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The Impact of Fiber Density and Layering in NFRP on Confined Concrete Compressive Strength

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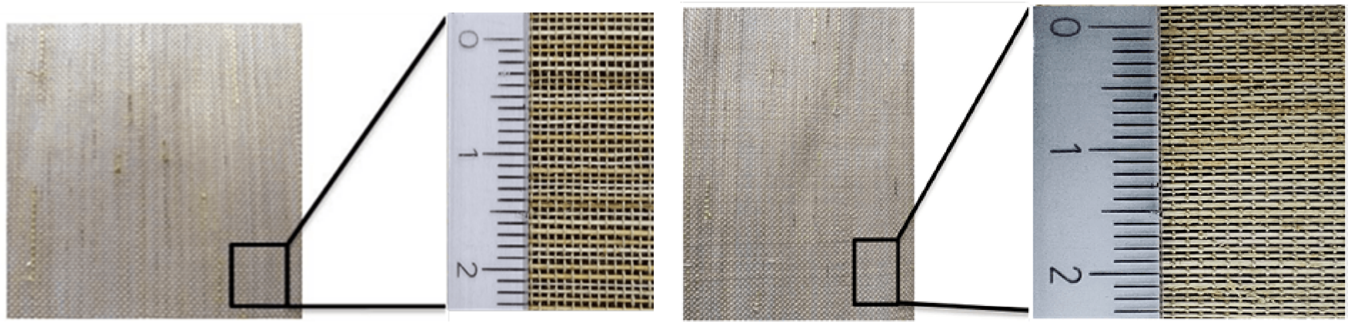
ABSTRACT Strengthening columns hold a crucial role in structural engineering and are frequently called for due to a range of factors, including heightened load requirements, structural degradation, design flaws, or the need for seismic retrofitting. Natural Fiber-Reinforced Polymers (NFRP) in concrete reinforcement has gained significant attention in recent years as a sustainable and eco-friendly alternative to strengthened reinforced concrete. NFRP jacketing presents an adaptable option, as it delivers an improved load-carrying capability as a confining effect. This paper explores the fundamental reasons behind the need for column strengthening and the advantages of employing NFRP jacketing as a preferred method. The study examined the influence of varying fiber densities and the number of fiber layers in NFRP on the mechanical properties of concrete, with a specific focus on its confined concrete compressive strength. The test specimen was a cylinder with a diameter of 150mm and a height of 300mm. NFRP, made from abaca fiber and resin, was attached around the specimen's circumference to provide a confinement effect. Axial load was applied to the test specimen. The findings indicated that introducing abaca fiber as an NFRP material increased confined concrete compressive strength by up to 37% compared to unconfined concrete. Additionally, the research offered valuable observations regarding the influence of varying the number of NFRP fiber layers on the behavior of confined concrete. Specifically, the study found that altering the number of layers, such as utilizing three layers of NFRP fibers, resulted in a measurable enhancement of approximately 15% in the stress experienced by the confined concrete specimen. Study findings suggest that natural fiber density and the number of layers play a role in enhancing concrete strength, however, their influence may not be significantly pronounced.

KEYWORDS Abaca Fiber; NFRP; Confined Concrete; Fiber Density; Natural Fiber

1 INTRODUCTION

The reinforced concrete (RC) column is a principal element in the RC structure that withstands axial compression load. However, the RC column may experience loss of strength due to seismic loading, corrosion of the reinforcement, and other reasons that can cause reinforced concrete column structures to suffer damage and deterioration (Balla et al., 2023). Strengthening the RC column is often required to enhance the performance of the column. The use of Fiber-Reinforced Polymers (FRP) for strengthening beams in flexural and shear performance is already well-accepted as a strengthening material that has been studied over the past few decades (Grace et al., 2000; Rizkalla et al., 2003; Barros et al., 2007; Belarbi and Acun, 2013; Balla et al., 2023). The mechanical properties of FRP material as a fundamental knowledge have been studied for many years. It has high tensile strength. A previous study (Grace et al., 2000) found that CFRP and GFRP laminates had a tensile strength of 310 MPa to 2937 MPa with a different type of epoxy used and fiber orientation. On the other hand, Mensah et al. (2020) studied BFRP and found that its tensile strength was 681.50 MPa. Besides its advantages related to strength, artificial FRP is associated with negative environmental consequences.

These days, the use of natural fiber as FRP material has been widely studied as an effort to utilize natural products and reduce negative effects on the environment (Wambua et al., 2003; Ku et al., 2011; Chen et al., 2020; Yinh et al., 2021; Hussain et al., 2022; Saidi et al., 2022). Natural fiber has the potential strength to be utilized as a strengthening material in the construction industry. Tong et al. (2017) completed a review related to natural fiber tensile strength, and it was found that sisal, kenaf, jute, and bamboo have tensile strengths of 1450-1500 MPa, 1300 MPa, 1400 MPa, and 910 MPa, respectively. A study by Nwankwo and Ede (2020) used kenaf fiber for flexural strengthening of RC beam with a cross-section



(a) Non-dense abaca fiber

(b) Dense abaca fiber

Figure 1 Type of abaca fiber

of 240 mm x 125 mm and 1860 mm in length. Kenaf fiber was attached at the bottom side of the beam. The study found that ultimate load increases and reduces beam deflection. Alam and Al Riyami (2018), used kenaf and jute FRP laminate for shear strengthening RC beam with a cross-section of 150 mm x 300 mm and 2300 mm in length. The results show that a maximum load increase of 35-36% with a tensile strength of kenaf and jute laminates was 131 MPa and 136 MPa respectively. The use of natural fiber as FRP material was also investigated on confined concrete strength (Rahman et al., 2018; Jirawattanasomkul et al., 2019; Wang et al., 2020; Saidi et al., 2023). Rahman et al. (2018), found that in confined concrete cylinders, jute exhibits a fairly good ductile performance in low-strength concrete but does not notably enhance the column strength, and the ductility is notably reduced, particularly for high-strength concrete. However, (Jirawattanasomkul et al., 2019) found that jute fiber was effective and appropriate for improving the confined concrete strength by up to 42%. This shows that the strength of FRP using natural fibers as a composite material as FRP material still greatly varies. (Ku et al., 2011) stated that the strength of FRP made from natural fibers depends on the interfacial adhesion between the matrix and the fibers. The type of resin used in the matrix affected the strength of FRP with natural fiber-based (Grace et al., 2000; Saidi et al., 2022). Therefore, studies regarding the use of natural fibers as FRP composite materials for structural strengthening still need to be explored. This study aims to investigate the use of abaca fiber (Musa Textilis), a natural leaf fiber species of banana grown, as an FRP composite material to confine concrete, varying in fiber density and the number of NFRP layers.

2 METHODS

2.1 NFRP

In this study, NFRP was fabricated from abaca fiber and epoxy resin. Two types of abaca fiber related to its densities, dense and non-dense abaca fiber, were used, as seen in Figure 1. The dense abaca fiber was 24% denser than the non-dense abaca fiber. Abaca fiber was produced in the fabric industry in Surakarta, the Center of Java. Both dense abaca fiber and non-dense abaca fiber had the same diameter of 0.1 mm.

Table 1. Parameter study and mechanical properties of NFRP sheet (Strengthened type: NFRP jacketing)

No.	Specimen	Fiber type	Number of NFRP layer	Tensile strength (MPa)	Elastic Modulus (GPa)	e Max (%)
1	AAE-L1	Non-dense fiber	1	42.04	4.15	1.24
2	AAE-L2		2	57.84	5.41	1.43
3	AAE-L3		3	67.80	6.14	1.54
4	ABE-L1	Dense fiber	1	60,42	5.73	1.37
5	ABE-L2		2	82.65	7.39	1.64
6	ABE-L3		3	67.81	6.11	1.57

The matrix in the NFRP composite material was epoxy resin and hardener with a 1:4 ratio. Sikadur 330 was used for the resin in this study. NFRP was produced by using the manual hand lay-up method. The detailed procedure for applying NFRP to the cylinder concrete specimen was explained in (Saidi et al., 2023). It was important to note that NFRP for each type of abaca fiber had three different numbers of the abaca fiber layer. Table 1 shows the parameters of the study. Tensile strength and modulus elastic for each specimen type were obtained by conducting a tensile test using a Universal Testing Machine Shimadzu AGS-X series 5 kN in Ecology and Ethnobiology Research Center, Cibinong, Bogor. Mechanical properties of NFRP were determined by using three specimens of NFRP sheets for each specimen type based on ASTM D638 standard.

2.2 Concrete

Ordinary Portland Cement was used in this study. The maximum aggregate diameter was 31.5mm, and the water-cement ratio was 0.45. The compression strength of concrete was obtained by testing concrete cylinders 150mm in diameter and 300mm in height. Concrete was made using a mix design with cement: fine aggregate: coarse aggregate was 1: 2.18: 2.18 in ratio.


(a) sample of cut abaca fabric for LP2 specimen
(b) wrapping process of abaca fabric continuously
(c) applied resin gradually
(d) NFRP confined-concrete cylinder

Figure 2 Fabricated NFRP-confined concrete process

2.3 Experimental Programme

A concrete cylinder with 150mm in diameter and 300mm in height was used in this study. Concrete cylinders were cured for 28 days in a water tank. NFRP was wrapped on the surface of the concrete cylinder circumference after curing time before conducting the compression test, which was meant for confining the concrete. The direction of the abaca fiber was wrapped on the cylinder as in Figure 1 (the horizontal direction of the abaca fabric had more strands). It was important to note that the same compound of resin and hardener used in fabricating NFRP sheets for tensile test specimens was used. Abaca fabric was cut based on the desired length according to the number of layers as mentioned in Table 1. The wrapping process was continuously conducted by gradually applying the resin, as seen in Figure 2. To make the concrete cylinder failure focus at the center of the specimen, another NFRP, which was 50 mm in length, was attached along the circumference of concrete at the top and bottom concrete as an overlap area, as seen in Figure 3.

A total of 18 confined-concrete cylinders, three for each of the specimens shown in Figure 1, and three concrete cylinders without any strengthening as controlled specimens were prepared. Five strain gauges were attached to the specimen's mid-height to capture the lateral strain of the concrete cylinder, as seen in Figure 3. LVDT was also used in the test to record axial strain. The test was carried out by applying axial compression load using a load cell and hydraulic jack. An increment of load and strain was recorded, and a failure pattern was also observed.

3 RESULTS

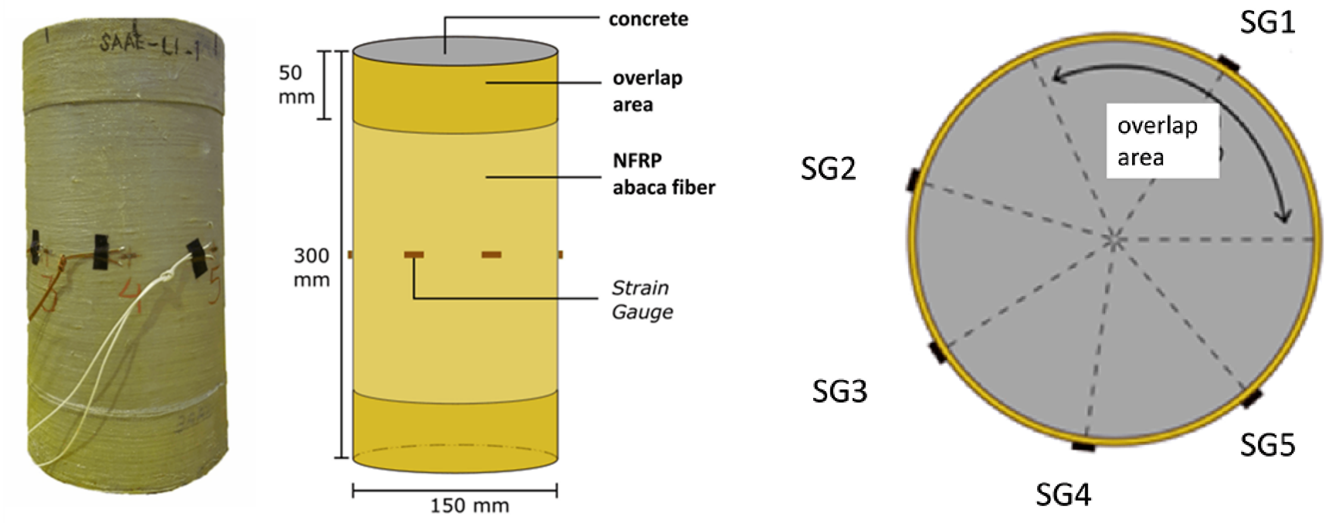
3.1 Maximum load and Compressive strength

Table 2 shows the compression test results for both the confined-concrete cylinder and the controlled specimen. It shows that the highest compressive strength value is obtained by the test specimen with three layers of NFRP and with high-density fiber type (ABE-L3), which is 45.53 MPa. The increase in compressive strength, when compared to the unconfined concrete specimen, is 37%. This indicates that using NFRP can increase the compressive strength of concrete. In line with the compressive strength, the maximum load that NFRP confined-concrete specimens can carry increases by approximately 22 tonnes. However, there is an inconsistency in load increment as the number of layers used increases. A specimen using dense fiber of NFRP exhibited inconsistent tensile strength. It can be observed that NFRP with two layers of fiber had higher tensile strength compared to NFRP using one layer and two layers of fiber. It might occur due to insufficient resin distribution during the NFRP manufacturing process and a void forming in the dense abaca fiber NFRP. The previous study (Chen et al., 2020) mentioned that natural fiber can achieve better structural performance, while NFRP laminates were fabricated by vacuum infusion. Similar behavior of tensile strength of dense NFRP sheets was shown (Table 1). There is an inconsistent tensile strength increment as the number of layers used increases. This could be an issue related to the specimen fabrication process which should be studied in the future.

Table 2. Compressive strength test of NFRP-confined concrete results

No.	Specimen	Average maximum Load (tonnes)	Average compressive strength (MPa)	Strength enhancement compare to unconfined concrete (%)
1	AAE-L1*	74.99	41.63	25.09
2	AAE-L2*	77.54	43.05	29.36
3	AAE-L3*	80.77	44.84	34.72
4	ABE-L1	71.01	39.42	18.45
5	ABE-L2	68.75	39.83	19.68
6	ABE-L3	82.13	45.53	37.00
7	Unconfined concrete	59.95	33.28	-

*results of Saidi et al. (2023)



(a) side view (b) top view

Figure 3 Specimen detail of NFRP-confined concrete

3.2 Stress-Strain Relationship

Figure 4 describes the stress-axial strain relationship between dense and non-dense fiber using NFRP for each number of NFRP layers. It can be observed that there is a similar trend for all types of specimens where NFRP confined-concrete specimens exhibit higher stiffness than unconfined specimens. However, there is not a significant difference when considering variations in fiber density. As seen in Table 2, with the same layer number, test specimens using dense fiber of NFRP generally have lower compressive strength than those using non-dense fiber of NFRP, except for specimens with three layers of fibers. However, the increase is insignificant.

The strain that occurs in the test specimen with NFRP confinement indicates that the test specimen is more ductile. The unconfined concrete specimen has a yield strain and ultimate strain of 0.2% and 0.29%, respectively. The yield strain of the test specimen with NFRP confinement is smaller than that of the unconfined test specimen, ranging from 0.11% to 0.19%, with its ultimate strain falling within the range of 0.41% to 0.81%.

When considering its lateral strain, it can be observed from Figure 5 that all types of test specimens exhibit a nearly identical trend. The lateral strain between the NFRP confined-concrete specimens in the elastic region is relatively similar to the unconfined-concrete specimens. However, the NFRP confined-concrete specimens have higher stress due to the lateral constraint caused by the installation of NFRP. When concrete is confined using NFRP wraps, it restricts the lateral expansion of the concrete when subjected to load. This confinement effect increases the load-carrying capacity of the concrete.

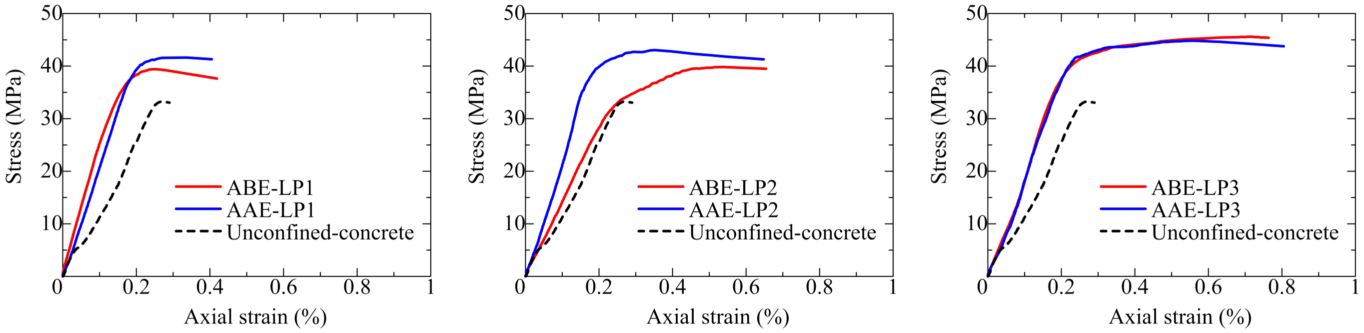
Table 3. Enhancement of confined concrete strength for each study parameter

No.	Specimen	Strength enhancement of dense NFRP to non-dense NFRP for each number of layer (%)	Strength enhancement of dense NFRP compare to single-layer (%)	Strength enhancement of non-dense NFRP compare to single-layer (%)
1	LP1	-5.309	-	-
2	LP2	-7.480	1.04	3.411
3	LP3	1.539	15.500	7.711

4 DISCUSSION

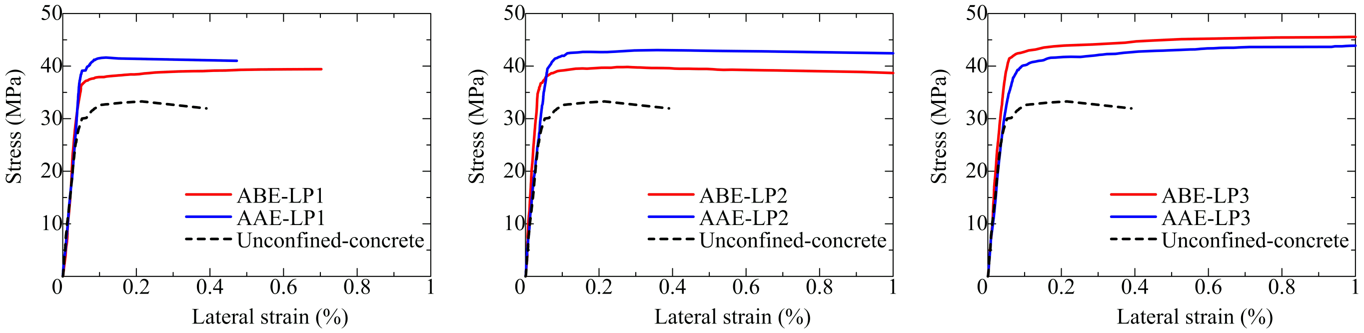
4.1 Fiber Density Effect on NFRP-Confined Concrete Behavior

The influence of fiber density of NFRP used can be described in Table 2, Table 3, Figure 4, and Figure 5. Specimens with three layers of dense NFRP fiber had higher stress than test specimens using non-dense NFRP fibers; the increase was 1.539%. The small increase could be due to the difference in fiber density between the two types of fibers used was also relatively small. Specimens with single and double layers of dense NFRP showed lower stress than test specimens using non-dense NFRP fibers. This result contradicts the results from Table 1, in which non-dense NFRP specimens had lower stress. It might happen due to the NFRP made for the tensile strength test and for wrapping the cylinder specimen was different, leading to different NFRP thicknesses. NFRP for wrapping cylinder specimens should be flexible; thus, it was challenging to control the same thickness and resin distribution. However, the density of fibers used to make NFRP is significant enough to affect the compressive strength of confined concrete test specimens.



(a) single layer of NFRP (b) double layer of NFRP (c) three layers of NFRP

Figure 4 Stress-Axial strain relationship



(a) single layer of NFRP (b) double layer of NFRP (c) three layers of NFRP

Figure 5 Stress-Lateral strain relationship

4.2 Number of NFRP Layer Effects on NFRP-Confined Concrete Behavior

Figures 4 and 5 illustrate the stress-strain relationship for various test specimens with variations in the number of NFRP layers used. The same trend is observed for all types of test specimen variations. The number of fiber layers used in NFRP significantly affects the confined concrete strength, especially for dense NFRP specimens, which can also be seen in Table 3. The concrete compressive strength or stress achieved by test specimens with two layers and three layers of non-dense fiber type NFRP only increases by approximately 3.411% and 7.711%, respectively, compared to the compressive strength of confined concrete using a single layer of NFRP. Test specimens with higher fiber density also exhibit similar results. There is no significant impact on concrete stress and strain with increasing NFRP layers from single to double layers of dense NFRP specimens. The concrete compressive strength or stress achieved by test specimens with two layers only increases by about 1% compared to the concrete compressive strength using a single layer of NFRP. However, for test specimens with three layers of NFRP fibers, there is a 15.5% increase in stress compared to using only one layer of NFRP fibers.

5 CONCLUSION

This study investigated the influence of using abaca fiber in NFRP material by examining fiber density types and the number of fiber layers in NFRP as study parameters. This study concludes that the use of abaca fiber in NFRP material can increase confined concrete compressive strength by 37% compared to unconfined concrete compressive strength. Therefore, using abaca fiber as NFRP material for a confining effect is advantageous. Three layers of dense abaca fiber NFRP can increase confined concrete stress by 15.5% compared to using only one layer of dense abaca fiber NFRP. The number of NFRP layers used in the study affects the confined concrete strength. However, differing fiber densities might not enhance significantly the confined concrete strength. Future studies with more abaca fiber densities need to be investigated, and uniformity of resin distribution should be considered when fabricating the specimens.

DISCLAIMER

The authors declare no conflict of interest.

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