

Utilization of Metakaolin and Steel Fiber to Enhance the Concrete Properties

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Abstract—Numerous combination of concrete are available in market but still achieving the desired strength with locally available materials has vast scope. The study investigates the strength determination of the composite concrete using supporting material like metakaolin and steel fiber. In general the normal concrete is good in compression and exhibit lower tensile strength. The proposed concrete in combination with steel fiber shows good tensile strength and other concrete properties. The compressive strength and tensile strength were determined and it was noted that the use of metakaolin and steel fiber increases the strength by 5% to 20%. Too much replacement of metakaolin also does not increase the strength.

I. INTRODUCTION

The development of the country is recognized by the financial status of it. It is the compliment of the living standards and infrastructure for any nation. Due to industrial development during the 20th century, has reduced the effort and number of labors required. Achieving challenging construction difficulties have become simpler. Migration of people from remote places to the urban areas has posed a severe demand for construction industry in the modern days. As the construction increases the demand for cement also increase, so it is essential to use other binders to reduce the usage of cement. For ordinary Portland cement (OPC) the strength and other properties may not vary much as it does by using additional binders. Use of metakaolin (supplement to cement) as a component in the concrete increases the compressive strength [3, 6] compared to OPC. The increase demand has given the room for severe exploitation of cement. So, the use of supplementary cementitious material are encouraged in the recent propaganda by all the industries. Diverse combination of supplementary materials to the cement has been attempted; these trials are specific to the aim desired. Many factors are considered, amongst them strength criteria in compression and tension is significant. The metakaolin is a cementitious material (CM), which undergoes similar reactions as cement, producing hydrates of calcium [6]. Some of challenges faced are the ability of concrete to withstand high temperatures and durability concerns can be taken care by using supplementary CM [4]

II. MATERIALS AND METHODOLOGY

The steel fibers (varying lengths and gauges, Fig. 1) are reinforced within the concrete consisting of cement, fine aggregates, coarse aggregates and metakaolin. When a load is applied to a body, which consists of a fiber embedded in a surrounding matrix the fiber, contributes to carrying capacity of the body. The load transfer generally arises as a result of different physical properties of the fiber and matrix. The incorporation of fiber into brittle cement matrix increases the, fracture toughness of the composite by crack arresting process. As fiber have large value of failure strains give up extensibility in composites problems. The mechanic properties are affected due to use of metakaolin and steel fibers, irrespective of water to binder ratio [16]

A. Metakaolin

Metakaolin is one of material having cementitious behavior, so studies have proved that it can used as partial replacement of cement. The use of metakaolin as substitute to cement (5% - 20%) was proved to have better mechanical and durable properties than normal concrete, and withstand extreme weathering actions [4, 7]. Use of supplementary CM provides better resistance to freezing – thawing cycle, calcium leaching and frost [5]. The properties of metakaolin and chemical composition are provided in the Table I and Table II.

TABLE I. TYPE SIZES FOR CAMERA-READY PAPERS

Sl. No.	Parameter	Value
1	Average Particle size (mm)	1.5
2	Residue 25 mesh (%)	0.5
3	BET Surface area (m ² /gm)	15
4	Pozzolanic reactivity (mgCa(OH) ₂ /gm)	1050
5	Specific gravity	2.5
6	Bulk density (gm/litre)	300 ± 30
7	Brightness	80 ± 2

TABLE II. CHEMICAL COMPOSITION OF METAKAOLIN

Sl. No.	Parameter	Value
1	SiO ₂ , Al ₂ O ₃ , Fe ₂ O ₃	96.88
2	CaO	0.39
3	MgO	0.08
4	TiO ₂	1.35
5	Na ₂ O	0.56
6	K ₂ O	0.56

B. Steel Fiber

The steel fibers, which are obtained as scrape from foundry and other labs, are used to enhance the strength of regular concrete. The fibers shape and length used in the study are not constant (Figure 1). The steel fibers obtained in scrape can be of varying shapes and sizes, with their differing shapes may attribute towards better shear bonding between the surfaces. In the study the strength of the concrete is determined by varying the constituents of cement with metakaolin and steel fiber. The other materials fine aggregates, coarse aggregates and water are added as per the design. It has been proved that use of nano metakaolin materials causes increase in compression and flexural strength [2]. The constituent materials used for the preparation are shown in the Fig. 2.

The metakaolin can be used in accelerated curing methods such as steam curing or carbon dioxide curing, since they achieve the strength for shorter duration [1, 9]. The preliminary tests on the constituents are also carried to determine the suitability for usage of them in the concrete. The tests are conducted as per the IS standards suggested by the codes [11, 12, 13, 14].

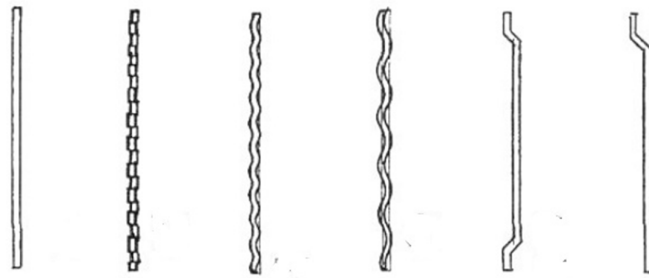


Figure 1. Steel fibers of varying shape and sizes [10] (Reproduced with permission through open access publishing)



Figure 2. Materials used in preparation (Steel fibers, cement, aggregates and Metakaolin)

III. EXPERIMENTATION AND RESULTS

The concrete samples with combination of metakaolin and steel fiber are used as supplements to study the behavior in terms of strength. The metakaolin is used proportionately varied from 5 % - 20 % and steel fiber between 0.5 % - 2 %. The concrete is designed for M20 characteristic strength, as recommended from earlier studies [8], and then the normal concrete is compared with the proposed work. The significant factors for a concrete is the strength in compression and tension. So, the cubes were prepared as per mix design based on IS: 10262:2009. Tests on trial mixes were conducted and mix proportion was finalized. Finally, a mix proportion that gives required 28 days' cube compressive strength with minimum cement content and required workability of 50 to 150mm is selected. The proposed mix was considered in preparation of the samples, 3 for each. The average value of the three samples is used and represented in the results section. The cubes were casted for each of the concrete combination. The sample for each 7days 14days and 28days curing were casted tested for compressive strength and split tensile strength.. The Universal testing machine with 400KN capacity was used in test. The compressive and split tensile strength tests were carried. The average value of all the samples was considered. In earlier study the combination of recycled coarse aggregate (RCA), metakaolin and recycled steel fibers (RSF) was used as constituents of concrete, and reduction in workability by RCA was compensated by metakaolin and RSF [15]. The results corresponding to strength characteristics for concrete are shown in Table III and Table IV.

From, Table III, compressive strength of the samples determines that the combination of cement with steel fiber (1.5%) and metakaolin (15 %) shows better desired strength than other ones. It also determines that the combination 3, Cement + Steel Fiber (1 %) + Metakaolin (10%) has showed lower strength than all the others. It can also be noted that increase in metakaolin beyond 20% and steel fiber beyond 2% does not fetch any improvement in the compressive strength.

TABLE III. COMPRESSIVE STRENGTH OF THE SAMPLES

Sl. No.	Concrete Constituents	Compressive Strength		
		7days	14days	28days
1	Cement + Steel Fiber (0 %) + Metakaolin (0%)	18.10	20.20	25.50
2	Cement+Steel Fiber (0.5 %) + Metakaolin (5%)	17.80	19.70	20.10
3	Cement + Steel Fiber (1 %) + Metakaolin (10%)	13.26	14.77	15.20
4	Cement+ Steel Fiber (1.5 %) + Metakaolin (15%)	17.20	24.50	26.20
5	Cement + Steel Fiber (2 %) + Metakaolin (20%)	18.28	19.11	20.20

TABLE IV. SPLIT TENSILE STRENGTH OF THE SAMPLES

Sl. No.	Concrete Constituents	Split Tensile Strength		
		7days	14days	28days
1	Cement + Steel Fiber (0 %)+ Metakaolin (0%)	1.8	2.0	2.6
2	Cement+Steel Fiber (0.5 %) + Metakaolin (5%)	1.62	1.83	1.91
3	Cement + Steel Fiber (1 %) + Metakaolin (10%)	1.73	2.1	2.48
4	Cement+ Steel Fiber (1.5 %) + Metakaolin (15%)	1.96	2.5	2.82
5	Cement + Steel Fiber (2 %) + Metakaolin (20%)	1.52	2.48	2.69

From, Table IV, split tensile strength it was noted that, all the samples showed good results for 28 days curing with marginal differences with all the designs. From the study it is observed that 15 % of metakaolin and 1.5% of steel fibers proved to be best when comparing to other designs. The results indicate that the compressive strength increases with the increase in the percentage of metakaolin by 15% and steel fibers up to 1.5% beyond that it reduces. This combination may be conserved to explore further by durability and other tests. The samples in curing, casting and testing are presented in the Fig. 3 and Fig. 4.



Figure 3. The samples in casting and curing



Figure 4. The samples in testing

The results indicate that the split tensile strength increases may not vary much by increasing the percentage of metakaolin and steel fibers. So selection of an optimum combination between all the mixes is important to achieve the objective.

IV. CONCLUSION

The study was carried to find the compressive strength and split tensile strength of the concrete samples. The samples were prepared using metakaolin and steel fiber along with cement, aggregates and water as the major constituents of the concrete sample. The study aims to reduce the usage of cement and increase the use of waste materials and check the results with regular cement mixed concrete samples. The regular tests are conducted and all the results are been tabulated.

From the results observed it can be concluded that.

- i. The metakaolin and steel fiber can be used as alternate for cement in future to increase the strength and it can be site specific.
- ii. The metakaolin possess cementitious property, so it can bind and provide good strength as compared to cement.
- iii. The usage of steel fiber provides good mechanical strength properties in the concrete blocks [17, 19]
- iv. The metakaolin at higher curing temperature increases the rate of hydration.
- v. The duo provides better durability for the concrete [18].

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