International Journal of GEOMATE, Oct., 2025 Vol.29, Issue 134, pp.11-21
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2025.134.3445
Geotechnique, Construction Materials and Environment

BOND STRENGTH OF BANANA STEM FIBER REINFORCED CONCRETE UNDER NON-STANDARD CURING

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ABSTRACT: Today, worries about the problems and impacts of environmental damage have become a reality, so the use and development of novel, environmentally friendly materials is a challenge. The presence of natural fibers in concrete materials, among others, functioned to improve the mechanical characteristics of concrete materials, retarded cracks in structural components up to certain loading levels, and reduce structural failure due to corrosion of reinforcing steel. The influences of the percentage of banana stem fiber and variation in bar diameters on the bond strength and other mechanical properties in non-standard curing conditions need to be investigated. This research presented a study of the use of banana stem fiber obtained from the waste of the banana pseudo stem, which is available in large quantities in Indonesia. This experiment method uses a push-off test on the cylindrical specimen. Results show that the larger the plain reinforcement diameter, the smaller the development of bond strength, so the bond strength of banana stem fiber reinforced concrete, called NBSFRC, is inversely proportional to the diameter of the plain reinforcement. The development of bond strength increased significantly at the early ages of the specimen for plain reinforcing bar diameters of 10 mm and 12 mm. Another aspect that may strongly affect the bond strength is the curing process that is not maximal, because after casting, the specimen cannot be immersed in the tub as other test specimens for curing to avoid fast corrosion, but only be wrapped in gunny sacks and watered daily.

Keywords: Bond Strength, Banana Stem Fiber, Mild Steel, Non-Standard Curing, Sustainable Materials

1. INTRODUCTION

Until now, concrete and steel reinforcement materials have been the raw materials of construction, which are the mainstay of construction experts to realize the idea. This is due to the superiority of concrete material in holding compressive stress when combined with reinforced steel material, which will produce an economical, efficient, and effective composite material. The concrete material also has several other favorable properties, especially (1) it is easily formed following the planner's wishes and (2) it can be poured directly to form a structural system such as beams, columns, plates, and other structural components. Nevertheless, the load-carrying capacity of reinforced concrete structures could decrease due to aging or cracking caused by extreme environments and corrosion, which means that concrete is not a maintenance-free structure. In line with the depletion of raw construction materials, global warming effects on the environment, and sustainability, researchers and construction practitioners have pursued novel, environmentally friendly materials with low costs. The use of natural lignocellulosic fibers has become popular worldwide, as they are abundantly low-cost materials that favor a series of technological properties when used in cementitious composites and other types of materials like soil and pavement. Also, due to the climate and geographic characteristics, Indonesia has abundant and great potential for natural industrial construction. The objective of this work is to present the main concepts about lignocellulosic fibers in cementitious composites, highlighting the innovation and advances in this topic in countries such as Indonesia, which has worldwide prominence in the production of natural fibers [1-5]. The usefulness of reinforced concrete as a structural material depends heavily on the strength and permanency of the bond between the concrete and the reinforcing bar, so for this reason, bond resistance has received much attention from researchers and engineers. In reinforced concrete design, the bond of reinforced concrete is crucial in transferring stress from the reinforcing bar to the concrete.[6]. The failure of reinforced concrete structures may be due primarily to the deterioration of the bond [6-18]. To have a composite action in reinforced concrete, perfect bond capacity is required, and conventional steel bars are usually considered to satisfy this bond performance.[1-7] and [8]. As an earthquake-prone country located in the Ring of Fire region, Indonesia needs to be fully aware of the disastrous impact that may arise from the bond failure of the structural element which has been one of the major problems that may cause bond failure to the interface of concrete and reinforcing bars that further may cause collapse of structures under earthquake attack especially in coastal offshore line region, and is the study's primary objective. The characteristic parameters for this complex problem have been suggested over the last few decades. According to previous researchers, the key factors include the concrete compressive strength, bar diameter, embedment length, geometry, and surface treatment scheme of the reinforcing bar, as well as temperature changes and environmental conditions [9-12]. Numerous experiments and developments have been conducted to establish a proper bond between steel and concrete.

Almost all reinforced concrete constructions are designed on the assumption that the concrete does not bear the tensile load at all. [1-5]. The tensile load is assigned to the reinforcing steel material through the bond strength in the contact plane between these materials.[5,7,13-14] The current concrete construction technology has developed very rapidly with various variations, innovations, and certain methods of design concepts, but it still takes into account some aspects of design, economy, environment, and availability of raw materials. Considering the various developments in material engineering technology, many research and innovation materials, including building materials and structural components, have been pursued today. Concrete is one of the main materials of civil engineering construction work that is often studied. The use of concrete has been widely performed and continues to progress rapidly, especially after the discovery of Portland cement and various types of additional materials.

Various research articles have been published recently on the bond strength of concrete with different methods or device setups, software, pull-out or push, in bending with notch configuration of beam specimens, concrete types, different concrete grades, and rebars, as well as different interface condition between rebar and concrete paste such as corroded, and oily surface rebar conditions and also extreme salty water environment. All of these will influence the load-carrying capacity of reinforced concrete structures, which can decrease due to aging or cracking, and this means retrofitting is required [9–16]

Fiber Reinforced Concrete is a composite material formed by hardening a mixture of cement, water, fine aggregate, coarse aggregate, and sometimes other admixture materials and incorporating discrete discontinuous fibers [1,2,4,6-7]. Material engineering technology has been evolving towards using natural fiber materials as an application of environmentally friendly, sustainable material technology while minimizing environmental concerns, so the development of environmentally friendly materials has become a challenge. This condition has motivated researchers to develop alternative materials that can reduce the amount of CO_2 and other detrimental toxic gases released into the environment, which in this case is related to human health protection, energy conservation, and global warming. Natural fiber-based concrete, as one of the mixed materials (admixtures), could also solve one of the environmental problems caused by natural material waste. Using natural fibers, the concrete financing side will become more economical than that without them. On the other hand, concrete engineering for structural concrete applications must still comply with the applicable standards. Indonesia has a huge natural potential, such as very fertile and abundant plants that are a source of very huge and diverse natural fibers, which can be innovated as a natural fiber material for concrete that functions as secondary reinforcement, where it has not been efficiently utilized, and fulfills the optimal economy.

However, in reality, cracks in concrete are often found because concrete cannot withstand tensile forces beyond a certain value due to temperature, moisture content, and loading changes. [4-5], [7-8]. Any efforts to improve the quality of concrete, especially in terms of tensile strength, have been tried in many ways, and among them is through the addition of fiber to the concrete mixture. The fiber used may vary in material type, length, diameter, or fiber form, which can affect the change in the mechanical and chemical properties of the concrete.[2,8,11,13] In the raw materials or industry, natural fibers such as banana stem fiber, pineapple leaf fiber, and others can replace synthetic fibers in composites such as automotive and concrete because they have many economic and ecological advantages. Constraints in using these fibers may be related to fiber quality standards and continuous supply in large quantities. In civil engineering, there is a need to know about fiber strength, processing, decomposition behavior, and mechanical properties associated with composites. The fibers can be mixed in a concrete mixture with varying concentrations and lengths in mechanical testing. The characteristics of these fibers are then compared with those of normal concrete. Through this comparison, we can know the mechanical properties of the fibers, especially bond strength. In this research, we use fiber from the banana pseudo-trunk (Musa paradisiaca Var Forma Typica) because this plant is easy to get in our environment (tropical area) and has rapid growth, so hopefully, in its development later, the demand for this fiber could be easily fulfilled. In addition, because of the nature of only giving one fruit, using stems from this banana plant will provide economic value to the community. In the pull-out test problem, if the adhesion or bond strength is insufficient, the steel rod will slip inside the concrete, and there will not be any composite action. Therefore, it is important to know the value of bond stress on reinforcement as a concrete reinforcement to consider the needs of anchorage. The use of fiber can increase the pull-out strength value through the tensile and friction values that arise between the fiber concrete and the reinforcing steel, as well as the tensile strength of the fibers. 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 properties of one of them, that is, by adding a fiber material to a certain percentage and dimension into a concrete mixture, which came to be known as fiber concrete.

This research aims to utilize natural fiber, considering the many types of plants in Indonesia that can produce fiber but are only disposed of as waste, which pollutes the surrounding environment. The natural fibers selected for fiber-forming materials in this study are banana stem fibers (*Musa paradisiaca* Var Forma Typica), often discarded after being cut and harvested from fruits. The presence of fibers in concrete materials, among others, improves the mechanical characteristics of concrete materials, prevents cracks in structural components up to certain loading levels, and reduces structural failure due to corrosion of reinforcing steel. How much economic value can be obtained depends heavily 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. Improving the quality of concrete by adding fiber to the concrete mixture needs to be deepened, given the need for concrete construction that can withstand tensile strength. [1-10]. It is, therefore, necessary to know the extent of the effect of adding these fibers to the mechanical properties of concrete, particularly the contribution of the fibers to the increase in the bond strength value [1-6,17-36].

From the above description, the problem to be studied in this research can be formulated as follows:

a. What is the influence of the diameter of reinforcement and fiber concrete on bond strength between mild steel and natural banana stem fiber concrete (NBSFRC)?

b. How strong is the bond stress between plain reinforcing steel and natural banana stem fiber concrete produced from each diameter of plain reinforcing steel and the anchoring length (embedment length)?

c. How much does adding natural banana stem fiber to concrete increase the strength value of fiber concrete bond strength?

2. RESEARCH SIGNIFICANCE

This research examines the effects of non - standard curing and fiber-reinforced concrete on bond strength values. Both in pull-out and push-out tests, insufficient bond strength may cause steel reinforcement to slip within the concrete, preventing effective composite action. To maintain the load-carrying capacity of reinforced concrete structures against cracking and aging, it is essential to enhance the bond strength between the reinforcement and the concrete matrix, which can be achieved by adding short, discontinuous fibers. Understanding the bond stress on reinforcement is crucial for assessing anchorage needs. While previous research has explored the use of synthetic fibers, there is limited literature on the bond strength of natural fibers, particularly regarding non-standard curing conditions and variations in reinforcement diameters. The results of this study aim to illuminate the role of natural fibers in improving mechanical properties, particularly their bond strength.

3. MATERIALS AND EXPERIMENTAL PROGRAM

3.1. Materials

3.1.1. Definition of Bond Strength

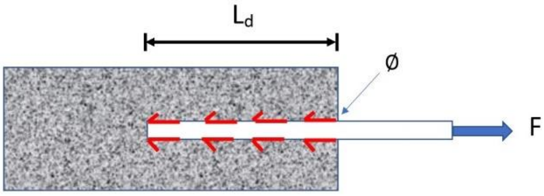
The strengthening of concrete may increase the tensile strength of the cross-section, but this depends on the compatibility between the two materials to work together to carry the outside load, under which the reinforcing element, such as the steel reinforcement, must undergo the same strain or deformation as the surrounding concrete to prevent discontinuity or separation of both types of materials. [6,7,8,14,15-17]. The modulus of elasticity and strength of the reinforcement must be much greater than that of the concrete to increase the capacity of the reinforced concrete sections, greater than the simple /non-concrete surfaces caused by the displacement of the tensile micro-current causes increased stresses on the slip; this total effect is called bond strength [1,6,18]. Factors affecting the bond strength include: Adhesion between concrete elements with steel reinforcement, Friction resistance (friction) to slip, Effect of concrete quality and tensile and compressive, the mechanical effect of anchoring/ embedment of reinforcement, diameter, span, and reinforcement all will affect crack growth.

3.2. Distribution of Bond Stress

The bond stress is the local elongated shear stress per unit of the surface area of the rod removed from the concrete to the bar to change the bar stress from one point to another along the length of the bar. The embedment length of a bar is required for embedment under certain conditions to ensure that a bar can be stressed to its yield point, with a reserve to ensure the hardness of the construction part [17-18].

3.3. Bond Strength Analysis

The relation between embedment length and bond strength could be explained in Fig 1 and Eq. (1) to (6) as follows



Source: redrawn from [14, 16-18]
Fig. 1 Anchorage bond for one reinforcing bar

From Figure 1, it can be found that at the ultimate condition:

Ab..fy = u. ld .Σ0 ………………………..………(1)

(for one reinforcing bar)

Ab.fy = u.ld .π. db ……………………………(2)

(for reinforcing bar having diameter db):

$$\boldsymbol{A_b} \quad = \frac{1}{4}.\boldsymbol{\pi}.\boldsymbol{db^2} \quad ………………………….…..(3)$$

$$\boldsymbol{A_b} \quad = \frac{1}{4}.\boldsymbol{f_s}.\boldsymbol{db}……………………………….(4)$$

One reliable way to determine average allowable bond stress is to perform a test under similar circumstances, each such test showing a maximum change in bar tension at a given anchorage length, then the permissible bond stress can be calculated from equation (5), which is rearranged into

$$ld \quad = \frac{1}{4u}.f_s.db \quad …………………… ..…….(5)$$

where:
Ab = Reinforcing bar cross-section area
Db = Reinforcing bar diameter
Id = Minimum embedment length.
Fy = Reinforcing bar yield strength.
u = Average bond strength

Average Bond Strength/Bond Stress:

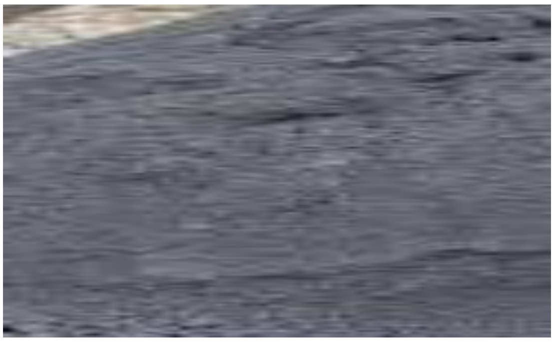
$$\boldsymbol{u} \quad = \frac{1}{4ld}.\boldsymbol{f_s}.\boldsymbol{db} \quad ……………………………(6)$$

3.4. Materials Composition Used

A type I Ordinary Portland Cement (OPC) with the trademark of Tonasa was used as the binder throughout this experimental program. Packaged in 50 kg bags, the cement had specific gravity, soundness, and initial and final setting times of 3.15, 0.51mm, 53, and 92 minutes.

The sand was from Girian village and had a specific gravity of 2.59; its grading conformed to ASTM Standards and was shown in Fig. 2 (a). The coarse aggregate was a mountain crushed rock of maximum size 19.2 mm obtained from the Crushed Stone Plant, in Tateli Village, Minahasa Regency, Indonesia, which has a specific gravity of 2.76, and abrasion of 31.02 percent as shown in Fig. 2. (b). The banana stem fiber used as an admixture material component of banana stem fiber concrete (NBSFRC) mix was taken from some places in Minahasa's regency and North Minahasa's regency namely in Tateli village, Sasaran Village, Tataaran Village, and Wusa Village Banana stem fiber (Musa paradisiaca Var Forma Typica) derived from old or fruiting stems (age approximately 10-12 months) dried in sunlight where the fiber characteristics are golden brown, and clean with variations of percentage and length variation as shown in Fig. 2. (c). and the mild steel used was produced or fabricated by PT Krakatau Steel with a diameter of 10 mm; 12 mm; 14 mm and 16 mm. as shown in Fig. 2 (d).

This study focuses on using banana natural pseudo-stem fiber concrete with a length of 3 cm with 0 %, 1%, and 2% fiber content in normal-weighted concrete. Designed compressive strength: 26 MPa; Water: From the drilling wells of the Faculty of Engineering at Sam Ratulangi University; Slump value (set): 80 - 100 mm.



(a)

(b)

(c)

d)

Fig. 2. Banana Stem Fiber Reinforced Concrete Composition Ingredient: (a).Cement(OPC Type I) (b) Fine Agg. (c) Coarse Agg. (d) Banana Stem Fiber. (e) Mild Steel

3.5. Test Procedure

During the bond strength test of a cylindrical specimen, the reinforcing steel cast together was subjected to vertical compression load until it failed. The contact area between reinforcing steel and concrete has a length (*Ld*) of 100 mm. Below the *Ld*, the hole or empty void is provided with a PVC pipe 20 mm in diameter, which will enable the reinforcing bar of mild steel to be pulled down or to be pressed axially down without friction, except for the *Ld* part, as shown in Fig. 3**.** below. The mechanical properties of the concrete tested consist of Compressive strength, Split tensile strength, and Push-Out Test strength; Specimen ages tested: 7, 14, and 28 days; The Concrete specimen consists of Cylinders 10/20 cm and Cubes 15 x 15 x 15 cm

3.6. Sample Preparation

In this research it was used a non-standard curing method where the specimen was not immersed in a water tank but only be done by wrapping all the specimens with a gunny sack or burlap cover, and was daily sprinkled regularly with water to reduce or avoid the effect of corrosion of the mild steel, as shown in Fig.5 below:

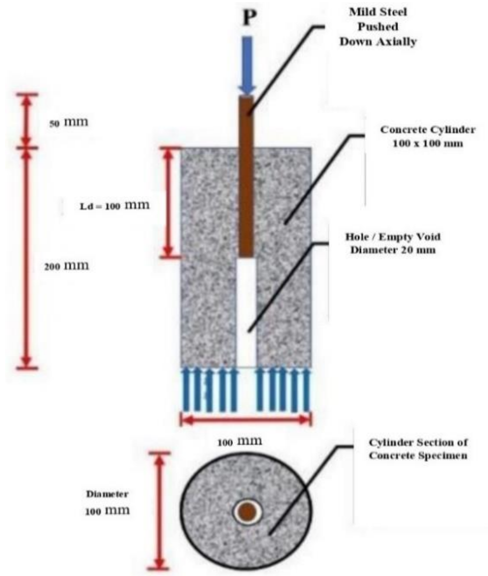


Fig. 3. Experiment Test Set Up

4. RESULTS AND DISCUSSION

4.1. Results

The results of the experiment were presented in Tables 1 to 4 below for the bond strength of natural banana stem fiber, hereinafter called NBSFRC (fiber content 1 % and 2 %), with reinforcing bar variation ϕ-10 mm; ϕ-12 mm; ϕ-14 mm and ϕ-16 mm as follows:

Table 1. The Results of Average Compressive Strength of NC-0% fiber, NBFRC-1% fiber, and NBFRC-2% fiber

Concrete Type	NC- 0% [MPa}	BSFRC-1% [MPa]	BSFRC-2% [MPa]
Specimen Ages			
7 days	22,723	23,497	21,981
14 days	23,45	23,866	23,715
28 days	26,815	27,691	27,427

Fig.5a. Specimens were wrapped with Gunny Sack (burlap cover)

Fig.5b. Wrapped Specimens were sprinkled uniformly every day with water until the date of specimen testing.

Table 2. The Results of Average Bond Strength of NBSFRC with 10 mm reinforcement on cylinder 10/20 cm at 28 days

Specimen code	Reinforcement Diameter	Fiber Content	Bond Strength (μ)
	[mm]	[%]	[MPa]
1	10	0	0.6996
2	10	1	0.9501
3	10	2	1.0361

Table 3. The Average Bond Strength of NBSFC with 12 mm reinforcement on a cylinder 10/20 cm at 28 days

Specimen code	Reinforcement Diameter	Fiber Content	Bond Strength (μ)
	[mm]	[%]	[MPa]
1	12	0	0.4967
2	12	1	0.7918
3	12	2	0.8678

Table 4. The Average Bond Strength of NBSFC with 14 mm reinforcement on a cylinder 10/20 cm at 28 days

Specimen code	Reinforcement Diameter	Fiber Content	Bond Strength (μ)
	[mm]	[%]	[MPa]
1	14	0	0.5179
2	14	1	0.7393
3	14	2	0.7613

Table 5. The Average Bond Strength of NBSFC with 16 mm reinforcement on a cylinder 10/20 cm at 28 days

Specimen code	Reinforcement Diameter	Fiber Content	Bond Strength (μ)
	[mm]	[%]	[MPa]
1	16	0	0.7132
2	16	1	0.8068
3	16	2	0.8260

4.2. Discussion

4.2.1.Regression Analysis

Regression analysis is used to analyze the relationship between two or more variables to obtain clearer results, and the results of tests that are still vague and unclear cause false readings. Regression is a line that forms a function that connects data points with the maximum possible proximity. Correlation measures the compatibility of a regression model used with data. The value of correlation is denoted by R. If the magnitude R = 0, then there is no match or relationship at all between the two data variables analyzed; otherwise, when R = 1, then the two data variables analyzed have a relationship (illustrated by a trend-line). [46]. The following results (Fig. 6), show the correlation between the development of compressive strength in three mixture proportions:

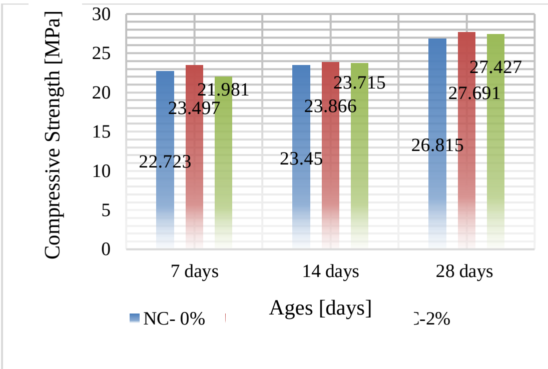


Fig. 6 The Development of Compressive Strength in Normal Concrete and Banana Stem Fiber Reinforced Concrete at 7, 14, and 28 days

Results showed that the compressive strength value is significant only from 0 to 7 days; after that, there is no significant development in all mixture proportions.

The development of bond strength value of the natural banana stem fiber reinforced concrete with the addition of fiber (1% and 2%) on the concrete age of 7, 14, and 28 days are shown in Fig 7 below.

Fig.7. shows that the development of bond strength with reinforcing bar 10 mm for normal concrete (0%) at 7 days is 0,4878 MPa while at 14 days is 0,6274 MPa and at 28 days is 0,6996 MPa which means that there is increasing 22,25 % at 7 to 14 days and 10,32 % at 14 to 28 days, so the total increasing at 28 days is 32,57 %. This means that at an early age, namely between 7 to 14 days, there is a significant increase in bond strength, and then at 14 to 28 days, there is only a slight increase. In Natural Banana Stem Fiber Reinforced Concrete hereinafter called NBSFRC with 1 % of fiber content, it was found that at 7 days the bond strength is 0,5637 MPa while at 14 days is 0,8949 MPa, and 0,9501 at 28 days, which means that there is

increasing about 37 % at 7 to 14 days and 5,81 % at 14 to 28 days, so the total increase at 28 days is 42,81 %. With 2 % fiber content, at 7 days is 0,9098 MPa, at 14 days is 1,0053 MPa, and at 28 days is 1,0316 MPa. In 2 % of fiber content, there is an increase in bond strength of about 9,5 % and 2,55 % respectively at both 7 to 14 days and 14 to 28 days. This shows that at 28 days there is a total of 12,5 %.

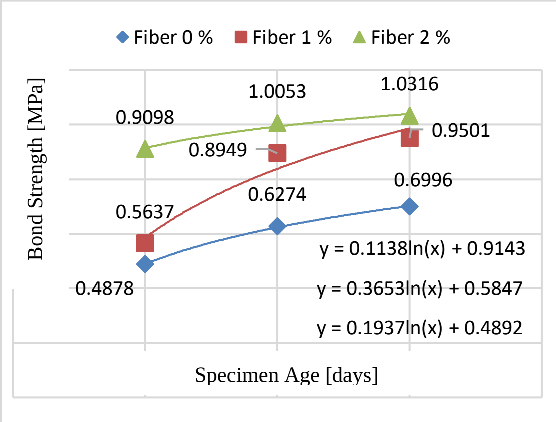


Fig.7.Correlation between bond strength and reinforcing bar 10 mm to the concrete specimen age.

As shown in Fig.8, the bond strength development with reinforcing bar 12 mm is 0,4016 MPa, 0,5211 MPa, and 0,5909 MPa, respectively, for normal concrete (0%) at 7 days, 14 days, and 28 days. The development of bond strength in 7 to 14 days is 22,93 %, while at 14 to 28 days, there is an increase of 11,81 %. The total increase at 28 days is 34,74 %. This result also shows that at an early age, namely between 7 to 14 days, there is a significant increase in bond strength, while between 14 to 28 days, there is only a slight increase.

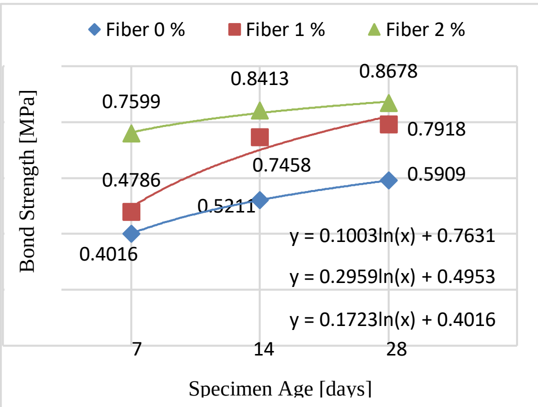


Fig.8. Correlation between bond strength and reinforcing bar 12 mm to the concrete specimen age

In NBSFRC with 1 % of fiber content, the bond strength development with reinforcing bar 12 mm is 0,4786 MPa, 0,7458 MPa, and 0,7918 MPa, respectively. The development of bond strength in 7 to 14 days is 35,82 %, while at 14 to 28 days, there is an increase of 5,81 %. The total increase at 28 days is 41,64 %.

This means that at 7 to 14 days, there is a significant increase in bond strength, and then after that, at 14 to 28 days, there is only a slight increase. Further to this, in NBSFRC with 2 % of the fiber content, bond strength development is 0,7599 MPa, 0,8413 MPa, and 0,8678 MPa, respectively.

The development of bond strength in 7 to 14 days is 9,68 %, while at 14 to 28 days, there is an increase of 3,05 %. The total increase at 28 days is 12,73 %. Similar to the result in reinforcing bar 10 mm, there is a significant increase in bond strength at an early age, and then after that, between 14 to 28 days, there is only a slight increase.

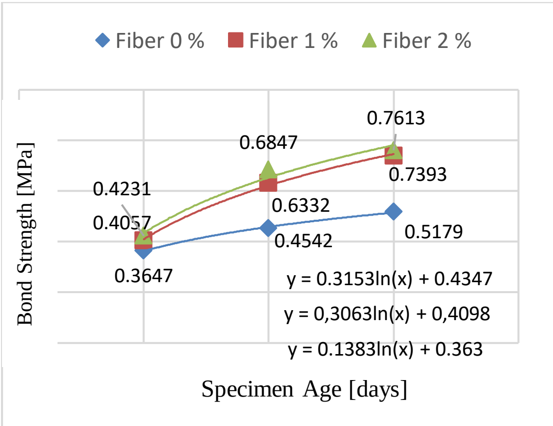


Fig.9.Correlation between bond strength and reinforcing bar 14 mm to the concrete specimen age.

In 2 % fiber content, the bond strength development of normal concrete with reinforcing bars of 14 mm is 0,4057 MPa, 0,6332 MPa, and 0,7393 MPa, respectively.

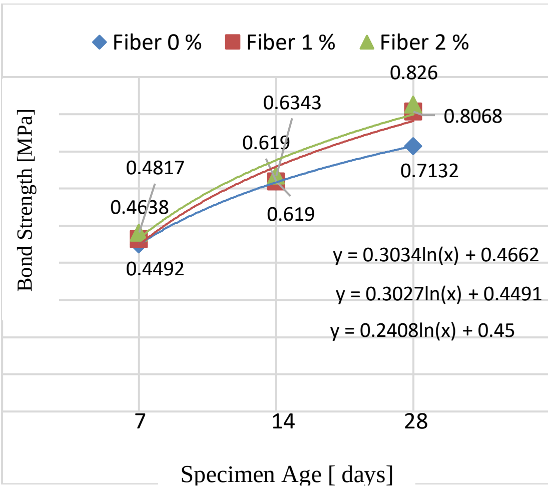


Fig.10.Correlation between bond strength and reinforcing bar 16 mm to the concrete specimen age.

With 2% fiber content, bond strength increases by about 38,2 % and 10 %, respectively, from 7 to 14 days and 14 to 28 days. This shows a total of 48,27 % at 28 days.

Based on Fig. 10, the development of bond strength of normal concrete with reinforcing bars of 16 mm is 0,4492 MPa, 0,619 MPa, and 0,7132 MPa, respectively. The development of bond strength in 7 to 14 days is 27,43 %, while at 14 to 28 days, there is an increase of 13,21 %. The total increase at 28 days is 40,64 %. In 1 % fiber content, the bond strength development of normal concrete with reinforcing bars of 14 mm is 0,4638 MPa, 0,6199 MPa, and 0,8068 MPa, respectively. The development of bond strength in 7 to 14 days is 25,18 %, while at 14 to 28 days, there is an increase of 23,17 %. The total increase at 28 days is 48,35 %. In 2 % of fiber content, there is an increase in bond strength of about 24,06 % and 23,21 % respectively at both 7 to 14 days and 14 to 28 days. This shows that at 28 days there is a total of 47,27 %.

Fig. 11 below shows the trend of the bond strength values at 28 days according to both the fiber content and diameter of the reinforcing bars. It showed a similarity between reinforcing bars 10 mm and 12 mm and between reinforcing bars 14 mm and 16 mm. The larger the diameter of the reinforcing bars, the smaller the bond strength value was confirmed.

Also, another aspect that may strongly affect the bond strength is the non-maximal curing process because, after casting, the specimen could not be immersed in the tub as other test specimens for curing to avoid fast corrosion, but only wrapped in gunny sacks and watered daily.

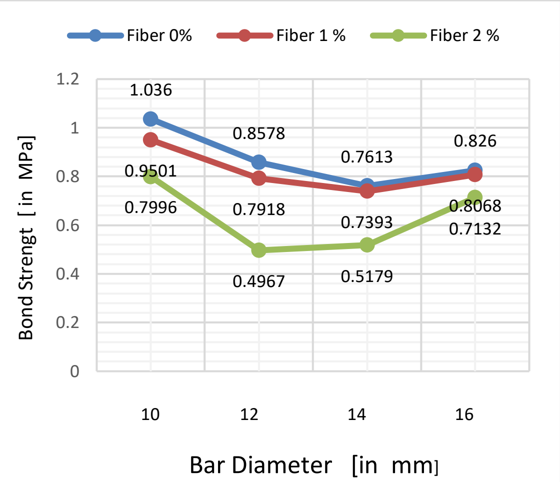


Fig.11. The development of bond strength value according to fiber content (0 %, 1 %, and 2%) in four variations of reinforcing bars at 28 days.

So, the effect of nonstandard curing and fiber effects on the reduced bond strength between concrete paste and mild steel was confirmed.

5. CONCLUSION

Based on the results and discussion can be summarized as follows:

The decrease in the compressive strength of concrete was attributed to both fibers and nonstandard curing, where fiber addition caused the contact area between aggregate and cement paste to become reduced, and this type of curing caused the hydration processes to become submaximal

The larger the reinforcement's diameter, the smaller the bond strength development. In other words, bond strength is inversely proportional to the diameter of the reinforcement.

Results also show that even though the larger contact area should produce greater adhesive strength, it does not. This is due to fiber orientation and uneven distribution of fibers, so the greater the fiber concentration, the smaller the contact area between the fiber concrete and the reinforcing bars.

Another factor that strongly affects the bond strength between reinforcing steel with the fiber concrete is the curing process which is not maximal in this experiment, because after casting, the specimen could not be soaked in the tub as other test specimens for curing to rapid corrosion which may occur in reinforcing bars, but only be wrapped in sacks and be sprinkled with water every day.

Bond strength development was significantly increased at early ages (7 days) for 10 mm and 12 mm diameters.

The optimum fiber content that yields high bond strength is 1%. Bond strength is directly proportional to compressive strength and split tensile strength values.

6. ACKNOWLEDGMENTS

The research was conducted, supported by LPPM Universitas Sam Ratulangi (Sam Ratulangi University Research and Community Service Institute) under RTUU SKIM (Sam Ratulangi's Frontier Applied Research Scheme Program). The technical assistance of Mr. Nyoman Nuryasa was valuable for performing the experiment and analysis. The authors wish to deeply thank all the support.

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