Influence Of Metakaolin On Mechanical Properties Of Concrete

Fatima Nawaz
Department of Civil engineering
University of Engineering and Technology
Peshawar, Pakistan
Fatima_cnu@hotmail.com

Muhammad Zaheer
Department of Civil engineering
CECOS University of IT and Emerging sciences
Peshawar, Pakistan
Engrzaheerkhan1993@gmail.com

Muhammad Luqman
Department of Civil engineering
IQRA national university
Peshawar, Pakistan
Engr.luqmankhan92@gmail.com

Muhammad Ismail Khan
Department of Civil engineering
Government technical college
Peshawar, Pakistan
Mikyktk30@gmail.com

***Abstract*—Industrialization enhanced the usage of construction materials specially the humongous work of construction industries utilizes a lot of cement which is too expensive and may causes the scarcity of cement resources. Being too expensive there is a need to replace cement with some by product. In this study metakaolin was used as a partial replacement of cement in concrete and cement paste. The energy dispersive X-ray (EDX) analysis was performed after calcining kaolinite clay at temperature of 700 0C. The high amount of silica, alumina and iron oxide indicated the pozzolanic potential of metakaolin. Normal consistency on cement paste and slump cone test on concrete were carried out by replacing 0 to 30% cement by metakaolin with 10% increment. Consistency of cement paste was found increased with enhancing of metakaolin percentage while reduction occurred in the workability of concrete. Compression, flexural and split tensile strength tests were conducted on concrete cylinders and prismatic beams for 7, 28 and 56 days for replacement level of cement i.e. 0, 10, 20 and 30% with metakaolin. An enhancement in compression, flexural and split tensile strength were observed by enhancing amount of metakaolin in concrete samples. However, highest strength (compressive, flexural and split tensile) were noticed for 20% replacement of cement with metakaolin.**

Keywords—Split Tensile Strength, Concrete, Ordinary Portland Cement, Pozzolana, Energy dispersive X-ray and metakaolin

I. INTRODUCTION

Concrete is most widely used material in construction industry [1]. It consists of cement, sand and coarse aggregates. However, cement is main binding material in concrete preparation. Recently, the annual production of cement has been reached to about 1.7 billion tons [2] [3]. Cement manufacturing process is not only costly but it also emits hazardous gases such as greenhouse gases which causes air pollution [4] [5]. For each ton production of cement, cement factories released up to 1.25 tons of CO_2, which causes environmental problems [6]. For this reason, researchers are working on cheap and easily available supplementary cementitious materials in concrete, which will not only decrease the use of cement content but will also increase the use of industrial waste effectively [7] [8].

Unlike other supplementary cementitious materials, like rice husk ash, fly ash metakaolin is not an industrial by product. It is obtained by calcination of kaolinite clay at a temperature of 650^{0}C to 880^{0}C. it is pozzolanic material which can be used with cement in order to improve the durability of concrete [9] [10].

The aim of this research is to examine the mechanical properties of concrete by incorporating metakaolin in various amount percent. Moreover, the consistency and workability of concrete is also investigated in this research work.

II. MATERIALS

A. Cement

Ordinary Portland cement manufactured by Kohat cement industry confirming ASTM C-150 was used in this study. The specific gravity of cement was found to be 3.05.

B. Fine aggregate (sand)

From local quarries, fine aggregates were obtained. The fineness modulus of sand was computed 2.40 numerically through Equation (1).

$$S.G\ of\ FA = (\text{weight at SSD})/(\text{jar weight in water} + \text{weight at SSD} - \text{weight of Mason (FA and water)}) \quad (1)$$

C. Coarse aggregate

From local resources coarse aggregate were obtained. The maximum size of coarse aggregate used in this study was 19mm with bulk density of 1497kg/m^3.

D. Metakaolin

Metakaolin as shown in Fig.1 was obtained from the calcination of kaolinite clay at 700^{0}C in PCSIR laboratory. The chemical composition of metakaolin is given in table 1.

Figure 1 showing metakaolin in powder form

Table 1 showing the chemical composition of metakaolin

Chemical composition	Percentage (%)
SiO2	49.30
CaO	0.88
AL2O3	42.10
Fe2O3	5.02
SO4	0.46
MgO	0.11
K2O	0.31
LOI	1.08

III. METHODOLOGY

A. Consistency test

ASTM C-187 were used for the determination of consistency of cement paste by using vicat apparatus [11]. The range penetration depth of in cement paste is 9 t0 11mm in 30 seconds. A ball shape is given to the cement paste specimen which after tossing six times in air is passed through standard ring and extra paste is removed from it via sharp edge tool. The specimen is than placed below the needle of 1mm dia and 5mm in length and the needle were allowed to penetrate into it. The time period was calculated as the needle touches the paste up to 30 seconds. For approaching standard penetration several trials were made by varying water content. The consistency test is shown in the Fig. 2.

Figure 2 showing cement paste consistency test

B. Slump test

Slump cone test was carried out on control concrete mix and metakaolin (MK) concrete mix according to ASTM C-143 standard procedure [12]. The replacement of cement incorporated by metakaolin was 0% to 30% at an increment of 10% each. In this experiment slump cone es filled up with concrete in three layers. The standard diameter rod (16mm) was used to stoke each layer with 25 blows, after that cone was lifted vertically and slump values were measured with the help of scale as shown in Fig. 3.

Figure 3 showing slump test of concrete

C. Compression test

Concrete cylinder specimens were prepared according to ASTM C-192 [13]. Cylinder samples were made in proportion of 1:2:4 with water to cement ratio of 0.40. The diameter of cylinder specimen was 76mm while its height was 152mm. Various mixtures were prepared in which metakaolin was used at 0%, 10%, 20% and 30% as a replacement of cement. Samples were tested after 7, 28 and 56 days of moist curing in universal testing machine (UTM) as shown in Fig.4 as per ASTM C-39 [14].

Figure 4 showing compressive test via UTM

D. Flexural test

Prismatic beam specimen of dimensions 100*100*350 mm was prepared by following the ASTM C-192. The prepared specimen for various mixtures were teste for flexural test as per ASTM C-78 [15]. Three specimens were prepared for each mix for 7, 28 and 56 days and the results obtained were the mean value of the three sample. Fig.5 is showing prismatic beam under flexural test.

E. Split tensile test

Cylinder specimens of dimensions i.e. 76mm diameter and 153mm height by following ASTM C-192 were prepared. The specimens were tested in universal testing machine (UTM) for split tensile test as per ASTM C-496 [16]. Three specimens were tested for each mix and the result obtained were the mean of the three. Fig.6 is having a cylinder experiencing split tensile test.

IV. RESULT AND DISCUSSION

A. Consistency test

Table 2 and Fig.7 showing normal consistency test results when metakaolin was used as a replacement in cement paste. From the results it is obvious that normal consistency increased with the increase of metakaolin in cement paste.

Table 2 *is showing the consistency penetration for various mixtures*

Paste Mix	**Cement (g)**	**Metakaolin (%)**	**Metakaolin (g)**	**Consistency (mm)**
C-Mix	300	0	0	25
Mk10	270	10	30	29
Mk20	240	20	60	32
MK30	210	30	90	39

Figure 5 showing flexural test

Figure 6 showing split tensile test

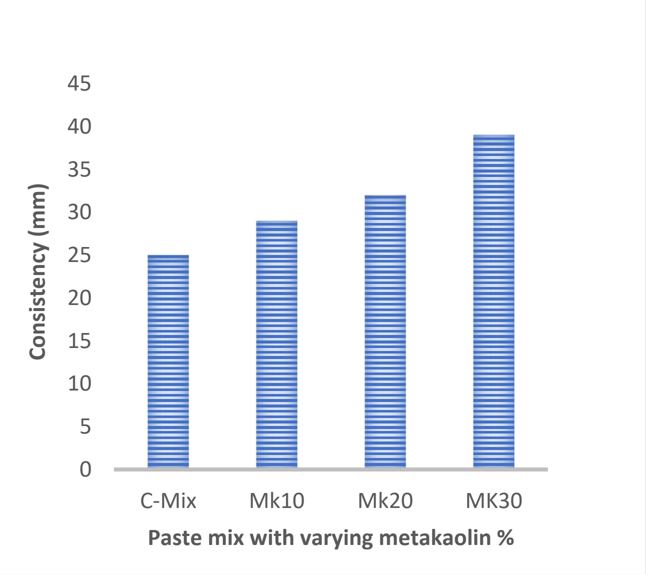

Figure 7 showing consistency penetration of various mixtures

B. Slump test

Table 2 and figure 8 showing the slump results measure for control mix (C-Mix) and metakaolin concrete mixes (MK). Significant reduction in workability values were computed when metakaolin was sed as a replacement of cement in concrete. The slump data for C-Mix and metakaolin concrete were in a range of 61mm to 95mm.

Table 3 *is showing slump test for various mixtures*

Mix	Metakaolin (%)	Slump height (mm)
C-Mix	0	95
Mk10	10	77
Mk20	20	68
Mk30	30	61

C. Compression test

In table 5 and Fig. 9 it is shown that there is increase occur in the compressive strength of the concrete with the increase in the percentage of metakaolin, but maximum strength achieved with addition of metakaolin is at 20%, however, after further increase of metakaolin the strength was found to be more than control mix. The maximum increase that occur at 20% increase in the metakaolin is 34.66%. This increase in strength is due to the pozzolanic property of metakaolin that begins after 28 days strength.

Table 4 *is showing compressive strength for various mixtures*

Mix	Compressive strength in MPa		
	7days	***28days***	***56days***
C-Mix	14.73	21.67	22.97
Mk10	15.32	24.71	28.48
MK20	19.01	25.27	30.57
MK30	16.63	22.86	27.21

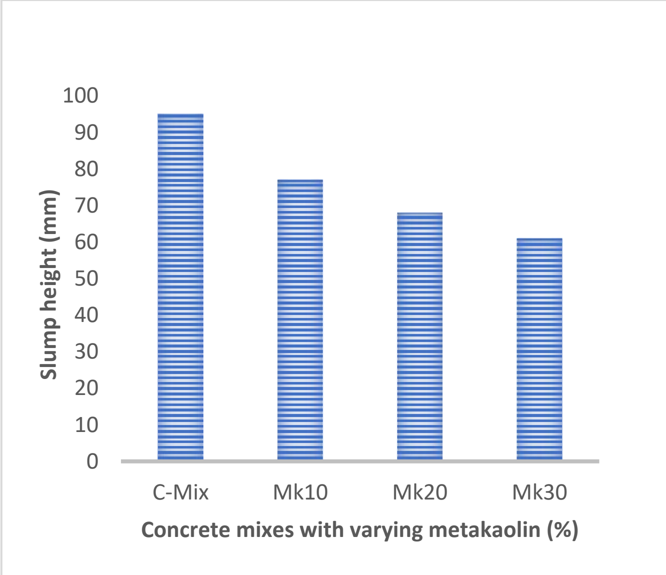

Figure 8 showing slump test for various mixtures

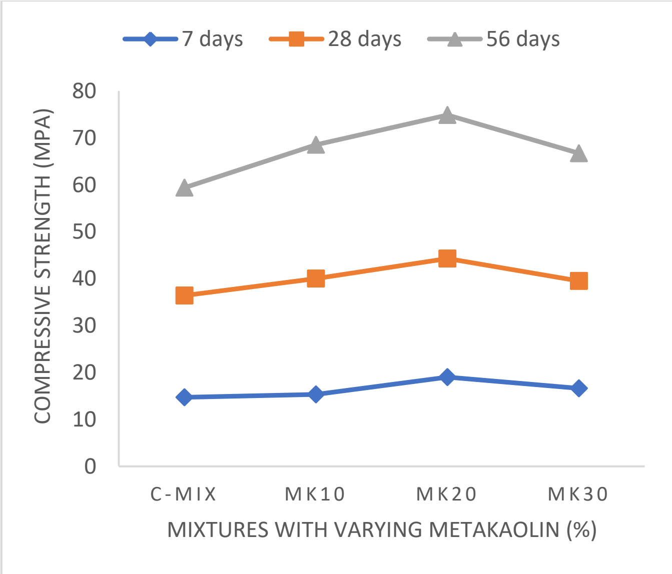

Figure 9 showing compressive strength of various mixtures

D. Flexural test

In table 6 and Fig. 10 it is shown that there is enhancement occur in flexural strength while increasing the percentage of metakaolin. The maximum increase in flexural strength occur at the

20% replacement of cement by metakaolin which is 28.26% although at 30% replacement still the strength of MK30 was greater than the control mix. After further increasing percentage of metakaolin beyond the 20% the increasing rate were found to be decreasing.

Table 5 *showing flexural test for various mixtures*

Mix	Flexural strength in MPa		
	7days	***28days***	***56days***
C-Mix	1.48	2.25	2.31
Mk10	1.86	2.61	3.01
MK20	1.99	2.72	3.22
MK30	1.67	2.38	2.49

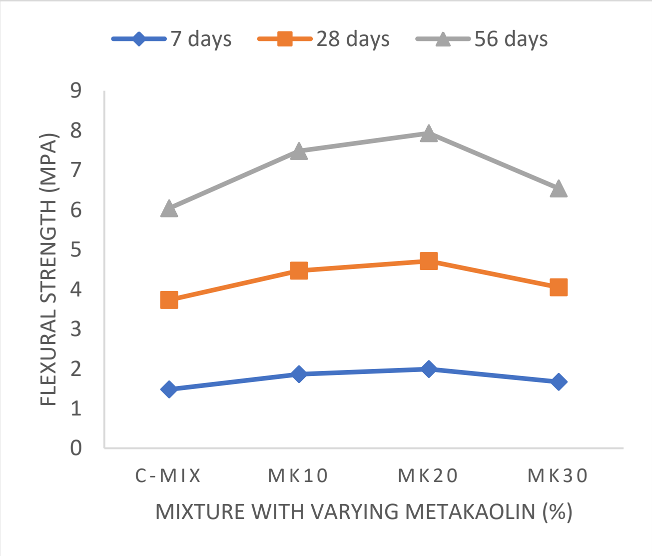

Figure 10 showing flexural strength for various mixtures

E. Split tensile test

In table 7 and Fig.11 it is shown that there is enhancement occur in the split tensile test with the increase in the percentage of metakaolin replacement over cement. The maximum enhancement in split tensile test were achieved at 20 percent replacement of cement by metakaolin which is 28.31% i.e. MK20 beyond 20% the increase rate of split tensile strength was found to be decreasing, though the strength of MK30 was still greater than control mix.

Table 6 *showing split tensile strength for various mixtures*

Mix	Split tensile strength in MPa		
	7days	***28days***	***56days***
C-Mix	1.03	1.31	1.44
Mk10	1.09	1.48	1.68
MK20	1.15	1.55	1.83
MK30	1.05	1.32	1.49

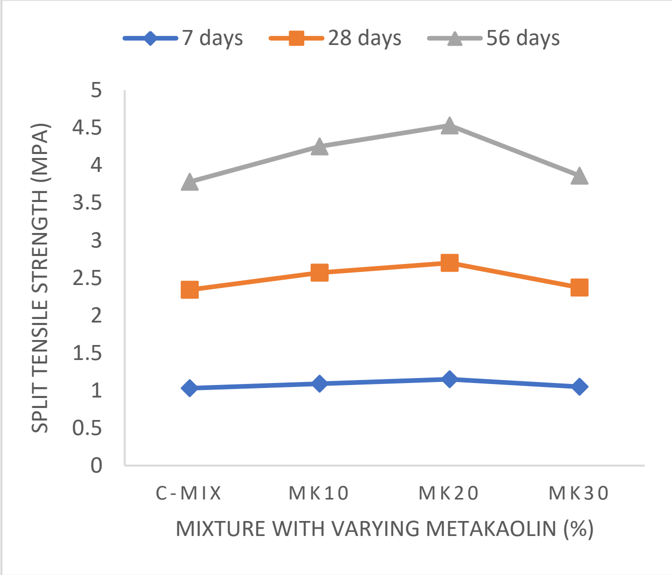

Figure 11 showing split tensile strength for various mixtures

V. CONCLUSIONS

i. More than 70% of silica, alumina and iron oxide indicates highly pozzolanic potential metakaolin.

ii. Maximum compressive strength of 30.75 MPa was obtained after 56 days of curing with 20% replacement cement with metakaolin. The compressive strength results showed 34.66% enhancement in strength as compared to control mix.

iii. Similar to compressive strength results, the trends of strength after 56 days for flexural and split tensile strength were maximum for 20% substitution of cement by metakaolin. As compared to control mix, flexural and split tensile strength of concrete were enhanced by 28.26% and 28.31% respectively.

iv. Though the strength of concrete was increased by incorporation of 30% metakaolin however, the rate increase in strength of concrete beyond 20% were lowered than that for 10 and 20% addition of metakaolin.

v. The normal consistency of cement was increased with the addition of metakaolin.

CONFLICT OF INTEREST
No conflict of interest

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