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BASIC BEHAVIOUR OF NATURAL BANANA STEM FIBER REINFORCED CONCRETE UNDER UNIAXIAL AND BIAXIAL TENSILE STRESS

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ABSTRACT: In order to study the basic behavior of natural banana stem fiber reinforced concrete, three type of tensile strength test namely split tensile strength, flexural strength and biaxial fatigue flexure strength were conducted. Comparison of these three type of tensile strength, their crack pattern and the way they fails were be analyzed and discussed. Results showed that the flexural strength value of the two type of biaxial tests are higher than the uniaxial test result(ASTM C-1550 have 47.046 % higher than ASTM C-78 and 37.871 % higher than ASTM C-496). The value of tensile strength as measured by ASTM C-1550-02 is slightly higher than the value of the flexural tensile strength as measured by the biaxial flexure test (21.062%). The lines of the crack pattern do not show clear macro fracture cracks before reaching the peak load. As observed, there are two peak load values found were the one occurred at the first cracked, after that the load stress curve decrease for a while and after a few seconds the load increase again to a value smaller than the first peak load value.This is because at the time of the first cracking in three axes symmetry, the load that can be maintained by the concrete specimen had reached its maximum but after that the load increase again because the stress has been transferred to the fiber, so the stress rises again until the fiber break off. This indicates that the fiber plays an important role in holding and redistributed the tensile load.

Keywords: Basic Behavior, Banana Stem Fiber, Tensile Strength, Biaxial, Uniaxial, Crack Pattern

1. INTRODUCTION

1.1 Background

The structure of concrete slabs such as rigid concrete pavement and slabs will have experienced repeated flexural fatigue load which will cause cracks in concrete components. For design considerations, there are a number of models that have been proposed in predicting the fatigue flexural strength that has been expressed in a number of Standards. Approaches to these models were developed based on experimental data which mostly obtained from the uniaxial compressive load, or uniaxial flexural load. However, the actual structure of the plates mentioned above undergoes a biaxial stresses condition (biaxial stresses). Therefore, it is logical to use the flexural fatigue model derived from the biaxial stress conditions for the design of the flexural strength of the concrete fatigue which undergoing a biaxial stress state in which there are now two testing methods used: The centrally loaded round panel test[1], and biaxial flexure test[2]. Both of these test methods used round panel and produce maximum biaxial flexural tensile stresses on the opposite side of the loaded slab[3]. Today, the development of concrete construction technology has grown very rapidly with various variations, innovations and certain types of design concepts but still pays attention to various aspects in the design, economy, environment, and availability of raw materials. By considering the various developments in the field of material engineering, currently, it is being pursued a number of research and innovation of materials including materials for buildings or structural components. One of the main elements of civil engineering construction work that is often studied is concrete. The use of concrete has been widely performed and continues to progress very rapidly especially after the discovery of Portland cement. In nowadays, material engineering technology has evolved towards the use of natural fiber materials as an environmentally friendly and sustainable material technology application because current concerns about environmental problems have become a reality and the development of environmentally friendly materials has become a challenge.

This condition has motivated the efforts of researchers to develop alternative materials that can reduce the amount of CO_2 and other toxic gases released into our environment, which in this case relate to the protection of human health and energy conservation. The manufacture of natural fiber-based concrete as a mixture (admixture) could also solve one of the environmental problems caused by the waste of natural materials utilization. Through the utilization of natural fibers, then from the concrete financing side will become more economical compared to without using natural fibers. On the other side, concrete engineering for structural concrete applications must still comply with the applicable standards.

Our country has a huge natural potential such as a very fertile and abundant plant which is a source of natural fiber that is very large and varied such as ijuk, jute, pineapple, banana, sago, rubber, palm oil, and others that could be innovated as natural fiber ingredients for the concrete material which will functions as secondary reinforcement, where it has not yet be utilized efficiently and meet the optimal economy. As a structural material, the concrete has an advantage in accepting the press load but is weak to the tensile load. The magnitude value of concrete tensile strength is generally around 1/10 - 1/20 of its compressive strength value.In concrete building design, generally, it only is taken into account the compressive strength of concrete, while the tensile strength is less taken into account. However, in reality, it is often found that cracks in concrete are caused because concrete could not withstand tensile forces beyond a certain value due to changes in temperature, moisture content, and loading. So in an effort to improve the quality of concrete, especially in terms of tensile strength, there have been many ways taken and among them is the addition of fiber in the concrete mixture. Through various research that has been done, the type of fiber that can be used as additives (admixture) on the mortar is plastic fiber, steel, carbon, glass and fiber from natural organic materials such as ijuk, jute, pineapple, banana, sago, and others. The fiber used may vary from material type, length, diameter, or fiber form, which may affect the change of concrete properties of both chemical properties and mechanical properties of concrete. Low fiber percentages are consistent with conventional mixing techniques, while higher percentages often require specialized placement techniques. As a raw material for the industry, natural fibers such as banana fiber, pineapple and others could replace synthetic fibers in composites such as for the automotive and concrete industries because they have many economic and ecological advantages. For example, the Daimler-Chrysler company as one of the pioneers in automotive development has implemented more than 30 components in their vehicles using banana fiber[4]. Constraints encountered in the use of these fibers may be related to fiber quality standards, as well as continuous supply in large quantities. In the field of civil engineering, the important things which need to know about fiber strength are its processing, decomposition behavior and mechanical properties related to composite. In mechanical testing, fibers could be mixed in a concrete mixture with varying concentrations and lengths. Characteristics of these fibers are then compared with concrete without fiber. Through this comparison, we could know the mechanical properties of the fibers (tensile properties, flexural tensile properties, compressive properties and biaxial bending properties)[5-8].

In this research, it was use fiber from the banana stem (*Musa paradisiaca Var.Forma Typical*) because this plant is easy to get in our environment (tropical area) and its fast growth so hopefully in its development later, the requirement of this type of fiber could be easily fulfilled. In addition, the utilization of stems from this banana plant will be able to provide economic value to the community[5-10].

1.2 Formulation of the problem

The tensile strength of the concrete is very low compared to the compressive strength. This phenomenon has prompted researchers to try to improve the mechanical characteristics or mechanical properties where one of them, that is, by adding a fiber material to a certain percentage and dimension into a mixture of concrete which then became known as fiber concrete.This research is aimed at the utilization of natural fiber considering that there are so many types of plants in Indonesia that could produce fiber but only be disposed of as garbage so that it pollutes the surrounding environment. On the other hand, through the utilization of natural fibers, it is expected to reduce the cost of construction and would increase the income as well as improve the living standards of farmers[5-7]. The natural fibers selected for fiber-forming materials in this study are banana stem fiber (*Musa paradisiacaVar Forma Typica*) which are often discarded after being cut and fruited. The presence of fibers in the concrete material, among others, serves to improve the mechanical characteristics of the concrete material, to prevent cracking of structural components to certain loading levels and to reduce structural failure due to corrosion of reinforcing steel[5-10]. How much is the economic value that could be obtained would much depend on the magnitude of the improvement of the mechanical characteristics of the banana stem fiber concrete material that will be seen through the results of this study? The concept of improving the quality of concrete by adding the fiber to the concrete mixture needs to be deepened, considering that the need for concrete construction that has enough strength to withstand tensile forces. It is, therefore, necessary to know the extent of the effect of adding this fiber (concentration of fiber) to the mechanical properties of the concrete.

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 0.5% of fiber and 1% in normal weighted concrete.

Design compressive strength: 26.75 MPa. Basic Concrete Material Compositions: (a). cement: Portland cement type I cement (brand Tonasa). (b). Fine Aggregate: The natural sand comes from the village of Girian.(c). Coarse Aggregate: Crushed stone (Ø 5 - 19 mm) from the village of Tateli. (d) Water: From the drilling wells of the Faculty of Engineering UNSRAT. (e). 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. (f). Slump value (set): 80- 90 mm.
2. Mechanical properties of concrete tested: (a). Compressive strength. (b). Split tensile strength and (c). Flexural strength. Biaxial flexure Strength.
3. Concrete Age Tested: 7, 14, 28 days (Compressive strength, Split tensile strength) while biaxial slab/panel flexure strength / flexural strength were be tested at 28 days and 56 days.
4. Concrete Test specimen. (a). Cylinder size 10/20 cm. (b). Beam size 10 x 10 x 50 cm. (c). Round panel/slab: 4.8 cm in thickness; 42 cm in Diameter; and 21 cm in radius.

1.4 Scope and Goals of the Research

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

1. Compressive strength, tensile strength, and flexural tensile strength.
2. To draw the graph of the uniaxial and biaxial flexural tensile strength relationships in natural fiber concrete slabs.

1.5 Research Significance

This experiment is to try to explain the basic post-crack behavior of plate-like FRC structural member which was be represented by a centrally loaded round panel. By this basic behavior, we could make a correlation between a mode of failure and the *in situ* behavior of structural element considered. Also, we could know the ability of FRC to redistribute the stresses which arise following cracking. Also, it would be possible to compare the type of flexural strength in biaxial and uniaxial mode.

1.6 Definitions

Concrete is a composite material formed by the hardening of a mixture of cement, water, fine aggregate, coarse aggregate (gravel or crushed stone), 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 [4-8].

According to ACI Committee, fiber concrete is a concrete compose with cement, fine aggregate, coarse aggregate and a small amount of fiber. Fiber reinforced concrete is essentially a material made by adding pieces of fiber into a certain amount of concrete mixture[5-8]. 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[5,11]. 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 the fiber surface. Fiber composites have greater tensile strength, both in first crack and in ultimate crack of concrete structures subjected to flexible loading[5-8]. 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[4,8,11,13,14]. 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[13-15]. Physically, fiber has the same role as aggregate inclusions. 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 placed in the required area. The fiber is short (discrete) and tightly 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 from fiber 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 [5,15].

1.7 Banana Stem Fiber

Banana tree (*Musaceae*) is a herbaceous fruit plant that originated from Southeast Asia (including Indonesia). Indonesia's banana production occupies the fifth place after India, Ecuador, Brazil, China and the Philippines with a magnitude of 3.6 million tons or 5% of world production. Rahman, (2006)[16] states that the ratio of fresh weight between stems, leaves, and bananas are 63%, 14%, and 23%, respectively. Banana stem has a specific gravity of 0.29 g / cm3 with a length of fiber of 4.20-5.46 mm and 33.51% lignin content[16][17]. Mechanical properties of banana fiber are as follows (Table 1).

Table 1: Mechanical properties of the banana fiber.

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

Source: [9][10][17]

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 greater than 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 bending strength is the four-point bend test, as shown in Fig.1.

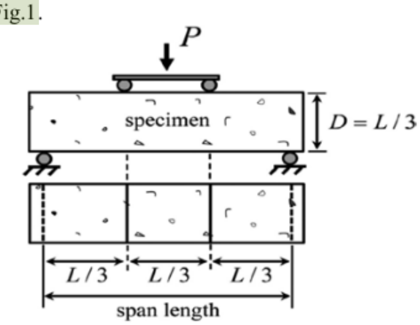


Fig.1. Flexural Bending Test (Four-point bend test ASTM C-78)[1]

Because of the symmetry, the bending moment is constant between the two loading points placed at the top of the specimen[1]. 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 strength according to beam theory is $\sigma N = ft$.

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

where:

ft = Nominal flexural strength
P_{max} = Maximum load
L = Length of beam
w = thickness of the beam
D = depth of beam

This equation is based on the theory of elasticity.

2.1 Splitting Tensile Strength of Cylindrical Concrete Specimens (ASTM C 496/C 496-04)

This test method consists of applying a diametrical compressive force along the length of a cylindrical concrete specimen (Fig.2). This loading induced tensile stresses on the plane containing the applied load and have relatively high compressive stress in the area immediately around the applied load.

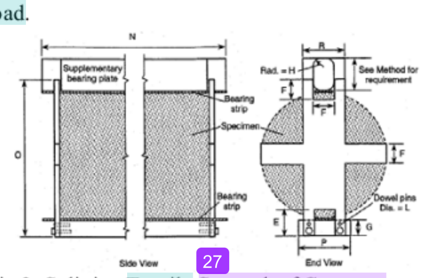


Fig.2. Splitting Tensile Strength of Concrete (ASTM C 496/C 496-04)[3]

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

where:
T = splitting tensile strength, psi [MPa]
P = maximum applied load indicated by the testing machine, lbf [N]
l = length, in [mm], and
d = diameter, in [mm]

2.3 The Biaxial Flexural Test with Centrally loaded circular plate test (ASTM C1550)

The test setup according to ASTM C1550 is shown in Fig.3.

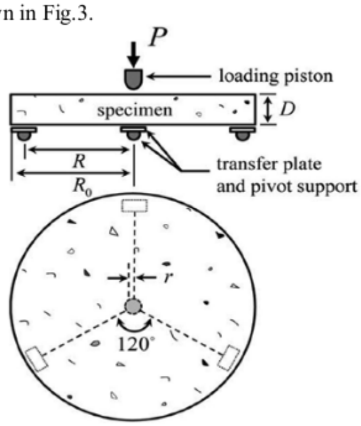


Fig.3. Test setup of biaxial flexural test with centrally loaded circular plate test[2]

A round plate with three plates of round pivot is used for this test. This round plate was given loading at its center, where the maximum stress that occurs is a biaxial stress. The stress distribution is triply axisymmetric (symmetrical on three axes). This method is very similar to the piston-on-three-balls test method used for testing on ceramics. Therefore, the biaxial strength can be obtained by the following formula:

$$f_t = \frac{3P(1+\upsilon)}{4\pi D^2}\left\{1+2\ln\left(\frac{R}{r_e}\right)+\frac{1-\upsilon}{1+\upsilon}\left[\frac{2R^2-r_o^2}{2R_o^2}\right]\right\} \quad (3)$$

$$r_e = \sqrt{1.6r^2 + D^2} - 0.675D \quad (4)$$

where:
R = the distance from center to the support
Re = the equivalent radius
r = the radius of the loaded area.
D = the thickness of round plate
υ = the Poisson's ratio of the material.

Since the test method was initially developed to measure the fracture toughness after the peak load, the stress evaluation for the above equation is not stated in ASTM C 1550. Equation (5) below applies to r < 0.5D.
The main advantage of the ASTM C1550 method is that it is a simple method and provides high-precision post-crack performance evaluation results. Because this method gives good tolerance to the unevenness of the test plate, the preparation of the specimen is not difficult. Also because the stress distribution is triply axisymmetric, the crack will form in the area between the platen and the center of the plate causing the plate to split into three parts.

2.4 The Fatigue Biaxial Flexure Test (ASTM C1550-08)

Recently a method of testing a biaxial flexure test is proposed to measure the biaxial flexure strength of the concrete as shown in Fig.4.

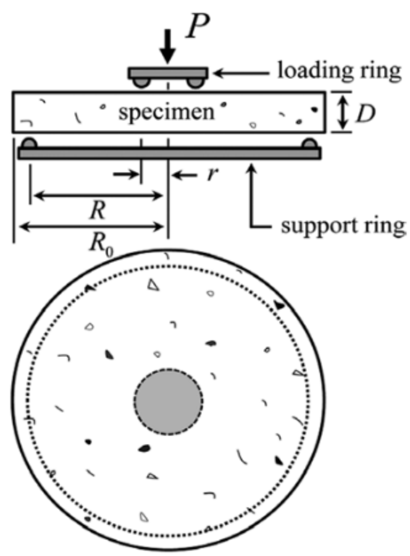


Fig.4. Biaxial flexure test Setup (ASTM C1550-08)[2]

Same as in ASTM C1550 method, this test using a round plate specimen. Loads are applied through plates equipped with steel rings. The stress field is axisymmetric. The mechanical analysis shows that in the region surrounded by the loading ring, the stress state caused by the load is evenly distributed on each horizontal plane. That is why it is easy to review the statistical randomness against the local strength of materials. The biaxial bending strength can be estimated by the following formula:

$$f_t = \frac{3P}{4\pi D^2}\left[2(1+\upsilon).\ln\frac{R}{r} + \frac{(R^2 - r^2)}{R_O^2}\right] \quad (5)$$

where: R_o= plate radius, R = supporting radius, r = loading ring radius.

3. MATERIALS USED

All materials (cement, coarse aggregate, fine aggregate, water, and fiber) required are prepared and placed in a good place that is not physically and chemically disturbed.Materials must be clean of dirt or 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, the water is 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 sunlight until 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 with length: 3 cm. Finally, the fiber weighs in accordance with the concentration or percentage of 0,5% and 1,0 % set against the weight of the aggregate.

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, cement and 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.

4. RESULTS AND DISCUSSION

Sand material originating from the village of Girian, crushed stone material from the village of Tateli already located in the testing laboratory. Material derived from the mountain and banana trunk can be seen in the Fig.5.

(a) (b)

Fig.5. Aggregate. (a). Coarse Aggregate from Tateli, and, (b). Fine Aggregate from Girian

Results of the banana stem fiber processing process (*Musa Paradisiaca Var Forma Typical*) could be seen in the following Fig.6.

(a) and (b) Banana Trunk,
(c) After Boiled, (d) Being Dry in Sun Exposed,
(e) Before being cutted, and (f) After be cutted.

Fig.6. The process of making banana stem fiber.

4.1 Compressive Strength Results

Results of the compressive strength test indicate that the local material from Girian Village and Tateli Village could be used to obtain the specified strength quality of concrete as it wants to be achieved in this research (Table 2).

Table 2. The concrete compressive strength results on 15x15x15cm cube specimen

f'c Design [MPa]	No. specimen code	Weight [kg]	Test Results P [KN]	Test Results f'c [MPa]	Average f'c [MPa]
25	Cube 1	7.81	597	26.55	**26.42**
	Cube 2	7.73	594	26.41	
	Cube 3	7.66	586	26.05	
	Cube 4	7.58	588	26.15	
	Cube 5	7.61	599	26.64	
	Cube 6	7.58	597	26.55	
	Cube 7	7.55	603	26.8	
	Cube 8	7.56	591	26.26	
	Cube 9	7.52	591	26.27	
	Cube 10	7.54	591	26.26	
	Cube 11	7.57	599	26.62	
	Cube 12	7.55	597	26.53	

Source: Test results

4.2 Flexural Tests Results

Results of each three average flexural tensile test are shown in Table 3.

Table 3. Results of the average of each three flexural tensile test

No. Specimen Code	Test Results Age [day]	Weight [gram]	P-max [kN]	P-max [N]	P-max [kg]	Calculation Results Volume Weight [kg/m3]	Flexural Strength [MPa]
1	28	11.455	186	190	189,7	2.292	6,51
2	28	11.65	188	192	191,8	2.32	6,58
3	28	11.99	182	186	185,6	2.396	6,37
4	28	11.75	179	183	182,6	2.356	6,27
					AVERAGE		**6,43**

Source: Test results

The average values of the split tensile test are given in Table 4.

4.3 Biaxial Tensile Test

Results of each three average biaxial tensile test according to ASTM C-1550 and BFT Test are shown in Table 5 and Table 6.

Table 4. Results of average split tensile strength.

No of Specimen Code	Test Results Age [days]	Weight [gram]	P-max [kN]	[kg/m3]	Calculation Results Volume Weight (γ) [kg/m3]	Split Tensile Strength (fsp) [MPa]
1	7	3510	1.9	1.938	2.242.038	6,051
2	7	3540	1.92	1.958	2.254.777	6,115
3	7	3540	1.8	1.836	2.254.777	5,732
4	7	3550	1.7	1.734	2.261.146	5,414
AVERAGE			**1.83**	1.867	**.253.185**	**5,828**
5	14	3550	2.1	2.142	2.261.146	6,688
6	14	3540	1.99	85.4	2.254.777	6,338
7	14	3570	1.93	1.969	2.273.885	6,146
8	14	3570	1.89	77	2.273.885	6,019
AVERAGE			**1.978**	2.017	**.265.924**	**6,298**
9	28	3590	2.23	2.275	2.286.624	7,102
10	28	3520	2.4	2.448	2.242.038	7,643
11	28	3500	2.41	3.57	2.229.299	7,675
12	28	3600	2.435	2.484	2.292.994	7,755
AVERAGE			**2.369**	2.416	**.262.739**	**7,544**

Source: Test results

Table 5. Results of the average of each three ASTM C-1550 Test.

Biaxial Tensile Strength [MPa]	
Specimen Group Code	ASTM C-1550
1	11.72
2	12.01
3	11.98
4	12.86
AVERAGE	12.14

Source: Test results

Table 6. Results of average of each three BFT Test

Flexural Tensile Strength [MPa]	
Specimen Group Code	BFT Strength
1	10.16
2	10.24
3	9.78
4	9.94
AVERAGE	10.03

Source: Test results

The result of the average of each of three biaxial tensile test specimen group are as follows (Table 7).

Table 7. Results of average of each three BTT Test

Biaxial Tensile Test [MPa]		
Specimen Group Code	ASTM C-1550	Biaxial Fatigue Tensile Test (BFT)
1	11.72	10.16
2	12.01	10.24
3	11.98	9.78
4	12.86	9.94
Average	12.14	10.03

Source: Test results

Comparison of both Uniaxial and biaxial flexural strength

Comparison of four type of uniaxial and biaxial flexural strength are shown in Table 8.

Table 8. Comparison of each three average of uniaxial and biaxial flexural strength.

FLEXURAL STRENGTH [MPa]				
Specimen Group Code	Flexural Strength	Split Tensile Strength	ASTM C-1550	BFT Strength
1	6.51	6.051	11.72	10.16
2	6.58	6.115	12.01	10.24
3	6.37	5.732	11.98	9.78
4	6.27	5.414	12.86	9.94
AVERAGE	6.43	6.55	12.14	10.03

Source: Test results

4.4 Discussion

The value of tensile strength test results with biaxial bending test according to ASTM C-1550 and BFT (Biaxial Fatigue Tensile Test) are shown in Fig.7 and Fig.8.

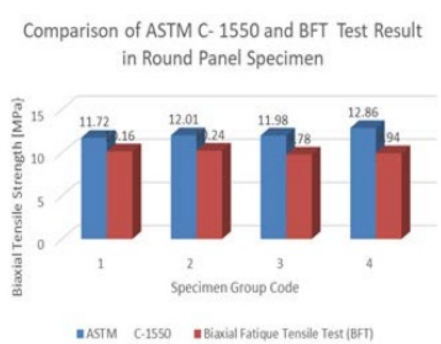


Fig.7. Result of biaxial tensile test

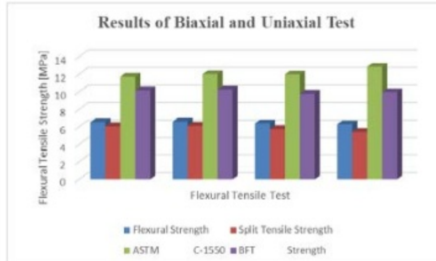


Fig.8. Results of Biaxial and Uniaxial Tests

4.4.1. Comparison of Four Type of Flexural Strength Test

Of the four forms of testing results, ASTM C-1550 provides the highest result of 12.14 MPa, then BFT of 10.03 MPa and the lowest is ASTM C-78 of 6.43 MPa (Fig.9).

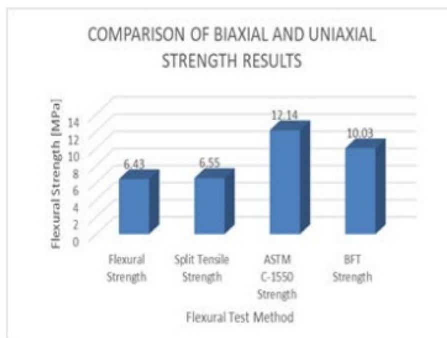


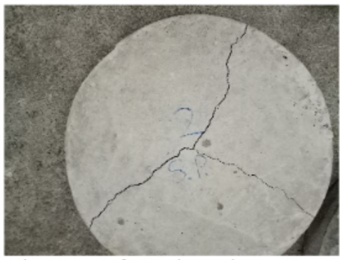
Fig.9. Comparison of Flexural Strength Results according to ASTM C-78, ASTM C 496/C 496-04, ASTM C-1550 and BFT

4.4.2. Cracks Pattern

The crack pattern of the four type of model could be seen and explain in Fig.10 as follows.

(a). Crack pattern of a beam specimen

The crack patterns of the three test models are shown in the Fig.10. The specimen for the four-point bent collapse with the crack spread or propagate from the bottom of the beam to the top (Fig.10 (a)). Crack patterns for round panel concrete plates tested according to ASTM C-1550 could be characterized by triple symmetry cracking, (Fig.10 (b)) in which the location of the crack is affected or determined by the three supports. In the BFT (biaxial fatigue test), there are 2 crack pattern patterns observed, namely the crack pattern in the form of a triple crack that approaches the symmetry while the other is a straight fracture pattern along the diameter of the specimen (Fig.10 (c)).



(b). Crack pattern of round panel concrete as tested according to ASTM C-1550-02

(C) Crack pattern of round panel concrete as tested according to BFT

Fig.10. The Crack Pattern.

This is because the in-plane stress is same in all directions, so the crack pattern is formed as above. From the observation, it was found that the test specimen collapsed after the formation of crack with three-axis symmetry i.e. radiation cracking which propagates radially on three axes.

The difference in the fracture pattern between ASTM C-78 and ASTM C-1550-02 and BFT could be descriptively explained by their bending pattern where ASTM C-78 has uniaxial flexural pattern while the other two ASTM C-1550-02 and BFT have a biaxial flexural pattern in which the emission of energy occurs radially from the center to the edge of the specimen. That is why the crack pattern for plates or slabs requires special handling at the edges.

5. CONCLUSIONS

Based on the above results and discussion it could be drawn following conclusions:

1. The flexural strength value of the two type of biaxial tests is higher than the uniaxial test result(ASTM C-1550 have 47.046 % higher than ASTM C-78 and 37.871 % higher than ASTM C-496). The value of tensile strength as measured by ASTM C-1550-02 is slightly higher than the value of the flexural tensile strength as measured by the biaxial flexure test (21.062%).
2. The crack pattern lines do not show clear cracked macro-fractures before they reach peak loads.
3. In observation, there are two peak load values where the first peak occurred at the time of the onset of the crack of round panel concrete, the load stress curve then decreases but after a few seconds the load increase again to a value smaller than the first peak load. This occurs because, at the time of the cracking of three axes, the load that can be withstood by the concrete specimen reaches maximum but after that, the load rises again because the stress has been transferred to the fiber, so the stress increase again until the fiber break. This condition indicates that the fiber plays an important role in holding the tensile load.

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