Number of layer effect of abaca fiber as natural FRP material for shear-strengthened reinforced concrete beam

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Abstract. In this paper, an experimental study was carried out to evaluate the number of layer effect of abaca fiber composite as natural reinforced polymer (NFRP) material for shear-strengthened reinforced concrete (RC) beams. Two externally bonded shear-strengthened beams with a different number of NFRP layers and a sound beam as a control beam were prepared. The test was conducted by applying two axial loads on the beam. The results showed that the use of one-layer and two-layer of abaca fiber composite as NFRP material for the shear-strengthened beam increased 9.78% and 9.92% of maximum load compared to sound beam respectively. Abaca fiber composite NFRP material contributed 11% and 18.57% of the total maximum shear load for one-layer and two-layer laminates respectively. In addition, externally bonded shear-strengthened beams affected the crack pattern and deflection value. However, debonding failure of NFRP laminates occurred in two-layer of the NFRP shear strengthened beam. It caused the beam did not work optimally.

1. Introduction

Strengthening of RC structures are one of the major parts of the construction industry nowadays. Environmental factors such as earthquakes and unexpected loading caused by usage changing of structure can affect and reduce the performance of existing RC structures. In [1], shear and flexural failure of RC concrete structures were still majority found due to earthquake in Pidie, Aceh 2016. Therefore, strengthening of existing RC structures come into a major need to improve and extend its service life. This becomes a demand for developing strengthening technology and method to meet environmentally friendly and economical needs.

Strengthening and repairing methods have been developed for shear and flexural performance of the RC structures. One of the methods is using fiber-reinforced polymer (FRP). The use of FRP composite materials externally or internally bond becomes an alternative which has been commonly used in the construction industry for strengthening and repairing RC structures [2-4]. It caused by the advantages of FRP materials, such as high tensile strength, high stiffness, and resistance to environmental damage such as corrosion [5-6]. There have been many studies about the usage and influence of FRP materials on the performance of RC structures. In [7], carbon fiber reinforced polymer (CFRP) can obstruct the initial crack and increase the ultimate load of the RC beam. However, the usage of synthetic materials may affect the environment. Synthetic material is hard to be recycled or reused and may affect human health when production and usage process [8]. Furthermore, synthetic FRP material has a relatively high cost which can be a problem in developing countries, such as Indonesia. It may lead to explore a possible
The usage of natural fiber as a composite material can be an alternative. Natural fiber has high tensile strength, abundant in nature, renewable, light, non-toxicity, and relatively low cost at production [9]. Various natural fibers have been explored and studied to produce a composite material [10-12]. Tensile strength of sisal, kenaf, jute, and bamboo were found to be approximately between 140 MPa to 800 MPa. A few studies have been developed related to the usage of natural composite FRP material for shear and flexural strengthened RC structures [12-15]. Based on these studies, natural fiber is a possible alternative for FRP material.

Although many studies related to the usage of natural composite FRP material for strengthening and repairing RC structures have been conducted, the researches are still at the infancy stage. Moreover, the strength of natural fiber depends on its composition and where it grows. Therefore, this study aims to evaluate the contribution of abaca fiber composite NFRP material for shear-strengthened RC beams.

2. Experimental Programme

2.1. Specimen design and material properties of concrete

The test specimen had a cross-section area of 150 x 300 mm² and length 2200 mm. Figure 1 shows the specimen geometry. The reinforcements used in this study had a yield strength of 448.54 MPa, 457.23 MPa, 487.63 MPa, and 494.56 MPa for the rebar diameter of ø6, D13, D16, and D19 respectively. Specimens were designed to be failed in the shear mode. A total of three specimens were prepared to evaluate the number of layer contribution of abaca fiber composite as NFRP material for shear-strengthened beams. It was included of two shear strengthened beams and a sound beam as a control beam. A detailed study parameter can be seen in Table 1.

The concrete was made using ordinary Portland cement. The mix proportion is shown in Table 2. The maximum used aggregate had a diameter of 19.1mm. The specimens were cured by sealing all its surface using wet fabric and it was watered periodically to keep the humid condition for 28 days. A compressive test of the concrete cylinder was conducted before the loading test of the beam to controlled the concrete quality. The compressive strength of the concrete for BN, BSTV1, and BSTV2 were 44.1 MPa, 38.69 MPa, and 42.79 MPa, respectively.

| No | Specimen | Number of abaca NFRP layer |
|----|----------|----------------------------|
| 1  | BN       | -                          |
| 2  | BSTV1    | 1                          |
| 3  | BSTV2    | 2                          |
Table 2. Concrete mixture proportion.

| W/C (%) | Unit (kg/m³) |
|---------|--------------|
|         | Water | Cement | Sand   | Aggregate | Superplasticizer |
| 43.0    | 203   | 474.5  | 920.9  | 753.5     | 2.7              |

2.2. Fabrication and tensile strength of abaca NFRP laminates

Abaca NFRP laminates were fabricated by hand lay-up method using glass mold. Polyester type Yukalac 157 was used in this study as an adhesive which had resin and hardener. The adhesive ratio between resin and hardener was 1:1. The fiber was pressed gently during the fabrication process to ensure there is no air void inside the laminate. The drying process was 24 hours. Figure 2 shows the fabricated of abaca NFRP laminates.

![Fabricated of abaca NFRP laminates.](image)

Before fixing the laminates on the beam, tensile strength was conducted. A total of three tensile test specimens were prepared based on [16]. The proportion of an abaca NFRP tensile specimen consisted of 1.2 grams of fibers and 4.2 grams of mixed resin and hardener. The results showed that the average of abaca fiber tensile strength and elastic modulus were 54.58 MPa and 3474.34 MPa respectively. The average elongation of abaca NFRP material was 1.58%.

2.3. Shear strengthening of beam specimen

Abaca NFRP were fixed on both side of the beam as shown in Figure 3. One-layer abaca NFRP has a width of 50 mm and length 350mm. The proportion of one-layer abaca NFRP laminate consisted of 3.8 grams of fibers and 13.5 grams of mixed resin and hardener. Abaca NFRP laminates were placed with 150 mm spacing.

Before fixing the abaca NFRP, loose particles at the bonding surface of the concrete beam were removed by using a grinder. Abaca NFRP was directly fixed on the concrete surface by using resin and hardener with a 1:1 ratio. The abaca NFRP layer was exceeded 25 mm for each side of the upper and lower beam, thus the length of abaca NFRP was 300 mm as shear span. The abaca NFRP fiber was pressed to avoid the trapped air inside the laminates. The laminates were set for 24 hours. The test was conducted by applying two axial loads on the beam as can be seen in the Figure 3.
3. Experimental Results and Discussion

3.1. Structural behavior of the shear-strengthened beam

Figure 4 shows the relationship between load and deflection of the beams. It can be seen that the maximum load for BN, BSTV1, and BSTV2 were 26.79 tf, 29.41 tf and 29.45 tf, respectively. Comparing to the sound beam, the maximum load of BSTV1 increased as 9.78% and BSTV2 as 9.92%. The use of abaca fiber composite as NFRP material slightly increases the maximum load. All specimens had almost the same load-deflection behavior. The deflection at the mid-span of the beams also presents in Figure 4. Strengthened beams had higher deflection compare to the sound beam. It is found to be approximately 19.87% and 19.67% higher than the sound beam for BSTV1 and BSTV2, respectively. Higher inclined angle of shear crack results in a high value of deflection [17].

The number of abaca NFRP layer has less effect to the load-deflection behavior. It can be happened due to the debonding of some NFRP laminates of BSTV2, thus the performance of abaca NFRP laminates did not optimal.

Figure 5 presents the stress-strain behavior of flexural reinforcement at the bottom part of the mid-span of the beam. Monitored strain gages is shown as a red dot in the figure. All beams had failed after yielding the flexural reinforcement and had almost the same trend of flexural strain development. The maximum stresses of the flexural reinforcements were 499.08 MPa, for BN and 504.02 MPa for BSTV1 and BSTV2. The yield loads of flexural reinforcement in BN, BSTV1, and BSTV2 were 13.86 tf, 10.03 tf, and 8.31 tf, respectively. Before reached the yield load, an initial flexural crack occurred in the mid-span of the beam. Initial flexural cracks occurred at 6.2 tf, 5 tf and 4 tf for BN, BSTV1, and BSTV2.
respectively. Concrete strength might contribute to the crack initiation development which BN beam had the highest concrete strength.

Similar stress-strain behavior was also found for all beams of shear reinforcement as can be seen in Figure 6. Red dot shows the location of the monitored strain. The maximum stresses of the shear reinforcements were 440.01 MPa, 451.32 MPa, 453.57 MPa for BN, BSTV1, and BSTV2 respectively. It shows that strengthened beams had slightly higher maximum stress. Results showed that initial shear cracks occurred at the loading of 7 tf, 6.4 tf and 6.3 tf. The yield loads of strain reinforcement were 15.83 tf, 19.27 tf, and 19.83 tf, respectively. Strengthened beams showed a delay in shear reinforcement yielding. It happened due to the contribution of abaca NFRP. High number of abaca NFRP layers slightly increases the yield load of shear reinforcement.

Figure 5. Strain behavior of flexural reinforcement.

Figure 6. Strain behavior of shear reinforcement.

Figure 7. Strain behavior of abaca NFRP.

Figure 8. Stress-strain relationship of abaca NFRP.

Figure 7 shows the strain development of abaca NFRP at the same location with shear reinforcement in Figure 6. The strain of abaca NFRP laminates were found to be exceedingly small before the shear crack occurred. The development strain of abaca NFRP laminate accelerated after shear crack initiated as can be seen in BSTV1. This behavior has the same trend as [15]. However, different behavior was found in BSTV2 abaca NFRP laminate. The elongation of abaca NFRP accelerated after the yield of shear reinforcement. Therefore, the number of layers affect the strain development of abaca NFRP. Abaca NFRP laminate showed brittle behavior as can be seen in Figure 8. However, abaca NFRP in both strengthened beams had reached its maximum tensile strength.
3.2. *Abaca NFRP material contribution of the beam internal force*

The load-internal force behavior of the strengthened beam is presented in Figure 9. The calculation of NFRP shear capacity was according to [18]. However, this code is presented for synthetic FRP and may affect the result of NFRP. It was found that the internal shear capacity of shear reinforcement at the strengthened side of the beam was 4.46 ton, while abaca NFRP contributed by 1.69 ton in BSTV1 which was 11% of the total maximum shear load. Meanwhile, from Figure 10, the internal shear capacity of shear reinforcement at the strengthened side of the BSTV2 beam was 4.49 ton while abaca NFRP could carry 2.73 ton which was 18.57% of the total maximum shear load. The contribution of shear reinforcement and abaca NFRP initiate when the first crack occurs. Higher number of abaca NFRP layers gives higher shear capacity due to the increase of the NFRP area.

![Figure 9. Contribution of abaca NFRP in BSTV1 shear capacity.](image1)

![Figure 10. Contribution of abaca NFRP in BSTV2 shear capacity.](image2)

3.3. *Crack pattern and failure mechanism*

![Figure 11. Failure mode and crack pattern of tested beams.](image3)
4. Conclusion

This paper evaluates the number of abaca NFRP layer effect for the shear-strengthened RC beam. The maximum tensile strength of abaca NFRP was 54.58 MPa. Abaca NFRP material contributed 11% and 18.57% of the total maximum shear load for one-layer and two-layer laminates respectively. The abaca NFRP slightly increased the shear capacity of the RC beam. However, debonding failure of abaca NFRP was found in BSTV2 specimen, thus might be affected the results. The study showed that a shear-strengthened beam with higher number of abaca NFRP layers can reduce the number of cracks.

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