Changes in the flexural strength characteristics of concrete due to the effect of coconut fiber addition on normal concrete

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ABSTRACT

Concrete has high compressive strength, long durability, and easy maintenance. Innovation in using waste such as coconut fibers can improve the mechanical quality of concrete, reduce pollution, and provide added economic value. Fiber concrete is commonly used on broad structural elements to overcome expansion shrinkage due to oxidation, temperature, and evaporation. This study aims to determine the effect of the addition of coconut fiber waste and the optimum percentage on the bending strength characteristics of concrete. This research method is an experiment that compares the results of the bending strength test with the consideration of deflection that occurs on the force received from the variation of coconut fibers as much as 0%, 1.75%, 2.25%, and 2.75% of the weight of cement with a coconut fiber length of 65 mm, a planned quality of f'c 20 MPa, and using test specimens measuring 15 cm x 30 cm for cylinders and 15 cm x 15 cm x 60 cm for beams. Based on analysis and discussion, the addition of coconut fibers influences increasing flexural strength for a certain percentage with the addition of coconut fibers as much as 2.25% of the weight of cement showing the best flexural strength value with less deflection produced than other variations of fiber concrete at the same amount of force when charged.

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1. INTRODUCTION

Concrete is a strong, durable, and easy-to-care construction material. Concrete consists of aggregate, cement, water, as well as additives. Innovations such as waste utilization can reduce pollution and create materials that have economic value. Cilegon City, with abundant coconut production (43,076 tons in 2022) produces coconut fiber waste that is often wasted. This waste can cause environmental problems if not managed properly.

Previous research has shown that coconut coir has superior properties, such as high tensile strength, and increases tensile strength, bending, and impact. Therefore, coconut coir can be used as a fiber additive to concrete as evidenced by research conducted by W. Ahmad et al., [1] and Hasbullah & Jasman stated [2] that there was an increase in *splitting-tensile* and *flexural strength* in the addition of coconut coir fibers to the concrete mixture, and this statement was supported by Omaliko et al., who stated that the incorporation of coconut coir in the mixture Up to the addition of a certain amount of fiber, it can increase the mechanical properties of concrete, one of which is the bending strength of concrete compared to normal concrete. [3]

The use of the length of fiber used follows suggestions and comparisons of results from previous studies. Research conducted by Hermanto & Shandy stated that the bending strength value of concrete blocks increases with the increase in the length of the coconut fiber used, as evidenced by the use of 6 cm fiber length has more optimal results compared to the length of 4 cm fiber and according to J. Ahmad et al., the variation in the optimal concrete dosage use depends on the length and diameter of the coconut fiber used, So that in this study, a coconut fiber length of 65 mm was used. [4][5]

The use of the total percentage of fiber use follows the suggestions and comparisons of results from previous studies. Research conducted by Saputro et al., stated that the increase in the bending strength of concrete increased with the increase in the percentage of coconut fiber used, compared to normal concrete and according to Shcherban' et al., stated that the optimal percentage of fiber use was 1.75% to the weight of cement, then according to J. Ahmad et al., the optimal dose of coconut fiber used in the manufacture of fiber concrete was from 2 to 3% of the volume of cement, and according to Bui et al [6][7][5][8], adding fiber content with a percentage of 2% can significantly increase flexural strength. Therefore, in this study, the total percentage of fiber used is between 1.5% to 3%, with percentage details of 1.75%, 2.25% and 2.75% of the total weight of cement.

2. METHODS

This research uses an experimental method conducted at the Civil Engineering Laboratory, Faculty of Engineering, Sultan Ageng Tirtayasa University, Banten. This experimental method aims to determine the causal relationship caused by the addition of coconut fibers to the normal concrete mixture with fiber percentages of 0%, 1.75%, 2.25% and 2.75%, with steps such as preliminary testing, concrete mixture planning, test specimen making, test specimen treatment, test specimen testing, result analysis, and conclusion drawn.

2.1 Preliminary Testing

Preliminary testing is an examination of the constituent materials of the test piece to determine whether the constituent material is suitable for use or not. The preliminary test consists of coarse and fine aggregate testing, cement testing, and coconut fiber testing with several sub-tests such as specific gravity check, moisture content, filter analysis, aggregate wear, air cavity against aggregate content weight, cement specific gravity, and coconut fiber inspection.

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

Figure 1. (a) Coarse Aggregate, (b) Fine Aggregate, (c) Cement, (d) Coconut Fiber

2.2 Calculating of Concrete Mixtures (Mix Design)

The planning of concrete mixture was carried out to determine the proportion of use of concrete constituent materials such as coarse and fine aggregate, cement, and water to make normal concrete with the planned quality, namely Fc 20 MPa, and the manufacture of fiber concrete with the addition of 65 mm long coconut fibers with a percentage of 1.75%, 2.25%, and 2.75% of the weight of cement.

Table 1. Concrete Mixture for 3 Cylindrical Test Specimens

No.	Specimen Code	Material				
		Coarse Aggregate (kg)	Fine Aggregate (kg)	Cement (kg)	Water (kg)	Coconut Fiber (kg)
1.	NWC	20,366	13,624	10	4,22	-
2.	CFC-1	20,366	13,624	10	4,22	0,175
3.	CFC-2	20,366	13,624	10	4,22	0,225
4.	CFC-3	20,366	13,624	10	4,22	0,275

Table 2. Concrete Mixture for 3 Beam Test Specimens

No.	Specimen Code	Material				
		Coarse Aggregate (kg)	Fine Aggregate (kg)	Cement (kg)	Water (kg)	Coconut Fiber (kg)
1.	NWC	40,732	27,248	20	8,44	-
2.	CFC-1	40,732	27,248	20	8,44	0,350
3.	CFC-2	40,732	27,248	20	8,44	0,450
4.	CFC-3	40,732	27,248	20	8,44	0,550

2.3 Specimen Testing

Testing of test pieces is carried out by two methods, namely compressive strength testing for cylindrical test pieces which refers to the SNI 1974:2011 standard on How to test the compressive strength of concrete with cylindrical test pieces and bending strength testing for beam test pieces which refers to SNI 4431:2011 concerning How to test the bending strength of normal concrete with two loading points. [9][10]

(a)

(b)

Figure 2. (a) Compressive Strength Test, (b) Flexural Strength Test

3. RESULTS AND DISCUSSION

In this study, data was obtained through experimental testing with variations in the addition of fibers used, testing the compressive strength and bending strength of concrete was carried out using *a Universal Testing Machine* (UTM) machine that produced a strain stress graph, then the *Modulus of Rupture* (MoR) and *Modulus of Elasticity* (MoE) will be discussed.

If the load is static or changes relativelyslowly over time and is uniformly applied to the transverse section or surface of a cross-section, then its mechanical behavior can be ascertained by a simple strain stress test. There are three main ways in the application of loads namely tension, compression, and shear but in practice many loads are torsional rather than pure shear with the strain stress graph:

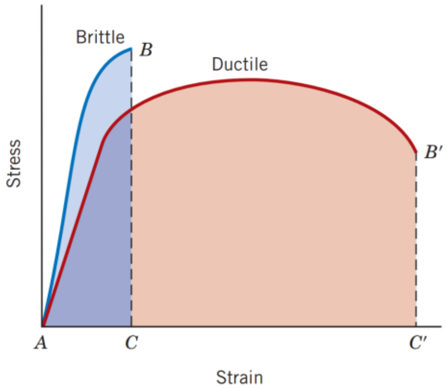


Figure 3. Strain Stress Graph [11]

Dactyl collapse is characterized by the formation of small cavities that enlarge, fuse, and form elliptical cracks perpendicular to the direction of tension, which then grow through the merger of microcavities and eventually cause fractures through rapid crack propagation at an angle of 45° to the axis of attraction where the shear stress reaches its maximum. [11]

Brittle collapse occurs without obvious deformation and with rapid crack propagation. The direction of movement of the crack is almost perpendicular to the direction of the given tensile stress and results in a relatively flat fracture surface. The surface of the material with brittle collapse has a characteristic pattern, that is, there are no signs of coarse plastic deformation, with collapse forming near the middle of the fracture cross-section. [11]

3.1 Compressive Strength Testing

Compressive strength testing Concrete compressive strength is a test with the aim of determining the strength of concrete calculated from the maximum load that can be withheld by a cylindrical test piece during a test that results in the test being destroyed when subjected to a certain amount of compressive force (SNI 1974, 2011).

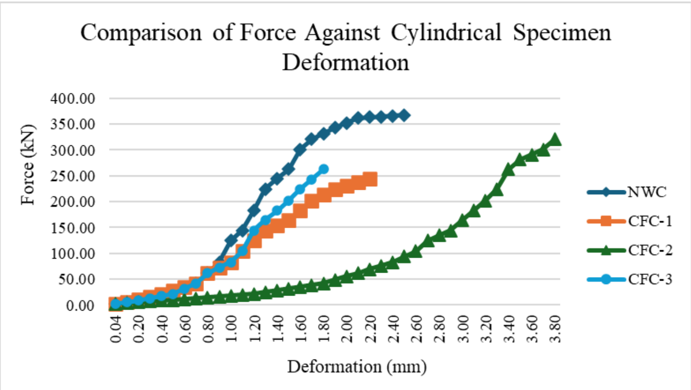


Figure 4. Comparison of Force Against Cylindrical Specimen Deformation

The Normal Concrete (NWC) test specimen shows a maximum force capacity with a value of 367.4 kN and a deformation of about 2.5 mm. A graph is obtained that rises steadily as the force increases, which means that the test specimen can withstand high loads with controlled deformation.

The 1.75% Fiber Concrete (CFC-1) test specimen shows that the test specimen can withstand a maximum force of up to about 224.8 kN with a deformation of about 2.0 mm. The results were obtained that the performance of this test piece was lower than that of normal test pieces and was indicated by a slightly faster deformation that increased compared to the force given.

The 2.25% Fiber Concrete (CFC-2) test specimen showed a maximum force of about 320.4 kN. This test piece has the greatest deformation with a value close to 4.0 mm so that it is more flexible than other test pieces but has a compressive strength value close to that of a normal concrete test piece.

The 2.75% Fiber Concrete test specimen shows the graph results rising to a maximum force of only about 262.8 kN with a deformation of about 1.5 mm. The performance of this test piece is like that of a normal concrete test piece but has a much lower maximum force compared to normal concrete.

3.2 Flexural Strength Testing

Flexural strength test Flexural strength is the value of the ability of a concrete beam placed on two laying to withstand force in a perpendicular direction of the axis of a given test piece until the test piece breaks, expressed in Mega Pascal (MPa) (force per unit area) (SNI 4431, 2011)

Modulus of Rupture (MoR) is a measure of the tensile strength of a concrete block which is defined as the comparison between the moment when the first crack occurs and the moment of resistance/ *modulus of section*. The R value is influenced by the size of the fine aggregate granules, the density of the concrete blocks and the ratio of moisture content to cement. R is expressed in MPa units which states the magnitude of the tensile strength of a concrete block without a repeating iron to withstand bending failure. [12]

Modulus of Elasticity (MoE) is a measure to determine the deformation and limit of a material that can survive in its elasticity expressed as the slope of the strain stress curve in the elastic deformation region or in accordance with the limit below the proportionality of a material. [13][14]

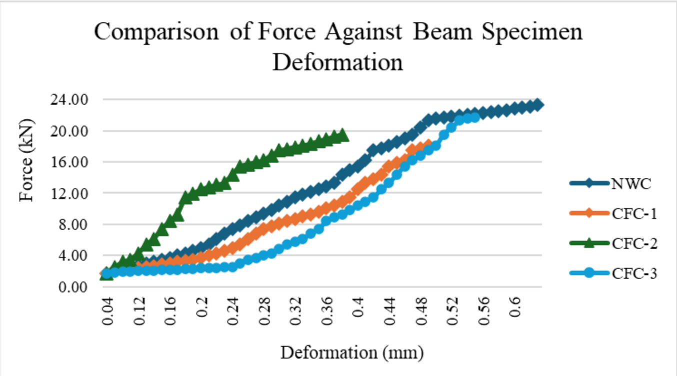


Figure 5. Comparison of Force Against Beam Specimen Deformation

The Normal Concrete (NWC) test specimen shows a maximum force capacity of about 23.3 kN with a deflection of about 0.6 mm. A graph is obtained that gradually rises as the force increases which means the test specimen shows that it can withstand the load with a controlled deflection.

The 1.75% Fiber Concrete (CFC-1) test specimen shows that the test specimen can withstand a maximum force of up to about 19.5 kN with a deflection of about 0.5 mm. The deflection is quite low compared to NWC and CFC-3 at most points. Stable until the force is close to maximum, showing reliable performance.

The 2.25% Fiber Concrete (CFC-2) test specimen showed the smallest deflection graph results with a value only close to 0.4 mm with a maximum force that can be withheld at about 19.5 kN. The smallest deflection, meaning that the material is rigid but unable to withstand large forces before it fails.

The 2.75% Fiber Concrete test specimen shows the graph results rising to a maximum force of about 21.8 kN with a deflection of about 0.5 mm. The performance of this test piece is like that of NWC but with higher deflection, this indicates that the material is more flexible but capable of withstanding large maximum forces.

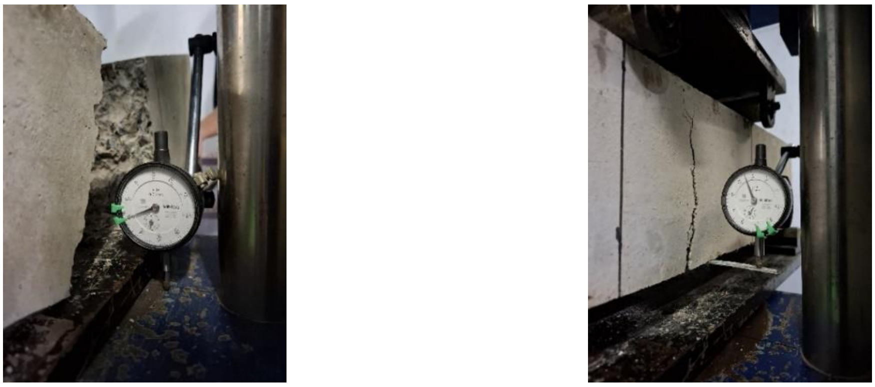
3.3 Concrete failure

The failure that occurs can be known from the relationship between the crack pattern on the concrete beam and what type of collapse occurs. Based on this relationship can provide a different type of collapse with a comparison between the shear span and the effective height, there are three types of failure based on the slimness of the beam. [15][16]

Flexural failure in *under-reinforced* beams usually occurs in the middle third of the span characterized by the melting of tensile reinforcement first compared to concrete due to the dominant bending stress with a ratio of shear span to cross-sectional height > 2.5. [17]

Diagonal tension failure occurs if the diagonal tensile strength is weaker than the bending, generally in beams with medium slimness (shear/height ratio 2.5-5.5), characterized by an initial crack that will appear in the middle of the span in the vertical direction, in the form of fine cracks due to bending.

Shear compression failure occurs in beams with a shear/height ratio of 1-2.5 where the crack begins with a vertical flexural crack in the middle of the span followed by an oblique crack leading to the neutral axis and is considered more ductile due to its stress distribution compared to other types of diagonal tensile failure. [18]



(a) **(b)**

Figure 6. (a) Normal Concrete Block Collapse, (b) Fiber Concrete Block Collapse

Based on Figure 6. Both normal concrete and fiber concrete have the same type of collapse, namely a bending collapse that occurs at a location that experiences a crack in the middle third of the span, and perpendicular to the direction of the main stress. However, the difference between the two types of collapse is that in the fiber concrete test piece, there is a bending collapse with the fiber still surviving (*post-crack ductility*).

3.4 One-Way ANOVA Testing

ANOVA (*Analysis of Variance*) testing is one of the statistical approaches of the metrics to compare two or more averages to analyze the differences between groups with minimal errors. One-Way ANOVA was used to evaluate the significance of more than two groups of data in representing populations. Before testing, a data homogeneity test is needed to ensure that the differences that occur come from between groups, not within groups, so that the validity of the test is maintained. [19][20][21]

ANOVA tests were conducted on the Modulus *of Elasticity value* to determine the optimum fiber percentage with a significant influence on flexural strength. Data homogeneity testing is required before ANOVA testing using the Levene Test, with the following results:

Tests

Method	Test Statistic	P-Value
Multiple comparisons	—	0.046
Levene	2.61	0.124

Figure 7. Data Homogeneity Test Results

The data homogeneity test with the Levene Test produced a P-Value of 0.124 (> 0.05), so that the Hypothesis 0 (H_0) was not rejected, indicating that the data was homogeneous. Thus, the One-Way ANOVA test can be conducted with the following results:

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	3	12874860	4291620	6.06	0.019
Error	8	5664759	708095		
Total	11	18539619			

Figure 8. Analysis of Variance Test Results

The ANOVA test results showed a P-Value of 0.019 (< 0.05), so H0 was rejected and H1 was accepted, indicating a significant difference between the groups. Dunnett's post-hoc test will be performed to determine significantly different pairs of groups, with the following results:

Dunnett Multiple Comparisons with a Control

Grouping Information Using the Dunnett Method and 95% Confidence

Factor	N	Mean	Grouping
0% (control)	3	1750	A
2.25%	3	4088	
2.75%	3	1767	A
1.75%	3	1587	A

Means not labeled with the letter A are significantly different from the control level mean.

Dunnett Simultaneous Tests for Level Mean - Control Mean

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
1.75% - 0%	-163	687	(-2141, 1816)	-0.24	0.990
2.25% - 0%	2338	687	(360, 4317)	3.40	0.023
2.75% - 0%	17	687	(-1961, 1996)	0.03	1.000

Individual confidence level = 97.95%

Figure 9. Dunnett Comparative Test Results

The results of the Dunnett test showed that the 2.25% factor had a significant difference to the control (0%) with a P-Value of 0.023 (< 0.05). Meanwhile, the factors of 1.75% and 2.75% did not show a significant difference (P-Value > 0.05) at the 95% confidence level.

Likewise, the previous study conducted by Waqar et al., with variations in fiber addition of 6%, 9%, and 12%, showed that the best modulus of elasticity result value was in the percentage of fiber addition of 9%. Then the research conducted by [22] Salain et al., with variations in fiber addition of 1%, 1.5%, and 2% showed the best results of the elastic modulus value in the addition of fiber as much as 1.5%. Then the research conducted by Katman et al., with variations in fiber addition of 1%, 2%, and 3% had the best elastic modulus value at the addition of fiber by 3%. Then the research conducted by Shcherban' et al., with variations in fiber addition of 1%, 1.5%, and 2% resulted in the best elastic modulus value at the addition of fiber of 1.5%. And the research conducted by Putri et al., with variations in fiber addition of 0.3%, 0.5% and 1%, the best elastic modulus occurred in the addition of fiber by 0.5%, with the following comparison of results: [23][24][7][25]

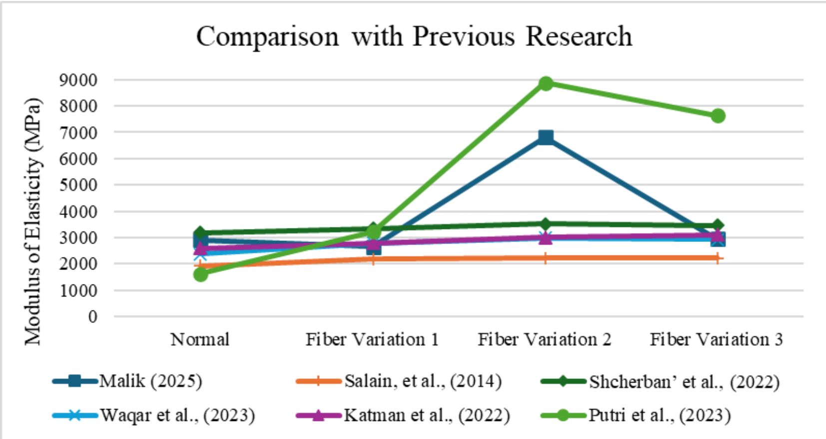


Figure 10. Comparison of Modulus of Elasticity Value with Previous Research

4. CONCLUSION

Based on the objectives and results of the study, the data showed that the addition of fiber of 2.25% had the least deformation value compared to other fiber concrete (1.75% and 2.75%). Concrete with the addition of 2.25% fiber shows high resistance to large deformation with less deflection produced than other fiber concrete at the same amount of force when charged. Therefore, the addition of a certain amount of fiber can increase its bending strength with an optimal fiber addition percentage of 2,25%.

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