Effect of Soorh Metakaolin on Concrete Compressive Strength and Durability

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Abstract—**Concrete durability is a key aspect for forecasting the expected life time of concrete structures. In this paper, the effect of compressive strength and durability of concrete containing metakaolin developed from a local natural material (Soorh of Thatta Distict of Sindh, Pakistan) is investigated. Soorh is calcined by an electric furnace at 800^{0}C for 2 hours to produce metakaolin. One mix of ordinary concrete and five mixes of metakaolin concrete were prepared, where cement is replaced by developed metakaolin from 5% to 25% by weight, with 5% increment step. The concrete durability was tested for water penetration, carbonation depth and corrosion resistance. The obtained outcomes demonstrated that, 15% replacement level of local developed metakaolin presents considerable improvements in concrete properties. Moreover, a considerable linear relationship was established between compressive strength and concrete durability indicators like water penetration, carbonation depth and corrosion resistance.**

Keywords-Compressive strength; Durability; Metakaolin; Soorh; Permeability; Carbonation depth; Corrosion

I. INTRODUCTION

Supplementary cementing materials (SCMs) are being utilized in concrete because of their economic and environmental advantages [1]. The usage of SCMs improves the properties of concrete, decreases the usage of cement and the construction cost [1]. Metakaolin is a pozzolanic material, produced by the heating of kaolin clay (alumino-silicate material) at a temperature between 700–850^{0}C [2-4]. Metakaolin is produced by different researchers using different temperatures and durations. Metakaolin was developed from calcined kaolin at 800 ^{0}C at 1 hour period in [5, 6]. Kaolin was thermally treated at 800 ^{0}C for 2 hours to develop the metakaolin in [4, 7-11]. The kaolin was calcined at 800 ^{0}C for 3 hours to prepare metakaolin in [12, 13]. The durability properties of concrete with inclusion of local metakaolin of Iran were investigated at 7, 28, 90 and 180 days by authors in [5]. The cement was replaced by local metakaolin as 0%, 10%, 12.5% and 15% by mass. It was found that metakaolin concrete has significant improvement in durability as compared to control concrete. It was observed that best substitution of cement by local metakaolin is 12.5% and 10 % at w/b ratio 0.4 and 0.35, correspondingly [5].The performance of metakaolin in high performance concrete were investigated in [14]. It was observed from test results that 15% replacement of cement with metakaolin had considerable improvement on durability properties of high performance concrete. Authors in [15] showed that 10% to 15% replacement of cement with metakaolin has significant improvement in concrete durability properties. Resistivity, UPV and corrosion behavior of carbon steel using (5–20%) replacement of cement with metakaolin were studied in [16]. It was found that 15% replacement of cement with metakaolin improves resistivity, UPV and corrosion of carbon steel. Authors in [23] studied different specific surface areas of MK activated with sodium silicate and NaOH They concluded that higher specific surface area of MK powders were characterized by quicker setting time, higher compressive strength and more homogeneous microstructure.

Approximately 0.8 tons of CO_2 is released in the environment while preparing one tone of cement, which is around 5–8% of global CO_2 emission [17]. The concrete structures are very common and cement is used to prepare the concrete. To decrease the cement manufacturing and therefore to decrease CO_2 release in atmosphere and the construction cost, an ecoefficient binder is very important for sustainability for possible cement replacement material. Thus the objective of this research is to examine the durability related properties and compressive strength of concrete with inclusion of local metakaolin produced from Soorh, which is abundantly available in District Thatta, Sindh, Pakistan and is not yet explored and used as cement replacement material.

II. EXPERIMENTAL WORK

A. Materials

Ordinary Portland cement and the Soorh raw material (local natural material) is used. In concrete specimen, clean natural hill sand retained from sieve ≠ 4 as fine aggregate and coarse aggregate retained from ¾ inch sieve was used. The specific gravity of fine and coarse aggregates was 2.72 and 2.84 respectively. Soorh is a type of clay abundantly available in Thatta district. Physical properties, chemical composition and mineralogical composition of Soorh clay and of metakaolin obtained by Soorh thermal treatment are shown in Tables I and II. According to ASTM C 618, the minimum requirement for a pozzolanic material and metakaolin is SiO2 + Al2O3 + Fe2O3 ≥ 70% and ≥ 85%, respectively. In metakaolin developed from Soorh we see that SiO2 +Al2O3 + Fe2O3 is found as 89.9 %, as shown in Table I. Therefore, the chemical composition of calcined Soorh satisfies the requirements of natural pozzolanic material and metakaolin and that justifies its use in concrete as per ASTM C-618. The Blaine fineness of developed metakaolin is less than the cement. From the data shown in Table II is obvious that after the calcination of Soorh, the quantity of quartz (raw impurity) decreased from 47.1% to 36.3%. Authors in [19] showed that the compressive strength of mortar can be equal or increased compared to control mortar by replacing the 30% of the cement in mortars with calcined clays having a high percentage of raw impurities (i.e. quartz more than 40%).

TABLE I. PHYSICAL AND CHEMICAL PROPERTIES OF CEMENT, SOORH AND DEVELOPED METAKAOLIN

Constituent	% By Weight of Cement	% By Weight of Soorh	% By Weight of Produced Metakaolin	Sum of Produced Metakaolin: SiO_2+Al_2O_3+Fe_2O_3
SiO_2	20.78	55.89	62.18%	89.9%
Al_2O_3	5.11	23.51	21.67 %	
CaO	60.89	-------	3.01%	
MgO	3	3.53	3.41%	
Fe_2O_3	3.17	8.15	6.05%	
K_2O	-----	5.89	1.85%	
Na_2O_3	-----	1.89	1.03%	
TiO_2	-----	1.14	1.03%	
In_2O_3	-----	-----	0.8%	
LOI (%)	1.71	7.4	0.5	
Blaine fineness (cm^2/g)	0.3008	0.2101	0.2339	
Specific gravity	3.15	2.64	2.60	

TABLE II. MINERAL COMPOSITION OF SOORH AND DEVELOPED METAKAOLIN

Minerals	Soorh (%)	Developed Metakaolin (%)
Quartz Si_2O_5	47.1	36.3
Illite $K(Al_4Si_2O_9(OH)_3)$	27.4	42.9
Stevensite $CaO_2Mg_2.9Si_4O_{10}(OH)_2.4H_2O$	12.1	16.5
Kalonite $Al_2Si_2O_5(OH)_4$	11.9	--
Calcite magnesium $MgO.06CaO_{0.94}(CO3)$	0.8	4.3
Hematite Fe_2O_3	0.7	--

B. Mix Proportions of Concrete

Plain concrete mix and metakaolin modified concrete mixes with w/c ratio of 0.55, slump range 25-50 mm were used. To prepare the metakaolin concrete mixes, the Ordinary Portland cement is replaced by metakaolin with 5%, 10%, 15%, 20% and 25% by weight of cement. Therefore, six different mixes were prepared. For all mixes, 10 cylinders of 100 mm diameter and 200mm length were cast for investigation of compressive strength, carbonation and corrosion of concrete. Five cubes of 100mm x 100 mm x 100 mm size cast for water penetration test.

C. Test Methods

The compression test was performed on the control specimens and metakaolin concretes using the universal testing machine ASTM C39. Water penetration test and corrosion of concrete was conducted with BS EN 12390-8:2009 and ASTM C876-80 respectively. Carbonation depth of concrete was conducted by using phenolphthalein method. The compressive strength of concrete specimen were carried out at the age of 7 and 28 days, while permeability test (water penetration depth) of concrete was performed at 28 days and corrosion potential test and carbonation depth test of concrete were performed at 28 and 180 days. Five specimens were used for each testing age.

III. RESULTS AND DISCUSSION

A. Concrete Compressive Strength

The compressive strength of 7 and 28 days ordinary and concrete prepared with (0 - 25%) substitution of cement by developed Metakaolin is highlighted in Figure 1. The compressive strength of Metakaolin concrete is increased compared to plain concrete with the replacement of cement by metakaolin in the inclusion range from 5% to 15%. The maximum compressive strength, 31.65 MPa (i.e. 15.43% increase compared to control) at 28 days have been achieved at 15% substitution of cement with Metakaolin. On further substitution of cement with developed Metakaolin, the Compressive Strength of metakalin concretes is found smaller compared to ordinary concrete. Authors in [16] found that 15% replacement of cement by metakaolin gave most favorable results compared to ordinary concrete and other replacement levels of cement with metakaolin. The reduction in compressive strength for MK20 and MK25 as compare to MK15 is due to the effect of the dilution of a clinker. The effect of dilution of clinker is an outcome of cement replacement with equal amount of Metakaolin.

B. Permeability (Water Penetration Depth)

The comparison of water penetration depth at 28 days of ordinary and concrete prepared with (0 - 25%) substitution of cement by developed Metakaolin is shown in Figure 2. The results of water penetration test at Figure 2 revealed that the water penetration depth of modified mixes is decreased compared to CM in the substitution range of 5 % to 15 %. The maximum reduction in water penetration depth is achieved at 15% replacement of (40% less from to control). On further substitution, water penetration depth. The 15% substitution provided 29% maximum reduction in permeability compared to plain concrete reported in [14]. Permeability is the major factor of durability properties of concrete. The lower permeability of concrete proved more resistance against chemical attacks [20].

TABLE III. MIX PROPORTIONS OF CONCRETE

Concrete Mix	Cement Kg/m^3	MK Kg/m^3	Total Binder Kg/m^3	w/b	Water Kg/m^3	Fine Aggregate Kg/m^3	Coarse Aggregate Kg/m^3	Slump (mm)
CM	346	--	346	0.55	190	692	1038	25-50
MK5	328.7	17.3	346	0.55	190	692	1038	25-50
MK10	311.4	34.6	346	0.55	190	692	1038	25-50
MK15	294.1	51.9	346	0.55	190	692	1038	25-50
MK20	276.8	69.2	346	0.55	190	692	1038	25-50
MK25	259.5	86.5	346	0.55	190	692	1038	25-50

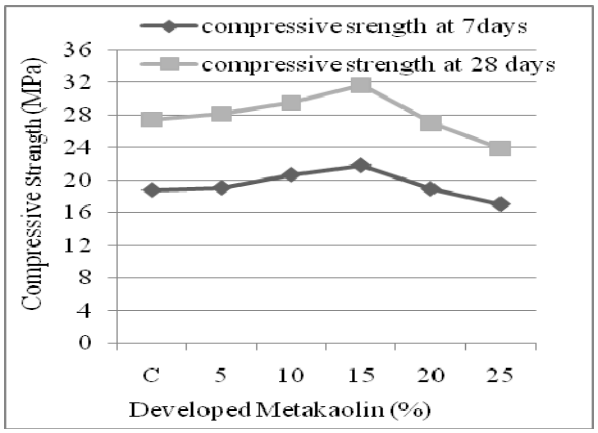

Fig. 1. Compressive strength of plain (C) and Metakaolin concrete

Concrete Corrosion Potential

The comparison of corrosion potential at 28 and 180 days of ordinary and concrete prepared with (0 - 25%) substitution of cement with Metakaolin is shown in Figure 3. The results of corrosion potential revealed that the corrosion potential of modified mixes is decreased compared to CM in the substitution range of 5% to 15%. The maximum decrease in corrosion potential is achieved at 15% substitution (5.7% decreased compared to control) and on further substitution, concrete corrosion potential is increased. It is that 15% replacement of cement with metakaolin is the optimum replacement level against steel corrosion [16].

C. Concrete Carbonation Depth

The comparison of carbonation depth at 28 and 180 days of ordinary and concrete prepared with (0 - 25%) substitution of cement by developed Metakaolin is shown in Figure 4. The results reveal that the carbonation depth of modified mixes is decreased compared to CM in the substitution range of 5 % to 20 %. The maximum decrease in carbonation depth is achieved at 15% substitution of cement with Metakaolin (31% less compared to control) and on further substitution the concrete carbonation depth is increased. The decrease in carbonation depth in metakaolin concrete is due to pozzolanic activity of mineral admixtures [21].

D. Correlation between Compressive Strength and Durability of Concrete Test Tesults

The correlation between compressive strength and durability indicators of concrete i.e., water penetration depth, corrosion potential and carbonation depth was found and highlighted in Figures 5 - 7. A significant linear relationship was established between compressive strength and durability related properties in the form of y = ax ± b and looks as the best fit for the figures with a good coefficient of correlation $R^2 \geq 0.83$. It is clear from Figures 5-7 that as the compressive strength increases water penetration, corrosion potential and carbonation depth decrease consequently i.e. the durability of concrete increases. Correlation among compressive strength and durability properties of metakaolin concrete was presented in [5, 22].

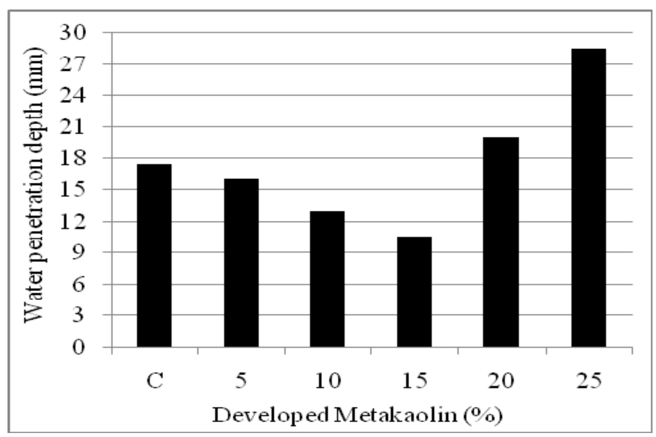

Fig. 2. Water penetration of ordinary and metakaolin concrete

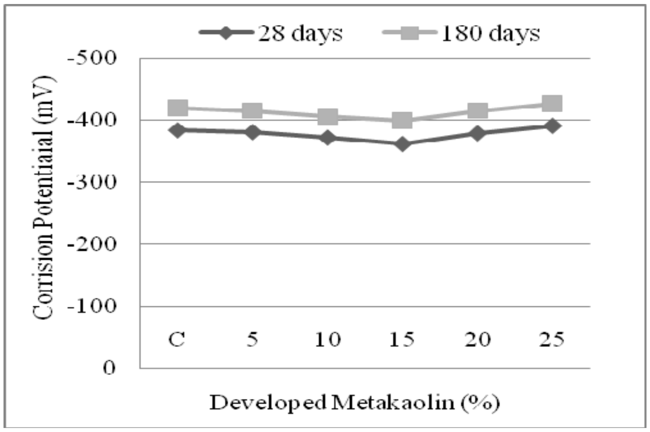

Fig. 3. Corrosion potential of ordinary and metakaolin concrete

IV. CONCLUSION

The concrete durability and compressive strength have been significantly improved with the substitution of cement by metakaolin in the substitution range of 5% to 15%. The maximum compressive strength 31.65 MPa (i.e., 15.43% more as compared to plain concrete), the maximum reduction in water penetration depth (i.e. 40% less than control), the maximum decrease in corrosion potential (i.e. 5.7% less than that of control) and the maximum decrease in carbonation depth (i.e. 31% less than ordinary concrete) are achieved at 15% replacement of cement with developed local Metakaolin. A significant linear relationship between test results of durability related tests and compressive strength of Metakaolin concretes was found. It can be concluded on the basis of the results of compressive strength, water penetration, corrosion potential and carbonation depth, that 15% substitution of cement with the Metakaolin in concrete is optimum.

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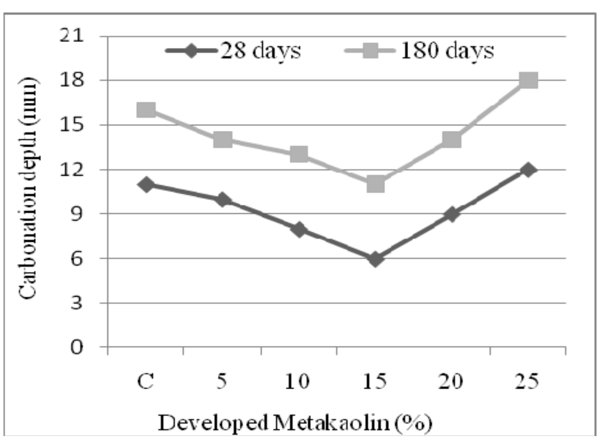

Fig. 4. Carbonation depth of ordinary and metakaolin concrete

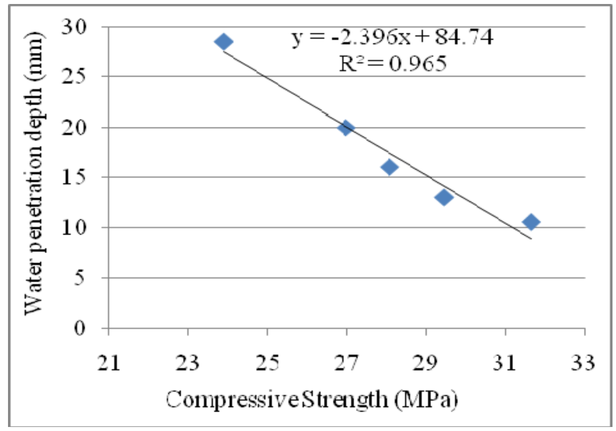

Fig. 5. Relationship of compressive strength and corrosion of metakaolin concrete

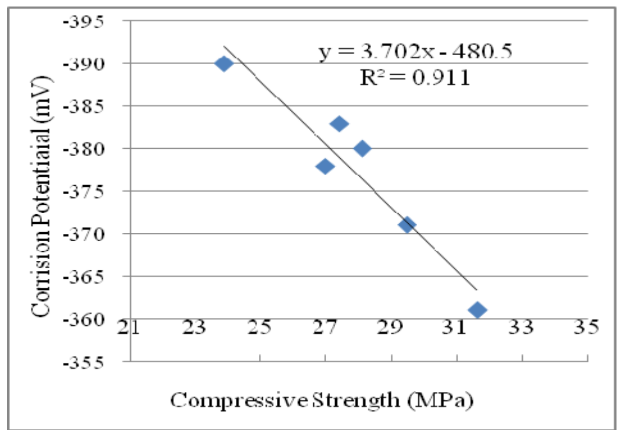

Fig. 6. Relationship of compressive strength and corrosion of metakaolin concrete

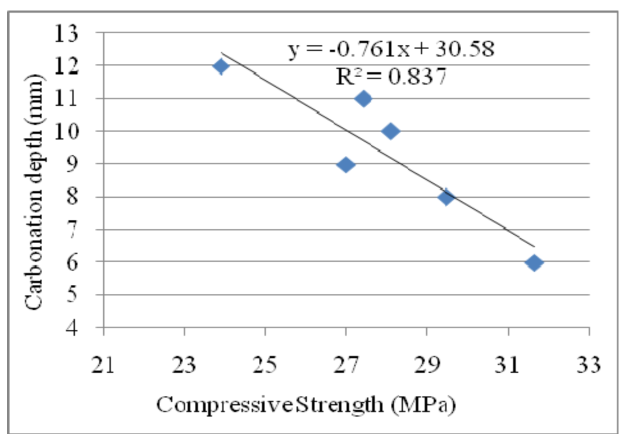

Fig. 7. Relationship of compressive strength and carbonation depth of metakaolin concrete

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