An experimental study on bond strength of abaca fiber as natural FRP material

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Abstract. The use of fiber reinforced polymer (FRP) has been implemented as an alternative for strengthening and repairing methods. Nowadays, the use of natural material for FRP has been developed in order to minimize the disadvantage effects to nature due to synthetic FRP material and economic reason. In this paper, an experimental study was carried out to evaluate the bond strength of abaca fiber as natural reinforced polymer (NFRP) material in reinforced concrete (RC) beams. The test specimen was a beam that had cross-section area of 100 x 100mm² and 300mm length. Single rebar was used in this study with 10mm diameter of rebar. Artificial crack was applied in order to consider the initial crack by using cardboard between the concrete. Two externally bonded strengthened beams with a different type of abaca fiber arrangement, bond length, and thickness were applied on the concrete surface. The test was conducted by applying a tension load on the beam until the specimen reach its failure. The results showed that the bond strength decrease as the bond length becomes longer because the maximum load was almost constant for different bond length. The maximum load was approximately around 4 tf for short and long bond length. The compatibility of abaca fiber and rebar was also monitored. Both abaca fiber and rebar able to stand the load compactly. Abaca fiber composite laminate had a similar trend with rebar at the same location where an artificial crack was made. Furthermore, the arrangement and thickness of the abaca fiber composite laminate affected the results.

1. Introduction
Degradation of RC structures can cause by environmental factors, ages, natural hazards, improper initial design, and maintenance. Strengthening and repairing existing RC structures is a common solution to improve and extend its service life. The use of FRP has been implemented as an alternative for strengthening and repairing methods. However, synthetic FRP material has a relatively high cost and may harm the environment due to its difficulties to recycle. In addition, during the production and application process may affect human health [1]. Therefore, the use of natural fiber has been developing nowadays. The advantages of natural fiber such as high tensile strength, environmentally friendly, light, and non-toxicity make it a possible alternative for FRP material [2]. Furthermore, natural fiber has a relatively low cost at production and easy to find in nature. In [2], various natural fibers were explored in order to know its’ possibility to produce a composite material. The tensile strength of various kinds
of fibers such as sisal, kenaf, jute, and bamboo was found to be approximately 227-700 MPa, 930 MPa, 400-800 MPa, and 140-800 MPa respectively. Meanwhile, abaca fiber has tensile strength of approximately 970 MPa [3]. The strength of natural fiber has a wide range because it depends on the composition of its constituent.

There have been many studies of FRP application in order to update the knowledge [4-6]. Based on their studies, the failure mode of RC structures coupled with debonding failure of FRP laminates. The bond between FRP and concrete is one of the important parts to achieve high load capacity. Some factors contribute to bond strength. Primary considerations include mechanical and physical properties on concrete, epoxy quality, surface preparation, application method, FRP material quality, and bond length [7-11]. Indeed, a number of researchers investigate the bond strength of FRP [12-16]. However, the synthetic material of FRP was used in their studies. Therefore, this study aims to evaluate the performance of abaca fiber composite laminate as a natural FRP material bonded to concrete. Influenced parameters such as fiber arrangement, bond length, and thickness of the laminate were discussed.

2. Experimental programme

2.1 Specimen design and material properties of concrete

The specimen used in this study was a beam with cross-section area 100 x 100mm² and 300mm length. Single rebar was put in the center of the specimen and had a diameter of 10mm. Artificial crack was made by applying cardboard between the concrete, as can be seen in Figure 1. Strain gauges were applied on the abaca fiber composite laminate every 50mm from the artificial crack and on the rebar. A total of six specimens was made in order to evaluate the effect of bond length, the thickness of abaca fiber composite, and abaca fiber arrangement for bond strength of abaca fiber. The detailed study parameter can be seen in Table 1 and Figure 2.

![Figure 1. Specimen geometry.](image)

**Table 1.** Parameter of the study.

| No | Specimen | Abaca fiber arrangement | Thickness of abaca fiber composite (mm) | Bond length (mm) |
|----|----------|-------------------------|----------------------------------------|-----------------|
| 1  | SAA-LP1-L | Randomly (Fig 2a)       | 0.78                                   | 120             |
| 2  | SAA-LP1-S | Randomly (Fig 2a)       | 0.78                                   | 75              |
| 3  | SAS-LP1-L | In the same direction (Fig 2b) | 0.78                                   | 120             |
| 4  | SAS-LP2-L | In the same direction (Fig 2b) | 1.875                                   | 120             |
| 5  | SAS-LP2-S | In the same direction (Fig 2b) | 1.875                                   | 75              |
| 6  | SAS-LP3-L | In the same direction (Fig 2b) | 2.150                                   | 120             |
The concrete was made using ordinary Portland cement. The mixed 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 was 58.33 MPa.

### Table 2. Concrete mixture proportion.

| W/C (%) | Unit (kg/m³) |
|---------|--------------|
|         | Water | Cement | Coarse aggregate | Fine aggregate |
| 43.0    | 228   | 651.43 | 420.17           | 560.23         |

2.2 Fabrication and tensile strength of abaca fiber composite laminates

The hand lay-up method using glass mold was used in this study for fabricating the abaca fiber composite laminate as a natural FRP material. Yukalac 157 was the type of polyester used in this study as an adhesive that 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 3 shows the fabricated of abaca fiber composite laminate.

![Fabricated of abaca fiber composite laminate](image)

**Figure 3.** Fabricated of abaca fiber composite laminate

Before fixing the laminates on the beam, tensile strength was conducted. Tensile test specimens were prepared based on [17]. The results show that the average of abaca fiber tensile strength was 17.023MPa, 14.054MPa, and 15.906MPa for SAA with 0.78mm thickness specimen, SAS with 1.875mm thickness specimen and SAS with 2.150mm thickness specimen, respectively.

Abaca fiber composite laminate was fixed on both sides of the beam, as shown in Figure 1. The laminate had 50mm width and length depends on the designed bond length. Before fixing the abaca fiber composite laminate, loose particles at the bonding surface of the concrete beam was removed by using a grinder. Abaca fiber composite laminate was fixed on the concrete surface by using adhesive Sikadur 330. The laminates were set for 24 hours. The test was conducted by applying tension loads on the beam, as can be seen in Figure 4.
3. Experimental Results and Discussion

3.1 Compatibility of abaca fiber composite laminate and rebar on bond strength

The test results on maximum load and bond strength of abaca fiber composite laminate present in Table 3. All specimens almost had the same maximum load, which resulted in a similar bond strength. The adhesive and resin that was used in the composite laminate affect the strength of natural FRP. In this study, the use of polyester in the matrix composite resulted in a brittle composite material, thus easier to break. It was shown in Table 4 that most of abaca fiber composite laminates had strain yield earlier than rebar. However, the strain yield of SAS-LP1-L and SAS-LP3-L was higher than rebar. The strain yield of SAS-LP1-L and SAS-LP3-L were 61.82µε and 62.88µε, respectively. The homogeneity of resin and fiber in a laminate greatly affects the results.

Table 3. Test results.

| No | Specimen   | Maximum load (tf) | Bond strength (MPa) | Failure mode                   |
|----|------------|-------------------|---------------------|-------------------------------|
| 1  | SAA-LP1-L  | 4.00              | 6.538               | Abaca fiber composite laminate breakage |
| 2  | SAA-LP1-S  | 3.99              | 10.434              | Abaca fiber composite laminate breakage |
| 3  | SAS-LP1-L  | 4.05              | 6.619               | Abaca fiber composite laminate breakage |
| 4  | SAS-LP2-L  | 4.10              | 6.669               | Abaca fiber composite laminate breakage |
| 5  | SAS-LP2-S  | 4.42              | 11.559              | Abaca fiber composite delamination |
| 6  | SAS-LP3-L  | 4.20              | 6.865               | Abaca fiber composite laminate breakage |

Figure 5 shows the load-strain behavior of SAS-LP3-L specimen. Abaca fiber composite laminate had a similar trend with rebar at the same location where an artificial crack was made (SR2). It concluded that abaca fiber composite laminate and rebar were compatible. Strain development of SR1 and SR3 was similar because it had the same location 50mm from the artificial crack while SR4 was located 100mm from the artificial crack. SR2 had higher strain due to its location near the crack.
Table 4. Strain yield of rebar and abaca fiber composite laminate.

| No | Specimen   | Strain yield (µɛ) | Rebar | Abaca fiber composite laminate |
|----|------------|-------------------|-------|-------------------------------|
| 1  | SAA-LP1-L  | 45.05             |       | 38.12                         |
| 2  | SAA-LP1-S  | 18.44             |       | 15.74                         |
| 3  | SAS-LP1-L  | 38.02             |       | 61.82                         |
| 4  | SAS-LP2-L  | 40.23             |       | 34.05                         |
| 5  | SAS-LP2-S  | 43.11             |       | 25.68                         |
| 6  | SAS-LP3-L  | 34.71             |       | 62.88                         |

Figure 5. Load-strain behavior of SAS-LP3-L specimen.

3.2 *Abaca fiber arrangement of composite laminate effect*

Figure 6 shows the load-strain behavior of abaca fiber composite laminate and rebar for SAA-LP1-L and SAS-LP1-L specimens. SAA-LP1-L had higher stiffness compared to SAS-LP1-L. Random distribution of fiber affected the load-strain behavior because most of the load was held by the resin. The consistency of abaca fiber was less in SAA-LP1-L laminate compared to the abaca fiber in SAS-LP1-L laminate, thus made the laminate more brittle than abaca fiber composite laminate in SAS-LP1-L specimens.

Figure 6. Load-strain behavior of a different type of abaca fiber arrangement.
3.3 Bond length effect
Table 3 informed that the bond strength decreases as the bond length becomes longer because the maximum load is almost constant for different bond lengths. Figure 7 presents the load-strain behavior of SAA-LP1 specimen with different bond length. It was found that shorter bond length showed higher stiffness than longer bond length specimen, although the maximum load was almost the same.

![Figure 7. Load-strain behavior of SAA-LP1 specimens.](image)

Strain distribution of SAA-LP1 was shown in Figure 8. In the specimen SAA-LP1 with a bond length of 75mm, the strain distribution shows almost uniform before the abaca fiber composite laminate broke. When applied load is 3tf, the strain increased at 0mm from the crack and linearly decreased at 50mm from the crack. It can be considered that the breakage of abaca fiber composite laminate occurred. In the specimen SAA-LP1 with a bond length of 120mm, strain in the area between 0mm and 50mm had uniform value, and linear distribution is observed in the area between 50mm and 100mm at the early stage of loading. The strain is near to zero as the location far from the crack (100mm). The same behavior was also found in all specimens. Figure 9 shows the strain distribution of SAS-LP3. In the specimen SAS-LP3 with a bond length of 75mm, the strain distribution shows almost uniform at the beginning of loading between 0mm and 50mm. As the load increase, the strain is observed to be increased higher than in the specimen SAA-LP1 at 0mm from the crack and linearly decrease at 50mm from the crack. In the specimen SAS-LP3 with a bond length 120mm, the trend is similar to SAS-LP3-S. It shows that the effective bond length affects the bond strength. The concept of effective bond length is defined through the strain distribution for which the effective bond length is the distance required for the strain to be vanished [12].

![Figure 8. Strain distribution of SAA-LP1 specimens](image)

![Figure 9. Strain distribution of SAS-LP3 specimens](image)
3.4 Thickness of abaca fiber composite laminate effect

Figure 10 shows the load-strain behavior of specimens with different thicknesses of abaca fiber composite laminate. SAS-LP2-L and SAS-LP3-L had higher stiffness compared to SAS-LP1-L. The thickness of the abaca fiber composite laminate affects the load-strain behavior. However, at the early stage of loading, all three specimens were found to be similar behavior.

Figure 10. Load-strain behavior of different abaca fiber composite laminate thickness.

4. Conclusion

This paper evaluates the bond strength of abaca fiber composite laminate as a natural FRP material. Both abaca fiber and rebar could work compatibly when load was applied. It was found that the bond strength decrease as the bond length becomes longer because the maximum load was almost constant for different bond length. Maximum load for different bond length was approximately around 4 tf. Effective bond length is required in order to calculate bond strength. Strain distribution for each specimen had the same behavior. The strain value decreased as the location far from the crack. Furthermore, the load and strain behavior of different arrangement and thickness of abaca fiber composite laminate had the same trend at the early stage of loading. However, the stiffness was changed at around 0.5 tf loading. Thus, arrangement and thickness of abaca fiber composite laminate affect the stiffness of the abaca fiber composite laminate.

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