

Utilisation of Fly Ash and Fibre in Concrete

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Abstract

Strength of fly ash concrete made with 10, 15, 20 % and fibre made with 0.1, 0.15, 0.20 % of cement replacement was evaluated in terms of its relation with compressive strength and workability test. Comparison was made between ordinary Portland cement and fly ash concrete and natural fibre. Test results indicated that strength of concrete having cement replacement up to 15% of fly ash and 0.15% of fibre was comparable to the normal concrete mix without fly ash and fibre. The results confirm that fly ash concrete and fibre concrete is a promising material for long term strength development. This was due to the fact that early age strength of fly ash and fibre concrete was lower as compared to strength of control concrete. From the viewpoint of sustainable development, it is a strongly viable solution as a building material in the years ahead.

Keywords: Cement Replacement, Coconut Coir Fibre, Compressive Strength, Fly Ash, Mix Ratio

1. Introduction

The introduction of fibres is brought in as a solution to develop concrete with enhanced flexural and tensile strength, which is a new form of binder that could combine Portland cement in bonding with cement matrices. Fibres are most generally discontinuous, randomly distributed throughout the cement matrices.

Concrete is acknowledged to be a relatively brittle material when subjected to normal stresses and impact loads, where tensile strength is approximately just one tenth of its compressive strength. As a result for these characteristic, concrete flexural members could not support such loads that usually take place during their service life. Historically, concrete member reinforced with continuous reinforcing bars to withstand tensile stresses and compensate for the lack of ductility and strength. Furthermore, steel reinforcement is adopted to overcome high potentially tensile stresses and shear stresses at critical location in concrete member. Even though the addition of steel reinforcement significantly increases the strength of concrete, the development of micro cracks

must be controlled to produce concrete with homogenous tensile properties. The development of human activity results in environmental degradation. The main challenge is to minimise this degradation to a level consistent with sustainable development¹. For civil engineers, the concept of sustainable development involves the use of high performance materials with reasonable cost with lowest possible environmental impact. The means of achieving it is to consume the waste products in construction industry. Fly ash can be successfully used in concrete due to the numerous advantages over ordinary plain concrete, such as increased compressive strength, improved workability, reduced permeability, reduced shrinkage, less bleeding and more economical etc².

2. Materials

2.1 Fibre Reinforced Fly Ash Concrete

It is well known that concrete is very good in resisting compressive forces, but it is found to be weak against tensile forces. It has the qualities of flexibility and ability

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to redistribute stresses, but it possesses a low specific modulus, a limited ductility and a very little resistance to cracking. The addition of fly ash to concrete further improves its compressive strength but contributes less to improve its other properties like tensile strength, ductility, resistance to cracking...etc³. The potentialities of fly ash concrete can be more exploited by imparting tensile resistance property to it. Investigations carried out by various researchers^{4,5} go to prove that the introduction of discrete uniformly dispersed randomly oriented steel fibres to plain concrete not only improves its resistance against tensile forces, but also imparts greater ductility and delays the onset of first flexural crack. In fly ash concrete composites also, the addition of such ash can improve its resistance against tensile stresses, delay the onset of flexural crack and improve ductility⁶. Thus, the addition of two materials; namely fibres and fly ash results in a new composite called Fibre Reinforced Fly Ash Concrete, which not only shows better resistance to compressive forces but also exhibits substantial resistance to tensile forces⁷.

Fly ash is one of the residues generated in the combustion of coal. Fly ash is generally captured from the chimneys of power generation facilities, whereas bottom ash is, as the name suggests, removed from the bottom of the furnace. Fly ash material solidifies while suspended in the exhaust gases and is collected by electrostatic precipitators or filter bags. Since the particles solidify while suspended in the exhaust gases, fly ash particles are generally spherical in shape and range in size from 0.5 μm to 100 μm . They consist mostly of silicon dioxide (SiO_2), which is present in two forms: amorphous, which is rounded and smooth, and crystalline, which is sharp, pointed and hazardous; aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3).

Table 1. Chemical composition of fly ash

Component	Bituminous	Sub bituminous	Lignite
SiO_2 (%)	20-60	40-60	15-45
Al_2O_3 (%)	5-35	20-30	20-25
Fe_2O_3 (%)	10-40	4-10	4-15
CaO (%)	1-12	5-30	15-40
LOI (%)	0-15	0-3	0-5

2.2 Role of Fibre

Coconut coir fibre contains cellulose, hemi-cellulose and lignin as major composition. These compositions affect the different properties of coconut coir fibres. The pre-

treatment of fibres changes the composition and ultimately changes not only its properties but also the properties of composites. Sometimes it improves the behaviour of fibers but some time its effect is not favourable. The role of fibers is essential to arrest advancing of crack by applying pinching forces at the crack tips, thus delaying their propagation across the matrix and creating a slow crack propagation stage. The ultimate cracking strain of the composite is thus increased by many times compared to that of unreinforced matrix. The introduction of small, closely spaced, randomly oriented fibers transfers an inherently brittle material with low tensile strength and impact resistance into a strong composite with superior crack resistance, improved ductility and distinctive post cracking behavior prior to failure^{4,8}.

Table 2. Physical and mechanical properties of coconut coir fiber

Physical and mechanical properties of coconut coir fibre	
Diameter (mm)	0.12
Length (mm)	40
Young's Modulus (GPa)	4.2
Toughness (MPa)	21.5+-2.4
Density (Kg/m^3)	1104 – 1370
Water absorption saturation	98.3 – 161.0
Elongation (%)	75

3. Present Study

The structural properties of both fiber reinforced concrete as well as fly ash reinforced concrete are well known, and their individual behaviour is also fully understood. In the present study, an effort is made to combine the structural properties of Coconut coir fiber reinforcement with those of cement-fly ash concrete. This would make it possible for a designer to combine the advantages of fly ash, like economically, increased strength, increased workability, reduced voids, etc., with those of fiber reinforcement; namely better resistance against cracking and spalling, higher ductility and well-defined post cracking behaviour.

3.1 Specific Gravity Test

Specific gravity tests were conducted for cement, fine sand and coarse aggregate and following results were obtained:

Specific gravity of cement = 3.13

Specific gravity of fine sand = 2.55

Specific gravity of coarse sand = 2.67

3.2 Mix Design

$$V = W + \frac{c}{Se} + \frac{1}{P} \frac{Fa}{Sfa}$$

$$C_a = \frac{1-P}{P} Fa \frac{Sca}{Sfa}$$

Solving these equations,

$$\begin{aligned} W &= 425 \text{ Kg/m}^3 \\ C_a &= 1163 \text{ Kg/m}^3 \\ F_a &= 535 \text{ Kg/m}^3 \end{aligned}$$

The mix ratio is 1:1.25:2.73 for M30.

3.3 Workability Test

Workability of concrete for various proportion of mix was conducted for fresh concrete and the results shown in the below Table 3.

Table 3. Workability of fresh concrete tests result

Proportion of Concrete	Slump Cone Test	Flow Table Test	Compction Factor Test
NC	70	55.3	0.85
FA ₁₀	95	52.5	0.887
FA ₁₅	118	43.66	0.92
FA ₂₀	135	30.33	0.94
F _{0.10}	62	58.1	0.84
F _{0.15}	57	63.4	0.82
F _{0.20}	48	67.1	0.79
FA ₁₀ -F _{0.10}	83	58.3	0.86
FA ₁₀ -F _{0.15}	73	61.1	0.848
FA ₁₀ -F _{0.20}	65	64.9	0.837
FA ₁₅ -F _{0.10}	115	48.38	0.91
FA ₁₅ -F _{0.15}	105	56.03	0.9
FA ₁₅ -F _{0.20}	89	62.94	0.853
FA ₂₀ -F _{0.10}	123.2	36.215	0.92
FA ₂₀ -F _{0.15}	113	44.115	0.91
FA ₂₀ -F _{0.20}	103.5	50.815	0.88

From above results in Table 3, the chosen w/c ratio 0.45 gives desirable results for all the proposed replacements hence this ratio is used throughout the project to find the mechanical strength of concrete with replacements¹¹.

4. Testing

The compressive strength of replacements is determined

by using cubical moulds of size 150 mm × 150 mm. Specimens are prepared in accordance with Indian Standard Specifications IS: 516-1959¹³. All the moulds were cleaned and oiled properly. These were securely tightened to correct dimensions before casting. Care was taken that there is no gaps left from where there is any possibility of leakage out of slurry.

4.1 Batching, Mixing and Casting of Specimens

A careful procedure was adopted in the batching, mixing and casting operations. The coarse aggregates and fine aggregates were weighed first with an accuracy of 0.5 grams. The concrete mixture was prepared by hand mixing on a watertight platform. The fly ash and cement were mixed dry to uniform color separately.

Similarly the fibre and cement were mixed dry to uniform color separately. On the watertight platform, the coarse and fine aggregates were mixed thoroughly. To this mixture, the mixture of cement, fly ash and fibre was added. These were mixed to uniform colour. Then water was added carefully so that no water was lost during mixing. Nine clean and oiled moulds for each category were then placed on the vibrating table respectively and filled in three layers. Vibrations were stopped as soon as the cement slurry appeared on the top surface of the mould.

The specimens were allowed to remain in the steel mould for the first 24 hours at ambient condition¹². After that these were de moulded with care so that no edges were broken and were placed in the curing tank at the ambient temperature for curing. The ambient temperature for curing was 27 ± 2°C⁹.

4.2 Testing of Specimens

Testing for compressive strength for three different percentages of fly ash replacement (FA 10, 15, 20) and three different percentages of fibre replacement (F 0.10, 0.15, 0.20) for 53 grade of cement are done and the results are tabulated separately for 3, 7 and 28 days of curing¹⁰.

From Table 4 the results show that 10% replacement of fly ash and 0.15% addition of fibre gives the maximum strength in 3 days of curing. Though the combined replacement shows variation in strength without a trend the combination of 10% fly ash replacement and 0.15% of fibre addition shows maximum compressive strength.

Table 4. Compressive strength for 3 days

S.No.	Fly Ash and Fibre Replacement %	Compressive Strength N/mm ²
1	NC	19.2
2	FA ₁₀	20.1
3	FA ₁₅	24.7
4	FA ₂₀	22.5
5	F _{0.10}	22.2
6	F _{0.15}	24.8
7	F _{0.20}	23.4
8	FA ₁₀ F _{0.10}	24.8
9	FA ₁₀ F _{0.15}	25.15
10	FA ₁₀ F _{0.20}	24.9
11	FA ₁₅ F _{0.10}	25.2
12	FA ₁₅ F _{0.15}	26.3
13	FA ₁₅ F _{0.20}	25.3
14	FA ₂₀ F _{0.10}	23.6
15	FA ₂₀ F _{0.15}	25.75
16	FA ₂₀ F _{0.20}	24.7

The 7 days results for compressive strength (Table 5) shows similar trend to 3 days results with only the combinational replacement and addition of fly ash and fiber showing variations and giving maximum compressive strength in higher percentages of replacement and addition (i.e. 20% of fly ash replacement and 0.15% addition of fibre).

Table 5. Compressive strength for 7 days

S.No.	Fly Ash and Fibre Replacement %	Compressive Strength N/mm ²
1	NC	23.7
2	FA ₁₀	26.4
3	FA ₁₅	27.9
4	FA ₂₀	25.3
5	F _{0.10}	27.7
6	F _{0.15}	28.2
7	F _{0.20}	35.3
8	FA ₁₀ F _{0.10}	28.55
9	FA ₁₀ F _{0.15}	29.3
10	FA ₁₀ F _{0.20}	28.3
11	FA ₁₅ F _{0.10}	29.3
12	FA ₁₅ F _{0.15}	31.2
13	FA ₁₅ F _{0.20}	29.05
14	FA ₂₀ F _{0.10}	27.3
15	FA ₂₀ F _{0.15}	29.7
16	FA ₂₀ F _{0.20}	28.9

Final strength results for 28 days (Table 6) for separate replacement and addition of fly ash and fiber shows the similar trend as seen in 3 and 7 days. But the maximum compressive strength is attained by the combinational replacement and addition, and in the percentage of FA₁₅F_{0.15}. The tests were done for M30 mix and hence the expected results were to be more than 30 N/mm². This required strength was attained by all the proposed replacements.

Table 6. Compressive strength for 28 days.

S.No.	Fly Ash and Fibre Replacement %	Compressive Strength N/mm ²
1	NC	31.3
2	FA ₁₀	34.1
3	FA ₁₅	38.7
4	FA ₂₀	34.8
5	F _{0.10}	33.6
6	F _{0.15}	35.3
7	F _{0.20}	32.3
8	FA ₁₀ F _{0.10}	36.4
9	FA ₁₀ F _{0.15}	38.8
10	FA ₁₀ F _{0.20}	36.8
11	FA ₁₅ F _{0.10}	40.2
12	FA ₁₅ F _{0.15}	43.3
13	FA ₁₅ F _{0.20}	41.3
14	FA ₂₀ F _{0.10}	35.2
15	FA ₂₀ F _{0.15}	38.3
16	FA ₂₀ F _{0.20}	37.3

5. Results and Discussion

The variations of compressive strength for various replacements are graphically shown (Figure 1, Figure 2, Figure 3, Figure 4 and Figure 5) indicating the increase of strength by the addition of fly ash and fiber.

Comparing the compressive strength attained by replacement of cement by fly ash on percentages of 10, 15 and 20, the 15% replacement shows higher compressive strength of 1.28 times of the normal concrete strength (19.2 N/mm²) in 3 days, 1.17 times of NC (23.7 N/mm²) in 7 days and 1.23 times NC (31.3 N/mm²) in 28 days.

Comparing the compressive strength attained by addition of fibre on percentages of 0.10, 0.15 and 0.20, the 0.15% replacement shows higher compressive strength of 1.29 times of the normal concrete strength (19.2 N/mm²) in 3 days, 1.18 times of NC (23.7 N/mm²) in 7 days and 1.27 times NC (31.3 N/mm²) in 28 days.

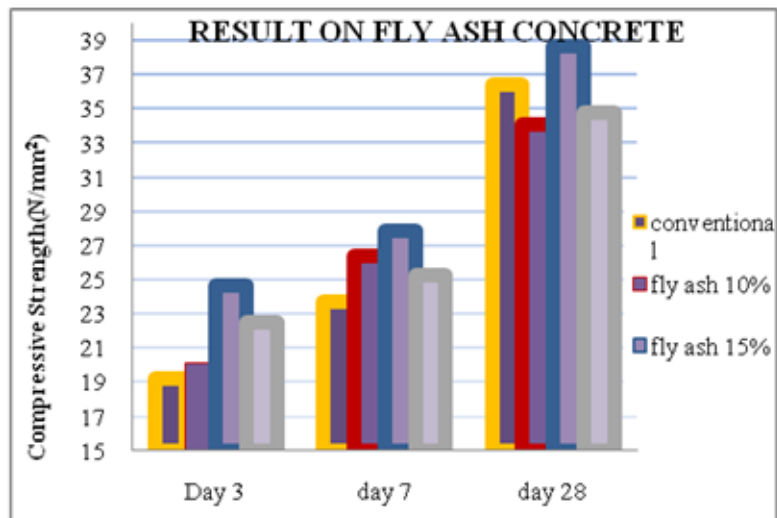


Figure 1. Variation of compressive strength of fly ash concrete.

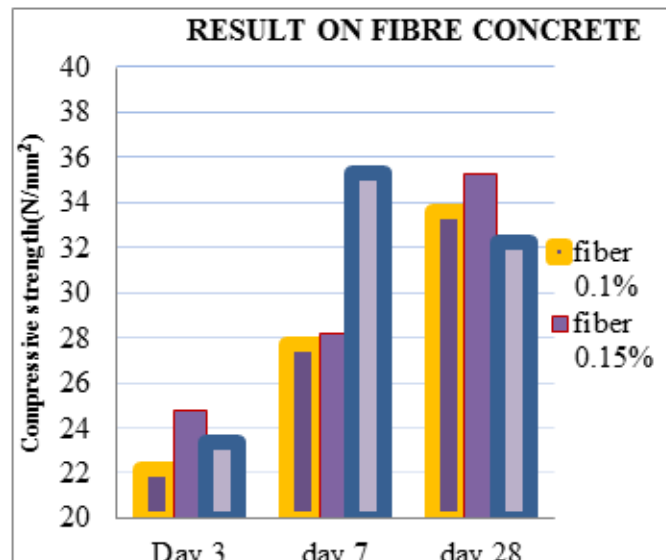


Figure 2. Variation of compressive strength of fibre concrete.

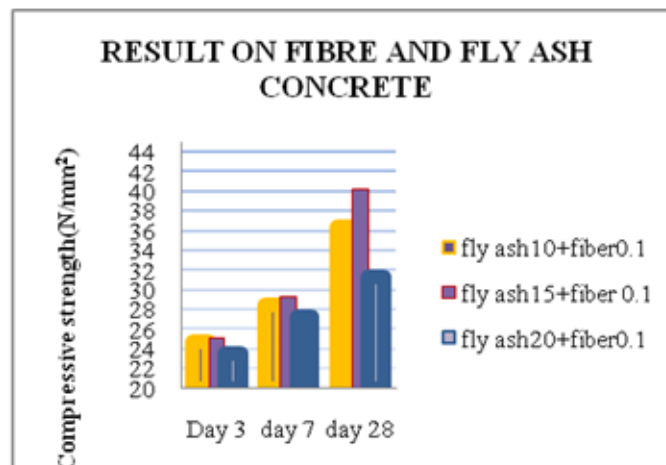


Figure 3. Variation of compressive strength of fibre and fly ash concrete.

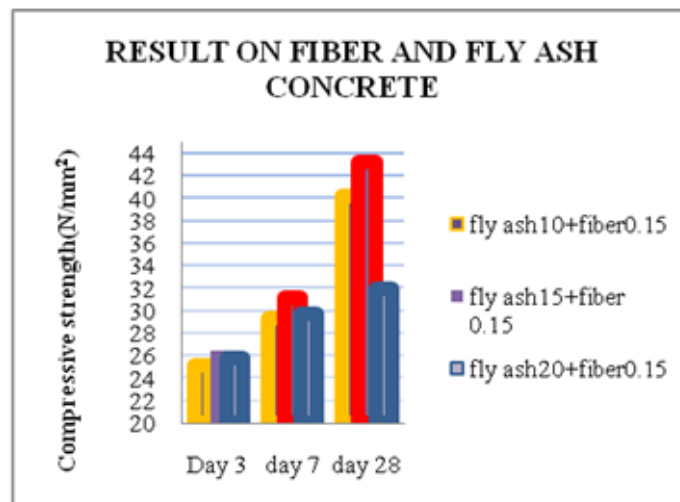


Figure 4. Variation of compressive strength of fibre and fly ash concrete.

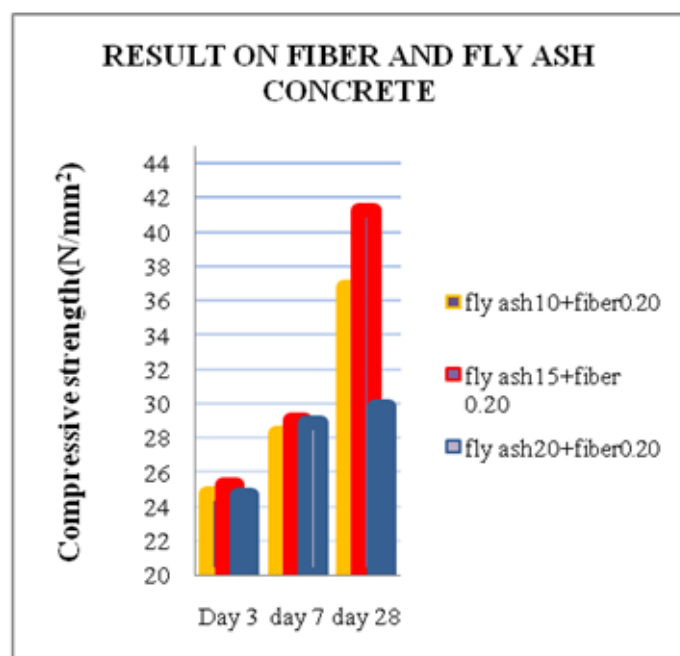


Figure 5. Variation of compressive strength of fibre and fly ash concrete.

Comparing the compressive strength attained by replacement of cement by fly ash in 10, 15 and 20 percentages and fibre on 0.10% addition, shows higher compressive strength at $FA_{15}F_{0.10}$.

Comparing the compressive strength attained by replacement of cement by fly ash in 10, 15 and 20 percentages and fibre on 0.15% addition, shows higher compressive strength at $FA_{15}F_{0.15}$.

Comparing the compressive strength attained by replacement of cement by fly ash in 10, 15 and 20 percentages and fibre on 0.20% addition, shows higher compressive strength at $FA_{15}F_{0.20}$.

The strength of concrete is increase with increase of fly ash because Fly ash chemically react with calcium hydroxide released by the hydration of Portland Cement to form additional calcium silicate hydrate but excess addition of fly ash considered as a waste it was not react with cement so strength reduce. Workability of concrete is increase due to ball bearing effect of addition of fly ash.

The strength of concrete increase with increase of fibre due to inter locking effect and excess addition of fibre it creates voids and decrease strength. Workability of concrete decreases due to the inter locking effect.

6. Conclusions

The experimental study leads the choice of replacement to 15% fly ash and 0.15% fibre in concrete as the results shown by them are higher compared to other replacements. On the other hand considering economical and sustainability factors choosing higher percentages of replacements are recommended. The mix is for M30 hence the strength required to be attained is 30N/mm² and as all the replacements have achieved this, the higher percentage of 20% fly ash and 0.20% of fibre replaced concrete is found to be efficient.

7. References

1. Cindy KE, Saylak D. Reducing greenhouse gas emissions in Texas with high-volume fly ash concrete.
2. Transportation research record. 2005. p. 167–74.
3. Sundarraj M. Study of compact ventilator. Middle - East Journal of Scientific Research. 2013; 16(12):1741–3. ISSN: 1990-9233.
4. Fraay A, Bijen JM. Cement-stabilized fly ash base courses. Cement and Concrete Composites. Elsevier. 1990. p. 279–91.
5. Saravanan T, Saritha G. Buck converter with a variable number of predictive current distributing methods. Indian Journal of Science and Technology. 2013; 6(S5):4583–8. ISSN: 0974-6846.
6. Joshi RC, Duncan DM, McMaster HM. New and conventional engineering uses of fly ash. ASCE TEJ. 1975. p. 791–806.
7. Srivatsan P, Aravindha Babu N. Mesiodens with an unusual morphology and multiple impacted supernumerary teeth in a non-syndromic patient. Indian J Dent Res. 2007; 18(3):138–40. ISSN: 0970-9290.
8. Sundara S, Rajan. Fiber reinforced concrete properties. ACI Journal. 1971.
9. Narayanan R, Palanjian AS. Effect of fiber addition on concrete strengths. ICJ. 1984; 58:100–3.
10. Srinivasan V, Saravanan T, Udayakumar R. Specific absorption rate in the cell phone user's head. Middle - East Journal of Scientific Research. 2013; 16(12):1748–50. ISSN: 1990-9233.
11. Lal AK. Use of fly ash in experimental construction: An appraisal. ICJ. 1992.
12. Almottiri FA. Jordan Journal of Civil Engineering. 2011; 5(2).
13. Kumaravel A, Pradeepa R. Efficient molecule reduction for drug design by intelligent search methods. International Journal of Pharma and Bio Sciences. 2013; 4(2):B1023–9. ISSN: 0975-6299.
14. Sridhar SKS. Fiber reinforced concrete. ICJ. 1971.