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STRENGTH AND DURABILITY STUDY ON POLYESTER FIBRE REINFORCED CONCRETE WITH TERNARY SUPPLEMENTARY CEMENTITIOUS MATERIALS

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Abstract-*The widely used construction material concrete is generally weak in tension and strong in compression. The plain concrete can be made strong in tension by providing reinforcement rods or fibres of sufficient quantity. Now a days the fibres are used as a secondary reinforcement, which act as a crack arrester ,improves toughness and mechanical properties. The effect of fibres on ternary blended concrete was less observed. The present study focused on the polyester fibre reinforced concrete with cement replaced by fly ash and metakaolin. At first the cement is replaced by 30% fly ash and made it constant for further mixes. After this the optimum percentage of metakaolin was found out. Metakaolin was replaced by 0 to 15% (0, 5, 10 and 15%) by weight of cementitious materials with the fixed 30% replacement of fly ash. Finally the polyester fibre was added into the mix with estimated optimum amount of metakaolin and fixed amount of fly ash. The fibre was added in the range 0 to 0.3% (0, 0.1, 0.15,0.2, 0.25 and 0.3%) by weight of cementitious materials. The mechanical properties such as cube compressive strength, flexural strength, split tensile strength and modulus of elasticity was studied. From that results the optimum percentage of fibre was decided. The study also involved the durability tests suchas: bulk diffusion test, sulphate resistance test and carbonation test for the fibre reinforced concrete with supplementary cementitious materials. The chloride penetration depths, sulphate resistance and carbonation depths of different mixes were obtained and analysed.*

Keywords*: Fly ash, Metakaolin and Polyester fibre.*

1. INTRODUCTION

The usage of industrial waste materials in concrete, both in regard to environmental pollution and the positive effect on a country's economy are beyond dispute. Several researches were performed on binary blends of supplementary cementitious materials with cement. But some of the them have shown that the overall desired properties of concrete can be obtained by the use of two supplementary cementitious materials as a ternary blend. In the present study the supplementary cementitious materials used were fly ash and metakaolin. The use of fibres in concrete started from the ancient times. Historically, horse hair was used in mortar and straw in mud bricks. Asbestos fibres were used in the early 1900's and concept of composite materials came into being in the 1950's and the fibre reinforced concrete was one the topics of interest. Due to the health problems there was a need to find alternatives for asbestos fibresand by the 1960's steel, glass and synthetic fibres like polyester fibres were used in concrete. Stillthe research is continuing on fibre reinforced concrete for attaining satisfactory results.

This study combines the concepts of both the fibre reinforced concrete and the ternary blended concrete. Here the used fibre was polyester fibre. One of the selected supplementary cementitious materials was fly ash which is a byproduct material and made its contribution fixed. The cement used was of OPC 53 grade. The second one was highly reactive metakaolin.To this ternary blend the polyester fibres of length 12mm and diameter 36 micron were added and the effect of fibres on the ternary blended concrete was obtained. Such an evaluation is important in the present times because the combination of more than one supplementary cementitiousmaterials in the concrete can save much amount cement and the cost. The use of fibres in the concrete can improve the tensile properties of the concrete and its ductility properties. This will reduce the required amount of reinforcing steel content and thereby the cost. The cost of earthquake resistant buildings can be reduced to an extent using this type of combinations. Moreover the environmental impact of large quantities of ordinary portland cement can be reduced by encouraging the use of supplementary cementitious materials which have disposal problems.

2. EXPERIMENTAL DETAILS

2.1 Materials

The cementitious materials used in this study were ordinary Portland cement 53 grade, fly ash from HitechPvt Ltd, Tuticorin and Metakaolin from Kerala Ceramics Limted, Kundara. The properties of cement is shown in Table 1. The chemical composition of fly ash and metkaolin are shown in Table 2 and Table 3. The fibre used was polyester fibre, obtained from Reliance India Ltd. and its properties are shown in Table 4. The coarse aggregate used was crushed stone of 20mm nominal size with specific gravity 2.65. The fine aggregate used was M sand with afineness modulus of 2.722.

Table-1 Properties of cement

SL. NO.	PARTICULARS	VALUES
1	Fineness of cement	6%
2	Specific gravity of cement	3.13
3	Consistency of standard cement paste	30.75%
4	Initial setting time	92min
5	Final setting time	267min
6	3^{rd} day compressive strength (N/mm^2)	28
7	7^{th} day compressive strength (N/mm^2)	32

Table-2 Chemical composition of fly ash

CHEMICAL COMPOSITION	PERCENTAGE (MASS)
SiO_2	60.28
Al_2O_3	31.76
Na_2O	2.1
P_2O_5	1.46
SO_3	0.97
Fe_2O_3	0.89
CaO	0.72
K_2O	0.69
TiO_2	0.64
MgO	0.52

Table-3 Chemical composition of metakaolin

CHEMICAL COMPOSITION	PERCENTAGE (MASS)
Silica	45.17
Ferric Oxide	0.50
Alumina	37.59
Titanium Oxide	0.50
Calcium Oxide	0.22
Magnesium Oxide	0.12
Sodium Oxide	0.31
Potash	0.07

Table-4 Properties of polyester fibre

Fibre Length	12mm
Diameter	36 micron
Young’s Modulus	4 GPa
Specific Gravity	1.36
Tensile Strength	500 MPa
Melting Point	>250^o C
Aspect Ratio	334

2.2 Mix proportioning

A total of 11 concrete mixes were prepared in two series with different cementitious materials and fibre constitutions. The cement was replaced by 30% fly ash which was made constant for all mixes in this study. The mix designation for the first series is shown in Table 5 and it was conducted for finding the optimum percentage of metakaolin with fixed percentage of fly ash mentioned above.Metakaolin was replaced by weight of cementitious materials in the range 0 to 15% (0, 5,10 and 15%). The first series involved only the cube compression test for finding the optimum amount of metakaolin. The second series was conducted for finding the optimum percentage of polyester fibre, added to mix with estimated optimum amount of metakaolin from the first series and fixed amount of flyash. The fibre was added to the mix in different percentages by weight of cementitious materials ranging from 0 to 0.3%(0, 0.1, 0.15, 0.2, 0.25 and 0.3%). The mix designation for the second series is shown in Table 6. The second series involved the tests such as: cube compression test, flexural strength test, split tensile strength test and modulus of elasticity for finding the mechanical properties and durability tests such as: bulk diffusion test, sulphate resistance test and the carbonation test for finding the durability properties. The mix designed was M30 grade and the quantities of different materials obtained after trials are given in the Table 7.

Table-5 Mix designation for the first session experiment

MIX	FLY ASH (% WEIGHT OF CEMENT)	METAKAOLIN (% WEIGHT OF CEMENT)
C	0	0
PO	30	0
P1	30	5
P2	30	10
P3	30	15

Table-6 Mix designation for the second session experiment

MIX	FLY ASH (% WEIGHT OF CEMENT)	METAKAOLIN (% WEIGHT OF CEMENT)	POLYESTER FIBRE (% WEIGHT OF CEMENT)
M0	30	10	0
M1	30	10	0.1
M2	30	10	0.15
M3	30	10	0.2
M4	30	10	0.25
M5	30	10	03

Table-7 Details of mix

WATER	CEMENT	COARSE AGGREGATE	FINE AGGREGATE	SUPER PLASTICIZER	W/C RATIO
152 ltrs	380 kg	1228.02 kg	677.73 kg	0.8 %	0.4

2.3 Specimen preparation and test

The concrete mixtures were prepared in a pan mixer. Cube specimens of dimensions 15 x 15 x 15 cm and 10 x 10 x 10 cm, cylindrical specimens of dimensions 15 x 30 cm and 10 x 20 cm and beam specimens of dimension50 x 10 x10 cm were casted for different tests. A total of 288 specimens were casted for finding both mechanical and durability properties.

The first session involved only the cube compression test for finding the optimum amount of metakaolin. It conforms to IS 516-1959. Nine cubes were casted for each mix for finding the compressive strength after 3, 7 and 28 days. The test was conducted in a compression testing machine of capacity 2000kN, at a loading rate of $14 N/mm^2$ per minute. The compressive strength was calculated from the failure load divided by the cross sectional area of the resisting load. The specimen used was of dimension 15 x 15 x 15 cm. The obtained results of compressive strength test for the first session are shown in Table 8. From which the optimum amount of metakaolin was found as 10% based on the mean target strength. The results obtained for the second session for finding the optimum percentage of polyester fibre is shown in Table 9. From the results the mix with 0.25% fibre content showed slight improvement over other mixes. The experimental set up and the prepared specimen are shown in Fig 1 and Fig 2.

Table-8 Compressive strength for different percentages of metakaolin

MIX	**STRENGTH AFTER 3 DAYS (MPa)**	**STRENGTH AFTER 7 DAYS (MPa)**	**STRENGTH AFTER 28 DAYS (MPa)**
C(0MK+0FA)	38	44	58
PO(OMK+30FA)	29	34.889	45.11
P1(5MK+30FA)	21.56	30.56	40.11
P2(10MK+30FA)	23.67	33	43.44
P3(15MK+30FA)	17.56	22.78	35.77

Table-9 Compressive strength for different fibre dosages

AGE (DAYS)	**M0 (MPa)**	**M1 (MPa)**	**M2 (MPa)**	**M3 (MPa)**	**M4 (MPa)**	**M5 (MPa)**
3	23.66	20	21.56	25.11	29.11	22.89
7	33	30.22	31.11	33.11	37.56	30
28	43.44	38.22	40.44	42	46.89	41.11


Figure-1 Compressive strength testFigure-2 Cube specimen for compressive strength test

The flexural strength test was conducted on beam specimen of dimension 50 x 10 x 10cm conforming to IS 516-1959. It was measured by breaking load under two point loading. The experimental set up and the beam specimen are shown in the Fig 3 and Fig 4. The test was conducted after 28 days. The obtained results are shown in Table 10. The mix with 0.25% fibre content showed a magical performance with an increase in flexural strength by 4.8 times as compared to the mix without fibre.

Table-10 Flexural strength after 28 days

MIX	**STRENGTH AFTER 28 DAYS,** f_{cr28} **(MPa)**
M0	1
M1	2.6
M2	3.8
M3	4.6
M4	4.8
M5	4.2


Figure-3 Experimental set up for flexural strength test   Figure-4 Beam specimen

The split tensile strength test conforming to IS 5816-1999 was conducted by applying diametric compressive force along the length of a cylindrical specimen (15cm diameter and 30cm long). The loading induced tensile stresses on the plane containing the applied load and caused tensile failure. Plywood strips ensured uniform loading along the length of the cylinder and it will reduce the localized stress concentration. The test was conducted after 28 days. The experimental set up and the cylindrical specimen are shown in Fig 5 and Fig 6. The obtained results are shown in Table 11. The mix with 0.25% fibre content showed a strength as 1.41 times greater than the mix without fibre.

Table-11 Split tensile strength after 28 days

MIX	**STRENGTH AFTER 28 DAYS, f_{t28} (MPa)**
M0	2.405
M1	2.193
M2	2.264
M3	2.546
M4	3.3943
M5	2.90


Figure-5 Split tensile strength test   Figure-6 Cylindrical specimen

The modulus of elasticity of concrete was experimentally determined as per IS 516-1959 from the slope of a stress-strain curve plotted based on uniaxial compression test conducted on concrete cylinder specimen having 15cm diameter and 30cm height. The axial deformation of the cylinder was measured using a dial gauge of accuracy 0.002mm fitted to a longitudinal compressometer of gauge length 200mm. A series of readings were taken within elastic limit and the stress-strain graphs were plotted. The test was conducted after 28 days. The experimental set up is as shown in Fig 7. The obtained results are shown in Table 12. The results showed that the modulus of elasticity was greater for the mix without fibre. But the mix with 0.25% fibre content showed satisfactory result (showed result greater than the analytical value $5000\sqrt{f_{ck}}$) as compared to other mixes with fibre content and supported its acceptance same as above tests.

Table-12 Modulus of elasticity after 28 days

MIX	STRENGTH AFTER 28 DAYS, E_{c28} (GPa)
M0	34.615
M1	25.058
M2	27.829
M3	28.290
M4	31.530
M5	28.007

Figure-7 Experimental set up for modulus of elasticity test

For obtaining the durability properties the tests conducted were bulk diffusion test, sulphateresistane test and carbonation test. The bulk diffusion test proposes to assess the chloride attack on concrete specimen by measuring the depth of chloride penetration into the concrete specimen. This test was conducted as per ASTM C 1556-03. In this test, cylinder of 100mm diameter and 200mm length was used as test specimen. After 7 days of water curing, the concrete specimens were exposed to 1.8 molar NaClsolution for 56 days and 90 days. After 56 days and 90 days of exposure the specimens were split by applying splitting tensile force. To the split face, 0.1 molar silver nitrate solution was sprayed to observe the colourchanges ie, up to the penetrated depth of chloride ion, a white precipitation will form and thus the depth of chloride ions was found out. Fig 8 shows the chloride effect on cylindrical specimen. The obtained results are shown in Table 13. The mix with 0.25% fibre content showed greater resistsnce against chloride penetration than the mix without fibre for 56 and 90 days.

Table-13 Chloride penetration depths after 56 and 90 days

MIX	DEPTH OF PENETRATION OF CHLORIDE IONS (mm)	
	56 DAYS OF CHLORIDE EXPOSURE	90 DAYS OF CHLORIDE EXPOSURE
M0	4	5
M1	5	7
M2	7	9
M3	9	10
M4	3	4
M5	10	13

Figure-8 Specimen under curing for bulk diffusion test

Figure-9 Chloride effect on cylindrical specimen

Naturally occurring sulphates of Sodium, Calcium, Potassium etc. that can attack hardened concrete are sometimes found in soil or dissolved water adjacent to concrete structures. Sulphate salts in ground water enter the concrete and attack the cementing materials. The two recognized chemical consequences of sulphate attack are ettringite and gypsum. This test was done according to ASTMC 452 test method. The specimens used for this study was cubes of dimension 10x10x10cm. The concrete specimens were water cured for 3 days and then it was introduced into Magnesium Sulphate solution and cured for another 56 and 90 days. The change in compressive strength was noted and compared with that of specimens that were water cured. The test was conducted at the end of 56 days and 90 days. Fig 9 shows the curing of specimen. Table 14 shows the obtained results. The mixes with 0.25% and 0.3% fibre content showed the least percentage loss of strength in between the water cured and the sulphate cured specimens as compared to the mix without fibre for 56 and 90 days. This result encourages the combination for improving the durability properties.

Table-14 Compressive strengths of water and sulphate cured specimen after 56 days

MIX	WATER CURED STRENGTH (MPa)	SULPHATE CURED STRENGTH (MPa)
M0	40	32
M1	26.5	21
M2	27.5	23
M3	30	25
M4	32.5	28
M5	28.5	27.5

Table-15 Compressive strengths of water and sulphate cured specimen after 90 days

MIX	WATER CURED STRENGTH (MPa)	SULPHATE CURED STRENGTH (MPa)
M0	44	35
M1	29	22.5
M2	30.5	24
M3	31	26
M4	34.5	29.5
M5	30.5	29

Figure-10 Cube specimen of size 10x10x10cm under curing for sulphate resistance test

The final one conducted was carbonation test. Here the concrete cylinder specimen (10x20cm) was split into two halves in the longitudinal direction and the freshly broken surface of concrete was sprayed with phenolphthalein solution. The area on the concrete face, where the calcium hydroxide in the concrete was unaffected by carbondioxide, the colour turned purple and the area where the carbonation occurred remains uncoloured. The natural effect of carbondioxide on the cylindrical specimen obtained is shown in Fig 10. The obtained results are shown in the Table 15. Again the mixes with 0.25% and 0.3% fibre content showed good resistance against carbonation as compared to the mix without fibre and once again supports the combination.

Table-16 Carbonation depths for mixes after 56 and 90 days

MIX	CARBONATION DEPTH (mm)	
	56 DAYS	90 DAYS
M0	6	8
M1	5	7
M2	3	4
M3	2	3
M4	1	2
M5	1	2

Figure-11 Cylindrical specimen for carbonation test

Figure-12 Natural carbonation effect on specimen

7. CONCLUSION

In this paper, the results of mechanical properties and durability properties of polyester fibre reinforced concrete with ternary supplementary cementitious materials were presented. The following conclusions can be drawn from the results.

1. The obtained optimum amount of metakaolin was found as 10% with 30% replacement of fly ash from the first series.

2. The optimum amount of fibre was found as 0.25% by weight of cementitious materials with 10% replacement of cement bymetakaolin and 30% replacement of cement by fly ash.

3. The flexural strength of the concrete showed improvement with fibre content than without fibre. Mix with 0.25% fibre content showed maximum strength which means the added fibre in the matrix acted as a crack arresting mechanism and improved the tensile strength of the concrete. Beyond the optimum percentage (0.25%) the flexural strength was reduced , which can be justified as the extra amount fibre reduced the free flow of concrete and the compaction achieved.

4. The split tensile strength was more for the mix with 0.25% fibre content as compared to the mix without fibre. This may be due to the inclusion of fibres into plain concrete resulting the change of brittle mode of failure into the ductile mode. Hence the energy absorption capacity and lateral stiffeness of the concrete improved with the presence of fibre. Mix with 0.25% fibre content gave satisfactory results for the modulus of elasticity of concrete also.

5. The mix with 0.25% fibre content showed good resistance against chloride attack. The mix with 0.3% fibre content showed maximum penetration of chloride attack. This may be due to the reason that the interfacial zones between the fibres and the cement paste provided additional connected rotes for chloride transport in concrete.

6. The strength loss of the mixes with 0.25% and 0.3% fibre content exposed to the sulphate environment was found minimum. Therefore the presence of polyester fibre, metakaolin and fly ash enhanced the sulphate attack resistance.

7. The carbonation decreased as the fibre content increased. The mix with 0.25% and 0.3% fibre content showed good resistance against carbonation, which means the added polyester fibres were effective in controlling the development of microcracks and pores in the concrete matrix. Hence the mix with 0.25% fibre content showed good performance in all the above tests and can be conclude that the optimum fibre content in this study was 0.25% with 10% replacement of cement by metakaolin and 30% replacement of cement by fly ash.

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