STRENGTH DEVELOPMENT AND WATER ABSORPTION OF CONCRETE CONTAINING METAKAOLIN, SILICA FUME AND RICE HUSK ASH

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ABSTRACT. This paper is concerned with strength and durability properties of concrete mixes after partial replacement by Rice Husk Ash (RHA), Metakaolin (MK) and Silica Fume (SF) in different concrete mixes. These binders were mixed in combination with each other also. The percentage of replacement of these mixes was varied from 5% to 10%. Eight numbers of different mixes were cast and tested for compressive strength, splitting tensile strength and water absorption. The compressive strength and tensile strength tests were conducted at the curing age of 3,7,28 and 60 days, whereas, water absorption tests were conducted on concrete specimens after 28 and 60 days of curing in potable water. The result shows that RHA decreases the compressive strength of concrete up to 28 days of curing but helps to develop the compressive strength at later ages of curing. Partial replacement of cement by MK, combination of MK and RHA; and combination of RHA and SF increases compressive as well as splitting tensile strength of concrete. After checking water absorption of all the mixes, it was found that replacing cement partially by RHA, MK and SF decreases the water absorption of the mixes.

Keywords: Strength, durability, RHA, Metakaolin, Silica Fume

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INTRODUCTION

Concrete is probably the most extensively used construction material in the world. It is only second to water as the most heavily consumed substance with about six billion tonnes being produced every year. Concrete is a composite construction material composed primarily of aggregate, cement and water. There are many formulations that have varied properties. The aggregate is generally coarse gravel or crushed rocks such as limestone, or granite, along with a fine aggregate such as sand. The cement, commonly Portland cement, and other cementious materials such as fly ash and slag cement, serve as a binder for the aggregate. Various chemical admixtures are also added to achieve varied properties. Water is then mixed with this dry composite which enables it to be shaped (typically poured) and then solidified and hardened into rock-hard strength through a chemical process known as hydration. The water reacts with the cement which bonds the other components together, eventually creating a robust stone-like material. Concrete has relatively high compressive strength, but much lower tensile strength.

According to this new vision, notwithstanding the energy consumption of cement production and the related carbon dioxide emissions, concrete can absorb these negative effects and become an environmentally sustainable material. This outstanding effect is mainly attributable to the opportunity of easily incorporating mineral additions in concrete. Such mineral additions are quite different in nature, composition, and origin. Thanks to concrete technology developments, particularly connected to advances in concrete admixtures, mineral additions are used quite frequently in concrete today. In fact, many by-products and solid recyclable materials can be used in concrete mixtures as aggregates or cement replacement, depending on their chemical and physical characterization. The capacity of concrete for incorporating these secondary raw materials is very wide and the main limit is their availability, which has to be comparable with the cement stream, since it is not worthwhile to develop new cementious materials if their availability on the market cannot be guaranteed. Focus is being shifted on developments in concrete technology that are already underway and are revolutionary in the sense that the goal is not a special concrete type meeting a particular engineering need. Instead, the goal is to transform all concrete into a general-purpose building material that is composed of eco-friendly components, and produce crack-free and highly durable structures. With increasing incidences of concrete deterioration, compressive strength alone cannot be considered as the sole criterion for evaluating the quality of concrete. Concrete is now specified in terms of both strength and durability. It is assumed that higher the compressive strength of concrete, better would be its durability. However, this assumption is not always true. A concrete mix satisfying the required strength may not necessarily be durable. Concrete durability is one of the most important considerations in the design of new structures and assessing the condition of existing structures. In order to reduce the porosity and make the microstructure of the concrete dense, use of supplementary cementitious materials or mineral admixtures has been very encouraging. Various materials in this category such as fly ash (FA), silica fume (SF), rice husk ash (RHA) and ground granulated blast furnace slag (GGBS), and Metakaolin (MK) have been used in cement/mortar and concrete to enhance their durability. Mineral admixtures are finely divided materials, which are added to concrete as partial replacement of Portland cement (PC). The combination of pozzolanic and pozzolanic /cementitious materials with cement has been used widely.

This study was conducted to investigate the effects of replacement of PC by MK, RHA and SF as binary and ternary blends, on the strength and water absorption properties of concrete. Compressive strength tests were carried out as per IS 516-1959, reaffirmed 2004. Splitting tensile strength test and water absorption tests were carried out as per recommendations of Bureau of Indian Standards.

BACKGROUND

This section deals with the review of the existing literature on the use of mineral admixtures in concrete. The most important investigations, related to the current investigation, are summarized and salient facts which seen to emerge from the research are discussed. The discussion is generally confined to the strength and durability characteristics of concrete with mineral admixture such as Metakaolin (MK), Rice husk ash (RHA) and Silica fume (SF).

Badagiannis and Tsivilis **(2009)** investigated the effect of MK on concrete durability. A Greek kaolin of low kaolinite content was thermally treated at defined conditions and the produced MK was finely ground. In addition, a commercial MK of high purity was used. Eight mixture proportions were used to produce high performance concrete, where MK replaced either cement or sand in percentages 10% or 20% by weight of control cement content .It was observed that MK concrete exhibited significantly lower chloride permeability, gas permeability and sorptivity. The addition of MK was found to refine the pore system of concrete, leading to a decreased mean pore size and improve uniformity of the pore size distribution. It was concluded that as the replacement levels of the mineral admixtures were increased, there was greater retardation in setting times. In case of concrete containing MK, this was only observed up to a replacement level of 10% at higher replacement level of 15% the retarding effect was found to reduce.
***Cassagnabere et al*. (2010**) investigated the compressive strength of cement-based materials at both early (1 day) and later (28 days) ages under steam curing conditions composed of cement (clinker+ slag) or combinations between clinker and mineral . Limestone and siliceous fillers, SF and four MK differing in their production process and impurity content were investigated. Considering performance, economic and environmental criteria, results in the laboratory showed MK as a very promising solution at a clinker replacement rate of 12.5-25% by mass. Compressive strength was significantly increased (1-day age) or practically the same as for reference mortars incorporating cement only (28-days age). It was concluded that in comparison with the reference concrete containing no MK and for an identical granular skeleton, the combination, clinker/MK was validated in the precast factory in full- scale trails for slip forming (25% replacement) and self–compacting (17.5% replacement) concrete applications: compressive strength and porosity were not affected.
Moser et al. **(2010)** evaluated the potential for binary and ternary blended of MK, with two differing particle size distributions and Class C fly ash to mitigate alkali- silica reactions (ASR) with a highly reactive fine aggregate using accelerated mortar bar test (AMBT) and concrete prism test (CPT) methods. The relative effectiveness of MK primarily results from the smaller particle size, higher degree of reactivity and chemical composition. Data showed that these contribute to a decrease in $Ca(OH)_2$ content, which correlates to lower expansion. It was also proposed that contributions to lower permeability and increased alkali binding also played a role in mitigating ASR. Metakaolin with higher surface area was less effective than the MK, with lower surface area, in decreasing ASR-induced expansion in binary blends
Vejmelkava et al. **(2010)** investigated an extensive set of parameters of high performance concrete (HPC) with MK including basic physical characteristics, mechanical and fracture-mechanical properties, durability characteristics, hydric and thermal properties and chloride binding characteristics. The experimental results showed that the replacement of PC by 10% of MK as an optimal amount lead in most cases either to improvements or at least does not

significantly impair substantial properties of the analyzed HPC. Basic physical properties and heat transport and storage properties were very similar to common HPC, mechanical and fracture – mechanical properties after 28 days were slightly worsened but later improved, water and water vapour transport parameters were substantially reduced ,frost resistance was better, resistance against de-icing salt was slightly worse but still met very well the required criteria. The chemical resistance of concrete with 10 % of MK instead of PC is distilled water and HCl was found better than for PC concrete ,in $MgCl_2$ it was slightly worse, and in NH_4Cl, Na_4Cl and CO_2 almost the same, carbonation was reduced and chloride binding capacity was increased.

***Mansour et al.* (2011)** studied the calcinations of local kaolin at various temperature (650-950 °C) and duration (2,3 and 4 h) to produce MK with a high pozzolanic activity. The pozzolanic activity was assessed by 28 days compressive strength and hydration heat methods. The maximum identified activity was obtained at 850°C for 3 hour duration. An increase of both hydration heat and compressive strength was obtained when OPC was replaced by 10% MK. The use of ternary blended cement improved the early age and the long-term compressive strength. The durability was also enhanced as better acidic resistance was observed.

***Siddiqui et al.* (2011)** investigated the effect of MK on the near surface characteristics of concrete. A control concrete having cement content $450Kg/m^3$ and w/c of 0.45 was designed. Cement was replaced with three percentages (5, 10, and 15%) of MK weight. Tests were conducted for initial surface absorption, sorptivity, water absorption and compressive strength at the ages of 35, 56 and 84 days. Test results indicated that with the increase in MK content from 5 to 15%, there was a decrease in the initial surface absorption; decrease in the sorptivity till 10% metakaolin replacement but at 15% MK replacement an increase in sorpivity was observed. All mixtures showed low water absorption characteristic i.e. less than 10%. It was found that compressive strength shared an inverse relation with sorptivity. Higher MK replacements of 15% were not helpful in improving inner core durability, even though it helped in improving surface durability characteristics.

***Guneyisi et al.* (2012**) investigated the effectiveness of MK in the improvement of durability of concretes to sulphate attack. Experimental parameters of the study were MK replacement levels, water/ cementitious materials ratio, initial curing procedure in terms of air curing and water curing, and type of the sulphate exposure regimes such as continuous and drying - immersion cyclic exposures. The tests were conducted at specified period upto 365 days. At the end of initial curing, concrete specimens were divided into three groups such that the first group was transferred into tap water to be used as control in the assessment of CS reduction while the other groups were immersed in 10% Na_2SO_4 solution for the period of 365 days under continuous or cyclic exposures. The results indicated that inclusion of MK as modifying agent increased the resistance of concrete against sulphate attack depending mainly on the MK replacement level, w/cm ratio and initial curing procedure adopted.

Gurunaathan and Thirugnanam (2014) carried out a study to replace part of cement by Ground Granulated Blast Furnace Slag (GGBS), Fly Ash (FA), Rice Husk Ash (RHA) and Silica Fume (SF) to improve the durability properties of concrete. In this paper, suitable admixtures have been added to improve the durability characteristics and the optimum percentage of replacement of cement by mineral admixtures with various proportions. ***Huang et al.(2017)*** investigated the effects of rice husk ash (RHA) on strength and permeability of ultra-high performance concrete (UHPC). RHA was manufactured by calcining rice husk at temperature of 500 °C and incorporated in UHPC mixture to replace different ratio of silica fume (SF) by weight. Flowability and air content of fresh mixture and the compressive and flexural strength at different curing ages were measured. The results show that the addition of

RHA to replace SF decreases the fluidity of fresh UHPC mixture and entraps more air bubbles. The addition of RHA enhances the compressive strength and impermeability of UHPC due to the refined pore structure. The permeability of cylindrical specimen increases notably with the increasing vertical loading and the lateral loading has an insignificant influence on the water absorption. ***Venu et al.*** (2018) studied the effect of supplementary materials in the concrete. Supplementary materials like metakaolin has been used in the concrete. Concrete having compressive strength 35 MPa is used in the experimental investigation. Mechanical properties like compressive strength, split tensile strength and flexural strengths are compared with modified concrete. Apart from that, the modified concrete has been evaluated using non-destructive tests like rebound hammer and ultrasonic pulse velocity. Also a relationship developed between the compressive strength and non-destructive tests. Based on the results, the performance of modified concrete is better than the normal concrete.

CONCLUSIONS FROM THE LITERATURE REVIEW

To investigate the benefits of mineral admixtures as partial replacement of PC in concrete is a subject of interest to many researchers all over the world and mineral admixtures have been observed to improve the strength and durability properties of concrete. Economic and environmental advantages by reducing CO_2 emissions are well known. From the study of literature, it is concluded that extensive literature is available on the strength and durability properties of Metakaolin and Silica fume. But there is a limited literature available on the properties of Rice Husk Ash.
However, all the supplementary materials have certain shortfalls. Addition of SF to PC causes an increase of hydration at early ages including a high early strength, but it can reduce the workability of concrete mix. On the other hand, MK contributes to hydration after improving the strength at medium and later ages. Hence, binary and ternary blended concrete [(PC-RHA),(PC-SF-MK)or (PC-SF-RHA)] with better performance could be produced.

EXPERIMENTAL METHODOLOGY

To achieve the objectives of the present study, an experimental program was planned to investigate water absorption and strength properties of concrete containing mineral admixtures as partial replacement of cement. Mineral admixtures used were Silica fume (SF), Metakaolin (MK) and Rice husk ash (RHA). This section outlines the experimental programme, planned for the present investigation, in detail. The basic properties of concrete constituent materials, concrete mix details along with method of casting and curing, workability of concrete, details of tests performed on hardened concrete are presented.

MATERIALS

The properties of materials used in concrete are determined in laboratory as per relevant code of practice. Different materials used in the present study were cement, 2 types of coarse aggregates, fine aggregates 10mm and 20mm, Silica fume and water. Results of the tests conducted to determine physical properties of materials are reported and discussed in this section. The materials in general, conformed to the specifications laid down in the relevant Indian Standard Codes.

Cement

In the present investigation, Ordinary Portland Cement (OPC) of 43 Grade was used for all concrete mixes. The physical properties of the cement as determined from various tests are listed in Table- 1.The particle size analysis of cement used is shown in Fig.1. The cement was tested as per IS: 8112-1989 and the results of various tests conducted are reported in the Table- 1 and Table 2.

Table1 Physical properties of cement

CHARACTERISTICS	UNITS	RESULTS OBTAINED	VALUE SPECIFIED (IS : 8112:1989)
Fineness (specific surface)	cm2/gm	3000	3500
Soundness (expansion by Le-Chatelier test)	mm	1.0	10 (maximum)
Specific gravity		3.15	
Normal Consistency (percent of cement by weight)	%	30	30
Setting time (i) initial (ii) final	minutes	110 270	30 (minimum) 600 (maximum)
Compressive strength (i) 3 days (ii) 7 days (iii) 28 days	MPa	24.50 33.75 44.45	23.0 33.0 43.0

Table 2 Chemical properties of cement

S. NO.	TEST PARAMETER	TEST VALUE IN %	IS:8112-1989 RECOMMENDATI-ONS IN %
1	Ratio of Lime to Silica, Alumina and Iron Oxide	0.90%	1.02 (Max.) 0.66 (Min.)
2	Ratio of Alumina to Iron Oxide	1.58%	0.66 (Min.)
3	Insoluble Residue	1.10%	2.0 (Max.)
4	Magnesia	2.60%	6.0 (Max.)
5	Total Sulphur content	1.30%	2.5 (Max.)
6	Total Loss on Ignition	1.20%	5.0 (Max.)
7	Total Alkali	0.49%	0.6 (Max.)
8	Chloride Content	0.08%	0.1 (Max.)
9	CaO : 61.3 %, MgO : 2.6%, SiO2 : 20.1%, Al2O3 : 6.80%, Fe2O3 : 4.30 %, SO3 :1.30%		

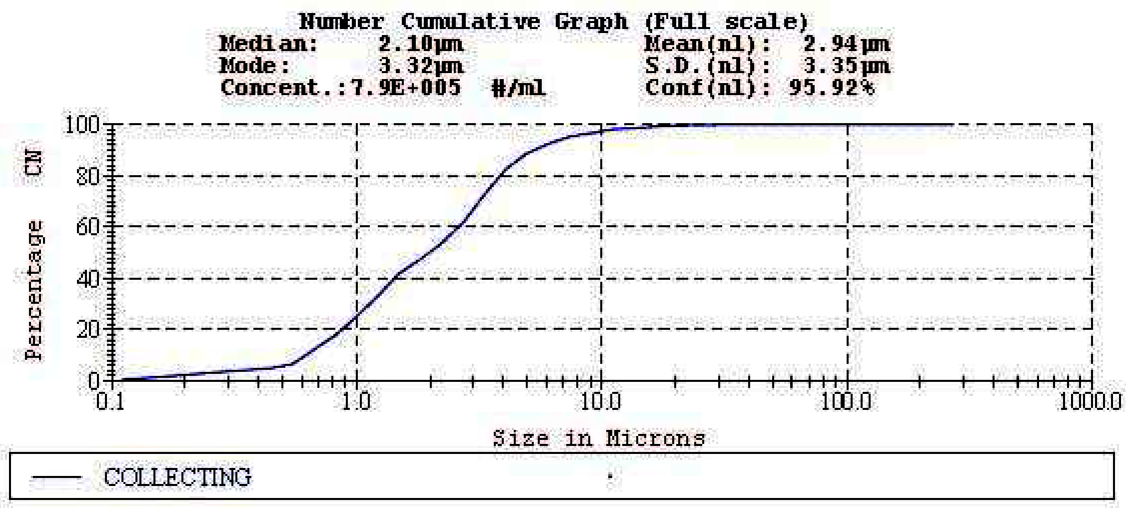

Figure 1 Particle size analysis of the cement

Aggregates

The aggregates provide about 75 per cent of the body of concrete and hence their influence is extremely important. The properties of these particles greatly affect the performance of concrete.

Fine aggregate

IS: 383 – 1970 defines the fine aggregate as the one passing through 4.75 mm IS sieve. The fine aggregate is often termed as a sand size aggregate. Locally available riverbed sand was used in the present study. The properties of the same are given in the Tables 3 and 4 sand conforms to grading Zone – III as per IS: 383 – 1970 respectively.

Table 3 Sieve analysis of fine aggregate

I.S. SIEVE DESIGNATION	WEIGHT RETAINED (gm)	PERCENTAGE WEIGHT RETAINED (%)	CUMULATIVE PERCENTAGE WEIGHT RETAINED (%)
4.75 mm	10 gm	1.0	1.0
2.36 mm	100 gm	10	11
1.18 mm	188 gm	18.8	29.8
600 micron	226 gm	22.6	52.4
300 micron	317 gm	31.7	84.1
150 micron	124 gm	12.4	96.5
Pan	35 gm	3.5	100

Table 4 Physical properties of fine aggregate

CHARACTERISTICS	RESULT OBTAINED
Fineness modulus	2.74
Specific gravity	2.67
Bulk density (loose) Kg/m^3	1675

Coarse aggregate

The coarse aggregate is defined, as that retained on 4.75 mm IS sieve. To increase the density of the resulting concrete mix, the coarse aggregate is frequently used in two or more sizes. Two types of aggregate with different sizes have been used in the present study. The details of the same are as below:

i. CA – I aggregate passing 20 mm sieve and retained on 10 mm sieve.

ii. CA – II Aggregate passing 10 mm sieve and retained on 4.75 mm sieve.

The properties and the sieve analysis of these aggregates have been listed in Tables 5 and 6. The percentage contributions of aggregates have been taken as 67% CA – I and 33% CA – II for proportioning of the concrete mix. The coarse aggregates used were washed to remove dust and dirt and were dried to surface dry condition.

Table 5 Physical properties of coarse aggregate

CHARACTERISTICS	RESULT OBTAINED
Fineness modulus	7.54
Specific gravity	2.64
Bulk density Kg/m^3	1600

Table 6 Sieve analysis of coarse aggregate

I.S. SIEVE DESIGNATION	WEIGHT RETAINED (gm)	PERCENTAGE WEIGHT RETAINED (%)	CUMULATIVE WEIGHT RETAINED (%)
40 mm	0	0	0
20 mm	0	0	0
10.0 mm	1131	56.55	56.55
4.75 mm	827	41.35	97.9
Pan	42	2.10	100

Metakaolin

Metakaolin METACEM 85 C was used in the current investigation. It was procured from20 MICRONS Limited, Vadodara, India. Particle size analysie of METACEM 85 C is given in Figure 2.

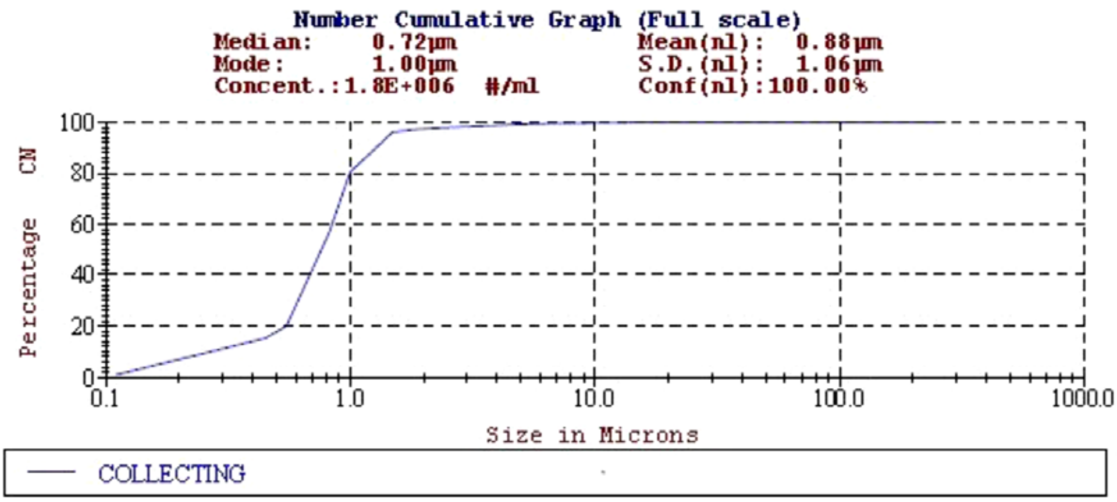

Figure 2 Particle size analysis of METACEM 85 C

Silica Fume

Silica fume was first discovered in Norway in 1947 when the Environmental controls started the filtering of the exhaust gases furnaces. The main portion of these fumes was a finely composed of a high percentage of silicon dioxide. Table 7 and 8 give chemical composition and physical properties of silica fumes respectively.

Table 7 Chemical composition of Silica Fume

CHEMICAL COMPOSITION	PERCENTAGE
SiO_2	89
Al_2O_3	0.50
Fe_2O_3	2.5
$Na_2O_3+K_2O$	1.2
CaO	0.50
MgO	0.60

Table 8 Physical properties of silica fume

PROPERTY	VALUE
Diameter of silica fume	0.1-0.2 micron
Surface area (m^3/kg)	30000
Density (kg/m^3)	150-170
Density(kg/m^3)(best suited as concrete additive)	500

Rice Husk Ash

Rice husk ash (RHA) fillers are derived from rice husks, which are usually regarded as agricultural waste and an environmental hazard. Rice husk, when burnt in open air outside the rice mill, yields two types of ash that can serve as fillers in plastics materials. The upper layer of the RHA mound is subjected to open burning in air and yields black carbonized ash. The inner layer of the mound being subjected to a higher temperature profile results in the oxidation of the carbonized ash to yield white ash that consists predominantly of silica.

Water

Generally, water that is suitable for drinking is satisfactory for use in concrete. As per IS: 456-2000 potable water is generally considered satisfactory for mixing and curing of concrete. Accordingly potable water was used for preparation of all concrete specimens.

Concrete Mixes

Concrete mixes with binary and ternary blends of cement and mineral admixtures were prepared with constant mix proportion and water/binder ratio as shown in Table 9. Different binder combinations are given in Table 10.

Table 9 Mix Proportions

W/C	WATER	CEMENT	FINE AGGREGATES	COARSE AGGREGATES
0.46	225	490	750	928

Table 10 Binder Proportions in Concrete Mixes

MIX NAME	ORDINARY PORTLAND CEMENT (%)	RICE HUSK ASH (%)	METAKAOLIN (%)	SILICA FUME (%)
M1	100	-	-	-
M2	90	10	-	-
M3	80	20	-	-
M4	90	-	10	-
M5	90	5	5	-
M6	80	10	10	-
M7	90	5	-	5
M8	80	10	-	10

TESTS ON CONCRETE

Fresh Properties

Workability is considered to be that property of plastic concrete which indicates its ability to be mixed, handled, transported and most importantly, placed with a minimum loss of homogeneity. More precisely, it defines that it can be fully compacted with minimum energy input. There should be no sign of any segregation or bleeding in a workable concrete.
The workability of all the mixes of concrete used in this work was controlled by conducting slump test. It was observed that the slump value for all the mixes was in the range of 75 – 100 mm, which is acceptable.

Compressive Strength Test

Cubes were tested for compressive strength using 2000 kN capacity compressive testing machine as per Indian Standard guidelines. Compressive strength tests were conducted on concrete cubes of size 150mm x 150mm x150mm cast from concrete of each mix sample after 3,7, 28 and 60 days of curing. These tests were carried out in accordance with IS: 516-1959 on Compression Testing Machine.

Splitting Tensile Strength

For determination of splitting tensile strength of samples, 2000 kN gauge was used. The testing of 150mm cubes was done at 3, 7, 28 and 60 days of curing.The specimens are kept between the two jaws of the machine in diagonal shape for determining the splitting tensile strength of the concrete cube specimen.

Water Absorption Test

Water absorption test was carried out on the cube size 150 ×150×150 mm. Two specimens for each curing period were tested. The standard procedure of water absorption test was adopted. The specimens were taken out from the curing tank after a curing time of 28 days and 60 days. They were surface dried with a moistened cloth and weighed. The specimens were then kept in an oven at 105^0C for 24 hours followed by the measurement of their weight. Finally the water absorption values were calculated using the following expression:

$$\frac{Weightof Ovendriedspecimens\ (W1)}{Weightofsurfacedriedspecimens\ (W2)} \times \mathbf{100}$$

RESULTS AND DISCUSSIONS

Compressive Strength

The compressive strength results are shown in Table 11. It is observed that, there is decrease in compressive strength as the increase the percentage of RHA in the mixes M2 and M3. This decrease in strength is up to 28 days curing only; at 60 days of curing the strengths of all the three mixes stand closer to each other. The effect of RHA decreases the compressive strength at earlier ages of curing but at later ages the compressive strength of the mixes comes closer to the strength of reference mix. This is due to the reason that RHA helps in developing later age strength.

Table 11 Compressive Strength Results of all mixes at different curing ages

MIX NAME	MIX DESCRIPTION	COMPRESSIVE STRENGTH (MPA)			
		3 Days	7 Days	28 Days	60 Days
M1	100%PC	22.8	24.5	29.5	39.0
M2	90%PC + 10% RHA	21.2	23	28.4	38.5
M3	80%PC + 20% RHA	17.1	21.9	27.25	37.8
M4	90%PC + 10% MK	26.6	29.5	36.8	49.3
M5	90%PC + 5% RHA + 5% MK	21.5	31.7	36.5	43.1
M6	80%PC + 10% RHA + 10% MK	22.5	29.0	33.0	41.2
M7	90%PC + 5% RHA + 5% SF	24.5	37.7	39.0	41.0
M8	80% PC + 10% RHA + 10% SF	20.2	25.8	38.0	44.0

In case of mix containing only Metakaolin, replacing cement by 10%, the compressive strength values show increasing trends at all ages of curing. This increase in strength of the mix M4 is 16.67% as compared to reference mix M1 at 3 days of curing and this increase is 26% at 60 days of curing. Metakaolin is helpful in increasing compressive strength of the mix M4.

Further, results in Table 11show that there is an increase in compressive strength at all ages of curing for the mix M5, except at 3 days of curing. There is gradual increase in the compressive strength values at 7, 28 and 60 days of curing for mix M5. At 28 days of curing, compressive strength of mix M5 containing 5% RHA and 5% MK, is 24% as compared to reference mix M1. The compressive strength values of the mix M5 increase due to the addition of 5% metakaolin..
The results also show that as we increase the percentage content of RHA and MK to 10%, the compressive strength increases at all ages of curing except at 3 days of curing. This increase in strength at 28 days of curing is about 12% than reference mix M1. But the compressive strength values of mix M6 are less than that of M5. At 28 days of curing, the compressive

strength value of M6 is 12% less than M5 mix. This is due to the reason that the increase in percentage of RHA to 10%.
Compressive strength values of the mix M7 increases as we replace cement by 5% RHA and 5% silica fume in M7. This increase in strength is about 32% than reference mix M1 at 28 days of curing. Effect of 5% RHA and 5% SF increases the compressive strength in the mix. Mix M7 has the maximum compressive strength at 28 days of curing among all the other mixes.

When the percentage of replacement of cement is increased and 10% RHA and 10% SF is used, different results are observed. At 3 days of curing the compressive strength of the mix M8 is about 2.6% less than reference mix M1. At 28 days of curing the compressive strength of the mix M8 is 29% more than the mix M1. Mix M8 has the maximum compressive strength at 60 days of curing among all the mixes. The later age strength of the mix M8 is even more than the compressive strength of the mix M7. This is due to the reason that Silica fume helps in RHA to maintain the potential of increasing the later age strengths of the mix.

Splitting Tensile Strength

As shown in the Figure 3, the splitting tensile strength of the RHA mixes M2 and M3 is more than the reference mix M1. At 28 days of curing, splitting tensile strength of mix M2 is about 13% more than the reference mix M1 and of mix M3 is about 15% more. This means that as we increase the content of RHA in the concrete mixes, the splitting tensile strength increases. Thus RHA helps in improving the splitting tensile strength of concrete.

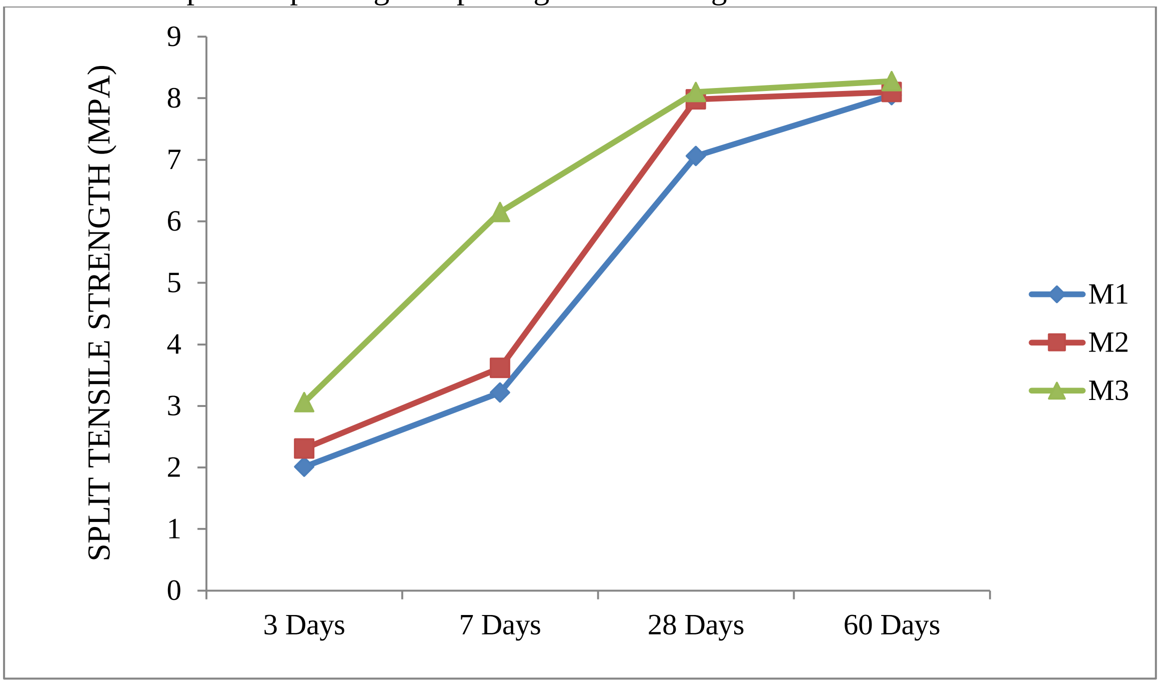

Figure 3 Variation of Tensile Strength with the addition of RHA

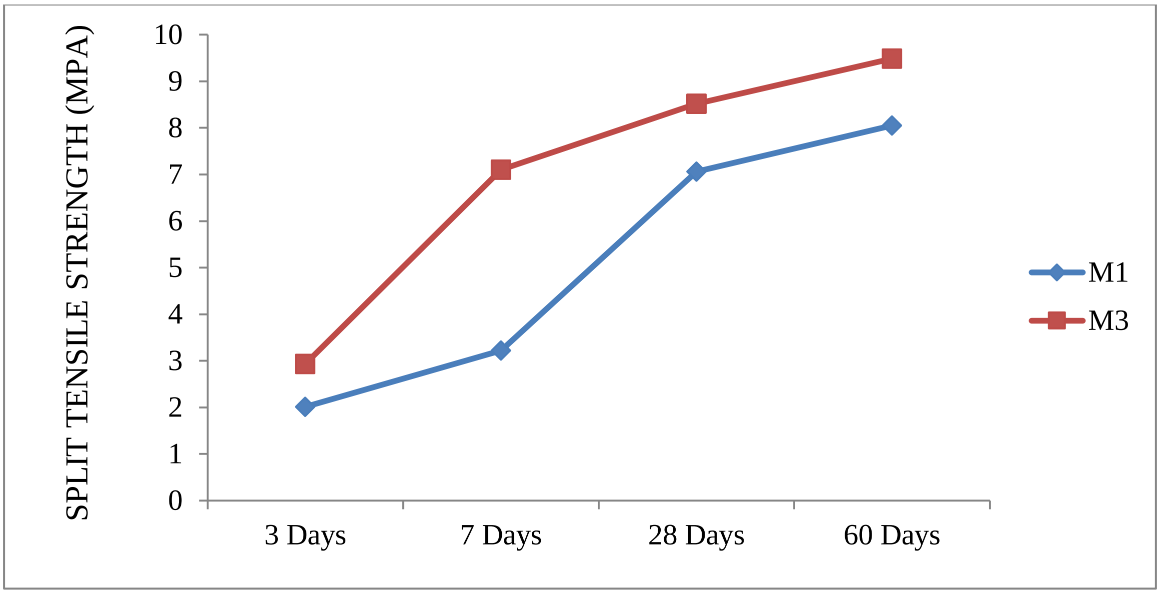

Figure 4 Variation of Tensile Strength with the addition of MK

Figure 4 show that the splitting tensile strength values for the mix M3 containing 10% metakaolin increase as compared to reference mix M1. This increase in strength is about 21% at 28 days of curing.

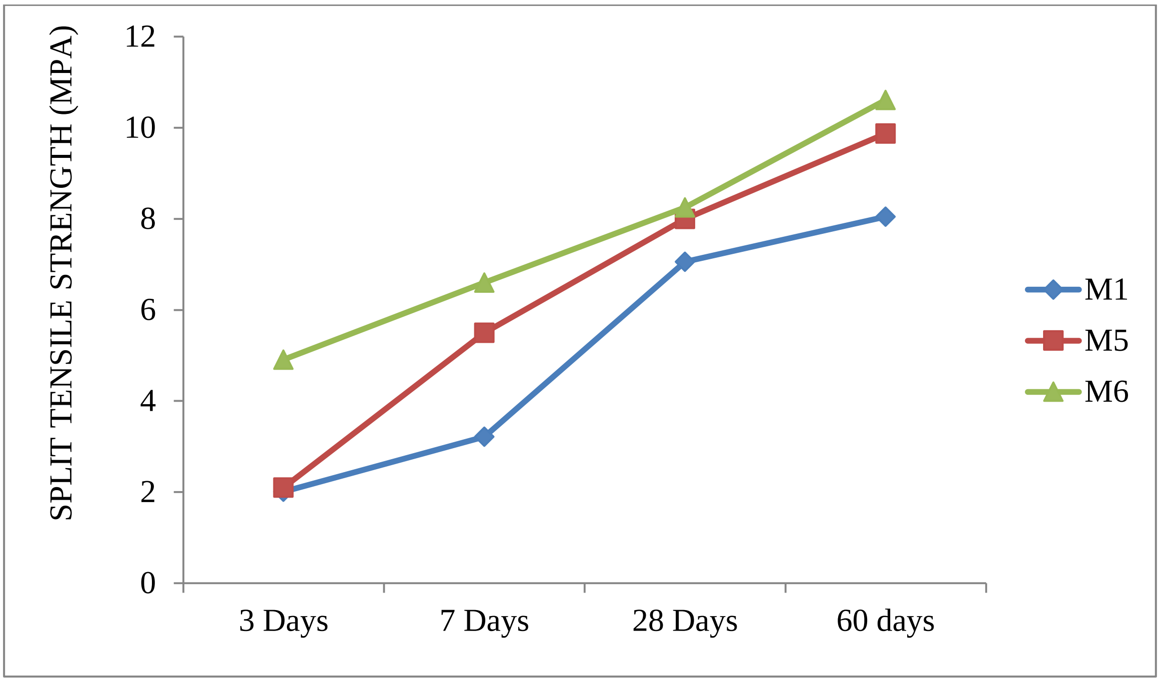

Figure 5 Variation of Split Tensile Strength with the addition of RHA and MK

Figure 5 shows, the splitting tensile strength values for the mixes containing both RHA and MK are more than the reference mix M1. The splitting tensile strength of mix M5 containing 5% RHA and 5% MK at 28 days of curing is about 13% more than the reference mix M1.The splitting tensile strength of mix M6 containing 10% RHA and 10% MK at 28 days of curing is about 17% more than the reference mix M1. It can be concluded that the mixes containing RHA and MK in combination give us more splitting tensile strength values as compared to normal concrete containing only cement.

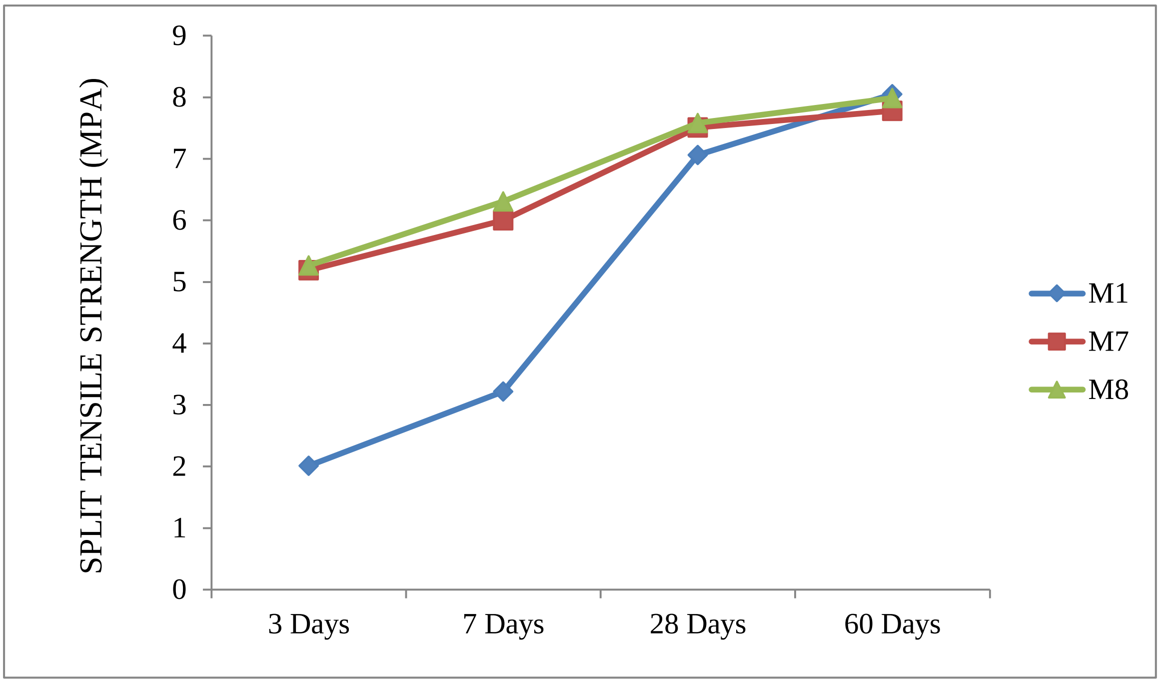

Figure 6 Variation of Split Tensile Strength with the addition of RHA andSF

Figure 6 shows the splitting tensile strength values for the mixes M7 and M8 increases as compared to the reference mix M1 upto 28 days of curing. But at later ages of curing the value of the strength is less than as compared to M1. The increase in strength at 28 days of curing for mix M7 is about 6.37% and for mix M8 is about 7%. It can be concluded that the combination of RHA and SF helps to increase the splitting tensile strength values of the concrete mixes.

Water absorption

The water absorption results for different concrete mixes are shown in Figures7-10. As shown in Figures, the result values show that as we replace the cement partially by RHA, MK and SF, water absorption of concrete mixes decrease. The effect of different binder materials and their combinations on the water absorption is discussed below.

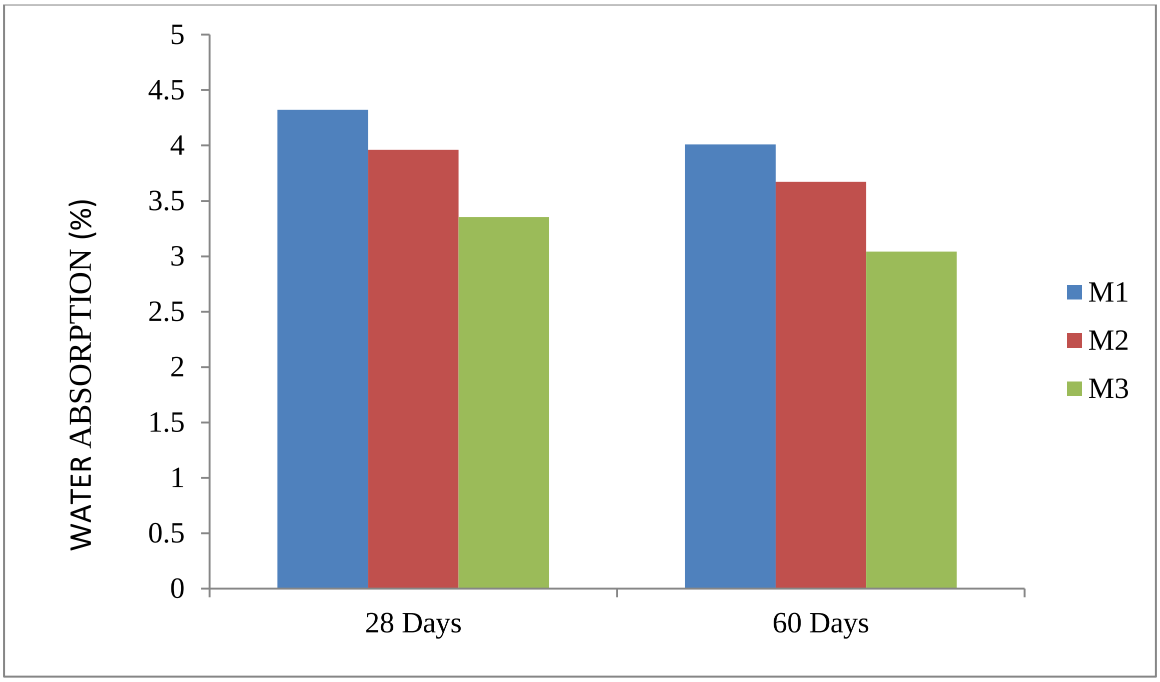

Figure 7 Variation in water absorption (%) of mixes containing only RHA after 28 and 60 days of curing age.

Figure 7 above shows that the absorption values decreases as we increase the RHA content in the concrete mixes. This absorption percentage at 60 days of curing is 4.010 for mix M1, 3.671 for mix M2 and 3.042 for mix M3. This decrease in absorption is due to the more fineness of RHA than cement.

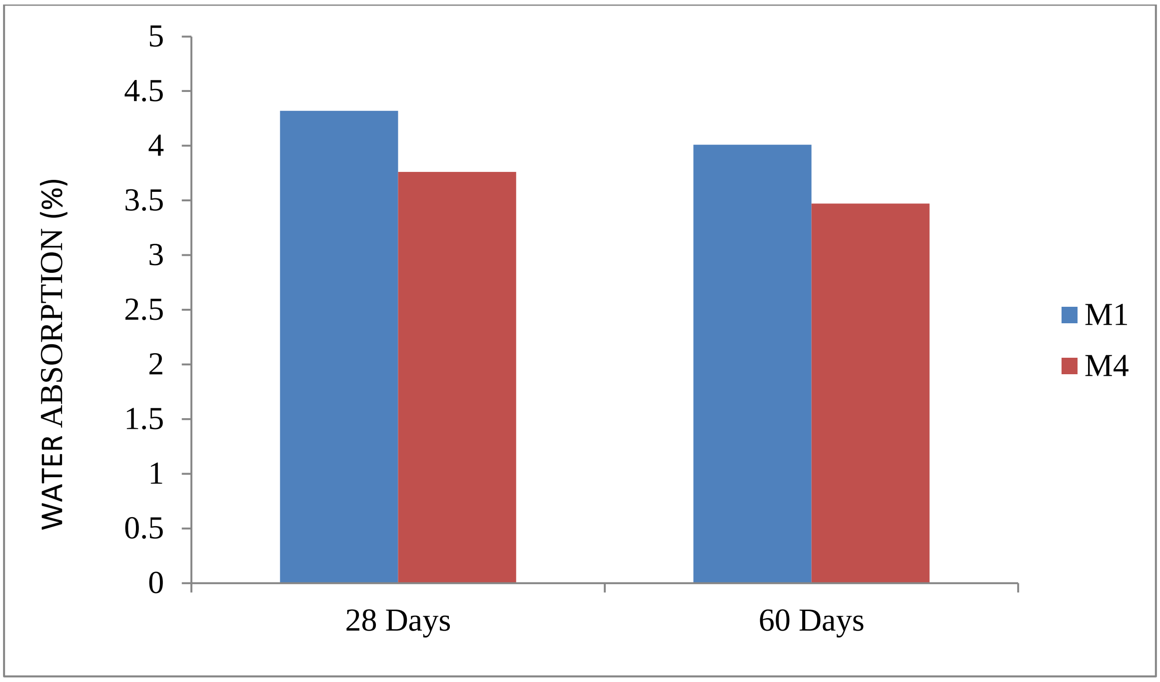

Figure 8 Variation in water absorption (%) of mixes containing only MK after 28 and 60 days of curing age

As from the Figure 8 above, the absorption values decrease as we increase the MK content in the concrete mixes. This absorption percentage at 60 days of curing is 4.010 for mix M1 and 3.473 for mix M4. This decrease in absorption is due to the more fineness of MK than cement.

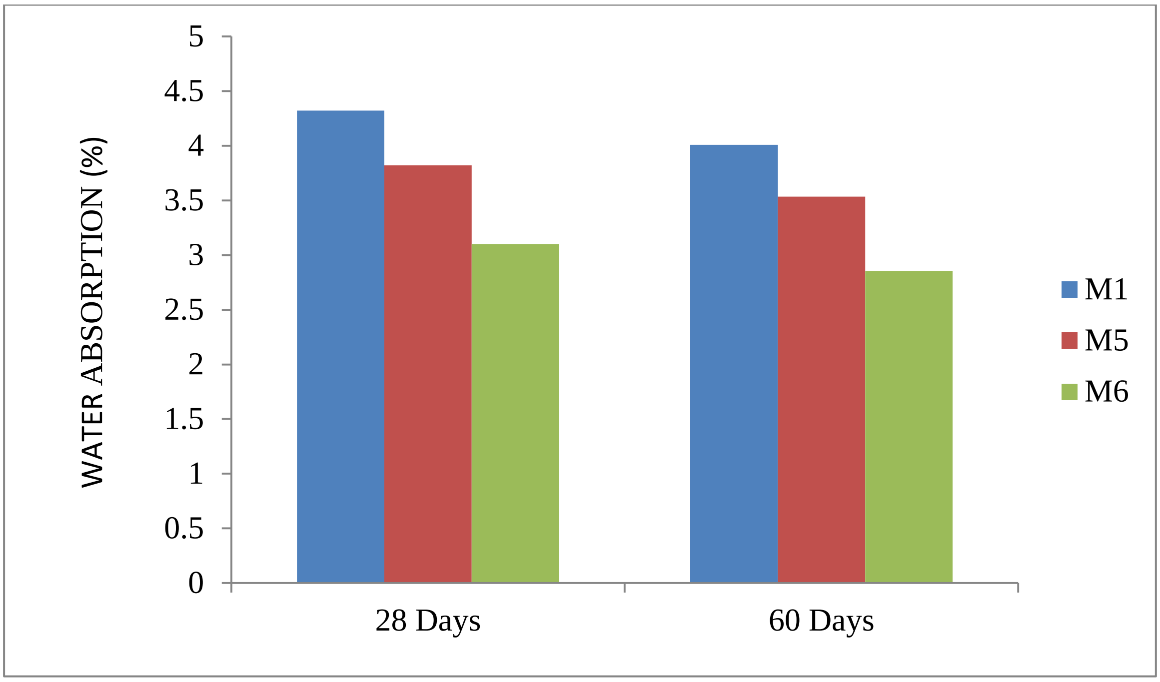

Figure 9 Variation in water absorption (%) of mixes containing RHA and MK after 28 and 60 days of curing age

As from the figure above, the absorption values decrease as we increase the RHA and MK content in the concrete mixes. This absorption percentage at 60 days of curing is 4.010 for mix M1, 3.534 for mix M5 and 2.856 for mix M6. This decrease in absorption is due to the more fineness of RHA and MK than cement.

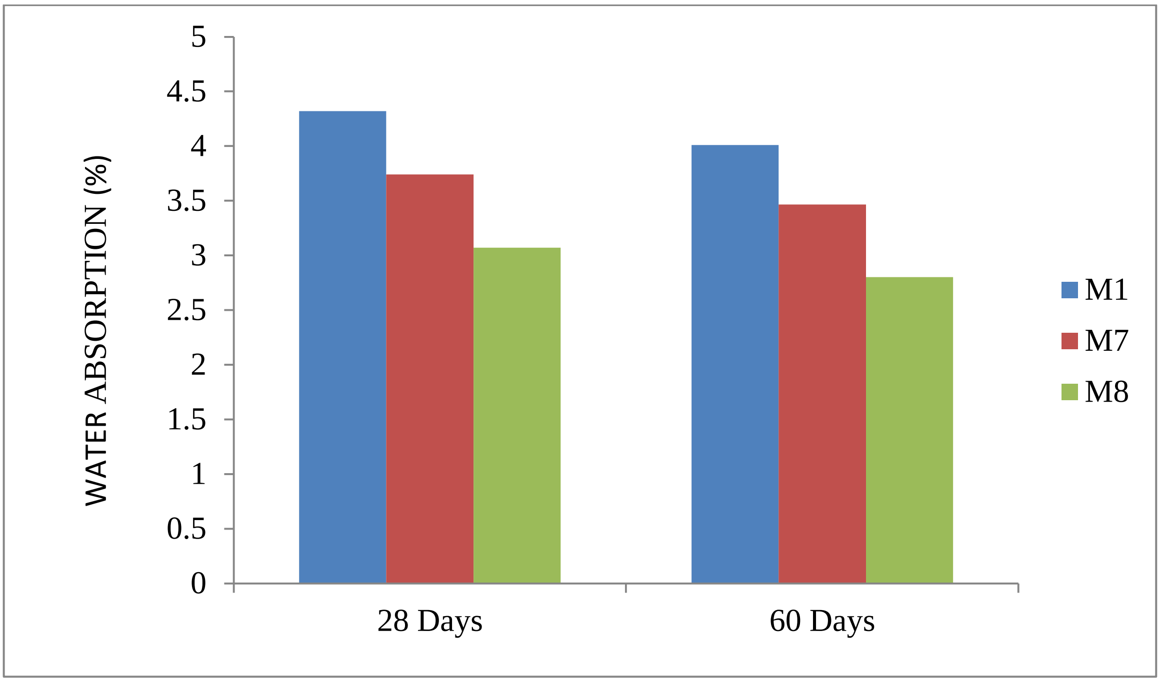

Figure 10 Variation in water absorption (%) of mixes containing RHA and SF after 28 and 60 days of curing age

Figure 10 above, shows that the absorption values decreases as we increase the RHA and MK content in the concrete mixes. This absorption percentage at 60 days of curing is 4.010 for mix M1, 3.465 for mix M7 and 2.802 for mix M8. This decrease in absorption is due to the more fineness of RHA and SF than cement. The mix M8 is having minimum water absorption among all the concrete mixes.

CONCLUSIONS

- Inclusion of Rice husk ash (RHA) decreases the compressive strength of the concrete mixes up to 28 days of curing but it helps to develop compressive strength of concrete mixes at later ages of curing.
- At 28 days of curing, splitting tensile strength of the different mixes were more than the reference mix M1. This means that as we increase the content of RHA in the concrete mixes, the splitting tensile strength increases. Thus RHA helps in improving the splitting tensile strength of concrete.
- Partial replacement of cement with Metakaolin increases both compressive and splitting tensile strength of the concrete mixes.
- Partial replacement of cement with combination of SF, MK and RHA increases the compressive strength as well as the splitting tensile strength of the concrete.
- Partial replacement of cement by RHA, SF and MK decreases the water absorption of the concrete mixes.
- Mix M8 with 10% RHA and 10% SF was found to have least water absorption among all concrete mixes.

REFERENCES

1. BADOGIANNIS E., AND TSIVILIS S. Exploitation of poor Greek kaolins: Durability of metakaolin concrete. Cement & Concrete Composites 31, 2009, pp128–133
2. CASSAGNABÈRE F., MOURET M., ESCADEILLAS G., BROILLIARD P. AND BERTRAND A., Metakaolin, a solution for the precast industry to limit the clinker content in concrete: Mechanical aspects, Constr. Build. Mater., 24, 2010, pp1109-1118.
3. GÜNEYISI E., GESOĞLU M., KARAOĞLU S. AND MERMERDAŞ K., Strength, permeability and shrinkage cracking of silica füme and metakaolin concretes, Construction Building Materials, 34, 2012, pp120-130
4. GURUNAATHAN K. and THIRUGNANAM G. S Effect of mineral admixtures on durability properties of concrete. International Journal of Advanced Structures and Geotechnical Engineering, Vol. 03, No. 01, 2014.
5. HUANG HUANGHUANG , GAO XIAOJIAN , WANG HUI , YE HUAN, Influence of rice husk ash on strength and permeability of ultra-high performance concrete. Construction and Building Materials 149, 2017, pp621-628
6. IS: 383- 1970, Indian Standard Specification For Coarse And Fine Aggregates From Natural Sources For Concrete Bureau of Indian Standards, New Delhi.
7. IS: 456-2000, Indian Standard Plain And Reinforced Concrete-Code of Practice (Fourth Revision), Bureau of Indian Standards, New Delhi.

8. IS: 516-1959, Methods of Test For Strength Of Concrete, Bureau of Indian Standards, New Delhi.

9. IS: 8112-1989, Indian Standard 43 Grade Ordinary Portland Cement Specification, Bureau of Indian Standards, New Delhi.
10. MANSOUR, SAID- MOHAMED, KADRI, EL-HADJ, KENAI, SAID, GHRICI, MOHAMED BENNACEUR, RACHID,Influence of Calcined Kaolin on Mortar Properties. Construction and Building Materials 25 (5), 2011, pp2275–82.
11. MOSER R.D., JAYAPALAN A.R., GARAS V.Y. AND KURTIS K.E., Assessment of binary and ternary blends of metakaolin and class C fly ash for alkali-silica reaction mitigation in concrete, Cement Concrete Research, 40, 2010, pp 1664-1672.
12. SIDDIQUE RAFAT AND KADRI EL-HADJ, Effect of metakaolin and foundry sand on the near surface characteristics of concrete, Construction and Building Materials, vol. 25, 2011, pp 3257–3266
13. VEJMELKOVA E., PAVLIKOVA M., KEPPRT M., KERSNER Z., ROVNANIKOVA, P., ONDRACEK, M. SEDLMAYER, M. AND CERNY R.: High Performance Concrete with Czech Metakaolin: Experimental Analysis of Strength, Toughness and Durability Characteristics, Construction Building Material, 24, pp1404–1411, 2010.
14. VENU MALAGAVELLI, SRINIVAS ANGADI AND J S R PRASAD, SUBODH JOSHI, Influence of metakaolin in concrete as partial replacement of cement. International Journal of Civil Engineering and Technology (IJCIET). Vol. 9, Issue 7, July 2018, pp. 105–111.