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An Experimental Programme on Fibre Reinforced Concrete made with OPC, Fly Ash and Metakaolin

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Abstract*: Most commonly used composite building material in construction industry is Concrete due to ease of construction and its properties like compressive strength and durability. The basic ingredient of Concrete having adhesive nature is Ordinary Portland Cement(OPC). OPC is being replaced with Fly Ash and Metakaolin as these mineral admixtures possess pozzolanic properties which credit for strength gain and cost reduction in concreting. In this investigation, OPC is replaced up to 40% with Fly Ash and Metakaolin for M35 grade of Fibre Reinforced Concrete(FRC). Natural sand is replaced completely with Manufactured sand (M-sand). Steel fibres @ 1% of binder are used. Mechanical properties like compressive strength and split tensile strength at 7 days and 28 days age are tested. Additionally durability tests like water absorption and sorptivity after 28days curing are conducted. The test results indicated that 30% replacement of OPC was optimum for strength criteria, workability of Concrete was decreased with increase in replacement of OPC with Fly Ash and Metakaolin together.

Keywords* : Fly Ash, Manufactured Sand, Metakaolin, Ordinary Portland Cement (OPC), Steel fibres, Sorptivity and Water Absorption.

I. INTRODUCTION

A typical Concrete is composite material composed of binding material, aggregates and water. Widely used binding material in concrete is cement which glues the concrete together and aggregates used acts as filler material in concrete. Demand for cement is drastically increasing in developing countries which leads to more production of cement. This increased demand for production of cement leads to emission of CO_2 which results in global warming. This adverse effect of uncontrolled global warming due to increased production of cement is to be minimised by developing an alternate approach of producing more environmentally friendly Concrete. Environmental friendly Concrete is made by partially replacing the amount of cement in Concrete with by-products materials or mineral admixtures such as Fly Ash and Metakaolin. Further, natural river sand which is used as fine aggregate in Concrete takes a million of years to form and it is not replenishable. Because of its limited supply and disproportionate cost of transportation from natural sources, shortage of good quality of natural sand occurs, causing serious menace to environment as well as the society. Hence, it is proper to replace natural sand with manufactured sand. As the Concrete is brittle in nature and can't resist tensile forces, fibres are used to enhance the tensile strength and to increase the structural integrity of the Concrete. And also cracking due to plastic and drying shrinkage of Concrete can be controlled by making use of addition of fibres in Concrete. In this experimental programme, steel fibres are used @ 1% of binders and an attempt is made to investigate the strength and durability properties of M35 grade of fibre reinforced concrete with partial replacement of OPC with Fly Ash and Metakaolin up to 40%.

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II. MATERIALS

The materials used for present investigation are Ordinary Portland Cement, Fine Aggregate, Coarse Aggregate, Steel Fibres, Fly Ash, Metakaolin, Super Plasticizer and Water. The material properties are discussed below:

A. Ordinary Portland Cement (OPC):

OPC of 53 grade conforming to IS 12269:1987 was used for all the concrete mixes in the present investigation. The properties of OPC are Specific gravity - 3.15, Normal consistency - 32%, Compressive strength - 3, 7, 28 days are 25.3MPa, 36.8MPa, 53MPa respectively, Initial setting time - 65 minutes and Final setting time - 270 minutes.

B. Fine Aggregate:

Locally available Manufactured sand was used as fine aggregate conforming to zone II IS 383:1970. The physical properties like specific gravity and water absorption were tested conforming to IS 2386:1963. The test result of specific gravity is 2.6. The water absorption of Manufactured sand is 2.5%

C. Coarse Aggregate:

Locally available crushed angular aggregate of size 20mm were used conforming to IS 383:1970. The physical properties like specific gravity and water absorption were tested conforming to IS 2386:1963. The test result of specific gravity of coarse aggregate is 2.64. The water absorption of coarse aggregate is 0.5%.

D. Water:
The water used is potable water which is easily available near the lab premises for mixing concrete ingredients and for curing the concrete specimens. The pH value of water shall not be less than 6.

E. Fly Ash:
Class F Fly Ash is the mineral admixture used. Fly Ash is a by-product obtained in thermal plants. It improves workability of concrete it sets slowly thus concrete with fly ash generates low heat of hydration. The properties of fly ash are colour – dark grey, specific gravity is 2.1.

F. Metakaolin:
Metakaolin is an artificial pozzolanic admixture obtained from calcination of clay mineral called kaolin at a temperature of 600 to 800ºc. The specific gravity of Metakaolin is 2.7.

G. Steel fibre:
The fibres used are hooked end steel fibres, which are randomly oriented and having aspect ratio of 40. In this investigation 1% of steel fibres are used in all concrete mixes.

H. Super plasticizer:
Super plasticizer is added to increase the workability of concrete. Master Rheobuild 920SH was used as super plasticizer. The properties of super plasticizer are State - Liquid, Colour - Dark Brown, Density - 1.2, pH - 8.40. IS 9103-1999 has recommended that super plasticizer can be added up to 1 to 2% of binder. In this investigation, super plasticizer used was 1.2% of binder.

III. EXPERIMENTAL INVESTIGATION

A. General
The experimental investigation was done to study mechanical properties such as compressive strength, split tensile strength and durability properties such as water absorption and sorptivity of Fibre Reinforced Concrete of M35 grade. In this study, steel fibres of 1% by weight of binder is used in every mix and replacement of cement is varied by 20%, 30%, 40% with Fly Ash and Metakaolin together for M35 grade of Concrete. The samples were casted and tested at 7 days and 28 days age to study the mechanical properties and at 28 days for durability properties. The following are the tests conducted to study mechanical and durability properties of all the mixes.

B. Compression Test:
The compression test was conducted on cubes of size 150mm x 150mm x 150mm are tested in accordance with IS 516-1969. 3 samples were tested at each of 7 days and 28 days. Each sample consists of 3 specimens.

C. Split Tensile Strength
It is the standard test to determine tensile strength of concrete in indirect way, this test was performed in accordance with IS 5816-1970.

D. Sorptivity Test
Sorptivity measures the rate of penetration of water into the pores of concrete by capillary action. The objective of this test is to determine sorptivity of fibre reinforced concrete of M35 grade as per ASTM C1585. Sorptivity is the cumulative change in volume of water absorbed per unit area against the square root of time. The sorptivity tests were done on cylindrical specimen of size 100mm diameter and 50mm height. After 28 days of curing, the specimens were oven dried at 110º C for 24hrs. The sides of specimens were sealed with electricians tape or sealant. Suction face and the face opposite to it were kept unsealed. The specimens were arranged as shown in the Figure 1 below.

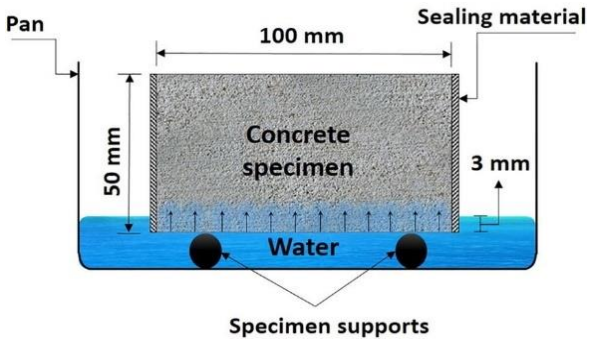

Fig 1: Illustration of Sorptivity Test

The rate of water absorption or sorptivity = K = the slope of I vs √t graph.
'I' value is calculated using the following equation,

$$I = \frac{W}{A \times d}$$

Where, W= the amount of water absorbed in kg, A=area of the cross section of the specimen that is in contact with water, d = density of the medium in which specimen was immersed (1000 kg/m^3 in this case medium is water).

E. Water Absorption
The aim of the test is to determine the total water absorption of fibre reinforced concrete of M30 grade. Concrete cube specimens of 100mm x 100mm x 100mm size were casted and cured for 28 days after the curing period, the specimens were oven dried at 110ºC for 24hrs and then specimens were immersed in water such a way that the height of water above specimen after immersion is 2 cm. The weight of the specimens was recorded at programmed interval and hence, the water absorption was established. At each interval, the quantity of water absorbed with respect to the mass of dry sample is expressed as:

$$M_i\% = \frac{m_i - m_0}{m_0} \times 100$$

Where, m_i = weight of the wet sample at time t; m_o= weight of dry sample.

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F. Mix proportion

The mix proportion of cement, fine aggregate and coarse aggregate for the present study designed as per IS 10262-2009 is 1:2.13:2.86, with water to binder ratio of 0.42.

G. Concrete Mixes

The four types of concrete mixes used are as follows:

i) P1: 100% OPC + Fine Aggregate (M sand) + Coarse Aggregate + Steel fibres @ 1% by weight of binder.

ii) P2: 80% OPC + 10% Fly Ash + 10% Metakaolin + Fine Aggregate (M sand) + Coarse Aggregate + Steel fibres @ 1% by weight of binder.

iii) P3: 70% OPC + 15% Fly Ash + 15% Metakaolin + Fine Aggregate (M sand) + Coarse Aggregate + Steel fibres @ 1% by weight of binder.

iv) P4: 60% OPC + 20% Fly ash + 20% Metakaolin + Fine Aggregate (M sand) + Coarse Aggregate + Steel fibres @ 1 % by weight of binder.

IV. TEST RESULTS

A. Compression Strength

The results obtained in Compression Strength test are represented by histogram vide Fig 2. It was observed that 30% replacement is optimum among all the replacements. The compressive strength is 4.5% more than target mean strength at 28 days.

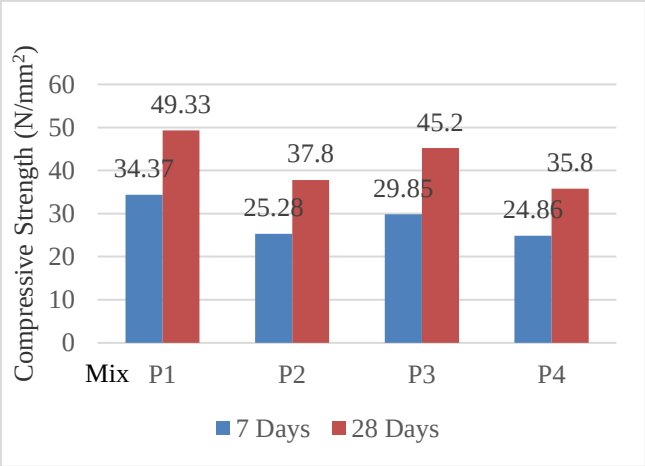

Fig 2: 7 days and 28 days Compressive Strength of concrete mixes P1, P2, P3 and P4

Table-I: 7 days and 28 days Compressive Strength of concrete mixes P1, P2, P3 and P4

Mix	Compressive Strength (N/mm²)	
	7 Days	28 Days
P1	34.37	49.33
P2	25.28	37.80
P3	29.85	45.20
P4	24.86	35.80

B. Split Tensile Strength

Split Tensile test results are represented by histogram vide Fig 3. It is observed that 30% replacement is optimum among all replacements.

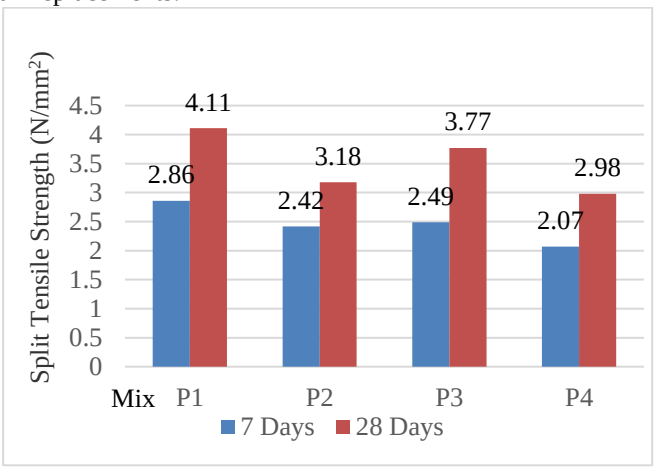

Fig 3: 7 days and 28 days Split Tensile Strength of concrete mixes P1, P2, P3 and P4.

Table-II: 7 days and 28 days Split Tensile Strength of concrete mixes P1, P2, P3 and P4.

Mix	Split Tensile Strength (N/mm²)	
	7 Days	28 Days
P1	2.86	4.11
P2	2.42	3.18
P3	2.49	3.77
P4	2.07	2.98

C. Workability

The slump values for all mixes are represented by histogram vide Fig 4. From this Fig 4, it is observed that workability is decreased with increased replacement of Ordinary Portland Cement.

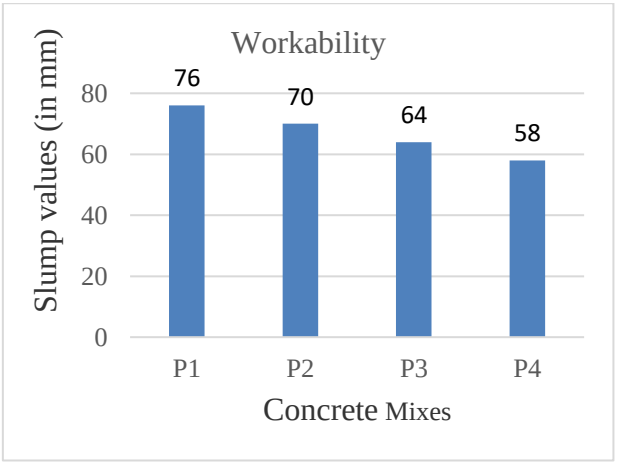

Fig 4: Slump values

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Table-III: Slump values

Mix	Slump (in mm)
P1	76
P2	70
P3	64
P4	58

D. Water Absorption

Results for water absorption test for all mixes are represented graphically vide Fig 5. It is observed that water absorption is minimum for P2 mix.

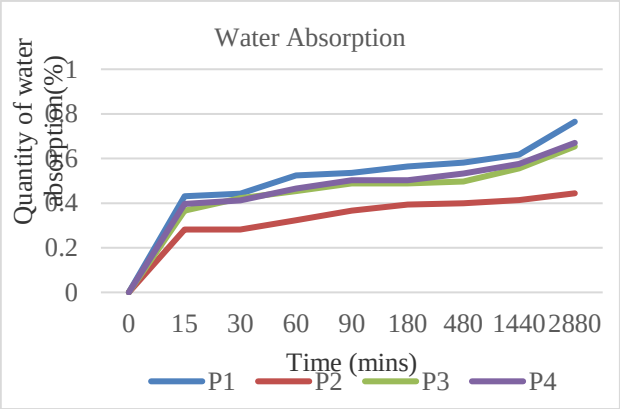

Fig 5: Water absorption values of concrete mixes P1, P2, P3 and P4.

E. Sorptivity

Results for sorptivity test for all mixes are represented graphically as shown in Fig 6. It is observed that rate of water absorption was decreased with increased replacement of Ordinary Portland Cement.

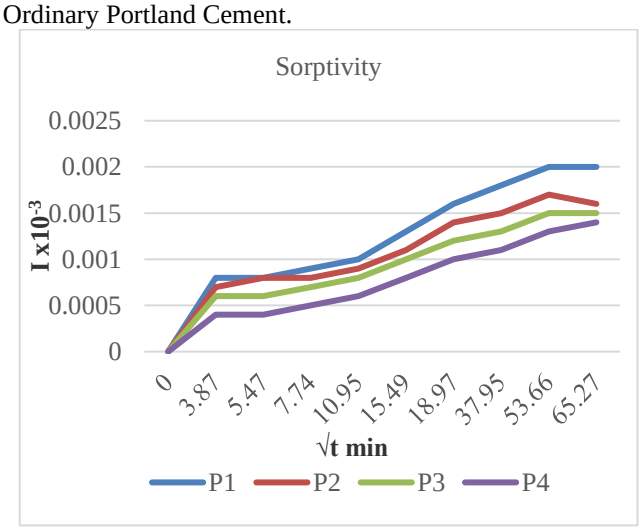

Fig 6: Sorptivity values of concrete mixes P1, P2, P3 and P4

V. CONCLUSIONS

Based on the experimental investigation, the following conclusions are made:

1. The workability of the Concrete was decreased from 76 mm to 58 mm i.e, for the mix with 100% OPC to 60% OPC respectively.
2. In this Study, 30% replacement of Cement was found to be optimum as 28-day compressive strength was about 4.5% more than the target mean strength.
3. The Split Tensile Strength was observed to be maximum when Ordinary Portland Cement was replaced by the Mineral Admixtures to an extent of 30%.
4. The durability properties like water absorption and sorptivity were improved with replacement of Ordinary Portland Cement by Fly Ash and Metakaolin together @ 20% and 40% respectively.

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AUTHORS PROFILE

Dr.N.Sanjeev, got his first degree from NIT Warangal in 1983. Joined government of India through UPSC Engineering Services (so called IES)-1983 batch and was Engineer in Charge for the construction of longest runway in Asia near Chennai. After 21 years of service retired from government service. Served private and corporate construction industries for 6 years up to level of Vice President. Worked as professor in KLU for 2 years and presently professor in civil engineering in Gokaraju Rangaraju Institute of Engineering and Technology since November 2014.

Kaza Prem Rakshit Kumar completed engineering in Institute of Aeronautical Engineering College (Hyderabad) in the batch of 2009-2013 with first class degree. Presently pursuing Master's in Structural Engineering in Gokaraju Rangaraju Institute of Engineering and Technology (Hyderabad), keenly interested to conduct experimental investigation on concrete made with different mineral admixtures.