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Experimental Study on Partial Replacement of Cement by Metakaolin in Glass Fibre Reinforced Concrete

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ABSTRACT

Concrete is a relatively brittle material, when subjected to normal stresses and impact loads. Tensile strength of concrete is approximately one tenth of its compressive strength. As a result for these characteristics, plain concrete members could not support loads and tensile stresses that occurred, on concrete beams and slabs. Concrete members are reinforced with continuous reinforcing bars to withstand tensile stresses and compensate for the lack of ductility and strength. The introduction of fibres is generally taken as a solution to develop its flexural and tensile strength. Fibre reinforced concrete (FRC) is concrete made primarily of cements, aggregates, and discrete reinforcing fibre. Fibres suitable for reinforcing concrete have been produced from steel, glass, and organic polymers (synthetic fibres). When concrete cracks, the randomly oriented fibres start functioning, arrest crack formation and propagation, and thus improve strength and ductility.

In this paper experiments were conducted to study the strength parameters and durability of glass fibre reinforced concrete.The various combinations of fibers and metakaolin will be done. Glass fiber will be used in concrete for production of fibre reinforced concrete. The optimum percentage was fixed as 0.4 % to the weight of cement by casting cubes ,cylinders and prisms with varying percentage of fiber i.e. 0%, 1%, 2%, 3%, and taking the percentage which will give maximum strength value. Metakaolin is a product confirming to engineering requirements in terms of physical and chemical properties. Cement will be replaced with Metakaolin by 5%, 10%, 15%, 20%, 25%, 30% to the weight of cement. The cubes, cylinders and prisms were casted of size 150x150x150mm, 150mm diameter x 300mmhigh, 700x150x150mm. Superplasticizer will be added for better workability and optimum dosage was determined by using marsh cone test. Thus various strength and durability test will be conducted.

I. INTRODUCTION

FIBERS IN CONCRETE:

Fibres can be defined as a small piece of reinforcing material possessing certain dimensional characteristics. The most important parameter describing a fibre is its Aspect ratio. "Aspect ratio" is the length of fibre divided by an equivalent diameter of the fibre. The properties of fibre reinforced concrete are very much affected by the type of fibre. Fibres are secondary reinforcement material and acts as crack arrester. Prevention of propagation of cracks originating from internal flaws can result in improvements in static and dynamic properties of the matrix. The concept that post cracking of concrete can be improved by the inclusion of fibre was first put forward by *Portar in 1910*, but little progress was made in the development of this material until 1963 when *RomualdiandBatson 1969* published their classic paper on the subject. Since then, there has been a wave of interest in fibre reinforced concrete and several interesting experiments have been carried out. Fibres are taken as a new form of binder that combines Portland cement in the bonding with cement matrices. Fibres are generally discontinuous, randomly distributed throughout the cements matrices. Several kinds of fibres such as steel, fibrillated polypropylene, nylon asbestos, polyester, coir, jute, sisal, kenaf, glass, and carbon have been tried and these are available in a variety of shapes, sizes, and thickness Fibres can be broadly be classified into two groups as Low Modulus High Elongation Fibres and High Modulus Fibres .

a) Low Modulus High Elongation Fibres

This group includes high elongation fibres having large energy absorption characteristics and are capable of imparting toughness and resistance to impact and explosive loadings. Fibres that are generally included in this group are nylon, polypropylene, polyethylene, rayon, acrylic and polyester fibres

b) *High Modulus Fibres*

This group includes fibres, which are capable of producing strong composites; they primarily impart strength and stiffness to the composite to varying degrees and resistance under dynamic loadings. Fibres that are included in this group are steel, carbon, asbestos, organic fibres etc.

Glass-Fibre Reinforced Concrete:-

Glass fibre is made up from 200-400 individual filaments which are lightly bonded to make up a stand. These stands can be chopped into various lengths, or combined to make cloth mat or tape. Using the conventional mixing techniques for normal concrete it is not possible to mix more than about 2% (by volume) of fibres of a length of 25mm.

The major appliance of glass fibre has been in reinforcing the cement or mortar matrices used in the production of thin-sheet products. The commonly used verities of glass fibres are e-glass used. In the reinforced of plastics & AR glass E-glass has inadequate resistance to alkalis present in Portland cement where AR-glass has improved alkali resistant characteristics. Sometimes polymers are also added in the mixes to improve some physical properties such as moisture movement.

Glass-fibre reinforced concrete

METAKAOLIN

Metakaolin

Metakaolin is the anhydrous calcined form of the clay mineral kaolinite. Minerals that are rich in kaolinite are known as china clay or kaolin, traditionally used in the manufacture of porcelain. The particle size of metakaolin is smaller than cement particles, but not as fine as silica fume.

Metakaolin is a pozzolan, probably the most effective pozzolanic material for use in concrete. It is a product that is manufactured for use rather than a by-product and is formed when china clay, the mineral kaolin, is heated to a temperature between 600 and 800ºC.

The T-O clay mineral kaolinite does not contain interlayer cations or interlayer water. The temperature of dehydroxylation depends on the structural layer stacking order. Disordered kaolinite dehydroxylates between 530 and 570 °C, ordered kaolinite between 570 and 630 °C. Dehydroxylated disordered kaolinite shows higher pozzolanic activity than ordered.[1]The dehydroxylation of kaolin to metakaolin is an endothermic process due to the large amount of energy required to remove the chemically bonded hydroxyl ions. Above the temperature range of dehydroxylation, kaolinite transforms into metakaolin, a complex amorphous structure which retains some long-range order due to layer stacking.[2] Much of the aluminum of the octahedral layer becomes tetrahedrally and pentahedrally coordinated.[3] In order to produce a pozzolan (supplementary cementitious material) nearly complete dehydroxylation must be reached without overheating, i.e., thoroughly roasted but not burnt. This produces an amorphous, highly pozzolanic state, whereas overheating can cause sintering, to form a dead burnt, nonreactive refractory, containing mullite and a defect Al-Si spinel.[4] Reported optimum activation temperatures vary between 550 and 850 °C for varying durations, however the range 650-750 °C is most commonly quoted.[5] In comparison with other clay minerals kaolinite shows a broad temperature interval between dehydroxylation and recrystallization, much favoring the formation of metakaolin and the use of thermally activated kaolin clays as pozzolans.

Concrete Application

Considered to have twice the reactivity of most other pozzolans, metakaolin is a valuable admixture for concrete/cement applications. Replacing portland cement with 8–20% (by weight) metakaolin produces a concrete mix that exhibits favorable engineering properties, including: the filler effect, the acceleration of OPC hydration, and the pozzolanic reaction. The filler effect is immediate, while the effect of pozzolanic reaction occurs between 3 and 14 days.

II. LITERATUREREVIEW

VenkateswaraluDampa(2018)A self-compacting concrete (SCC) is the one that can be placed in the form and can go through obstructions by its own weight and without the need of vibration. Since its first development in Japan in 1988, SCC has gained wider acceptance in Japan, Europe and USA due to its inherent distinct advantages. The major advantage of this method is that SCC technology offers the opportunity to minimize or eliminate concrete placement problems in difficult conditions. It avoids having to repeat the same kind of quality control test on concrete, which consumes both time and labor. Construction and placing becomes faster & easier. It eliminates the need for vibration & reducing the noise pollution. It improves the filling capacity of highly congested structural members. SCC provides better quality especially in the members having reinforcement congestion or decreasing the permeability and improving durability of concrete. The primary aim of this study is to explore the feasibility of using SCC by examining its basic properties and durability characteristics i.e. water absorption, shrinkage, and sulfate resistance. An extensive literature survey was conducted to explore the present state of knowledge on the durability performance of self-consolidating concrete. However, because it usually requires a larger content of binder and chemical admixtures compared to ordinary concrete, its material cost is generally 20- 50% higher, which has been a major hindrance to a wider implementation of its use. There is growing evidence that incorporating high volumes of mineral admixtures and micro fillers as partial replacement for Portland cement in SCC can make it cost effective. However, the durability of such SCC needs to be proven. This research work consists of: (i) development of a suitable mix for SCC that would satisfy the requirements of the plastic state; (ii) casting of concrete samples and testing them for compressive strength, shrinkage, water absorption, sulfate resistance. Local aggregates, cement, admixtures and additives produced by the local suppliers were used by in this work. The significance of this work lies in its attempt to provide some performance data of SCC so as to draw attention to the possible use of SCC

EXPERIMENTAL WORK
OUTLINE OF PRESENT WORK:

In this present experiment polyester fiber was used in concrete for production of fibre reinforced concrete. The optimum percentage was fixed as 4 % to the weight of cement by casting cubes ,cylinders and prisms with varying percentage of fiber i.e. 0%.0.1%,0.2%,0.3% and taking the percentage which gave maximum strength value. Metakaolin is a product confirming to engineering requirements in terms ofphysical and chemical properties. Cement was replaced with Metakaolin by 5% to the weight of cement. By taking 0.1% of fiber and 5% replacement of Metakaolin cubes, cylinders and prisms were casted of size 150x150x150mm, 150mm diameter x 300mmhigh,700x150x150mm.Superplasticizer was added for better workability and optimum dosage was determined by using marsh cone test. Thus various strength and durability test were conducted. The following tests were performed.The various combinations are to be done.

1) OPC
2) OPC+ Metakaolin(5%)
3) OPC+ Nylon Fiber (0.1%)
4) OPC+ Nylon (0.1%) +Metakaolin (5%)

III. TEST RESULTS AND DISCUSSIONS

TEST RESULTS OF CEMENT:

Effect of Metakaolin in normal consistency of cement:

% of cement replaced byMetakaolin (%)	Consistency (%)
0	31
5	36

It is observed here that the consistency percentage is increasing as the percentage of Metakaolin increases as a cement replacement, but the change is not so abrupt.

Effect of Metakaolin on Compressive strength of cement:

% of Metakaolin with cementReplacement	3 days strength (MPa)	7 days strength (MPa)
0	15.98	23.15
5	19.6	27.12

It was observed that 3 days and 7 days compressive strength increases about 25% and 43% that is from 15.98 MPa to 23.15 MPa and 19.6 to 27.12 respectively, as Metakaolin percentage increases from 0 to 5%.

Effect on slump and compaction factor:

Test results of slump and compaction factor

Parameters	Slump (mm)	Compaction Factor
0% of Metakaolin	106	0.9
5% of Metakaolin	48	0.85
5% of Metakaolin + SP	114	0.92

Slump and Compaction factor value was influenced by replacement of cement with Metakaolin.

TEST RESULTS OF HARDENED CONCRETE:

OPTIMUM DOSAGE OF FIBERS:

Test results of optimum percentage of fibers

Fibre percentage	Compressive strength at 7 days(N/mm^2)	Split tensile strength at 7days (N/mm^2)	Flexural strength at 7 days (N/mm^2)
0%	23.02	2.46	3.75
0.1%	25.6	2.84	3.98
0.2%	30.1	3.31	5.56
0.3%	27.56	3.02	5.12

Compressive strength of cube:

Test results of compressive strength of cubes:

Parameters	7 days compressive strength (N/mm^2)	28 days compressive strength (N/mm^2)
OPC	23.02	30.86
OPC+Metakaolin	29.78	33.28
OPC+ Nylon Fiber	27.36	31.23
OPC+ Nylon Fiber+Metakaolin	30.81	36

Comparison of compressive strength of cubes and cylinders:

Test results of comparison of compressive strength of cubes and cylinders

Parameters	**Cube compressive strength at 60 days (N/mm²)**	**Cylinder compressive strength at 60 days (N/mm²)**
OPC	35.62	38.33
OPC+Metakaolin	55.95	53.71
OPC+ Nylon Fiber	48.21	43.5

SPLIT TENSILE STRENGTH:

Test results of split tensile strength of concrete

Parameters	**7 days split tensile strength (N/mm²)**	**28 days split tensile strength (N/mm²)**
OPC	2.43	3.95
OPC+Metakaolin	2.70	4.44
OPC+ Nylon Fiber	3.11	4.96
OPC+ Nylon Fiber+Metakaolin	2.89	4.73

FLEXURAL STRENGTH:

Test results of flexural strength of concrete

Parameters	**7 days flexural strength (N/mm²)**	**28 days flexural strength (N/mm²)**
OPC	3.87	5.73
OPC+Metakaolin	4.04	6.08
OPC+ Nylon Fiber	4.46	6.75
OPC+ Nylon Fiber+Metakaolin	4.78	7.17

Test results of modulus of elasticity

Parameters	**Modulus of Elasticity(Gpa)**
OPC	22.14
OPC+Metakaolin	23.45
OPC+ Nylon Fiber	31.08
OPC+ Nylon Fiber+Metakaolin	26.87

POISSON'S RATIO:

Parameters	Poisson's Ratio
OPC	0.105
OPC+Metakaolin	0.161
OPC+ Nylon Fiber	0.166
OPC+ Nylon Fiber+Metakaolin	0.336

5.3.8 DENSITY OF CUBES AND CYLINDERS:

Parameters	Density of cubes at 60 days(Kg/m³)	Density of cylinders at 60 days(Kg/m³)
OPC	2534.23	2379.63
OPC+Metakaolin	2567.89	2455.13
OPC+ Nylon Fiber	2524.17	2427.23
OPC+ Nylon Fiber+Metakaolin	2493.96	2319.89

DURABILITY TESTS:

ACID RESISTANCE TEST:

Parameters	Loss of weight at 30 days(%)	Loss in compressive strength at 30 days(%)
OPC	4.32	13.65
OPC+ Metakaolin	2.46	6.98
OPC+ Nylon Fiber	3.23	11.86
OPC+ Nylon Fiber+ Metakaolin	1.46	5.58

ALKALINE ATTACK:

Parameters	Loss in weight at 30 days(%)	Loss in compressive strength at 30 days(%)
OPC	4.06	10.41
OPC+ Metakaolin	2.49	7.11
OPC+ Nylon Fiber	2.92	8.56
OPC+ Nylon Fiber+ Metakaolin	1.81	5.21

FREEZE AND THAW:

Parameters	Compressive strength (Mpa)	
	Without freeze and thaw	Cubes at -18°C
OPC	39.02	24.55
OPC+ Metakaolin	46.88	36.12
OPC+ Nylon Fiber	52.02	48.01
OPC+ Nylon Fiber+ Metakaolin	57.65	42.78

INITIAL SURFACE ABSORPTION TEST (ISAT):

Parameters	Average rate of penetration of water (ml)
OPC	17.6
OPC+Metakaolin	10.4
OPC+ Nylon Fiber	14.8
OPC+ Nylon Fiber+Metakaolin	12.1

WATER ABSORPTION AND POROSITY:

Parameters	Saturated water absorption at 60 days(%)	Porosity at 60 days(%)
OPC	2.34	3.24
OPC+Metakaolin	2.22	2.34
OPC+ Nylon Fiber	2.46	4.06
OPC+ Nylon Fiber+Metakaolin	1.98	2.21

IV. CONCLUSION

In this present study with the stipulated time and laboratory set up an afford has beentaken to enlighten the use of Metakaolin in fiber reinforced concrete in accordance to theirproficiency. It was concluded that

- With replacement of cement with Metakaolin the consistency increases about 18.46%. Use of Metakaolin which burned properly in controlled temperature improves the strength of mortar. Improvement in strength is not significant.
- With the use of superplasticizer it possible to get a mix with low water to cement ratio to get the desired strength.
- The maximum compressive strength of cubes and cylinders at 28 and 60 days were obtained for the combination OPC+RHA and increase in percentage was 25.66% for cubes at 28 days, 55.15% and 40.56% for cubes and cylinder at 60 days.
- In the case of split tensile strength the maximum strength was obtained for the combination OPC+ Nylon FIBER. It was about 27.98% and 25.56% at 7 days and 28 days respectively. Therefore addition is found to have better influence on split tensile strength compared to Metakaolin.
- In the case of flexural strength the maximum strength was obtained for the combination OPC+ Nylon. It was about 26.87% and 25.42% at 7 days and 28 days respectively.
- From stress-strain graph plotted, the modulus of elasticity of concrete was found. The value was found to be maximum in the combination in which fiber only was added and minimum in 5 % of Metakaolin replacement.
- The maximum value of poisson's ratio is 0.336 was obtained for the combination OPC+FIB+Metakaolin and minimum value is 0.161 for the combination OPC+FIB.
- In the comparison of density of cubes and cylinders for 60 days. The maximum value was obtained for the combination OPC+Metakaolin. The values are 2567.89Kg/m^3 for cubes and 2493.98Kg/m^3 for cylinders. Thus addition of RHA increases density of concrete.
- From the durability studies, namely acid attack and alkaline attack, It has been observed that there is an increase in resistance for the combination OPC +Metakaolin+FIB.
- The incorporation of RHA improved resistance to acid attack. This is due to silica present in Metakaolin which combines with calcium hydroxide and reducing compounds susceptible to acid attack.

- The loss of compressive strength of cubes was found to be 5.46% at 30 days for the combination OPC+ Metakaolin + FIB. This combination gives better acid resistance
- The loss of compressive strength of cubes was found to be 5.43% at 30 days for the combination OPC + Metakaolin + FIB. This combination gives better alkaline resistance
- The permeability of water was decreased by addition of Metakaolin and fiber which gave minimum value of 1.96 and thus affects better durability.
- By addition of Metakaolin and fiber, the volume of pores in concrete decreases and thus reducing the ingress of water.
- The least porosity value was obtained for the combination OPC+Metakaolin+FIB and the value is 2.22 at 60 days which is 33.2% lower than OPC.

- In case of initial surface absorption test(ISAT),permeability of water was decreased by addition of Metakaolin. This is due to physical and chemical properties of Metakaolin.
- Maximum value of compressive strength obtained after freeze and thaw cycles was 48.36 for the combination OPC+FIB and it was almost 49.19 % increased compared to conventional concrete.

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