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EFFECT OF METAKAOLIN ON THE ENHANCEMENT OF CONCRETE STRENGTH

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ABSTRACT

In this study, metakaolin (MK) is considered as the partial replacement of cement to enhance the fresh and hardened properties of concrete. The mix design was targeted for M40 grade concrete to achieve desired strength. The total percentage of supplementary cementing material (SCM) replaced in this study was 0-20%. Five different concrete mixes were prepared such as without replacement of cement with MK (0% MK) was treated as the conventional concrete, whereas in other cases the cement was replaced by 5% to 20% of MK with reducing water to binder ratio (w/b) of 0.35 and 0.30 and increasing doses of super-plasticizer (SP). The mix specimens were immersed in curing tank for 7, 28, and 90 days. The fresh concrete test was carried out to determine workability. The mechanical properties were assessed by means of compressive strength, split tensile strength and flexural strength. The experimental results concluded that with decrease in w/b ratio, the doses of SP increases to achieve desired slump value and increases strength of concrete. Substitution level of 10% MK for w/b ratio 0.35 and 0.30 had significantly improved the effect on the mechanical characteristics of concretes.

KEYWORDS: Metakaolin, Workability, Compressive Strength, Flexural Strength, Split Tensile Strength.

In recent decades, the construction industries have encountered many challenges. The positive approach of construction industry towards modernisms will work as a catalyst for the development of durable, cheap and new construction materials compared to the conventional ones, resulting low cost and energy competent structure. The worldwide demand of cement based materials has increased for high-strength and high performance concrete. Changeover of usual construction materials fully or partially with the industrial by product (e.g. fly ash, rice husk ash, blast furnace slag and silica fume) and natural product (limestone, calcined clay and pozzolan) to improve the strength, durability, workability, toughness and to make it cost effective. Supplementary cementitious materials (SCM) are acknowledged to be efficient in the development of strength and durability properties of concrete [AFNOR, 2004]. MK increases micro-hardness relative to control specimens at water to binder ratios of 0.5 and 0.6 because MK densifies and strengthens the microstructure of the hydrated cement matrix. The Portland cement was substituted by flash-calcined metakaolin (MKF) to study the performance and durability of concrete. For the substituted concrete many technical benefits can found such as lower permeability, higher strength, and decreased chloride ion penetration. The results presented in this paper display that to achieve desire workability slightly higher superplasticizer was used [San Nicolas et. al., 2014]. The combination between clinker/MK and mineral admixtures to investigate the compressive strength of cement-based materials at both early and later ages under steam curing situation. It was seen that a significant decrease in strength occur at 1, 7 and 28 days when cement was replaced with limestone filler (F1) or siliceous filler (F2). This was studied that partial replacement of cement by MK could increase the strength and could be positive from economic point of view [Cassagnabère et. al., 2010]. The mechanical properties of the MK and silica fume (SF) concrete was investigated and demonstrated that MK concrete had relatively higher strength development than control specimen depending on the replacement level of MK and w/b ratio [Poon et. al., 2001].

MK is the most popular mineral admixture used in production of high strength concrete. The study aims at reveal the effectiveness of utilization of MK on the enhancement of concrete strength.

EXPERIMENTAL INVESTIGATIONS

Materials

The cementitious materials used in the concrete mixes were ordinary Portland cement (OPC) and metakaolin. Metakaolin is highly pure kaolinitic clays can be calcined at comparatively low temperature 600-700°C to keep silica and alumina in amorphous state. The physical properties of these materials are given in Table 1.

Table 1: Physical properties of OPC and MK

Physical properties	OPC	MK
Specific gravity	3.15	2±0.1
Compressive strength 3days (MPa)	30	----
7 days	43	----
28 days	51	----
Initial setting time (Min)	121	----
Final setting time (Min)	410	----

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Ordinary Portland Cement 43 grade (OPC), zone II fine aggregate, natural coarse aggregate (20 mm passing), MK and Super-plasticizer (SP) - (CONXL – PCE DM - 360) in an adequate amount in the mixes to achieve desired slump value of 25-50 mm and tap water are used. The properties of aggregates are given in Table 2.

Table 2: Properties of aggregates

Properties	Value obtained experimentally as per IS:383-1970	
	Coarse aggregate	Fine aggregate
Specific gravity	2.78	2.68
Abrasion value, %	47.46	-----
Flakiness index,%	21.18	-----
Crushing value, %	24.50	-----
Impact value, %	29.63	-----
Water absorption,%	0.22	0.80
Fineness modulus	6.93	2.76 (Zone-II)

MK is refined kaolin clay that is fired (calcined) under carefully controlled conditions to produce an amorphous alumino silicate that is reactive in concrete. Like other pozzolans (fly ash and silica fume are two common pozzolans), metakaolin reacts with the calcium hydroxide (lime) by-products produced during cement hydration. Mixing MK to the concrete mixture even in low substitute will greatly enhance the strength and durability of concrete mixtures. MK sample are shown in Fig. 1. The chemical composition and physical properties of silpozz are presented in the Tables 3-4.

Figure 1: MK Sample

Table 3: Chemical composition of MK

Oxides	Average (%)
SiO_2	52.8
Al_2O_3	36.3
Fe_2O_3	4.21
MgO	0.81
CaO	< 0.10
K_2O	1.41
LOI	3.53

Table 4: Physical properties of MK

Properties	Metakaolin
Brightness	85±1
Oil absorption (%)	60±5
Moisture (%)	0.50
Ph of 10% solution	6±1
Particle size	
Average (d50)	1±1
<10 Microns (%)	95±2
>2 Microns (%)	80±1
Residue on 400	Nil
Specific gravity	2±0.1
Bulk density (gms /lit)	320±20

Mix Proportions and Identification

The details of mix proportions investigated in this research given in Tables 5-8. Two mix proportions for two different types of w/b are prepared i.e. 1:1.576:3.035 and 1:1.268:2.552 for the w/b 0.35 and 0.30 respectively. M40 grade concrete is designed as per standard specification IS: 10262-2009 to achieve the target mean strength 48.25 MPa for both the w/b (0.35 and 0.30). Total 10 mixes were prepared. Five mixes are prepared for each w/b. The enhancement of concrete strength is carried out using two water-binder ratios. MK is replaced by 0-20% and four sets of concrete mixes were prepared for each w/b (5-20%) and compared the value with control specimen (M0). HC1 indicates high strength concrete for w/b 0.35 and HC2 indicates high strength concrete for w/b 0.30. M used for MK.

Table 5: Details of concrete mix (HC1) proportion along with identification

Concrete mix proportions	Mix Identity
C 100% + MK 0% + FA 100% + CA100%	HC1M0
C 95% + MK 5% +FA 100% + CA 100%	HC1M5
C 90% + MK 10% + FA 100% + CA 100%	HC1M10
C 85% + MK 15% + FA100% + CA100%	HC1M15
C 80% + MK 20% + FA 100% + CA 100%	HC1M20

Table 6: Details of concrete mix (HC2) proportion along with identification

Concrete mix proportions	Mix Identity
C 100% + MK 0% + FA 100% + CA100%	HC2M0
C 95% + MK 5% +FA 100% + CA 100%	HC2M5
C 90% + MK 10% + FA 100% + CA 100%	HC2M10
C 85% + MK 15% + FA100% + CA100%	HC2M15
C 80% + MK 20% + FA 100% + CA 100%	HC2M20

Mixing, casting and curing details

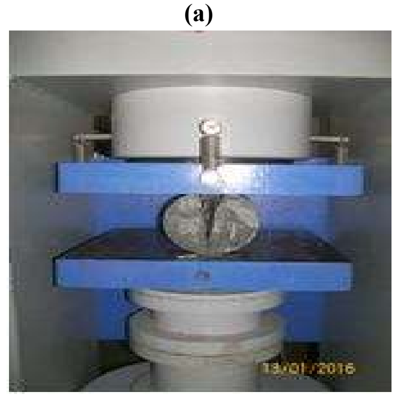
The batching, mixing and casting of concrete was accomplished properly. The required quantity of all dry materials such as coarse aggregate, fine aggregate, cement, and MK were weighed (by mass) and placed in the concrete mixture, and it was thoroughly mixed in dry condition for one minute. Then the specified quantity of water was added during mixing. Further required quantity of SP was then added for achieving the desired workability. Workability of fresh concrete was measured by slump test immediately after the mixing. The slump value was lying in between 25 mm to 46 mm. For curing, the specimens were removed from the moulds after 24 h of casting and placed in water tank at normal temperature (27°C- 30°C) for 7, 28 and 90 days as shown in Fig. 2. The specimens were tested in compression testing machine to know the compressive and split tensile strength and flexural testing machine to know the flexural strength.

Compressive strength tests were performed using 150 mm cubic moulds according to IS codes IS: 516 –1999, Method of Test for Strength of Concrete and IS: 5816-1999 Splitting tensile strength of concrete-Method of Test.

Figure 2: Concrete samples after 24 hrs of casting

Three samples per batch were tested using compressive testing machine (CTM) with capacity of 3000 KN, and the average value was considered as shown in Fig. 3. Cylindrical specimens of 100 mm diameter × 200 mm height were used to determine the split tensile strength of concrete. Flexural strength tests were performed with prism of dimension 500 × 100 × 100 mm using flexural testing machine with capacity of 100 KN.

(a)



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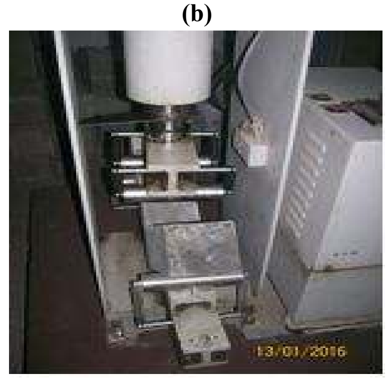

(c)

Figure 3: (a) Compressive strength test , (b)Split tensile strength test and (c) Flexural strength test

TEST RESULTS AND DISCUSSION

Fresh Concrete Test Results

Slump test

The workability of fresh concrete mixture was observed by slump test as shown in Fig. 4. Fresh concrete mix was prepared and then slump test was conducted immediately after the mixing. Slump value of concrete with w/b ratio 0.35 obtained in the range between 25-46 mm and for w/b ratio 0.30 the slump value ranges between 26-40 mm. Due to the reduction of w/b ratio the amount of SP required to be increased to get the desired slump value.

Figure 4: Slump value of concrete

Hardened Concrete Test Results

Compressive strength

The compressive strength of specimens relatively increased in the early ages of concrete i.e. in 7 days. As compared to controlled and other specimen the strength is more where replacement level of cement is 10% with MK. HC1M10 has the increased percentage change in strength throughout all time. The percentage increased strengths are 61.47% at 7 days, 32.89% at 28 days, and 23.21% at 90 days. Fig. 5 represents that the compressive strength increases up to 10% replacement of cement with MK then the strength reduces a little bit. HC1M20 has early strength higher than HC1M5. It is observed that at all age of curing, the compressive strength of all concrete mixes with MK, increased.

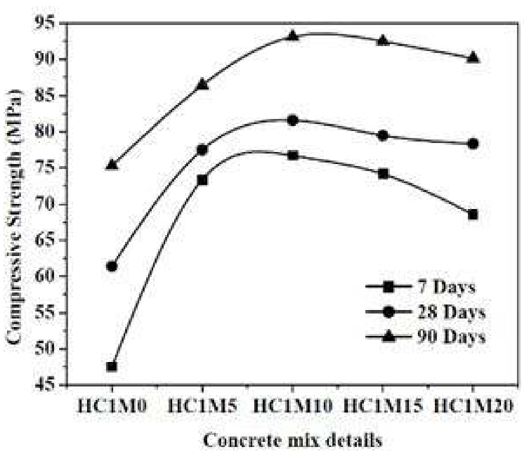

Figure 5: Compressive strength vs. concrete mix details of HC1

Fig. 6 represents that the compressive strength of specimens relatively increased in the early ages of curing. As compared to controlled and other specimen the strength is more where replacement level of cement is 10% with MK for w/b ratio 0.30. HC2S10 has the increased percentage change in strength throughout the time. The percentage increased strengths are 21.22% at 7 days, 24.75% in 28 days, and 24.78% in 90 days as compared to the controlled specimen.

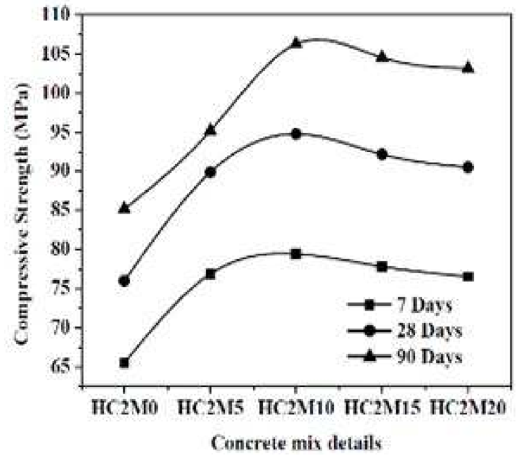

Figure 6: Compressive strength vs. concrete mix details of HC2

Fig. 7 indicates that HC2 have higher compressive strength as compared to HC1 because of the reduced w/b ratio with increased amount of SP. Due to less w/b ratio in HC2, the amount of SP added to the mixture is more than that of HC1. Each mix of MK containing HC1 is compared with HC2 to find the relative increase in strength. It is seen that the relative strength of HC2M20 is greater than that of HC1M20 respectively. The early strength i.e. 7 days test results shows that the increase in strength in HC2M20 is 11.60%. At 28 days and 90 days the relative change in strength is 15.50% and 14.42% respectively.

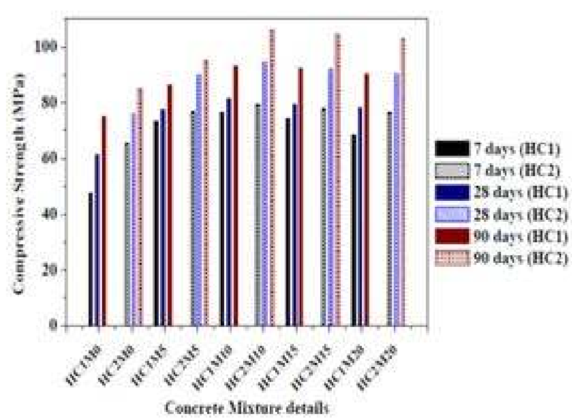

Figure 7: Compressive strength vs. concrete mixture details

Split tensile strength

It is represented that the percentage increase in split tensile strength is more in 10% replacement of cement with MK i.e. HC1M10. The percentage change in strength is 39.71% in 7 days, 23.86% in 28 days, and 18.18% in 90 days. Fig. 8 shows that HC1M10 has higher split tensile strength than other MK replacement levels. HC1M20 has higher strength than HC1M5 in early days.

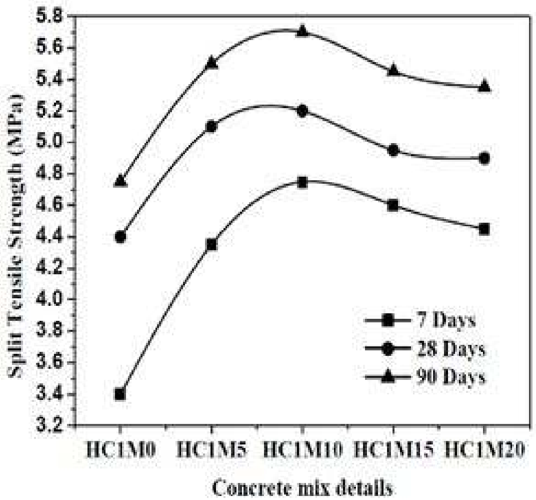

Figure 8: Split tensile strength vs. concrete mix details of HC1

The Fig. 9 shows that the cement replacement of 10% with MK has increased in strength of 15.48% at 7 days, 18.48% at 28 days, and 27.55% at 90 days when compared with HC2M0. HC2M10 has more strength than that of other MK substitution. The graph represents here that HC2M20 has high strength than that of HC2M5 and HC2M10.

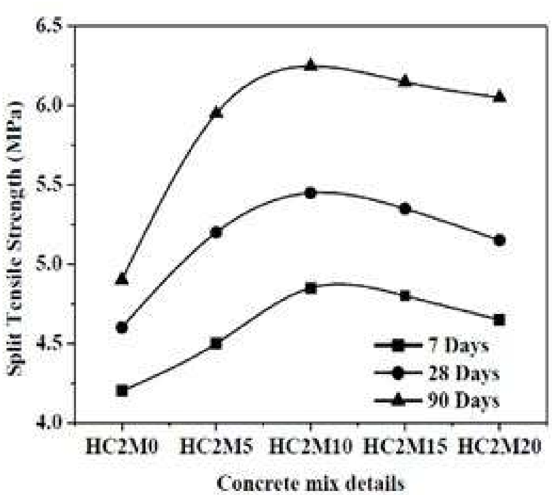

Figure 9: Split tensile strength vs. concrete mix details of HC2

Fig. 10 indicates that HC2 have more split tensile strength than HC1 because of the addition of different amount of SP. Due to less w/b ratio in HC2 the amount of SP added to the mixture is more than that of HC1. Each mix of HC1 is compared with HC2 to find the relative increase in strength. It is seen that the relative strength of HC2M20 is greater than that of HC1M20. The early strength i.e. 7 days test results shows that the increase in strength in HC2M20 is 4.50%. At 28 days and 90 days the relative change in strength is 5.10% and 13.08% respectively.

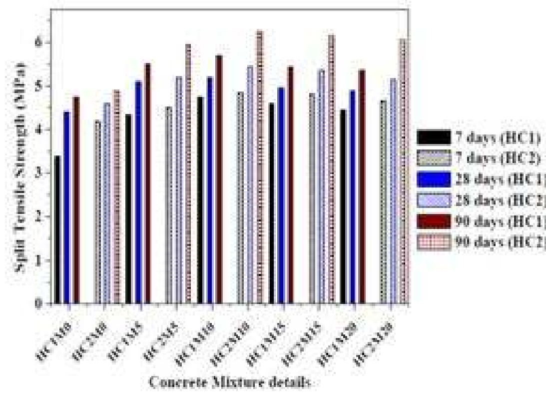

Figure 10: Split tensile strength vs. concrete mixture details

Flexural strength

Fig. 11 represents the Flexural tensile strength results for the partial replacement of cement with MK. Here HC1M10 has maximum flexural strength and the increase in flexural strength is 45% at 7 days, 29.58% at 28 days, and 26.25% at 90 days as compared to control specimen due to pozzolanic reaction.

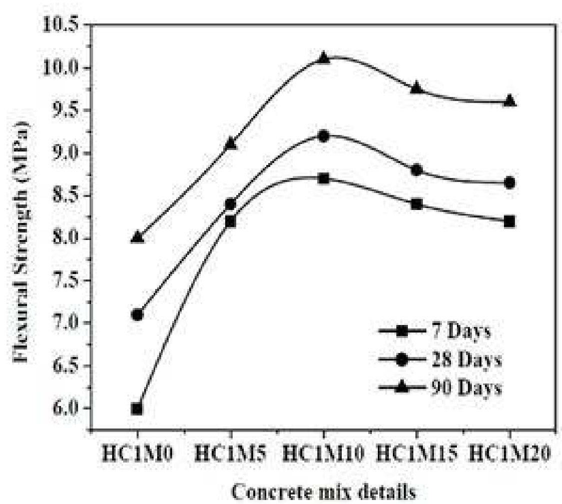

Figure 11: Flexural strength vs. concrete mix details of HC1

Figure 12 represents that the percentage change in flexural strength is maximum in concrete when cement is replaced with silpozz in 10% i.e. HC2M10 in every stage of curing. The increase in flexural strength of HC2M10 is 30.15% at 7 days and change in flexural strength is more i.e. 27.70% at 28days, and 31.71% at 90 days. All the analysis is represented to show that the change in strength in HC2M10 is increased at 7 days, 28 days and 90 days than other mixes.

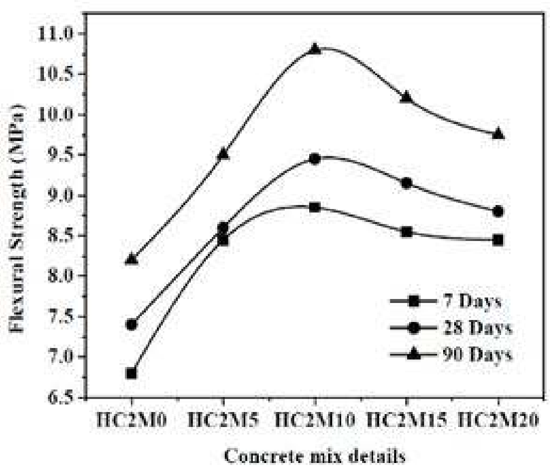

Figure 12: Flexural strength vs. concrete mix details of HC2

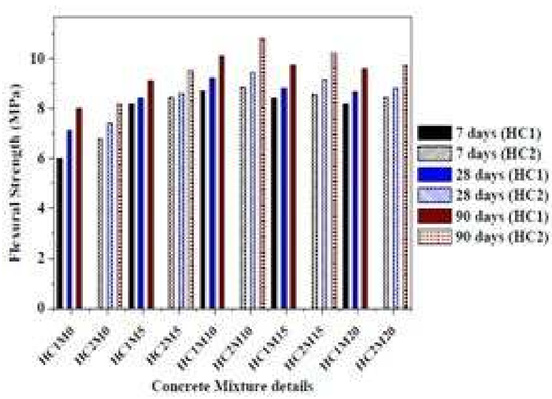

Figure 13: Flexural strength vs. concrete mixture details

For each mix, HC1 is compared with HC2 to find the relative increase in strength. It has been seen that HC2 has higher mechanical properties than other samples.

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CONCLUSION

This paper present the results of an experimental investigation carried out on strength enhancement of concrete mixes using MK and super-plasticizer. Ten concrete mixes are used in two different series, with w/b i.e. 0.35 and 0.30 and evaluated the effect of MK on enhancement of concrete strength. The Slump value, compressive strength, split tensile strength and flexural strength test results are presented. Based on the above results the following conclusions may be drawn:

The fresh concrete results of this research indicate that as w/b decreases, super plasticizer dose need to be increased, so as to increase the workability of concrete.

As age of curing increases, mechanical properties of concrete increase.

The strength enhancement of concrete mix prepared with combination of cement, MK and SP.

The strength enhancement of concrete mixes containing MK is dependent on the rate of OPC hydration as well as the reaction between MK and SP. Therefore, the influence of the MK on the strength enhancement is relatively higher as comparable with control mix.

As w/b ratio decreases, the compressive strength, flexural strength and split tensile strength of concrete increases at all age.

For w/b ratio 0.35 and 0.30, the concrete mix containing 80% cement, and 10% MK give maximum mechanical properties.

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