanical characteristics of concrete materials that behave brittle and weak to tensile[14][19].

1.7 Banana Stem Fiber

Banana tree (*Musaceae*) is a herbaceous fruit plant that originated from Southeast Asia (including Indonesia). Indonesia's banana production occupiesthe third place after India and China with a magnitude of 8 million metric tonnes or 9% of world production[20] states that the ratio of fresh weight between stems, leaves, and bananas are 63%, 14%, and 23%, respectively (Fig.1)[21][22].

Fig.1. Banana Tree

Mechanical properties of Banana Fiber (BF) are asfollows (Table 1).

Table 1. Mechanical properties of the BF[2][22][23].

Specific gravity	:	0,29 g/cm^3
Density	:	1,35 g/cm^3
Cellulose content	:	63-64 %
Hemicellulose content	:	20%
Lignin content	:	5-31,5 %
Average tensile strength	:	600 MPa
Average tensile modulus	:	17,85 GPa
Length increment	:	3,36 %
Diameter of banana stem fiber	:	5,8 μm

Basically, all types of fibers could be used as additives that can strengthen or improve the properties of concrete. Its usage much depended on the intent of adding fiber to the concrete of either natural or artificial materials, but the thing to note is that the fiber must have a tensile strength greaterthan the tensile strength of the concrete.

2. EXPERIMENTAL PROCEDURE

2.1 Four-point bend test (ASTM C-78)

An extensive test used to determine the bendingstrength is the four-point bend test, as shown in Fig.2.

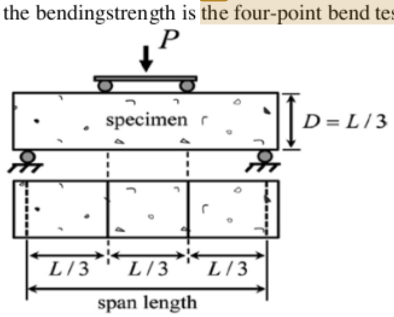

Fig.2. Flexural Bending Test (Four-point bend testASTM C-78)[24]

Because of the symmetry, the bending moment is constant between the two loading points placed at the top of the specimen[24]. Therefore, the flexural tensile stress is uniform throughout the thickness. The bottom surface of the specimen between the two points of loading experiences a constant uniaxial stress field. The nominal flexural strengthaccording to beam theory is $\sigma N = ft$.

$$f_t = \frac{P_{max} L}{w D^2} \quad \text{.............. (1)}$$

where:

f_t	=	Nominal flexural strength
P_{max}	=	Maximum load
L	=	Span length of beam
w	=	thickness of the beam
D	=	depth of beam

This equation is based on the theory of elasticity.

2.2 Splitting Tensile Strength of CylindricalConcrete Specimens (ASTM C 496/C 496-04)

This test method consists of applying a diametrical compressive force along the length of acylindrical concrete specimen (Fig.3). This loadinginduced tensile stresses on the plane containing theapplied load and have relatively high compressive stress in the area immediately around the applied load.

$$T = \frac{2P}{\pi l d} \quad \text{.............. (2)}$$

where:

T = splitting tensile strength, psi [MPa]

P = maximum applied load indicated by the testing machine, lbf [N]

l = length, in[mm]

d = diameter, in [mm]

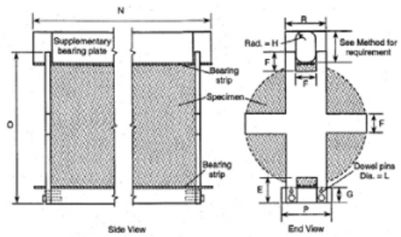

Fig.3. Splitting Tensile Strength of Concrete (ASTM C 496/C 496-04)[25]

3. MATERIALS USED

All materials (cement, fine aggregate, water, and fiber) required are prepared and placed in a good place that is not physically andchemically disturbed. Materials must be clean of dirtor organic substances. The process of separation of banana stem fiber begins by cutting banana stems approximately 25 to 30 cm and then be boiled for approximately 4 to 5 hours. Once boiled, then soaked for several days until the fiber can be easily separated. During the immersion process, wateris replaced at least every other day. Next, separate the fibers from the banana stem sheath. Then the fiber is soaked in 5% NaOH solution. The fiber is then washed using aquadest to neutralize. After that,the fiber being dry with directly exposed to sunlightuntil the weight remains where the color of the fiber is golden brown. Furthermore, the dried fiber is cleansed of all the dirt. Then, be cut into pieces withlength: 3 cm. Finally, the fiber weighs in accordance with the concentration or percentage set against the weight of the cement.

3.1 Material Inspection

In order to obtain good quality concrete, it is necessary to know some aggregate properties such as granular arrangement, mud content, adverse substance content, absorption, the weight of content,and specific gravity. These properties of the material are required to determine the water, cementand aggregate requirements used in the composition of the concrete mixture. For this purpose were examined the physical properties of aggregate or aggregate mechanical properties in the Laboratory of Materials and Construction Faculty of Engineering UNSRAT as the initial step of making the specimen according to ASTM Standards.

3.2 Aggregate

Fine aggregat originating from the village of Girian already located in the testing laboratory can be seen in the Fig.6.

Fig.6. Fine aggregate from Girian

3.3 Banana Stem Fiber

Results of the banana stem fiber processing process(*Musa Paradisiaca Var Forma Typical*) could be seen in the following Fig.7.

	
Banana Stem	Banana Trunk

Fig.7. The process of making banana stem fiber.

4. RESULTS AND DISCUSSION

4.1 Compressive Strength Results

Based on the results of the compressive strength test of FLWC with and or without using banana stem fiber is presented in Fig.8. Fig.8 shows the average compressive strength growth of FLWC with or without the use of natural banana stem fibers of around 88% at the age of 14 days concrete material (87% without fiber and 89% using fiber) compared to the compressive strength value of 28 days. Utilization of banana fiber by 0.05% of the amount of cement only increases the compressive strength of FLWC material by about 6%.

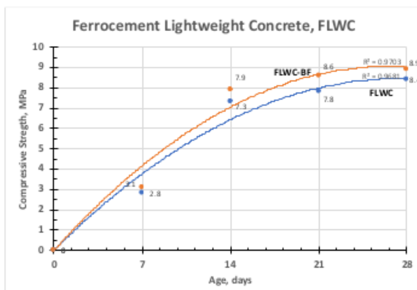

Fig.8. Compressive strength and FLWC age relationship.

4.2 Tensile Strength Results

The results of the tensile strength test of FLWC with and or without using banana fiber are presented in Fig. 9. The growth rate of the tensile strength of FLWC with or without the use of natural banana stem fibers tends to be the same as the growth in compressive strength. At the age of 14 days, the tensile strength of FLWC is around 63% without using natural fibers and 93% when using banana fibers compared to its tensile strength at 28 days. Utilization of banana fiber by 0.05% of the amount of cement in FLWC can actually increase the tensile ability of FLWC at 28 days of age by 83%.

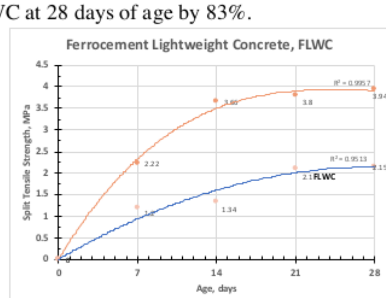

Fig.9. Compressive strength and FLWC age relationship.

4.3 Flexural Test Results

The flexural strength of FLWC was obtained from the Sandwich Wall Panel (SWP) specimen as shown in Fig.10 and Fig.11 which represents the flexural tensile behavior at 7, 14, 21 and 28 days of 3 types of FLWC specimens without fiber and by using Banana Fiber (BF). The flexural strength of FLWC test specimens aged 7, 14 and 21 days compared to 28 days respectively was between 35-40%, 40-56% and 82-96% while for FLWC_BF was at intervals of 34-46%, 50-61% and 59-69%. Based on these results it can be seen that the growth rate of flexural tensile strength for FLWC without using banana fiber is relatively faster compared to FLWC_BF. Besides that, it can also be seen that the magnitude of the flexural tensile strength value will tend to increase in the smaller dimensions of the test object as shown in Fig.10 and Fig.11.

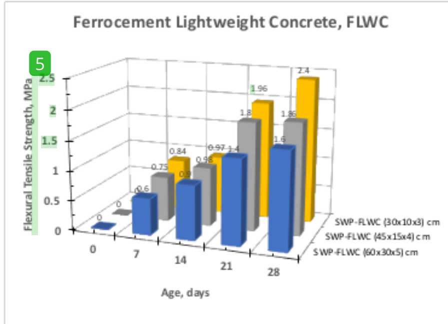

Fig.10. Flexural tensile strength and FLWC age relationship.

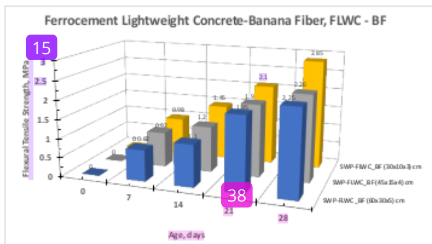

Fig.11. Flexural tensile strength and FLWC_BF age relationship.

Fig.12, Fig.13 and Fig.14 show the benefits of using fiber in FLWC.

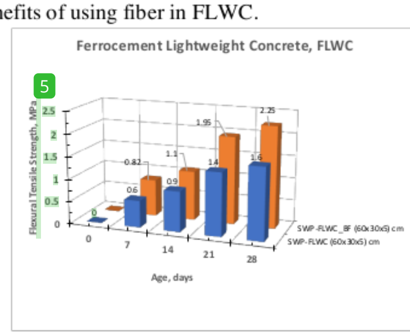

Fig.12. Flexural tensile strength and SWP-FLWC 60x30x5 cm age relationship.

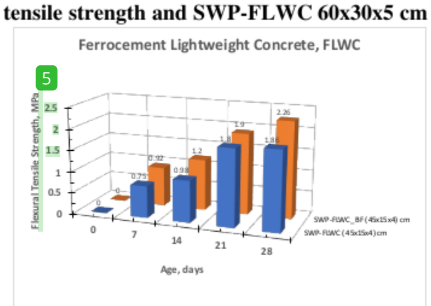

Fig.13. Flexural tensile strength and SWP-FLWC 45x15x4 cm age relationship.

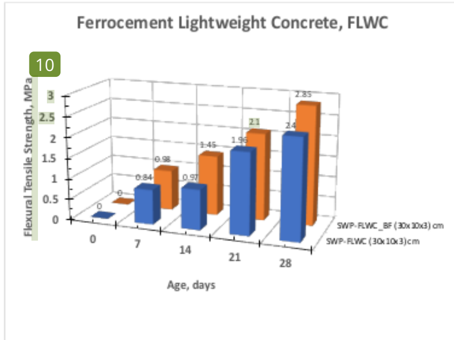

Fig.14. Flexural tensile strength and SWP-FLWC 30x10x3 cm age relationship.

Increases in flexural strength FLWC_BF aged 28 days by 19%, 22% and 40% compared to FLWC respectively were obtained from SWP test specimens 30x10x3 cm, 45x15x4cm and 60 x 30 x 5 cm as shown in Fig.12, Fig.13 and Fig.14. The three figures also show that the magnitude of the increase in the flexural strength value of FLWC_BF at 28 days is positively correlated with the dimensions of the specimen. The average value of FLWC_BF increase at 28 days of age is about 26% (Fig.15).

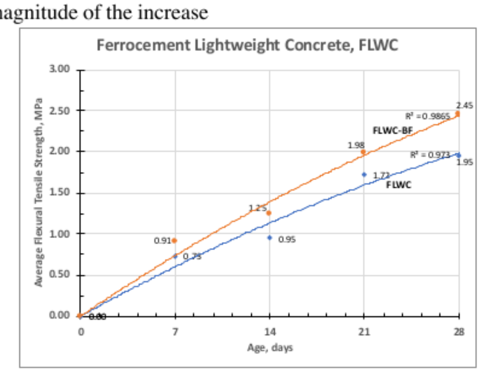

Fig.15. Average flexural tensile strength and SWP-FLWC_BF age relationship.

5. CONCLUSIONS

Based on the results and discussion above, it can be concluded as follows.

1. Utilization of banana stem fiber of 0.05% by weight of cement in the composition of the FLWC mortar did not provide a significant increase in compressive strength, which was only around 6% for the age of the specimens 28 days. On the other hand, there was a significant increase in the tensile strength of FLWC_BF aged 28 days, both obtained through the split tensile test on cylindrical specimens, which was 83%, and the flexural tensile test on 3 types of SWP-FLWC_BF specimens, namely 19%, 22%. and 40% each for SWP test objects 30x10x3 cm, 45x15x4cm and 60 x 30 x 5 cm.
2. The flexural tensile strength values of FLWC and FLWC_BF are negatively correlated with the dimensions of the SWP test object. On the other hand, the percentage increase in flexural tensile strength FLWC_BF correlates positively with the dimensions of the SWP specimen.

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No Conflict of Interest between Corresponding Author and All the Authors.

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