Pertanika J. Sci. & Technol. 27 (3): 1381 - 1396 (2019)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Study of Combined Effect of Metakaolin and Steel Fiber on Mechanical Properties of Concrete

Nihar Ranjan Mohanta* and Sandeep Samantaray

Department of Civil Engineering, Gandhi Institute of Engineering and Technology, Gunupur 765022, Odisha, India

ABSTRACT

This study reports the results of an experimental study on mechanical properties of plain and metakaolin (MK) concretes with and without steel fiber. To develop the metakaolin reinforced concrete, Ordinary Portland cement was partially replaced with MK 3%, 6%, 9%, 12%, 15%, 18% by weight of the total binder content. Steel fiber with length 50 mm and diameter 0.70 mm was utilized to produce fiber reinforced concrete. Concrete was designed with water to cement (w/b) of 0.464. First water absorption test was investigated then compressive strength and split tensile strength were calculated by replacing metakaolin with cement at the end of 7 days, 28 days, and 56 days of curing period. Again the effectiveness of MK and steel fiber reinforcement with different percentage of steel fiber i.e. 0.25%, 0.5%, 1% of the weight of cement was taken. Then the compressive, split tensile strength of the concretes was investigated. All tests were conducted at the end of 7 days, 28 days, and 56 days of curing period. It was found that for replacement of metakaolin the compressive strength and split tensile strength were increased up to 9% replacement of metakaolin and decreased after that. It gave the maximum value at 9% of replacement of metakaolin. Addition of steel fiber to the different percentage of metakaolin also increased the strength then that of metakaolin reinforced concrete. The results revealed that incorporation of MK and utilization of different types of steel fibers significantly affected the mechanical properties of the concrete.

Keywords: Compressive strength, curing, metakaolin, steel fiber, split tensile strength

ARTICLE INFO

Article history:
Received: 09 May 2018
Accepted: 16 April 2019
Published: 24 July 2019

E-mail addresses:
niharthenew@gmail.com (Nihar Ranjan Mohanta)
samantaraysandeep963@gmail.com (Sandeep Samantaray)
* Corresponding author

ISSN: 0128-7680
e-ISSN: 2231-8526

INTRODUCTION

Concrete is one of most widely utilized development materials on the planet, with two billion tons set worldwide every year. It is alluring in numerous applications since it offers impressive quality at a moderately minimal effort. Concrete can largely be created of locally accessible ingredients, can be used in various fields and requires minimum maintenance. Supplementary cementitious materials (SCMs) are finely ground strong materials that are utilized to supplant some portion of the bond in a solid blend. These materials respond artificially with hydrating concrete to shape a changed glue microstructure. In addition to their positive environmental impact, SCMs may improve concrete workability, mechanical properties, and durability.

Now a day's cement concrete is the most widely used construction material. Due to the vast use of concrete production of cement has also grown rapidly. According to central pollution control board cement industry is recognized as one of the most polluted industry in India. The main pollutant emitted from cements industries are dust, carbon dioxide, nitrogen oxide and sulphur oxides which are very dangerous for our environment. So to reduce the amount of cement in concrete replacement of cement with metakaolin is partially used. Metakaolin results as a promising binding material for high performance concrete. It increases the mechanical properties of concrete up to a certain replacement of cement it is very economic and largely available in our country which can be used to prepare high performance concrete. Hence by using metakaolin concrete we can reduce the amount of cement in construction field leads to eco-friendly environment.

Wild et al., (1996) reported results on strength development of concrete; where cement was partially replaced with MK (5% to 30%). Poon et al., (2001) studied the mechanical and durability properties of high performance metakaolin (MK) concrete an silica fume concretes and found that the performance of the MK used in this study was superior to the silica fume in terms of strength development of concrete. Bai et al. (2000) carried out the review regarding the use of claimed clays and metakaolin as a pozzolan for concretes. They found that the use of met kaolin as partial cement replacement material in mortar and concrete had been studied widely in recent years. Guneyisi et al. (2007) investigated on the use of MK as a supplementary cementing material to improve the performance of concrete. The results indicated that it increased the strengths of the concretes in varying magnitudes, depending mainly on the replacement level. Lin et al. (2008) evaluated the mechanical properties of cement-based composites and found that the combination of steel fibers and silica fume could greatly increase the mechanical properties of cement-based composites. Katkhuda et al. (2009) conducted an experiment by replacing cement with different percentages of silica fume at different constant water-binder ratio keeping mix design. They concluded that tensile, compressive and flexure strengths increased with silica fume incorporation but the optimum replacement percentage was not constant because it depended on the water–cementitious material (w/cm) ratio of the mix. Dinakar et al. (2013) used Metakaolin and cement with low water/binder ratio of 0.3 for development of high performance concretes. They concluded that mechanical properties of concrete had higher values at 10% replacement of cement by Metakaolin. John (2013) found that the partial replacement of cement with Metakaolin helped in achieving high strengths in concrete. At 15% replacement of cement with Metakaolin content improves the strength characteristics such as of cube compressive strength, split tensile strength and flexural strength. Kumar and Rao (2014) studied that, better results were achieved by adding mineral admixtures like metakaolin with silica fume, fly ash and steel fibres in HPC. Al Menhosh et al. (2018) studied long term durability properties of concrete modified with metakaolin and polymer admixture and got maximum strength durability on replacing Portland cement with metakaolin and polymer. Nadeem et al. (2014) studied performance of fly ash and metakaolin concrete at elevated temperature and got that for all mixes major strength and durability loss occurred after 400^0c. El-Din et al. (2017) studied mechanical performance of high strength concrete made from high volume of metakaolin and hybrid fiber and concluded that replacing the cement with 15% of metakaolin enhanced mechanical properties of the mixture.

Pollution due to cement industries is the biggest problem for construction. Cement also responsible for producing heat in concrete by using metakaolin we can achieve more strength in concrete which is also not harmful for our environment. It also increases the durability of concrete. Hence more research will be needed in this field.

MATERIALS AND METHODS

For this study cement, fine and coarse aggregate, water, Metakaolin, and steel fiber were required. Brief descriptions of all materials are given below.

Concrete

Concrete is a uniform mixture of coarse aggregate, fine aggregate, cement and water. Most concretes used are lime-based concretes such as Portland cement concrete or concretes made with other hydraulic cements, such as calcium aluminates cements. Asphalt concrete, which is frequently used for road surfaces, is also a type of concrete. The cement maximally used is ordinary Portland cement and other cementitious materials such as fly ash, silica fume, metakaolin are treated as a binder for the aggregate. When aggregate is mixed together with dry Portland cement and water, the water reacts with cement which bonds the other components and the mixture forms fluid slurry that is easily poured and moulded into shape. The cement reacts chemically with the water and other ingredients to form a hard matrix that binds the materials together into a durable stone-like material. Various additives (such as pozzolans or super plasticizers) are included in the mixture to improve the physical properties of the wet mix or the finished material. Concrete has relatively high compressive strength, but very low tensile strength. The ultimate strength of concrete is mainly affected by the water cement ratio, the design procedure, mixing placement and curing methods. All things being equal, concrete with a lower water cement ratio makes a stronger concrete than that a higher ratio .The quality of the pastes formed by the cement and water largely determines the character of the concrete.

Cement

Cement is an extreme ground material having adhesive and cohesive properties which provides a binding medium to other aggregates. The manufacture of cement is mainly classified into two types dry and wet process In the wet process, the limestone brought from the quarries then crushed to powder Then, it is taken to a ball or tube mill where it is mixed with clay and water is added to it to form a slurry. The slurry is then stored in tanks under constant agitation and fed into rotary kilns. Where In the dry process the raw materials are ground mixed and fed to the rotary kiln in the dry state. Ordinary/Normal Portland cement is one of the most widely used cement.

Fine Aggregate

Fine aggregate is natural sand and these are the aggregates which are mainly passed through 4.75 mm IS sieve. By the size of the aggregates these are also classified as coarse sand, medium sand, fine sand. According to IS classifications sands are graded as zone-1 to zone-4 for various grain sizes. The finer of aggregate will be in ascending order from Zone-1 to Zone-4. The fine and coarse aggregate are placed and mixed separately. Fine aggregate is mainly used for the preparation of mortar for plastering work.

Coarse Aggregate

These are the aggregates which are retained on 4.75 mm sieve and these are classified into various types i.e crushed gravel, uncrushed gravel and partially crushed gravel. Maximum up to 40 mm size of aggregate is preferred for construction work. In concrete coarse aggregates are the major parameters for giving strength to the concrete.

The various purpose and uses of coarse aggregates are as follows:

1. It increases the volume of concrete, and hence cost will be reduced.
2. It provides shapes to the concrete
3. It increases hardness, durability of the concrete
4. It is the major parameter to resist the fire attack

Water

In generally water which is used for drinking should be used in construction work. Various acids, oils, alkalis, organic impurities should not be present in water which is used for construction. Hard water and soft water also make concrete weaker .Water has mainly two functions in concrete mix. Firstly it makes a chemical reaction with the cement to form cement paste in which the inert aggregate is held in suspension until the cement past has hardened .And secondly it acts as a lubricant in the mixture of fine aggregate and cement.

Metakaolin

Metakaolin is an admixture which is formed by the calcinations of clay mineral kaolinite. The particle size of metakaolin is smaller than cement particles, but not as fine as silica fume. It is manufactured for specific purpose under controlled conditions. Metakaolin is produced by heating kaolin a natural clay temperature between 650^{o}C to 900^{o}C. This treatment, called calcinations, which radically modifies the particle structure making it a highly reactive and can be used with the replacement of cement.

Steel fiber

In this study steel fiber of length 50 mm and diameter 0.70 mm is utilized. Steel fiber reinforced concrete is a low cost solution for un-cracked section design of concrete members. Use of steel fiber reinforcement in concrete enhances the ability of structural members to carry significant stresses. The use of fibers increases the toughness of concrete under any type of loads. Fibers in concrete have the ability absorb more energy. Addition of steel fibers into the concrete improves the crack resistance capacity of the concrete and these are generally used to improve the tensile strength of concrete.

Mix Design of M20 Grade Concrete

1. Design stipulations
   (a) Maximum water cement ratio =0.464
   (b) Workability is between 40-50 mm slump value
2. Materials Supplied
   (a) Cement: Ordinary Portland Cement
   (b) Coarse Aggregate: 20 mm and 10 mm
   (c) Fine Aggregate: Sand Conforming to Grading zone IV

Mix Proportion

Concrete was first mixed properly by replacing cement with metakaolin of 3%, 6%, 9%, 12%, 15%, and 18% of the weight of the cement and were tested for 7 days, 28 days, 56 days of curing. For each proportion two specimens of cube and cylinder were made and compressive strength and split tensile strength were calculated respectively with their respective days. Then after for each percentage of metakaolin replacement i.e. 0%, 3%, 6%, 9%, 12%, 15%, 18% steel fiber of 0.25%, 0.5%, 1% was added of the weight of cement for each respective proportions. Cube and cylinder were made for each percentage of steel fiber and again compressive strength and split tensile strength were calculated respectively.

Mixing of Concrete

Mixing of concrete should be done thoroughly by hand mixing so that a uniform quality of concrete was obtained. The slump should be in between 40-50 mm.

Compaction

Compaction is done with the help of tamping rod and vibrator I the entire specimen. Care is taken to remove voids from the concrete. Then the surface of the concrete is leveled and smoothened by metal trowel.

Curing of Concrete

Curing is done to prevent the loss of water which is essential for the process of hydration and hence for hardening. It also prevents the exposure of concrete to a hot atmosphere and to drying winds which may lead to quick drying out of moisture in the concrete and there by subjecting it to contraction stresses at a stage when the concrete would not be strong enough to resist them, This was done for the period of 7 days, 28 days and 56 days.

Testing Procedure

Testing of Fresh Concrete. Slump test in accordance with TS 2871 standard was performed for each mix in the fresh state. Mixes with metakaolin and fiber reinforcement gave slump test results of around 40 to 50 mm, however it was observed that all metakaolin and fiber reinforced mixes responded well to mechanical vibration and could be placed and compacted without much effort.

Testing of Hardened Concrete. 7 days, 28 days and 56 days of compressive strength and split tensile strength of each mix were determined in accordance with TS3114 ISO 4012 standard. Average of the test results of two specimens belonging to a mix was accepted as the 7 day, 28 day, 56 day compressive strength and split tensile strength of that mix. Specimens were tested so that the direction of loading was 90^o with the direction of casting.

Water Absorption Test

This test is performed to determine water absorption of the cubes and cylinders. Procedure for water absorption test is given below:

(a) Dry the cubes and cylinder in a ventilated oven at 105^{o}C to 110^{o}C till they attain practically constant weight, then weigh the brick and let the weight be W_1 kg.

(b) Immerse these cubes and cylinder in water completely at 27^{o}C for 24 hours.

(c) Then remove the cubes and cylinders from water and wife of its surface with a damp cloth then weight them, and let it weight be W_2 kg.

(d) Then the water absorption percentage = $\frac{W_2 - W_1}{W_1} \times 100$

RESULTS AND DISCUSSIONS

The result of water absorption for 7 days, 28 days, 56 days curing of cubes and cylinder are given in Table 1 to 3.

From the above experiment it was found that the water absorption capacity of the cubes were decrease gradually from the days of curing i.e from 7 days, 28 days, 56 days respectively. For 7 days of curing water absorption value was maximum and for 56 days water absorption value was minimum. Again for different percentage of replacement of metakaolin the water absorption capacity values were also changes. For every cubes and the water absorption capacity values gradually decreased from 0%, 3%, 6%, 9%, 12%, 15%, 18% respectively. The water absorption capacity was more for 0% and least for 18%. According to the water absorption capacity the strength of cubes was also varies.

Mechanical Properties

Compressive Strength. From the above experiment the compressive strength of cubes with different percentage of metakaolin replacement for different curing day's i.e. for 7 days, 28 days, 56 days were calculated (Table 4). The compressive strength was increased according to the period of curing i.e. the strength was increases from 7 days, 28 days, and 56 days of curing period respectively. The strength was more for 56 days of curing of cubes and least for 7 days of curing of cubes. Again strength was also varied according to the percentage of metakaolin replacement. The strength was increased firstly i.e. replacement up to 9% of metakaolin the strength was increases then after the strength gradually decreases. The maximum compressive strength was found as 48 (N/mm^2) and 48.44 (N/mm^2) respectively for two specimens for 9% replacement of metakaolin for 56 days of curing. Similarly the minimum compressive strength was 27.11 (N/mm^2) and 25.78 (N/mm^2) for two specimens for 18% replacement of metakaolin. Adding of steel fiber with different percentage i.e. 0.25%, 0.5%, 1% to the different percentage of metakaolin also increases the strength of cubes (Table 5). Comparison graph of compressive strength for cubes with steel fiber in context to various percentage of metakaolin for 7 days, 28 days, 56 days of curing are displayed in Figure 1, Figure 2 and Figure 3 receptively. The strength of cubes was also increased up to 9% then after the strength was decreased. By incorporation of steel fiber to the different percentage of metakaolin the maximum strength was found as 51.56 N/mm^2 for 1% of steel fiber with 9% of metakaolin for 56 days of curing.

Table 1
Water absorption value for 7 days curing of cubes and cylinder

	Water absorption value for 7 days curing of cubes							**Water absorption value for 7 days curing of cylinder**						
Percentage	Initial Wt (i)	Final Wt (i)	Initial Wght (ii)	Final Wght (ii)	Water absorption Percentage (i)	Water absorption Percentage (ii)	Average water absorption	Initial Wght (1)	Final Wght (1)	Initial Wght (2)	Final Wght (2)	Water absorption Percentage (i)	Water absorption Capacity (2)	**Average water absorption**
0	8.710	8.790	8.820	8.910	0.918	1.020	0.969	13.230	13.300	13.350	13.430	0.529	0.599	**0.564**
3	8.420	8.480	8.650	8.720	0.713	0.809	0.761	13.410	13.470	13.170	13.230	0.447	0.455	**0.451**
6	8.850	8.910	8.620	8.670	0.678	0.580	0.629	13.150	13.20	13.240	13.300	0.456	0.453	**0.454**
9	8.720	8.770	8.560	8.610	0.573	0.584	0.578	13.320	13.370	13.430	13.480	0.375	0.372	**0.373**
12	8.530	8.580	8.480	8.530	0.586	0.589	0.587	13.290	13.340	13.450	13.490	0.376	0.297	**0.336**
15	8.470	8.510	8.530	8.80	0.472	0.586	0.529	13.020	13.060	13.080	13.120	0.307	0.305	**0.306**
18	8.640	8.680	8.570	8.410	0.463	0.478	0.470	13.110	13.140	13.180	13.220	0.228	0.303	**0.265**

Table 2
Water absorption value for 28 days curing of cubes and cylinder

	Water absorption value for 28 days curing of cubes							**Water absorption value for 28 days curing of cylinder**						
Percentage	Initial Wt (i)	Final Wt (i)	Initial Wght (ii)	Final Wght (ii)	Water absorption Percentage (i)	Water absorption Percentage (ii)	Average water absorption	Initial Wght (1)	Final Wght (1)	Initial Wght (2)	Final Wght (2)	Water absorption Percentage (i)	Water absorption Capacity (2)	**Average water absorption**
0	8.410	8.470	8.660	8.710	0.713	0.577	0.645	13.330	13.380	13.290	13.330	0.375	0.300	**0.337**
3	8.840	8.890	8.960	9.010	0.566	0.558	0.562	13.270	13.300	13.120	13.160	0.226	0.304	**0.265**
6	8.590	8.630	8.810	8.850	0.466	0.454	0.46	13.100	13.130	13.080	13.120	0.229	0.305	**0.267**
9	8.600	8.630	8.870	8.900	0.348	0.338	0.343	13.050	13.080	13.120	13.150	0.229	0.229	**0.229**
12	8.550	8.580	8.950	8.970	0.350	0.223	0.286	12.990	13.010	13.140	13.170	0.153	0.152	**0.1525**
15	8.720	8.740	8.530	8.560	0.229	0.351	0.29	13.150	13.170	13.210	13.240	0.153	0.227	**0.190**
18	8.550	8.570	8.500	8.520	0.234	0.235	0.234	13.020	13.040	13.050	13.070	0.153	0.153	**0.153**

Percentage	Water absorption value for 56 days curing of cubes							Water absorption value for 56 days curing of cylinder						
	Initial Wt (i)	Final Wt (i)	Initial Wght (ii)	Final Wght (ii)	Water absorption Percentage (i)	Water absorption Percentage (ii)	Average water absorption	Initial Wght (1)	Final Wght (1)	Initial Wght (2)	Final Wght (2)	Water absorption Percentage (i)	Water absorption Capacity (2)	Average water absorption
0	8.810	8.850	8.560	8.600	0.454	0.467	0.460	13.310	13.340	13.230	13.260	0.225	0.226	0.225
3	8.960	8.990	8.930	8.960	0.334	0.336	0.335	13.350	13.380	13.320	13.340	0.225	0.150	0.187
6	8.950	8.980	8.840	8.860	0.335	0.226	0.280	13.270	13.300	13.150	13.180	0.226	0.228	0.227
9	8.460	8.480	8.710	8.730	0.236	0.229	0.267	13.000	13.020	12.980	12.100	0.154	0.154	0.159
12	8.630	8.650	8.560	8.580	0.231	0.233	0.232	13.110	13.130	13.170	13.190	0.153	0.151	0.152
15	8.750	8.770	8.940	8.950	0.228	0.112	0.170	13.030	13.040	13.090	13.100	0.076	0.076	0.076
18	8.770	8.780	8.540	8.560	0.114	0.117	0.115+	13.210	13.220	13.150	13.170	0.076	0.152	0.113

Table 4
Compressive strength of cubes during different days of curing

Percentage of Metakaolin replacement	7 days of curing			28 days of curing			56 days of curing		
	Strength (N/mm^2)(i)	Strength (N/mm^2) (ii)	Avg Strength (N/mm^2)	Strength (N/mm^2) (i)	Strength (N/mm^2) (ii)	Avg Strength (N/mm^2)	Strength (N/mm^2) (i)	Strength (N/mm^2) (ii)	Avg Strength (N/mm^2)
0	29.78	31.56	30.665	36,445	34.667	35.556	37.78	39.11	38.445
3	35.11	37.78	36.445	41.778	41.778	41.78	43.11	44	43.56
6	36.89	39.11	38.005	42.222	42.667	42.45	44.889	47.111	46
9	39.56	40	39.78	44	43.111	43.56	48	48.44	48.22
12	35.56	34.67	35.115	37.778	39.556	38.67	39.56	41.33	40.44
15	30.67	29.33	30	34.222	32.889	33.56	34.22	36.44	35.33
18	27.11	25.78	26.445	31.556	30.667	31.113	32.44	33.33	32.88

Table 5
Compressive strength of cubes after adding with steel fiber

Percentage of metakaolin replacement	Percentage of Steel fiber	Average Strength (N/mm^2) (7 days)	Average Strength (N/mm^2) (28 days)	Average Strength (N/mm^2) (56 days)	Percentage of metakaolin replacement	Percentage of Steel fiber	Average Strength (N/mm^2) (7 days)	Average Strength (N/mm^2) (28 days)	Average Strength (N/mm^2) (56 days)
0	0	30.66	35.56	38.91	12	0	36.44	38.67	36.23
	0.25	30.67	35.56	41.24		0.25	35.115	39.11	42.0
	0.5	32	37.33	38.78		0.5	37.78	40	38.32
	1	32.89	38.67	43.21		1	38.22	41.78	37.46
3	0	36.445	41.78	43.65	15	0	30	33.56	38.26
	0.25	37.33	42.22	40.23		0.25	32	35.11	37.43
	0.5	38.22	43.11	44.35		0.5	33.78	36	34.23
	1	39.56	43.56	39.23		1	34.67	37.33	33.21
6	0	38.005	42.45	43.27	18	0	26.445	31.11	28.32
	0.25	37.78	43.56	46.45		0.25	28	32.44	35.24
	0.5	39.56	45.33	46.38		0.5	28.44	33.3	32.59
	1	40.44	46.67	49.51		1	29.78	33.78	37.67
9	0	39.78	43.56	48.42					
	0.25	40.44	45.33	51.56					
	0.5	44	47.11	49.98					
	1	43.11	48.44	51.23					

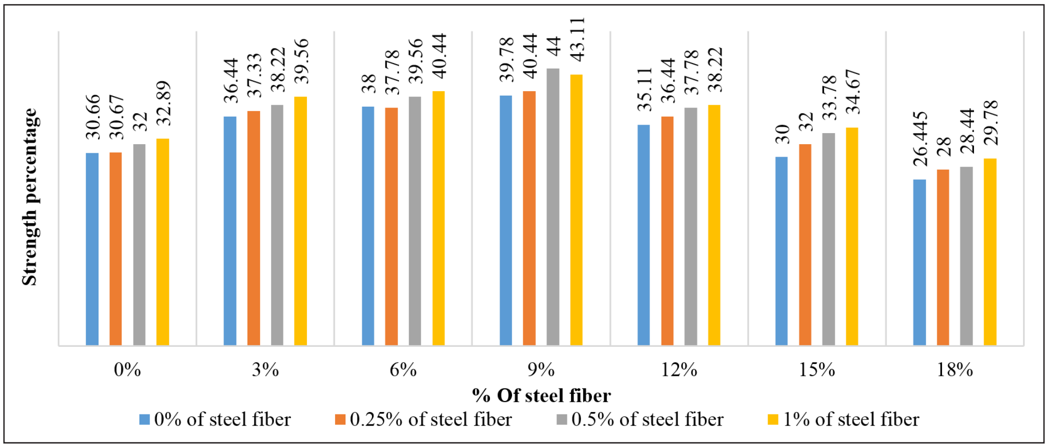

Figure 1. Compressive strength of cube with steel fiber in different percentage of metakaolin for 7 days of curing

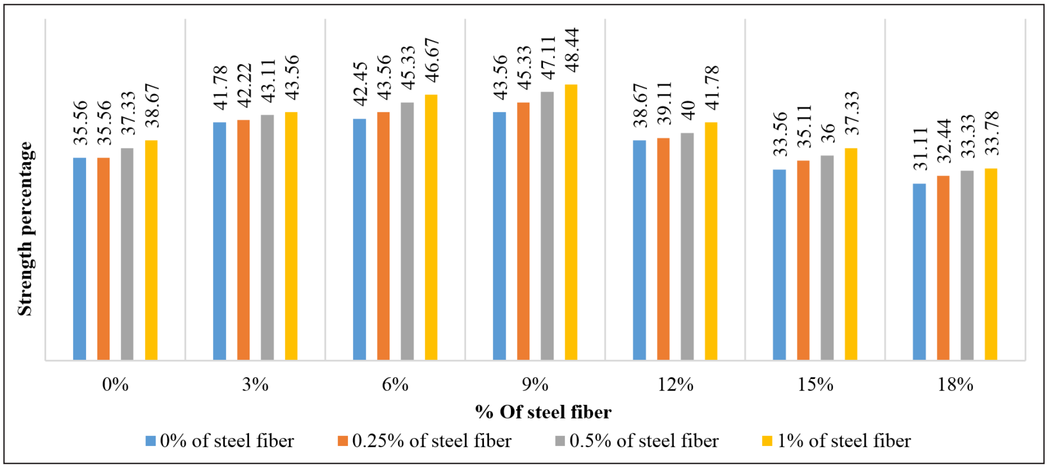

Figure 2. Compressive strength of cube with steel fiber in different percentage of metakaolin for 28 days of curing

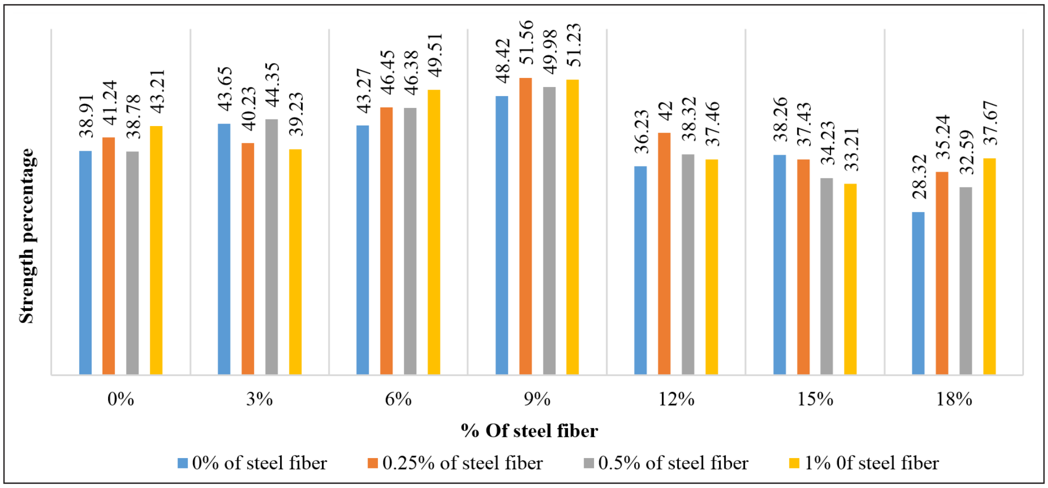

Figure 3. Compressive strength of cube with steel fiber in different percentage of metakaolin for 56 days of curing

Split Tensile Strength. From the above experiment the split tensile strength of cubes with different percentage of metakaolin replacement for different curing days i.e. for 7 days, 28 days, 56 days were calculated (Table 6). The split tensile strength was also increased according to the period of curing i.e. the strength was increased from 7 days, 28 days, and 56 days of curing period respectively. The strength was more for 56 days of curing of cylinders and least for 7 days of curing of cylinders. Again strength was also varied according to the percentage of metakaolin replacement. The strength was increased firstly i.e. replacement up to 9% of metakaolin the strength was increased then after the strength gradually decreased. The maximum split tensile strength was found as 3.68 N/mm^2 and 3.54 N/mm^2 respectively for two specimens for 9% replacement of metakaolin for 56 days of curing. Similarly the minimum split tensile strength was 2.123 N/mm^2 and 1.840 N/mm^2 for two specimens for 18% replacement of metakaolin for 7 days of curing. Adding of steel fiber with different percentage i.e. 0.25%, 0.5%, 1% to the different percentage of metakaolin also increased the strength of cylinders (Table 7). A comparison sketch for split tensile strength of cylinders when steel fiber was added with various percentage of metakaolin for 7 days, 28 days, 56 days of curing are shown in Figure 4, Figure 5 and Figure 6 Respectively. The strength of cylinders was also increased up to 9% then after the strength were decreases. By incorporation of steel fiber to the different percentage of metakaolin the maximum strength was found as 4.11 N/mm^2 for 1% and 0.5% of steel fiber with 9% of metakaolin for 56 days of curing.

Table 6
Split tensile strength of cylinder during different days of curing

Percentage of Metakaolin replacement	7 days of curing			28 days of curing			56 days of curing		
	Strength (N/mm^2) (i)	Strength (N/mm^2) (ii)	Avg strength (N/mm^2)	Strength (N/mm^2) (i)	Strength (N/mm^2) (ii)	Avg strength (N/mm^2)	Strength (N/mm^2) (i)	Strength (N/mm^2) (ii)	Avg strength (N/mm^2)
0	2.123	2.55	2.34	2.69	2.97	2.83	2.97	2.83	2.9
3	2.41	2.69	2.55	3.113	3.25	3.182	3.25	3.25	3.25
6	2.83	2.83	2.83	3.40	3.25	3.325	3.40	3.68	3.54
9	2.97	3.113	3.042	3.25	3.68	3.465	3.54	3.68	3.61
12	2.55	2.69	2.62	2.97	2.83	2.9	3.113	2.97	3.041
15	2.263	2.41	2.34	2.69	2.97	2.83	2.97	2.83	2.9
18	1.840	2.123	1.98	2.406	2.55	2.48	2.55	2.83	2.69

Table 7
Split tensile strength of cylinders after adding with steel fiber

Percentage of metakaolin replacement	Percentage of steel fiber	Average strength (N/mm^2) (7 days)	Average strength (N/mm^2) (28 days)	Average Strength (N/mm^2) (56 days)	Percentage of metakaolin replacement	Percentage of steel fiber	Average strength (N/mm^2) (7 days)	Average strength (N/mm^2) (28 days)	Average strength (N/mm^2) (56 days)
0	0	2.34	2.83	3.39	12	0	2.62	2.9	3.98
	0.25	2.41	3.11	3.41		0.25	2.83	3.25	3.65
	0.5	2.69	3.25	3.36		0.5	3.11	3.40	3.73
	1	2.83	3.25	3.45		1	3.25	3.54	3.82
3	0	2.55	3.18	3.62	15	0	2.34	2.83	3.51
	0.25	2.83	3.25	3.65		0.25	2.69	2.83	3.23
	0.5	2.97	3.40	3.23		0.5	2.83	3.11	2.91
	1	2.97	3.54	3.58		1	2.83	3.25	3.10

Table 7 (*continue*)

Percentage of metakaolin replacement	Percentage of steel fiber	Average Strength (N/mm^2) (7 days)	Average Strength (N/mm^2) (28 days)	Average Strength (N/mm^2) (56 days)	Percentage of metakaolin replacement	Percentage of steel fiber	Average strength (N/mm^2) (7 days)	Average strength (N/mm^2) (28 days)	Average strength (N/mm^2) (56 days)
6	0	2.83	3.33	3.71	18	0	1.98	2.48	3.32
	0.25	3.113	3.54	3.65		0.25	2.26	2.69	2.87
	0.5	3.25	3.54	3.23		0.5	2.41	2.69	2.51
	1	3.40	3.82	3.14		1	2.55	2.83	2.98
9	0	3.04	3.47	3.82					
	0.25	3.25	3.82	3.97					
	0.5	3.25	3.95	4.11					
	1	3.54	3.95	3.99					

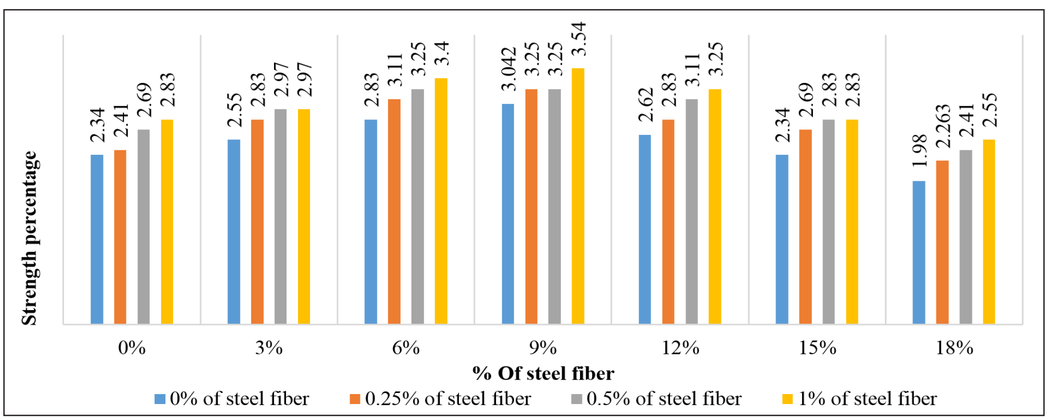

Figure 4. Split tensile strength of cylinder steel fiber with different percentage of Metakaolin for 7 days of curing

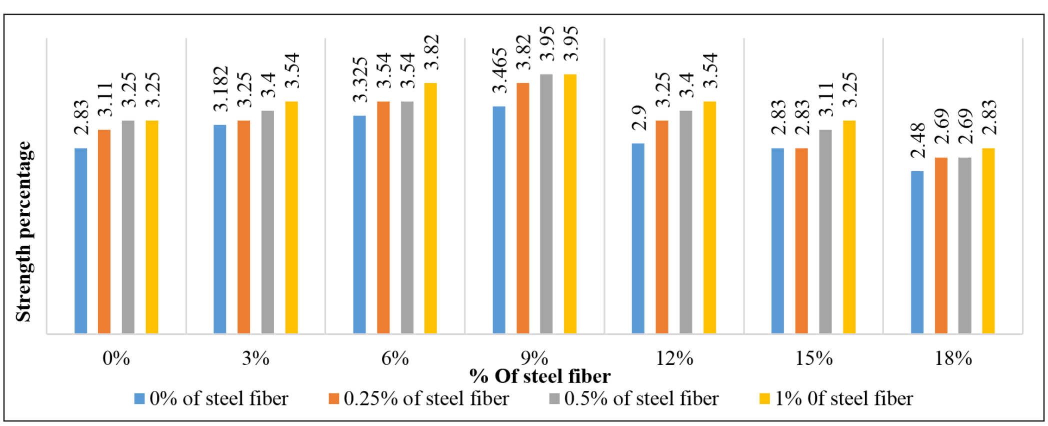

Figure 5. Split tensile strength of cylinder steel fiber with different percentage of Metakaolin for 28 days of curing

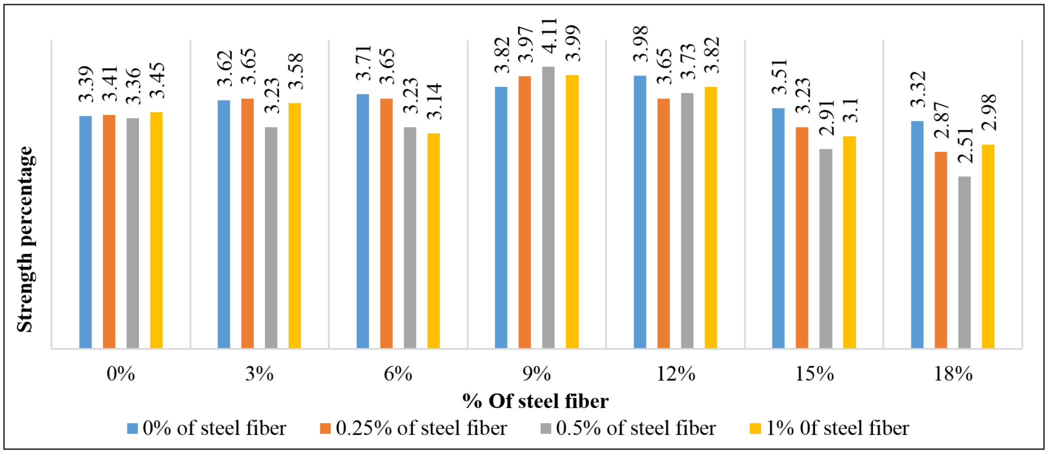

Figure 6. Split tensile strength of cylinder steel fiber with different percentage of Metakaolin for 56 days of curing

The main ingredient of metakaolin is silica (52.57%) and alumina (40.42%). Silica imparts strength to the concrete but alumina but if present in excess reduces the strength. Hence up to a certain replacement that is 9%, the mechanical properties increases after adding more that is 12%, 15%, 18% the presence of alumina also increases which affects the strength of concrete. One more reason is while increasing percentage of metakolin, water absorption capacity of concrete also increases which also affects the strength.

CONCLUSION

The following conclusions may be drawn based on the experimental results.

The water absorption capacity of cubes and cylinders were decreased by day wise i.e. more for 7 days, relatively less for 28 days, lesser for 56 days. **U**se of MK as a replacement material resulted in enhanced mechanical properties of concrete. The highest compressive strength value was measured as 48.44 N/mm^2 and highest split tensile strength value was measured as 11.56 N/mm^2 for concrete with w/c ratio of 0.464. The compressive strength and the split tensile strength of cube and cylinder were increased to a certain limit of replacement of metakaolin i.e. 9% then after further replacement the values of compressive strength and split tensile strength of cube and cylinder were decreased. The inclusion of steel fibers also contributed more compressive strength as well as more split tensile strength than that of simple replacement of metakaolin. More steel fiber will enhance the strength. The maximum compressive strength was found as 48.44 N/mm^2 for 1% incorporation of steel fiber at 9% metakaolin replacement and maximum split tensile strength was found as 3.95 N/mm^2 for 0.5% and 1% incorporation of steel fiber at 9% replacement of metakaolin. By incorporation of steel fibers remarkable improvement in characteristic and split tensile strength capacities of the concretes were observed. This difference in the behavior of steel fiber reinforced concretes may be attributed to the dispersion and orientation of the steel fibers within the concrete. In steel fiber reinforced concrete the compressive strength were increased 0%-3% by the incorporation of 0.25% of steel fiber, 4%-11% by the incorporation of 0.5% of steel fiber and 6%-15% by the incorporation of 1% of steel fiber than that of metakaolin replacement. Similarly the split tensile strength was increased 3%-10% by the incorporation of 0.25% of steel fiber, 6%-18% by the incorporation of 0.5% of steel fiber, 14%-25% by the incorporation of 1% of steel fiber than that of simple metakaolin replacement. From the experiment it was concluded that the increase in water absorption capacity will decrease the strength. Different materials such as pulverized fuel ash, marvel powder, rice husk ash, coconut shell ash, glass powder, limestone fines, ground granulated blast furnace slag may be added with concrete instead of metakaolin which affects the mechanical properties.

ACKNOWLEDGEMENT

This work has been partially supported by the Department of IGIT Sarang and GIET University.

REFERENCES

Al Menhosh, A., Wang, Y., Wang, Y., & Augusthus-Nelson, L. (2018). Long term durability properties of concrete modified with Metakaolin and polymer admixture. *Construction and Building Material, 172*, 41-51.

Bai, J., Sabir, B. B., Wild, S., & Kinuthia, J. M. (2000). Strength development in concrete incorporating PFA and metakaolin. *Magazine of Concrete Research, 52*(3), 153-162.

Dinakar, P., Sahoo, P. K., & Sriram, G. (2013). Effect of metakaolin content on the properties of high strength concrete. *International Journal of Computer Science and Mathematics, 7*(3), 215-223.

El-Din, H. K. S., Eisa, A. S., Aziz, B. H. A., & Ibrahim, A. (2017). Mechanical performance of high strength concrete made from high volume of metakaolin and hybrid fibers. *Concrete and Building Materials, 140*, 203-209.

Guneyisi, E., Gesoglu, M., & Mermerdas, K. (2007). Improving strength, drying shrinkage and pore structure of concrete using metakaolin. *Materials and Structures, 41*(5), 937-949.

John, N. (2013). Strength properties of metakaolin admixed concrete. *International Journal of Scientific and Research Publications, 3*(6), 1-7.

Katkhuda, H., Hanayneh, B., & Shatarat, N. (2009). Influence of silica fume on high strength lightweight concrete. *International Scholarly and Scientific Research and Innovation*, *3*(10), 407-414.

Kumar, A. V. S. S., & Rao, K. (2014). A study on strength of concrete with partial replacement of cement with quarry dust and metakaolin. *International Journal of Innovative Research in Science and Technology, 3*(3), 10467-10473.

Lin, W. T., Huang, R., Lee, C. L., & Hsu, H. M. (2008). Effect of steel fiber on the mechanical properties of cement-based composites containing silica fume. *Journal of Marine Science and Technology, 16*(3), 214-221.

Nadeem, A., Memon, S. A., & Lo, T. Y. (2014). The performance of fly ash and Metakaolin concrete at elevated temperatures. *Construction and Building Materials, 62*, 67-76.

Poon, C. S., Lam, L., Kou, S. C., Wong, Y. L., & Wong, R. (2001). Rate of pozzolanic reaction of metakaolin in high-performance cement pastes. *Cement and Concrete Research*, *31*(9), 1301-1306.

Wild, S., Khatib, J. M., & Jones, A. (1996). Relative strength, Pozzolanic activity and cement hydration in super plasticized metakaolin concrete. *Cement and Concrete Research*, *26*(10), 1537-1544.