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Preliminary Study of NFRP-Confined Concrete for Enhancing Compressive Strength

Taufiq Saidi*), Muttaqin Hasan, Zahra Amalia
Civil Engineering Department, Universitas Syiah Kuala, Banda Aceh, Indonesia
*Corresponding author : taufiq_saidi@usk.ac.id

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Abstract- A column is a structural element that carries axial compressive loads. This compressive axial load causes the shortening of the structural column. It causes the column to be subjected to a tensile force in its axis perpendicular to the compression axis. This tensile force causes the column to collapse—reinforcement methods to improve the quality of concrete in resisting higher axial compressive loads. Strengthening the column with external restraints is expected to increase the strength of the concrete. The use of synthetic Fiber Reinforced Polymer (FRP) as a composite material for external restraint on structures is widely used for strengthening concrete structures. Considering the environmental impact, natural FRP materials have been developing nowadays. One of the natural fibers that have been researched and used as a composite material for Natural Fiber Reinforced Polymer (NFRP) is abaca fiber. This research aims to find the contribution of abaca fiber in increasing the compressive strength of confined concrete as a preliminary study. This study conducted the test by applying a compressive load to concrete specimens reinforced with NFRP restraints. Specimens were cylinders with a diameter of 150mm and 300mm in height. NFRP was applied at the cylinder circumference area (jacketing method) by using manual wet-layup techniques. The NFRP was investigated with variations in the number of NFRP layers. The results showed that NFRP-confined concrete has a higher compressive strength of 34.73% than the controlled specimen.

Keywords: natural fiber, confined concrete, abaca fiber

Introduction

Column capacity to withstand compressive loads is influenced by its constituent components. A collapse in the column can be caused by the tensile force in the lateral direction when the column is subjected to an axial load. Concrete strength in a short column needs to be considered to maintain the building structure. Therefore, a concrete reinforcement method is needed to be developed to improve the concrete strength in resisting earthquake loads. Providing external restraint to the concrete is an alternative way to increase concrete strength. A number of studies have been investigated related to confined concrete and found that it can increase earthquake resistance (Li *et al.*, 2004; Tamuzs *et al.*, 2006; Guo *et al.*, 2019). External restraint on concrete can significantly increase the strength and ductility of concrete (Ozbakkaloglu *et al.*, 2013; Wang *et al.*, 2018; Baasankhuu *et al.*, 2020). One external concrete confinement method is applying Fiber Reinforced Polymer (FRP) to the concrete surface. FRP is a composite material with a polymer resin matrix reinforced with fibers (Ozbakkaloglu *et al.*, 2013). FRP can be used for external reinforcement (external confinement) in concrete structures. As mentioned by (Lim & Ozbakkaloglu, 2015), external restraint on concrete using different types of synthetic FRP can increase the compressive strength of concrete by 72.635% for Aramid-FRP, 101.464% for Carbon-FRP, 65.315% for Glass-FRP.

Furthermore, several studies have been developed for other material types of FRP, such as Polyethylene Naphthalate Fiber Reinforced Polymer (PEN FRP) and basalt (Baasankhuu *et al.*, 2020). The use of synthetic FRP materials requires relatively high costs, and production processes are not environmentally friendly (Burgoyne & Balafas, 2007). Therefore, natural fiber as a material based on FRP could be an alternative to overcome this problem. In (Wang, 2020) stated that using natural fibers for composite materials has advantages

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such as reducing the negative impact on the environment, being abundant in quantity, having a light mass, economical production costs, and can be renewed. Several studies on applied natural fiber as FRP material have been developed (Sen and Jagannatha Reddy, 2013; Alam *et al.*, 2015; Hasan *et al.*, 2021; Saidi *et al.*, 2021a; Saidi *et al.*, 2021b; Saidi *et al.*, 2022). Natural fibers such as abaca fiber can be an alternative composite material for Natural Fiber Reinforced Polymer (NFRP). Abaca fiber has a maximum tensile strength of 54.58 MPa, a modulus of elasticity of 3,474.3 MPa, and a maximum strain of 1.58% (Wang, 2020). A higher number of abaca-fiber-layer in composite FRP material increase its tensile strength. The tensile strength of three-layer abaca fiber in composite FRP material was 111.45 MPa (Saidi *et al.*, 2022). Based on previous studies, abaca fiber has the potential as a natural fiber for FRP composite material. However, further research is needed to provide additional information regarding using natural FRP as a concrete reinforcement material. Therefore, as a preliminary study, this study aims to investigate the concrete confinement strength using abaca fiber as natural fiber in FRP composite material. Besides its tensile strength as NFRP material, abaca fiber was used in this study due to its ease of obtaining in Indonesia.

Materials and Method

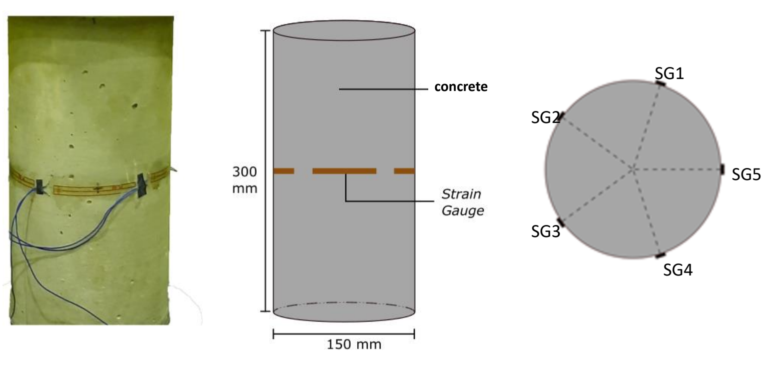
Test Specimen and Concrete Materials

Nine specimens of NFRP-confined concrete were manufactured, and the test was carried out by applying monotonic axial loading compression. All specimens have a diameter of 150mm and 300mm in height. Three specimens of unconfined concrete with the same size and concrete strength were also prepared as controlled specimens. The concrete strength in this study was 33.28 MPa, with a water-by-cement ratio of 0.45. Concrete mix designs, as in Table 1, were used. The specimens were cured in a water tank until 28 days.

Table 1. Concrete mix design

Material	Mix Composition
Water	186.76 Kg/m3
Cement	410.93 Kg/m3
Coarse Aggregate	898.96 Kg/m3
Fine Aggregate	898.96 Kg/m3

In controlled specimens, after curing time, five strain gauges at mid-height of the specimen for measuring longitudinal strain were applied, as seen in Figure 1. To fabricate NFRP-confined specimens, abaca fiber sheets were cut according to the size of the concrete specimen. It was 300mm in height, and the length of the abaca fiber was adjusted to the variation in the number of NFRP layers which terminated with an overlap region of 150mm. NFRP was applied by using manual wet-layup techniques. The concrete specimen was wrapped by a cut abaca fiber sheet continuously, and epoxy resin and hardener were impregnated to the sheet gradually until the concrete specimen surface was completely covered, as seen in Figure 2. At the top and bottom ends of the concrete specimen, a layer of 50mm abaca fiber sheet was applied, which serves as a barrier to the location of the NFRP rupture. Therefore, the destruction of the NFRP-confined concrete focuses on the center of the concrete.



(a) (b)

Figure 1. Controlled specimen detail: (a) side view; (b) top view

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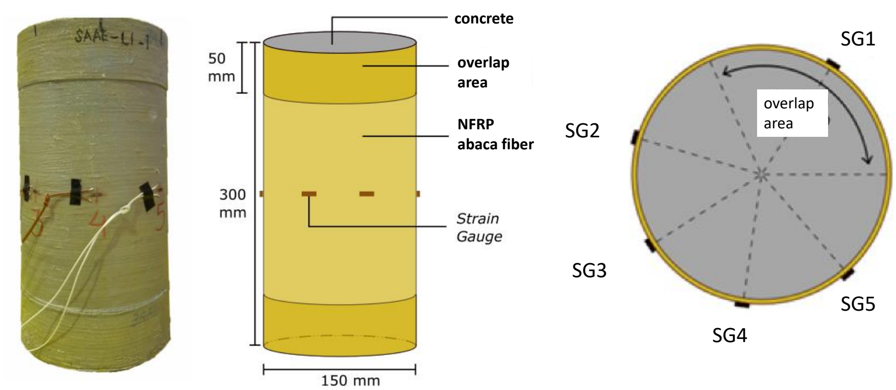
(a) (b) (c) (d)

Figure 2. Fabricated NFRP-confined concrete process

The drying process was carried out on the NFRP-confined concrete specimens by leaving the specimens in a dry place for 3 days. As conducted in the controlled specimens, five strain gauges at mid-height of the specimen for measuring longitudinal strain were applied, as can be seen in Figure 3.



(a) (b)

Figure 3 Specimen detail of NFRP-confined concrete: (a) side view (b) top view

Parameter Study

A detail of the experimental design is shown in Table 2. A different number of NFRP layers was investigated. A specimen without any strengthening was also prepared in order to compare the results.

Table 2. Parameter of the study

No.	Specimen	Strengthened type	Number of NFRP layer
1	B-SAAE-L1	NFRP jacketing	1
2	B-SAAE-L2		2
3	B-SAAE-L3		3
4	BN	Without any strengthened	-

Mechanical Properties of Single Abaca Fiber

The tensile strength test of a single abaca fiber was conducted in Ecology and Ethnobiology Research Center, Cibinong, Bogor, by using a Universal Testing Machine Shimadzu AGS-X serial 5 kN. The specimen was prepared based on (ASTM D3822) standard, which can be seen in Figure 4. The mechanical properties of this single abaca fiber are presented in Table 3.

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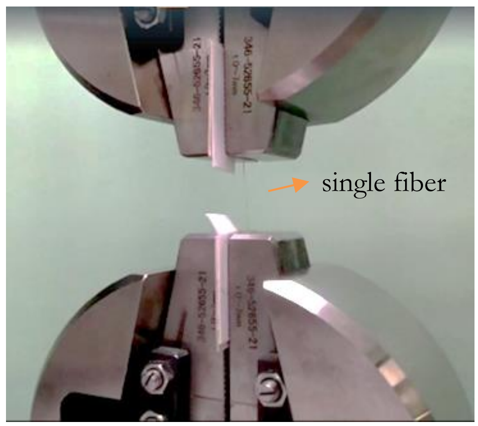
(a)

(b)



(c)

Figure 4. Single fiber specimen: (a) Single fiber (b) Specimen preparation for testing (c) Specimen testing

Table 3. Material properties of single abaca fiber

No.	Specimen	Diameter	Tensile strength	Tensile strength average	ε Max	ε Max average	E	E average
		mm	MPa	MPa	%	%	MPa	MPa
1	Abaca 1	0.14	1231.2	1760.2	4.28	3.74	17870.4	41381.5
2	Abaca 2	0.11	2202.4		3.83		50516.6	
3	Abaca 3	0.10	1847.0		3.12		55757.4	

Mechanical Properties of NFRP

The properties of the unidirectional abaca fiber sheets used for tube fabrications are provided in Table 4. Fabrication of NFRP from abaca fiber sheets was conducted in the same manner in the previous study of this research series (Saidi *et al.*, 2022). Abaca fiber was impregnated by using thermosetting resin as its matrix. The study by Purboputro & Harianto (2017) stated that to achieve load distribution properly, and the fiber must adhere to the matrix used and be compatible. The composition of the epoxy resin as the matrix in the production of NFRP composite material was made of two components which were resin and hardener, by a 1:4 ratio. The Abaca fiber sheet and fabrication process of NFRP can be seen in Figure 5. The tensile strength test was conducted in Ecology and Ethnobiology Research Center, Cibinong, Bogor by using Universal Testing Machine Shimadzu AGS-X serial 5 kN. The specimen was prepared based on (ASTM D638) standard which can be seen in Figure 6.

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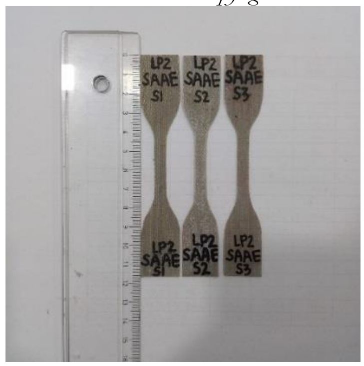
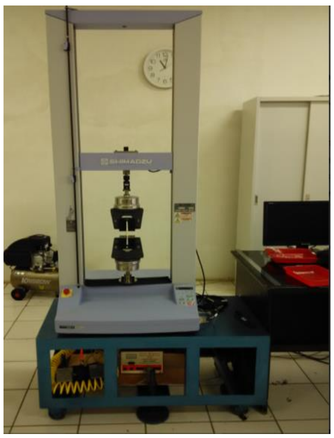


Figure 5. Detail specimen of NFRP sheet



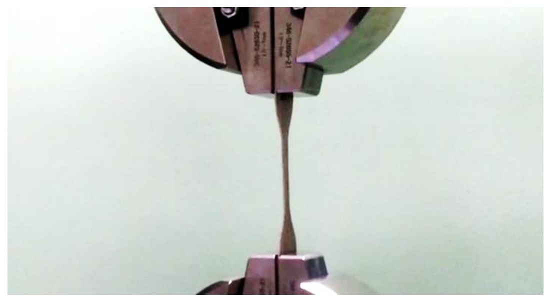


Figure 6. NFRP sheet testing

Table 4. Material properties of abaca composite

No.	Specimen	Tensile Strenght	Average	ε Max	Average ε Max	E	Average E
		MPa	MPa	%	%	GPa	GPa
1	LP1-SAAE-S1	36.25	42.04	1.24	1.24	3.23	4.15
2	LP1-SAAE-S2	50.57		1.49		4.31	
3	LP1-SAAE-S3	39.29		0.98		4.90	
4	LP2-SAAE-S1	47.25	57.84	1.29	1.43	4.81	5.41
5	LP2-SAAE-S2	55.81		1.28		5.64	
6	LP2-SAAE-S3	70.47		1.73		5.77	
7	LP3-SAAE-S1	69.67	67.80	1.56	1.54	5.92	6.14
8	LP3-SAAE-S2	64.38		1.53		5.88	
9	LP3-SAAE-S3	69.36		1.52		6.63	

Testing Procedure

The compressive strength test of NFRP-confined concrete was conducted by applying an axial load to the concrete. The test was carried out using a load cell which was pumped using a hydraulic jack with a loading rate of ±0.184 tons/second. In order to measure the axial strain of the specimen, three LVDTs were placed, as can be seen in Figure 7, while lateral strain was obtained by strain gauges applied on NFRP-confine concrete surface.

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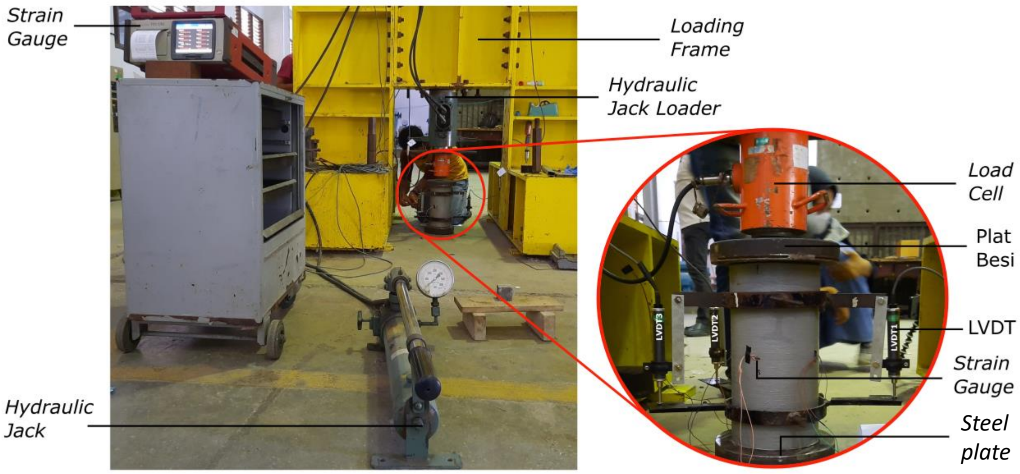

Figure 7. Compressive test of specimen

Results

The results obtained from the compressive strength test of NFRP-confined concrete with a concrete strength of 33.28 MPa can be seen in Table 5. The stress-strain relationship can be seen in Figure 8. The compressive strength test results of NFRP-confined concrete are maximum load and NFRP-confined concrete compressive strength for variations in fiber layers.

Table 5. Compressive strength test of NFRP-confined concrete results

No.	Specimen	Maximum Load	NFRP-confined concrete strength
		ton	MPa
1	B-SAAE-L1-1	80.65	44.77
2	B-SAAE-L1-2	69.34	38.49
3	B-SAAE-L2-1	80.89	44.91
4	B-SAAE-L2-2	74.20	41.19
5	B-SAAE-L3-1	79.34	44.04
6	B-SAAE-L3-2	82.20	45.63

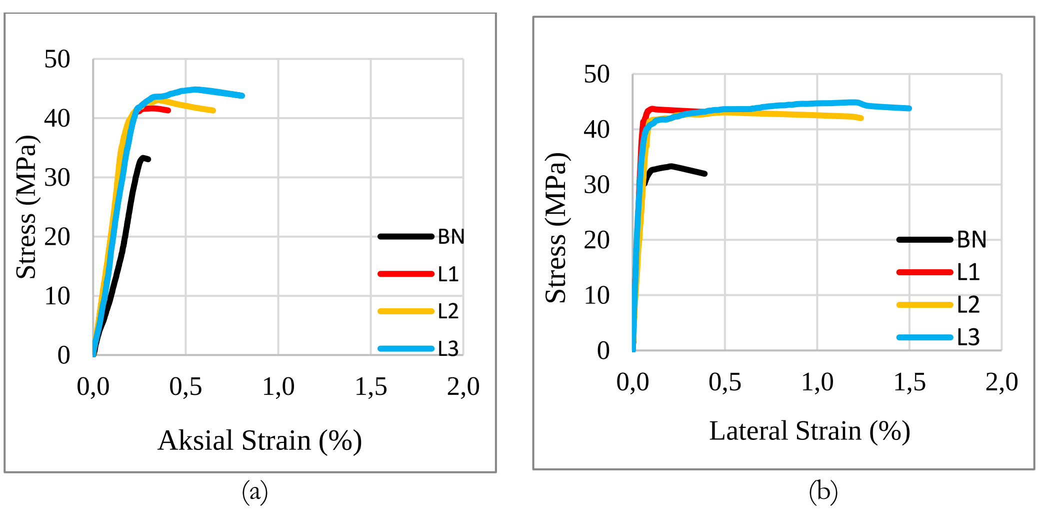

Figure 8. Stress-strain relationship of NFRP-confined concrete: (a) axial strain dan (b) lateral strain

Based on Table 5 of compressive strength test results for NFRP-confined concrete, the average of one-layered NFRP-confined concrete, two-layered NFRP-confined concrete, and three-layered NFRP-confined concrete are 41.63 MPa, 43.05 MPa, and 44.84 MPa, respectively. Figure X describes that in the elastic region, the stress-strain behavior of NFRP-confined concrete is linear. It is similar to stress-strain behavior in

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unconfined concrete. In the plastic region, the curve shows a nonlinear transition where cracks propagate in the concrete core and lateral expansion of the concrete increases.

Discussion

Contribution NFRP as Confined Concrete Materials to Compressive Strength

The compressive strength test results of NFRP-confined concrete are shown in Table 6. Concrete compressive strength increases with the increase in the number of layers of abaca fiber NFRP. Compared to the controlled specimen, the greatest improvement in compressive strength is 34.73% for three-layered NFRP-confined concrete. After cracks propagate in the plastic region, as can be seen in Figure 8, NFRP begins to work by limiting the concrete core, which can lead to an increase in compressive strength. It denotes that the use of NFRP as a strengthened material of confined concrete contributes to compressive strength.

Table 6. Comparison of NFRP-confined concrete Compressive Strength with controlled specimen

No.	Specimen	Compressive Strength	Percentage Increase
		MPa	%
1	BN	33.28	0.00
2	B-SAAE-L1	41.63	25.10
3	B-SAAE-L2	43.05	29.35
4	B-SAAE-L3	44.84	34.73

Number of NFRP Layer Effects to Compressive Strength

Based on Table 6, the increase of compressive strength for each number of layers of NFRP was calculated. The increase in the compressive strength of two-layered NFRP (B-SAAE-L2) against one-layered NFRP (B-SAAE-L1) is 3.41%, while three-layered NFRP (B-SAAE-L3) against one-layered NFRP (B-SAAE-L1) is 7.71%. The compressive strength of concrete increases with the increase in the number of layers of NFRP as the tensile strength is higher with a higher number of NFRP layers. However, it is not that significant compared to the increase of tensile strength results with a higher number of NFRP layers in Table 4. It could be happened due to the fabrication of NFRP used in the cylindrical concrete being different from the fabrication of NFRP in the tensile strength specimen.

Failure Mode of NFRP-confined concrete

The failure mode that occurred in the test specimen of NFRP-confined concrete can be seen in Figure 9. The failure mode for NFRP-confined concrete with an overlap length of 150 mm and 90 mm is a sudden explosion. There are no debonding failures that occurred in NFRP-confined concrete. Failures that occur are characterized by vertical rupture of the NFRP. The location of the overlap position also greatly influences the failure mode.

Figure 9. The failure mode of NFRP-confined concrete

Conclusion

NFRP-confined concrete, by using abaca fiber, increases the compressive strength of concrete. Compared to the controlled specimen, the highest percentage increase in compressive strength was 34.73% for three-layer of the abaca fiber NFRP. The contribution of one-layer and two-layer of abaca fiber NFRP in concrete

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compressive strength compared to the controlled specimen was 25.10% and 29.35%, respectively. A different number of abaca layers used in the NFRP-confined concrete has a slight effect on its compressive strength NFRP-confined concrete failure was a brittle failure which sudden explosion of NFRP and concrete at the same time. Based on the study's results, it can be concluded that abaca fiber has the potential strength to be used as an NFRP material to provide a confining effect on concrete. Further study should be conducted by developing a parameter study and using displacement control in the testing method.

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