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Evaluation of Porosity and Permeability for High Strength Concrete using Rice Husk Ash and Metakaolin as Partial Replacement to Cement

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The most well-known pozzolanas are rice husk ash (RHA) and metakaolin (MK), which are commonly used in concrete construction. The addition of pozzolana to concrete improves its long-term durability. Following multiple research findings from various countries, concrete's growth is focused on improving its performance, resulting in the improvement of high-strength concrete. This high-strength concrete has a variety of improved properties, including increased durability by providing resistance to chemically varying environments, improved economic status, CO_2 reduction by reducing amount of cement (cement has been partially replaced by mineral admixtures-MK and RHA), increased ecology balance by balancing natural resource consumption and more. The objective of this research is to investigate the impact of mineral admixtures on the durability of high-strength concrete. The key to achieving effective results, such as low porosity and low permeability, has always been proper material proportioning. The concrete utilized in this project is of M60 grade. Curing for 3, 7, 14, 28, 56 and 90 days is preferred, with three sample blocks (different combinations) each. After several experiments, where durability is carefully assessed, these different concrete compositions are preferred. Research has shown that carefully proportioning mineral admixtures to concrete can improve durability performance even further. For example investigations on saturated absorption of water, porosity and acid resistance, salt water resistance, alkalinity, permeability, resistance to abrasion, impact strength and rapid chloride penetration. Blending cement with supplementary cementing materials (SCM) has consistently resulted in numerous advantages, including cost savings in concrete, increased early strength, waste item reuse, reduced water retention and reduced water penetration.

KEYWORDS

Durability, Porosity, Permeability, Metaeolin, Rice husk ash

1. INTRODUCTION

Because the materials for manufacturing of concrete are obtained from earth's surface, causing depletion of the earth's natural resources every year, putting strains ecologically on the planet. Furthermore, human advancements on the planet deliver solid wastes in the form of agricultural, industrial and wastes from urban and rural societies abundantly of over 2500 million tonnes every year, putting environmental strains on the planet [1]. Silica fume, rice husk ash, flyash, blast furnace slag and materials from structure destruction are most widely used materials from aforementioned solid wastes. When these industrial and agricultural byproducts are used as partial replacement material, cost and energy benefits are realised. The utilization of byproducts is a sustainable method for disposing of massive amounts of materials elsewhere would be disposed of in other ways. CO_2 outflow is controlled by lessening utilization of Portland cement, because of fast advancement, developing natural concerns and necessity to save natural resources and energy. Steps are taken to employ the use of waste materials of modern and agro items in construction sector as a pozzolanic material to supplant ordinary Portland cement to produce high strength/high performance concrete. Utilization of mineral admixtures as a pozzolanic cementitious material in concrete gives few points of interest, for example enhanced strength and durability characteristics. Low material cost of cement savings and environmental benefits are the effects of the transfer of waste materials. One of the powerful approaches to diminish

Table 1. *Physical characteristics of ordinary Portland cement*

Physical characteristics	Result	Specification [6]
Specific gravity	3.11	-
Mean grain size (μm)	20	-
Fineness (m^2/kg)	325	225 (min.)
Initial setting time (min)	55	30 (min.)
Final setting time (min)	220	600 (min.)
Standard consistency (%)	34	-
Soundness, Le-Chatelier's (mm)	2	10 (max.)
Compressive strength at 28 days (N/mm^2)	61	53 (min.)

Table 2. *Chemical characteristics of ordinary Portland cement*

Chemical characteristics	Percentage	Specification [6]
SiO_2	21.54	-
Al_2O_3	4.68	-
Fe_2O_3	2.46	-
CaO	62.58	-
SO_3	1.8	-
MgO	1.08	6 (max.)
Na_2O	0.24	-
K_2O	0.87	-
Cl	0.06	0.1 (max.)
Ignition loss	2.58	4 (max.)
Insoluble residue	0.2	3 (max.)

the environmental impact and to conserve the natural assets of the earth is to utilize alternative binders. The cement replacement materials in this way turn into a test for national improvement and forward planning. In many developed countries, supplementation of cement production with pozzolana is especially attractive and there are many blended cement projects. Silica fume, rice husk ash, bagasse ash and metakaolin are outstanding and have settled mineral admixtures. Neville (1988) indicated that high-performance concrete is the same as manufactured concrete, even though it usually contains fly ash, silica fume, pulverised granulated blast furnace slag and superplasticizer [2].

Shrinkage behaviour of HPC with a high cementitious material content, low cement-to-water ratio and low maximum aggregate size was investigated and the justifications for how wet curing is necessarily have been included. Even in many countries, these mineral admixtures are industrial and agricultural byproducts. These are currently considered wastes. These concerns encourage scientists to investigate the attainability of minimizing and utility of cement consumption in concrete without compromising its properties. Moreover, a less generation and use of cement causes a significant decrease in contamination in nature. ACI 211.1 described various techniques for choosing mixture ratios for high-strength concrete and refining these ratios based on experimental batches [3]. Low water-to-cement ratios are often achieved by using chemical admixtures and particularly designed cementitious materials within high-strength concrete compositions. ACI Committee 363 stated that a significant increase in temperature in concrete can be expected when high cement levels are present [4]. Mixtures having the right amount of retarder added to achieve the required hardening rate at the anticipated temperature. Mixtures can be created with different dosages at varied rates. Retarders also frequently result in an increase in strength that is commensurate to the dosing rate. Generally, however, there is an offset effect that lessens the fluctuations in strengths caused by temperature. The temperature-induced loss of later age strengths is temperature dependent, although it can be somewhat offset by raising the dosage of the retarder to control the rate of hardness. Kartini (2011) conducted an extensive study which indicates that the RHA can be used for partial replacement of cement [5]. Complete research on the Malaysian environment and rice husk ash must be done to determine whether RHA is suitable for replacing cement in terms of workability, compressive strength and durability.

1.1 Rusting of steel in concrete

Steel in concrete is used as it is profoundly impervious to rust or corrosion. The steel bar in the concrete has ferric oxide (Fe_2O_3) as a thin surface film, which passivates steel bar from corrosion. When this film depassivates or wear off, corrosion starts. The depassivation happens as alkalinity of pore water in concrete diminishes. This is induced via carbonation, particularly near the cracks. The reserve alkalinity of concrete is high because of the presence of crystalline $Ca(OH)_2$. The pH is consistent notwithstanding when extraordinary measures of chloride ions enter concrete. When compared to regular concrete, the permeability measured in rice husk ash (RHA) concrete was extremely low, ranging from 100-1000 C; it is based on experimental examination by Ramasamy (2012), which revealed that RHA concrete exhibited greater resistance than the

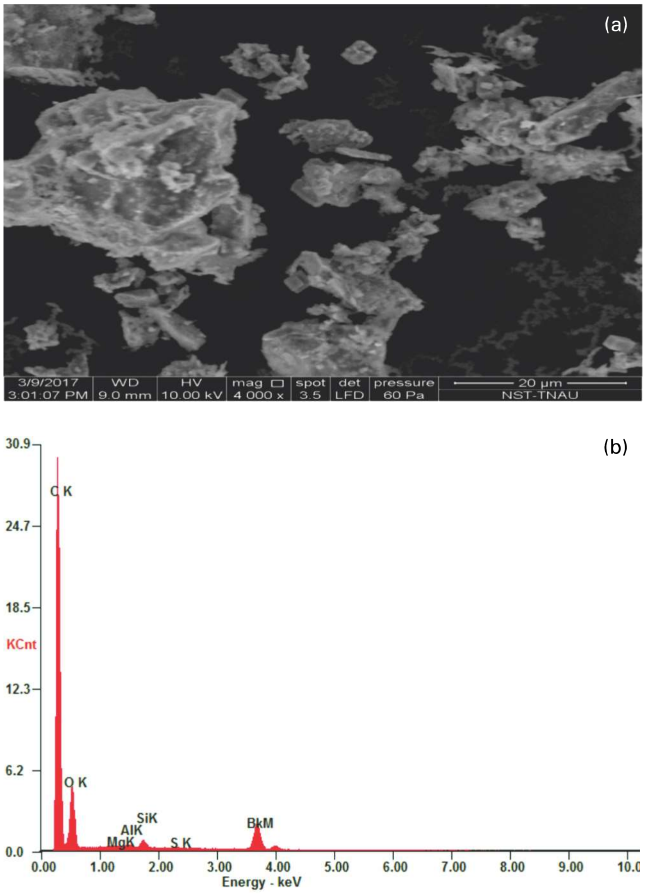

Figure 1. *(a) SEM and (b) EDAX images of ordinary Portland cement*

control concrete.

Consequently, HPC needs to fulfill the fundamental needs. In general view, it is porosity that affects the alkalinity in concrete, leading to decay or rusting of steel. New innovations over the recent three decades have prompted enhanced significance of development of concrete industry. The research aim at enhancing concrete's performance as an engineering material. To enhance concrete's performance, various modern advancements have been explored. Among them are high strength concrete consisting of fibre reinforced concrete, superplasticizer, latex-modified concrete and epoxy coated reinforced steel. Numerous scientists trust that the total volume of concrete made by the utilization of these innovations is not prone to be vast. The HSC and HPC innovations are considered in detail because of their significance in durability .

2. MATERIAL AND METHOD

2.1 Cement

Ordinary Portland cement (OPC) grade 53 complying to IS 12269 (2013) was utilized [6]. The cement was tested as per IS 4031 (1988) and IS 4032 (1985) [7,8]. The outcomes of the cement samples are shown in tables 1 and 2. From SEM and EDAX analysis, the grain size and chemical constituents are obtained which is shown in figure 1.

Table 3. *Sieve analysis of fine aggregates*

IS sieve	Retained wt (gm)	Retained wt (%)	Cumulative retained (%)	Passing (%)
4.75	3	0.3	0.3	99.7
2.36	14	1.4	1.7	98.3
1.18	127	12.7	14.4	85.6
0.6	221	22.1	36.5	63.5
0.425	288	28.8	65.3	34.7
0.3	153	15.3	80.6	19.4
0.18	145	14.5	95.1	4.9
0.15	29	2.9	98	2
Pan	20	2	100	0

Table 4. *Physical characteristics of coarse aggregates*

Characteristics	Values
Relative density	2.98
Water absorption (%)	1.75
Bulk density (kg/m^3)	1886.35
Fineness modulus	5.5

2.2 Fine aggregate

In this present investigation, locally accessible Karur river sand was utilized as fine aggregate and tested according to IS 2386 (1963) [9]. The outcomes of sample are shown in table 3. Particle size distribution was done according to IS 383 (1970) [10]. The river sand falls under zone-II, the fineness modulus of sand utilized was 3.78 and with specific gravity of about 2.66. The grading curves are shown in figure 2a.

2.3 Coarse aggregate

The hard inert blue granite crushed stone aggregates of 10 mm (40%) and 12.5 mm (60%) size coarse aggregates were utilized in the present exploratory work. It was tested according to IS 2386 (1963) [9]. The test outcomes and characteristics of coarse aggregates are shown in tables 4 and 5, respectively. The grading curves are shown in figure 2b.

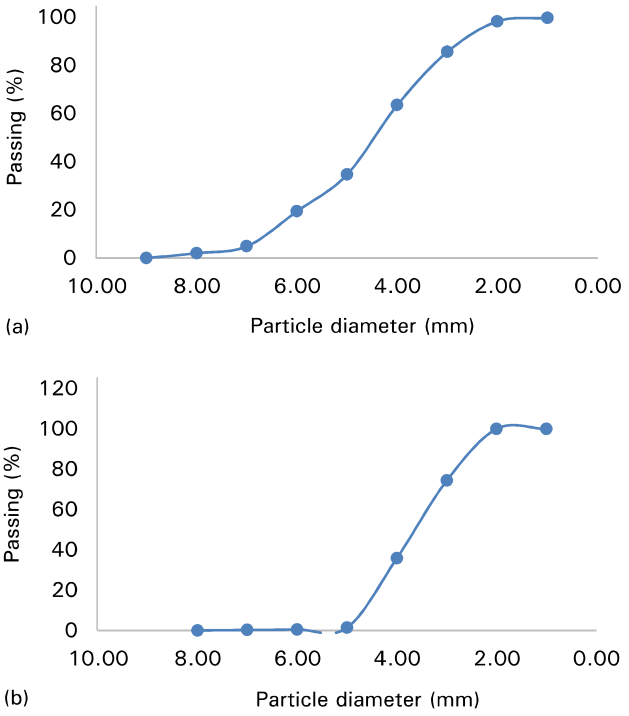

Figure 2. *Grain size distribution of aggregates: (a) fine and (b) coarse*

Table 5. *Sieve analysis of coarse aggregates (10 mm- 40% and 12.5 mm- 60%)*

IS sieve	Retained wt (gm)	Retained wt (%)	Cumulative retained (%)	Passing (%)
20	0	0	0	100
16	0	0	0	100
12.5	512	25.6	25.6	74.4
10	770	38.5	64.1	35.9
6.3	690	34.5	98.6	1.4
4.75	18	0.9	99.5	0.5
2.36	5	0.25	99.75	0.25
Pan	5	0.25	100	0

2.4 Metakaolin

Metakaolin for the present research work was acquired from Astra Chemical, Chennai. The physical and the chemical characteristics of metakaolin are presented in table 6. From SEM and EDAX analysis, the grain size and chemical constituents are obtained for metakaolin (Figure 3).

2.5 Rice husk ash

Commercially accessible rice husk ash supplied by NK Enterprises, Orissa was utilized in the present research.

Table 6. *Characteristics of metakaolin*

Physical characteristics	Metakaolin
Specific gravity	2.6
Blaine's surface area (m^2/kg)	2350
Average particle size (μm)	2.5
Bulk density (kg/m^3)	595
Chemical characteristics (%)	
SiO_2	52
Al_2O_3	46
MgO	0.03
Fe_2O_3	0.6
CaO	0.09
Na_2O	0.1
K_2O	0.03
Loss on ignition	1

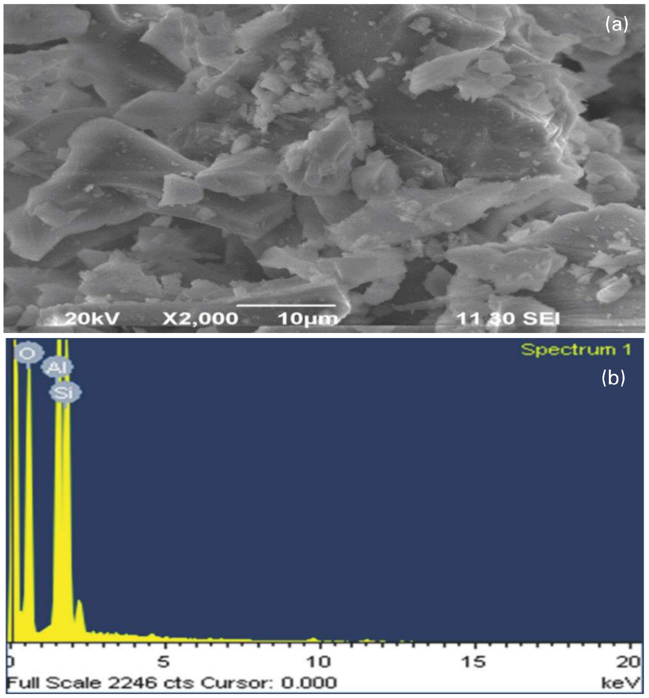

Figure 3. *(a) SEM and (b) EDAX images of metakaolin*

The physical and chemical characteristics of RHA are given in table 7. From SEM and EDAX analyses, the grain size and chemical constituents are obtained for rice husk ash (Figure 4).

2.6 Mix proportioning

The mix design is done in light of combination of BIS and ACI formulated by Perumal and Sundararajan (2004)

Table 7. *Characteristics of rice husk ash*

Physical characteristics	Rice husk ash
Specific gravity	2.22
Blaine's surface area (m^2/kg)	315
Average particle size (μm)	5
Bulk density (kg/m^3)	425
Chemical characteristics (%)	
SiO_2	85
Al_2O_3	0.5
Fe_2O_3	0.26
TiO_2	0.01
CaO	1.45
MgO	0.6
Na_2O	1.8
K_2O	3.21
Loss on ignition	4

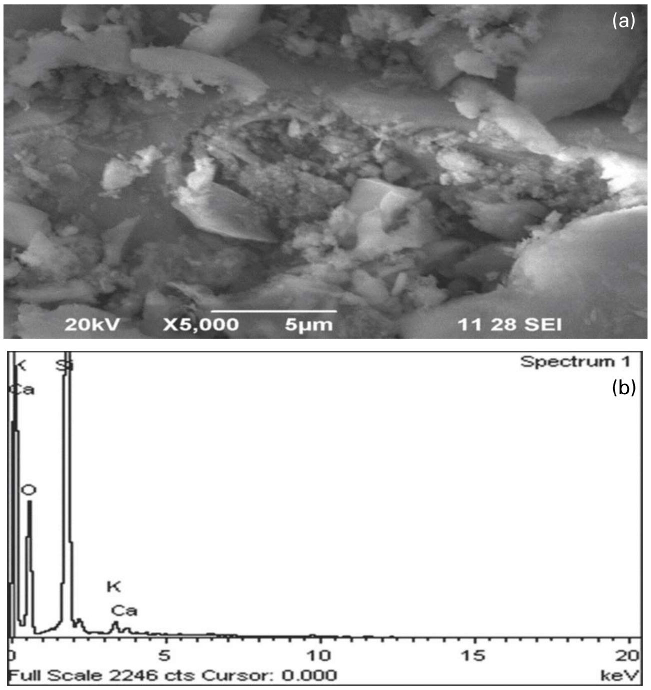

Figure 4. *(a) SEM and (b) EDAX images of rice husk ash*

Table 8. *Material quantities required for various different combinations of metakaolin and rice husk ash*

Mix identity	Cement (kg/m^3)	MK (%)	RHA (%)	Metakaolin wt (gm)	RHA wt (kg/m^3)	FA wt (kg/m^3)	CA wt (kg/m^3)	Water (L/m^3)	SP (L/m^3)
Mc	500	0	0	0	0	765.38	1100	152.06	4.92
M1	425	5	10	25	50	722.02	1100	152.06	4.87
M2	412.5	7.5	10	37.5	50	714.51	1100	152.06	5.41
M3	400	10	10	50	50	706.99	1100	152.06	5.9
M4	412.5	5	12.5	25	62.5	714.94	1100	152.06	6.76
M5	400	7.5	12.5	37.5	62.5	707.43	1100	152.06	7.21
M6	387.5	10	12.5	50	62.5	699.91	1100	152.06	7.62
M7	400	5	15	25	75	707.86	1100	152.06	8.52
M8	387.5	7.5	15	37.5	75	700.38	1100	152.06	8.89
M9	375	10	15	50	75	692.82	1100	152.06	9.22

[11]. Concrete blends were designed to accomplish M60 grade concrete to determine compressive strength at constant water-binder ratio of 0.31. Rice husk ash and metakaolin were used to replace cement partially. Various combinations used were 0%, 5 + 10%, 7.5 + 10%, 10 + 10%, 5 + 12.5%, 7.5 + 12.5%, 10 + 12.5%, 5 + 15%, 7.5 + 15% and 10 + 15% by weight of cement (Table 8). A concrete pan mixer was utilized to mix the dry and wet concrete for adequate time untill a uniform blend was accomplished. As per BIS 516 (1959) and BIS 5816 (1999) specifications, all the mixes were tested to evaluae the compressive and split tensile strength of blended concrete mixes with MK and RHA [12,13].

2.7 Testing methods

2.7.1 Porosity: The water absorption for concrete is the degree of porosity or volume of pores present in hard concrete, that is inhabited by the water in the saturated state. It indicates the amount of water that has been expelled on drying a specimen in saturated state. The porosity acquired from absorption test is

Figure 5. *(a) Experimental setup for permeability test and (b) cubes casted for the test*

identified as the effective porosity. The formula used for computing effective porosity is:

$$\text{Effective porosity} = \frac{\text{Volume of voids}}{\text{Bulk volume of speciments}} \quad ...(1)$$

The volume of voids is estimated from the volume of the water captivated by a specimen dried in an oven or water volume lost during oven drying a specimen in a saturated state at 105^{0}C of constant mass. Specimen's bulk volume is determined by difference in specimen's mass in air and in submerged state.

$$\text{Effective porosity (n)} = \frac{W_s - W_d}{W_s - W_{sub}} \times 100 \quad ...(2)$$

Where W_s is specimen weight at complete saturated state, W_d is specimen weight after oven drying and W_{sub} is weight of specimen submerged in water. The porosity test on 100 mm HPC cube specimens was done in this study.

2.7.2 Permeability: The permeability test was conducted according to IS 3085 (1965) [14]. The apparatus consists of three square cells setup mounted on the stands. The cells are connected with pipe through the valve. A pressure regulator is placed in pressure chamber with two pressure gauges: one gauge with 0-20 kg/cm^2 and the other with 0-15 kg/cm^2 (Figure 5). The pressure is controlled by turning pressure regulator in clockwise direction. A pressure chamber is fitted with Schrader valve for supply of source water. Cubes of 150 mm standard size were casted and then allowed to cure for 28 and 56 days. Post the curing period, they were dried for about 2 days. The containers were held in a manner to collect water permeating from specimen. Using compressor, at rate of 0-5 MPa pressure was applied to water column due to which the water from cubes passes through the funnel and was collected at the bottom in a cointainer. Throughout the experiment, humid conditions were maintained to limit water loss through evaporation. The amount of water collected, operating pressure, observation time, etc., at regular intervals were recorded. The test was carried out until the uniform rate of flow was attained. The coefficient of permeability is determined using equation 3.

$$K = (QL) / (ATH) \quad ...(3)$$

Where K is permeability co-efficient (cm/sec), Q is quantity of water (mm) percolating over the entire period of test after the steady state is recorded, A is effective area of specimen (cm^2), T is time (sec) over which Q is measured, H is pressure head (cm) and L is specimen length (cm).

3. RESULT AND DISCUSSION

3.1 Water absorption test

The test results for porosity of the HPC mixes at 28 and 90 days are shown in table 9. The effect of MK and RHA on porosity with various percentages of cement replacement is shown in figure 6a. The effective porosity of the MK and RHA based mixes blended with water-binder ratio of 0.31 at 28 days ranged between 2.97-2.42 whereas at 90 days, it ranged between 2.62-2.22. From experimental outcomes, it is noticed that the porosity of HPC blended mixes with MK and RHA is conpared to control mix (without admixtures). MK and RHA are found to contribute more to improvement of porosity than compressive strength. The MK and RHA based HPC blended concrete demonstrated least porosity values for 7.5 + 12.5% mix. It is additionally noticed that the MK and RHA based blended mixes at 28 days exhibited porosity rate of 7-24% lesser than the mixes of concrete without MK and RHA. Duval and Kadir (1998) showed porosity value of 7.23-8.07% for flyash based concrete mixes [15]. In contrast, the value

Table 9. *Porosity results of high pressure concrete M60 mixes*

Designated mix	MK (%)	RHA (%)	Porosity on 28 days (%)	Porosity on 90 days (%)	Porosity reduction compared to conventional concrete (28 days) (%)
Mc	0	0	3.22	2.8	-
M1	5	10	2.97	2.62	7.76
M2	7.5	10	2.77	2.54	13.98
M3	10	10	2.62	2.45	18.63
M4	5	12.5	2.52	2.32	21.74
M5	7.5	12.5	2.42	2.22	24.84
M6	10	12.5	2.47	2.57	23.29
M7	5	15	2.52	2.62	21.74
M8	7.5	15	2.57	2.67	20.19
M9	10	15	2.59	2.73	19.57

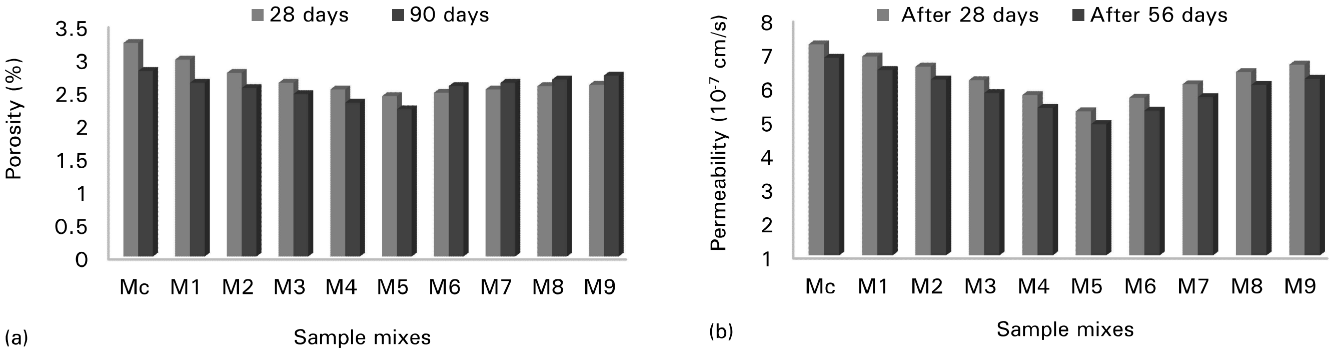

Figure 6. *Influence of metakeolin and rice husk ash on (a) porosity and (b) permeability of high performance concrete mixes*

to be reasonable; also it demonstrates the exceptional durability properties for MK and RHA based HPC mixes.

3.2 Permeability test

The values of permeability coefficient are found to be significantly small for HPC mixes (Table 10). Graphical representation of permeability variation at 28 and 56 days for different percentage of RHA and MK are shown in figure 6b. RHA and MK expansion with the concrete contributes better interlocking between the cement paste and aggregates. Permeability value was seen in decreasing order for HPC from mix 1 to mix 5 and in increasing order from mix 6 to mix 9. This can be attributed to acute fineness. From the results, it can be concluded that usage of RHA and MK achieved practically impermeable concrete. Kartinii *et al.* (2010), in their study, analysed that control concrete was about 3-7 times more porous as compared to RHA 20 and RHA 30 concrete mixes. The reason for such value was presence of RHA which caused decline in permeability [16]. Malathy and Subramanian (2003) achieved the permeability coefficient of around 6.5x10^{-7} to 7.6 x10^{-7} cm/s for different mixes of concrete containing 5-15% replacement of cement by silica fume [17]. The observations illustrate that mixes of HPC developed in

Table 10. *Permeability results of HPC M60 mixes*

Mix	MK (%)	RHA (%)	Permeability coefficient (10^{-7} cm/s)	
			After 28 days	After 56 days
Mc	0	0	7.24	6.84
M1	5	10	6.88	6.48
M2	7.5	10	6.58	6.2
M3	10	10	6.18	5.8
M4	5	12.5	5.74	5.36
M5	7.5	12.5	5.26	4.88
M6	10	12.5	5.66	5.28
M7	5	15	6.06	5.68
M8	7.5	15	6.42	6.04
M9	10	15	6.64	6.22

this current research were examined to have implied impressive performance from permeability aspect.

4. CONCLUSION

The objective of this research is to investigate the impact of mineral admixtures on the durability of high-strength concrete. Replacement of cement with rice husk ash and metakaolin in various mixes is studied. The cubes casted for 28 and 90 days were tested for porosity and permeability properties. In case of porosity, best results were observed for 7.5 + 12.5% HPC mix for both 28 and 90 days of curing period. This is because the micro-structure in cement paste matrix is enhanced by micro-pore filler effects and pozzolanic action of MK and RHA, forming fine and discontinuous pore structures. Hence, it is presumed that replacement of cement with MK and RHA upto 7.5 + 12.5% enhances the durability properties of concrete, furthermore meeting the requisites of strength characteristics. This conclusion is on par with 10% peak limit for mineral admixtures in concrete mix as proposed by IS: 456 (2000) [18]. Water percolation test showed low values for all concrete sample blends consisting metakaolin and rice husk ash compared to control mix, after 28 and 90 days. The significant reduction in permeability is due to the formation of dense matrix and interfaces due to incorporation of MK and RHA. The presence of MK and RHA in concrete blends acts as micro-pore fillers, leading to reduction of pores and thus ensuing fine and discontinuous pore structures. The reduced permeability is due to pore refining. Thus, increasing impermeability of concrete. Replacement of cement with metakaolin and rice husk ash, a byproduct and a waste industrial material, in concrete mixes can lead to productive utilization of both materials and significant reduction in cement usage.

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