An Experimental and Characteristic Study of Abaca Fiber Concrete

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Abstract. The natural fibers can be an effective material to reinforce in concrete to improved durability and strength, more compared to effect of synthetic materials on concrete. This study states about the effect of concrete with abaca fiber. The specimens of concrete were cast with the addition of 0.5, 1.0 and 1.5% of abaca fiber and the respective tests were carried out on 7, 14 and 28 days of healing to assess compressive strength, split tensile strength, flexural strength and impact strength. The addition of super plasticizer along with the fiber helped in reducing the water content to match the high water absorption capability of the fiber in the concrete. Among the above mentioned fiber percentage added to the concrete, it was observed that 0.5% gives the maximum compressive strength, which concludes to be the optimum percentage of abaca fiber addition. Optimum percent of abaca fiber was achieved with the split tensile strength, flexural strength and impact strength. Scanning electron microscope and X-ray diffraction analysis was conducted on reinforced concrete with 0.5 percent abaca fiber to test the picture structure and elementary concrete composition.

1. Introduction
The conventional concrete (CC) is low in flexure strength and resistant to deflection. It was found that the crack formation formed in the concrete was the reason for the lack of energy. These properties can be improved in the concrete by adding fiber which has a function to bridge across cracks. [1]. Abaca also called as Manila hemp which is a natural fiber belongs to the banana family of plants in Philippines. It is considered as one of the strongest of the fibers that is naturally available. It undergoes extraction from the leaf sheath through stripping by manual or mechanical method and is then washed and dried for further use [2]. Abaca plants are grown on a large scale and the waste product of the cultivation is extracted as fiber, without any additional cost involved, where these abaca fiber (AF) has been used as a raw material for manufacturing a large number of products like, ropes, tea bags, and etc. [3].
Abaca also called as Musa textile is a natural fiber with high tensile strength which is due to the architecture of the cell walls. The chemical composition includes cellulose (56-68%), hemicellulose (19-25%), lignin (5-13%), pectin (0.5-1%), lipid, cuticula (0.2-3%) and water content of 1.4% [3 and 4]. It possess great influence on some of the mechanical properties such as fire resistance, water absorption and bio degradability [5 and 6]. Cellulose is an important component for the strength and stability of the cell fibre. This is solid, strongly crystalline and dissolves not in organic solvents. This was also used in silk paper and in other utilization [7 - 10]. That existence of organic matter and cellulose affects the fibre's versatility[5, 11].As it contains 15% of lignin, it exhibits high stiffness compared to other fibers. It also possesses high cellulose content which is responsible for the high tensile strength of the fiber. Many fibers have been used to enhance the property of concrete, but most of them have been synthetic which has adverse effect on nature. However, the use of AF has shown a positive improvement in the strength of concrete. Being natural it is a best alternative to synthetic fibers. The organisation of the paper involves with abstract, introduction, experimental investigation, result and discussion and conclusion.

2. Experimental

2.1 Materials Used

The AF that has been used in this study was purchased through online from the known source. The AF was delivered in long strips, which were first left to dry in direct sunlight to eliminate any moisture content present. It was then cut into small lengths of 40 mm size as required to be used in the concrete mix. The aspect ratio of the AF was calculated by considering the ratio of the diameter to the length of fiber. The diameter of the AF was measured by recording three values using the screw gauge at the mid as well as at the end section of the fiber. The average value at the mid-section as well as at the end section was found to be 0.32 mm and 0.45 mm. The least of these values was chosen to be the diameter. The aspect ratio fiber used was found to be 104.

The 53 grade ordinary portland cement (OPC) was used with specific gravity of 3.11. The entire cement quantity used for the experiment was within three months from the manufacture date. The processed sand (M-sand) was employed to fine aggregates and aggregates running by 20 mm and being held as a coarse aggregate in 12 mm sieve. The aggregates were thoroughly washed with ordinary water to remove dust particles present on them and were kept for drying under direct sunlight for about 24 hours. The fine aggregates used were graded appropriately to give least void ratio and be free from pernicious materials such as clay, silt and chloride defilement. Fine and coarse mean specific gravity was found to be 2.62 and 2.75 respectively.
2.2 Mix proportion

Design mix of M40 grade was done as concrete mix and the mix proportion was found to be 1:2.2:3.1. The water-cement ratio was taken as 0.4, which was designed with the consideration of the super plasticizer added at 1% to decrease the water content in the design of the concrete mix.

2.3 Cast of specimen's details

The 150 x 150 x 150 mm cube was cast for compressive strength test, the 150 mm diameter and 30 mm height cylinder were casted for split tensile strength testing and the 500 x 100 x 100 mm regular beam was cast for flexural strength testing, respectively. To test the impact strength of concrete, prism of size 100 mm in diameter and 63.5 mm of height was casted.

2.4 Method of Testing

Workability of AFRC and CC was determined using slump cone test and compaction factor test. The slump and consistency of AFRC at various percentages of AF was found and highlighted in Table 1. The test was done according to IS 1199 – 1959 [12]. Analysis was performed on scanning electron microscopic (SEM) to study the texture and orientation of AFRC materials. The study was carried out on the powdered sample of AFRC with 0.5% of AF at 14 and 28 days of curing period as shown in the Figure 4 and 5. The sample provided for the analysis were crushed and finely powdered. The SEM analysis of abaca fibre was also done to study the morphology of the structure of the fiber. The SEM image of raw abaca fibre is show in the Figure 3. It was performed in accordance with ASTM E 2809 – 13 [13].

X-ray diffraction (XRD) analysis was performed on the powdered sample of AFRC with 0.5% of AF at 28 days of curing period. The sample provided for the analysis were crushed and finely powdered. The various diffraction patterns were obtained for the sample and the same is shown in the Figure 6. The obtained results were further studied to find the various components that dominate in the concrete structure. Ultrasonic pulse velocity (UPV) test is indeed a non-destructive test performed to test the consistency of the concrete by calculating the velocity for a high frequency wave made to pass via the material specimen. The corresponding time taken by each ultrasonic pulse to pass through the concrete specimen is measured. It was conducted in accordance with ACI Committee 544.2R-89 [14] and the values of UPV are shown in the Table 1, and the test was conducted according to IS 13311-1 [15]. Rebound Hammer also a non-destructive test was conducted on the concrete specimen after the curing period of 7, 14 and 28 days. This experiment was carried out to provide a simple and quick measure of a concrete specimens' compressive ability. It was carried out in accordance with IS 13311-2 (1992) [16]. The main aim of the test was to find the correlation between the compressive strength and the respective rebound number. Compressive strength experiment was carried out with the goal of finding the optimal amount of AF in concrete. An average of three specimens was taken from a particular batch at every curing period for testing. Cubes was positioned in the testing system for compression, so that the load was transferred to the reverse side of the cast. The study was conducted at 7, 14, and 28 days of concrete curing on the specimens. The research was conducted as per IS 516:1959 [17]. Split Tensile Strength test of the concrete was determined by splitting the cylinder across the vertical diameter, when placed in the compressive testing machine. The samples are positioned horizontally between the plates, and the load before the failure was applied. Pursuant to IS 5816: 1999, the study was performed on the specimens at 7, 14 and 28 days of curing time [18]. Flexural strength testing was conducted as per IS 516-1959 [17]. The beam was tested in the compressive testing unit, and before the malfunction, threepoint loading was applied to the specimen. The study was performed on the specimens at a curing time of 7, 14 and 28 days. Concrete impact resistance was measured by lowering the iron ball over the concrete prism to obtain the specimen's initial and final crack. The study was performed at a curing time of 7, 14, and
28 days. The results obtained in blows were converted in to impact energy. The entire test was performed for a curing duration of 7, 14, and 28 days. The study result of 28 days test, however, were taken for comparison and validation.

3. RESULTS AND DISCUSSION

3.1. Workability

In addition to 0.5, 1.0 and 1.5 per cent of AF, the slump cone test and compaction factor test was performed to determine workability of concrete. These tests were also carried out for CC with 0% AF. The results obtained for the test of the slump cone and compaction factor indicate that the workability for all concrete mix is small. However, the concrete is compacted using table vibrator for preparation of mould.

| Workability          | CC   | 0.50% AF | 1.0% AF | 1.5% AF |
|----------------------|------|----------|---------|---------|
| Slump value (mm)     | 18   | 10       | 8       | 4       |
| Compaction Factor    | 0.819| 0.812    | 0.831   | 0.841   |

3.2. Non-Destructive Testing (NDT)

Ultrasonic pulse velocity (UPV) test was performed for CC and AFRC with 0.5, 1.0 and 1.5% at 7, 14 and 28 days of curing period and the results are shown as a graphical representation in Fig. 3. The 28 days UPV value of 0.5, 1.0 and 1.5% AFRC was 7.86, 7.47 and 6.88 km/sec and CC was 7.65 km/sec. Whereas, 0.5% AFRC has 5% and 7.9% higher than 1.0 & 1.5% of AFRC and 2.7% higher than CC. For CC and AFRC, the rebound hammer test was performed with 0.5, 1.0 and 1.5 percent at 7, 14 and 28 days of healing duration and the findings are shown as a graphical representation in Fig. 4. The 28 days rebound hammer value of 0.5, 1.0 and 1.5% AFRC was 52.96, 48.53 and 40.25 N/mm² and CC was 48.42 N/mm². The 0.5% AFRC has 8.3% and 17% higher than 1.0 & 1.5% of AFRC and 8.5% higher than CC.

![Figure 3. UPV value of AFRC & CC.](image)
3.3. Compressive Strength Test

For CC and AFRC, compressive strength test was performed with 0.5, 1.0 and 1.5 percent at 7, 14 and 28 days of healing time, and the results are shown as a graphical representation in Fig. 5. The 28 days compressive strength value of 0.5, 1.0 and 1.5% AFRC was 49.51, 42.96 and 34.96 N/mm² and CC was 42.04 N/mm². The 0.5% AFRC has 13.2% and 18.62% higher than 1.0 & 1.5% of AFRC and 15% higher than CC. Thus, it can be stated that the addition of 0.5% of AF to the concrete is the optimum value for AFRC.

3.4. SEM Analysis

Fig. 3 show the SEM analysis of AF. It can be observed that the AF has a long, continuous and thorny rough surface. It also has cavities present in it which runs throughout the length of the fiber. The properties possessed by the AF helps it in forming a strong bond with the concrete particles and hence it increases the tensile strength of the concrete. The SEM micrographs of AFRC with 0.5% of AF at 14 and 28 day of curing are shown in Fig. 7 and 8 respectively. From the respective analysis, it can be observed that the non-hydrated particles in Fig. 7 are more in quantity compared to the same in Fig. 8. It can be stated that the bonding between the particles is poor and hence the strength of the concrete is
less. In Fig. 8, it is observed that the non-hydrated particles are reduced and the voids in the sample are lesser in comparison to Fig. 7. Hence, it can be stated that the AFRC sample is strongly bonded and the strength has increased after the 28 day of curing.

![Figure 6. Raw SEM analysis of AF.](image)

![Figure 7. SEM analysis of AFRC at 14 day.](image)

![Figure 8. SEM analysis of AFRC at 28 day.](image)

3.5. XRD Analysis

Fig. 9 shows the XRD pattern of AFRC with 0.5% addition of AF at 28 day of curing period. It is observed that the major crystalline phase is Quartz [ICSD = 01-086-1629] and Anorthite [01-089-1462] corresponding to (1, 0, 1) and (-2, 0, 4) planes at 2θ = 26.686 and 27.885 respectively. The above result states that the major compounds are Silicon Oxide and Anorthite. These compounds are helpful in the hydration process which aids in the C-S-H formation. The other minor crystalline compounds found are Calcium Hydroxide [ICSD =01-081-2040], Calcite [ICSD = 00-005-0586] and Calcium Silicate Hydrate [ICSD = 00-003-0239] corresponding to (1, 0, 1), (1, 0, 4) and (1, 0, 0) planes at 2θ = 34.111, 29.406 and 20.985 respectively.

![Figure 9. XRD analysis of AFRC at 28 day.](image)

3.6. Split Tensile Strength Test

Split tensile strength test was performed at 7, 14 and 28 days for 0.5% AFRC and CC and the results are shown in Fig. 10. The tensile strength value of 0.5% of AFRC split 28 days was 3.28 N/mm² and 3.08 N/mm² of CC. Adding 0.5% of AF to concrete has demonstrated a 6% improvement in AFRC’s split tensile strength relative to CC.
3.7. Flexural Strength Test

The flexural strength analysis was performed at 7, 14 and 28 days for 0.5% AFRC and CC, and the results are shown in Fig. 11. The 28 days split tensile strength value of 0.5% AFRC was 11.75 N/mm² and CC was 10.5 N/mm². The addition of 0.5% of AF to the concrete has shown an increase of 10.6% in the flexural strength of AFRC when compared to CC.

3.8. Impact Strength Test

Impact strength test was performed for 0.5% AFRC and CC at 7, 14 and 28 days and the results are shown in Fig. 12. The initial and final impact energy obtained for 0.5% AFRC at 28 days was 338.13 and 417.69 N.m. similarly, for CC the initial and final impact energy was achieved at 238.68 and 298.35 N.m. from the results 0.5% AFRC has an increase of 29.4 and 28.5% in initial and final impact resistance of AFRC when compared to CC.
4. CONCLUSION

The experimental studies performed on the application of AF in concrete has strengthened the mechanical properties of concrete. The AFRC with an addition of 0.5% of AF has raised the compressive strength by 17.8% compared to the CC and indicates that the optimum percent of AF to be applied to the concrete is 0.5%. The addition of 1.0 and 1.5% of AF has slightly affected the strength of the concrete compared to 0.5% of AF. The SEM image of AFRC at 28 days shows more calcium carbonate precipitate which is the important factor to gain in strength. The other mechanical properties such as split tensile, flexural and impact strength at 0.5% of AFRC shows 6.5, 11.9 and 28.5% higher than CC. in overall AF being natural fibre, it can be used in concrete to improve its mechanical property where instead of using artificial fibres.

5. REFERENCES

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