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COMPRESSIVE STRENGTH, ULTRASONIC PULSE VELOCITY AND TRANSPORT PROPERTIES OF SELF-COMPACTING HIGH PERFORMANCE CONCRETE MADE WITH IRAQI METAKAOLIN

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ABSTRACT

In this research, the influences of hardened and transport characteristics of self-compacting high performance concrete (SCHPC) containing Iraqi metakaolin(MK) were studied. Concrete mix was made by adding Iraqi metakaolin as a replacement to the Portland cement (PC) by 0%, 5%, 10% and 15% of dry weight. The hardened characteristics of SCHPCs were indicated by compressive strength (CS) and ultrasonic pulse velocity (UPV) tests, whilst, the results of water absorption and porosity testswere utilized to appraise the transport properties of SCHPCs. The results indicated that the MK replacement gave a general improvement in the compressive strength, UPV and transport properties of SCHPC mixes. Increasing the replacement of MK increased the CS, and UPV. SCHPC with 10% MK cement replacement exhibited higher values of compressive strength, and UPV compared with control mix of SCHPC for 28, 56 and 90 days hence it was considered as the optimum. While, the concrete with 5% and 15% of MK gave results less than that of the 10% MK concrete. However, in both cases, these were greater than the control concrete. Whereas, the transport properties as assessed via water absorption and porosity tests are significantly improved of SCHPC mixtures when PC is replaced by MK, with the SCHPC containing 10%MK exhibiting the best improvement at all ages. Generally, the partial replacement of cement by MK enhances the the hardened and transport properties of SCHPC and is economical and environmentally friendly as well.

Key words: Compressive strength; Iraqi metakaolin; Self-compacting high performance concrete (SCHPC); Transport properties; and Ultrasonic pulse velocity.

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1. INTRODUCTION

The progress that associated with concrete technology has raised the need to develop the new kind of concrete which is the self-compacting high performance concrete (SCHPC). The concepts of self-compacting and high performance are the main merits accompanied by SCHPC. In general, a concrete that satisfies the performance requirement of self-compacting concrete (SCC) and high performance concrete (HPC) can be indicated as SCHPC. An SCHPC is a concrete, which gives outstanding execution in term of ,passing, filling, strength, segregation resistance, transport characteristics, and durability. The hardened characteristics of SCHPC are further enhanced by adding high-range water reducer (HRWR) because of the improvement in the dispersion of binder particles and the enhancement in the densification of paste. In addition to the HRWR, supplementary cementitious materials (SCMs) are generally added to SCHPC to earn improvement in the strength, durability and reduction in the cement (PC) content of concrete. Incorporation of SCMs in concrete is associated with many advantages. These advantages represent by improving and increasing rheological and strength characteristics, enhancing the pumping, placing and finishing of concrete and the resistance to chloride ions and sulphate attack.

Recently, the importance of the environmental parts of construction sector has increased significantly. Hence, lowering the amount of carbon dioxide emitted to atmosphere during cement manufacture becomes a necessity. Researchers find out that replacing Portland cement partially or fully in concrete by more environmentally friendly alternative binders can be a promoting solution. These binders can represent by waste and by-product materials such as ground granulated blast furnace slag (GGBFS), silica fume (SF), fly ash (FA), and metakaolin (MK). Metakaolin resulted from thermal decomposition of kaolin with no carbon emission. In Iraq, GGBFS is not a locally available material and silica fume is an expensive material which limited its use to the highly expensive and demanding concrete buildings. In the same time, the country has a significant amount of kaolin (K) clays which was used in the past to produce porcelain. Thus, metakaolin can be used as silicate binder alternative to silica fume or GGBFS in the concrete sector in Iraq.

The use of MK as a pozzolanic binder in concrete mixtures increases widely. MK is a pozzolanic binder, but, unlike the other materials, not being a by-product as it is manufactured under carefully controlled environments (Justice et al., 2005) [1].It is produced by treating kaolin which is one of the widely available natural minerals by heat. Kaolin is a fine clay with white color that has conventionally been utilized as a coating for paper and in the production of porcelain. The first use of MK dated back to the1962, being incorporated in the concrete that made the Jupia Dam in Brazil. However, it has been available commercially from the 1950s onwards. MK normally have 50-55% $SiO2$ and 40-45% $Al2O3$ (Poon et al. 2001) [2] with small amounts of other oxides such as CaO, $Fe2O3$, MgO, and $TiO2$. MK has a white color, which makes it attractive to architectural applications such as color matching. In addition, MK powders are highly invariable in performance as well as appearance because of the controlled nature of the processing (Ding, 2002) [3].Therefore, a very higher degree of pozzolanic reactivity and purity can be obtained. Thus, MK has a high potential to work as pozzolanic materials, since it is able to enhance many properties of concrete as well as minimizing cement consumption.

Previous studies have revealed a significant attention to MK since it has been shown to have both microfiller as well as pozzolanic properties(Wild et al. 1996; Wild and Khatib 1997; Poon et al. 2001) [4, 5, 2]. Also, using mathematical modeling, MK has been successfully utilized to develop high strength self-compacting concrete (HSSCC) (Dvorkin et al. 2012) [6]. The concrete and fresh mortar properties, including flow table, slump, and compacting factor, are significant as they have a direct impact on the choice of handling and consolidation equipment, with a potential impact on the properties of hardened concrete (Mindess, 2003) [7]. Additionally, MK containing concretes demand a higher amount of superplasticizers since some of the superplasticizers is absorbed on the of MK particles due to being very fine. The addition of MK to SCC improves viscosity and yield stress resulting in a significant reduction in bleeding, slump flow, and segregation due to its high fineness. Wong and Razak (2005) [8] indicated the impact of MK on the compressive strength of concrete. Mixes were made with different ratios of w/cm of 0.27, 0.30 and 0.33. The results showed that the use of MK didn’t result in an immediate strength improvement but rather mixture have higher strengths than the control mix at 7 days and after. The use of MK as a pozzolanic material not only enhances the strength and durability properties of the concrete but also reduces carbon dioxide (CO_2) and other greenhouse gas emissions associated with cement production.

High performance concrete (HPC) contains metakaolin such as durability and basic physical properties, chloride binding characteristics, Fracture mechanical and mechanical characteristics, and thermaland hydric properties were evaluated. The results pointed that the use of 10% metakaolin as a replacement to PC gave the better improvement in strength but does not significantly impair substantial properties and it was found that the storage and heat characteristics as well as the physical properties were much the same to those of the normal HPC (Eva et al. 2010) [9]. Moreover, ultrasonic pulse velocity is defined as the traversed distance of the pulse or sonic wave per unit transit time. Generally, a high ultrasonic pulse velocity through concrete indicates that the concrete is of good quality. An ultrasonic pulse velocity above 4575 m/sec states the ‘excellent’ quality of concrete whereas an ultrasonic pulse velocity below 2135 m/sec reveals the ‘very poor’ condition of concrete (Shetty 2001) [10]. The ultrasonic pulse velocity of SCHPC is expected to be much higher than that of ordinary concrete. This is due to the structure of the refined pores and the dense microstructure of SCHPC. However, no considerable studies have been conducted on the non-destructive evaluation of SCHPC using UPV method.

A major issue facing engineers is the achievement of acceptable durability levels of concrete. That is in order to minimize the lifecycle cost while improving the performance of concrete structures. However, the advantages of utilizing additional binder materials, regarding the durability of concrete, were well established [11], and the utilization of materials including MK, GGBFS, and SF is currently considered a commonplace. The durability properties studied in this research are porosity and water absorption. The porosity affects the microstructure and consequently the concrete absorption, depending on the relative quantities of the pores of various sizes and types. When the porosity is reduced, the water absorption is also decreased. It was reported that SCHPC provides a water absorption in the range of 3 to 6% (Schutter et al. 2003) [12]. Absorption, on the other hand, is generally utilized for determining the quantity of water that is absorbed under specific conditions. It must be noted that water absorption mechanism is different from water capillary absorption of concrete. Water absorption refers the porosity degree of a material (Siddique, 2013) [13].Capillary and total porosity are expected to be small in SCHPC (7 to 15%) as compared to ordinary concrete due to compacted pore structure. The SCHPC pore system is more refined than that in ordinary concrete (Attiogbe et al. 2002) [14].

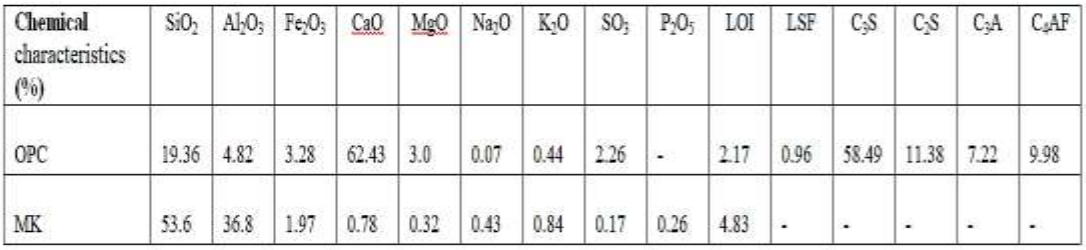
For centuries, concrete has been utilized in the construction, with adjustments being made for improving its performance, mainly in respect to strength and durability. The utilization of PM has found to be very effective in improving the characteristics of concrete especially strength and durability. Thus, the global trend towards "green and sustainable living" as it applies to the concrete industry involves minimizing the impact of concrete production on the environment. This can be accomplished by the exhaustion natural resources consumed in the concrete manufactures by increasing the utilization of waste and by-product materials. Therefore, this study aimed to indicate the effect of utilizing Iraqi MK which is available commercially as pozzolanin the development of SCHPC. This development was assessed by evaluating the compressive strength, UPV and transport properties. For this purpose, four types of SCHPC mixtures were prepared and cast. These mixtures are the control mixture incorporated PC only and the new developed mixes made of binary cementitious blends of MK. and cement. The experimental work consisted of two parts. The first part involved investigating the hardened properties by carrying out the compressive strength and ultrasonic pulse velocity tests with the rheological properties including the workability of the SCHPC mixtures. The transport properties of SCHPCs was assessed based on the results of water absorption and porosity tests, in the two part of this study. The entire test results were compared with those of control mix.

2. EXPERIMENTAL PROGRAM

2.1. Materials

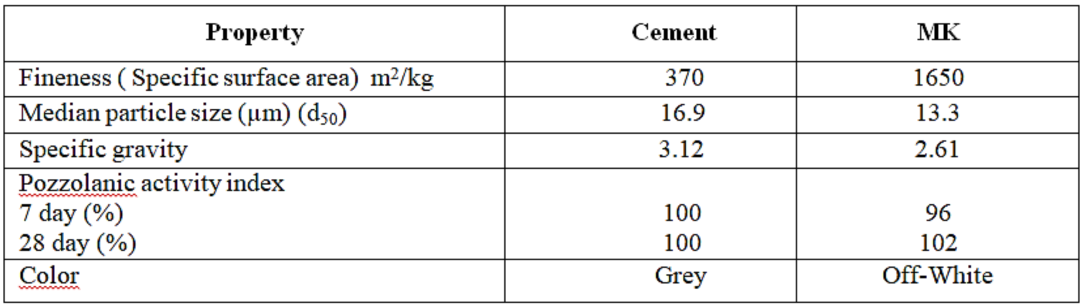
In all mixtures, ordinary Portland cement (PC) (type I), crushed gravel with the maximum size of 10 mm as coarse aggregates and natural sand that has maximum size of 4.75 mm as fine aggregates. These materials adhered to the Iraqi specification No. 5/1984 [15] for cement and Iraqi specification No. 45/1984 [16] for aggregates. The pozzolanic material used as a partial substitution to OPC in the binary mixtures is Iraqi metakaolin(MK). The origin of metakaolin was Iraqi kaolin clay gathered from Dewekhla region in Al-Anbar. The clay was grinded then placed in the furnace to burn at a temperature up to 800ºC± 20ºC, for 2 hours to produce the MK, after that it was left to cool at an ambient temperature of 24 ºC. In accordance to (Ambroise et al. 1994; and Liew et al. 2012) [17, 18], MK is prepared by activating kaolin thermally at temperature of 800 ºC for 2 h. Finally, the MK was grinded by the air blast technique in AL-Zahra′a Shop in Baghdad, to obtain a reactive material with more fineness. The chemical and physical characteristics of the MK and its strength activity index were determined and listed in Table 1 and 2.A high range water reducing agent (HWRA), Superplasticizer (SP), (commercially available as Glenium 54) was used in the experiments to produce the required flowing ability of SCHPC. HWRA additive was a modified polycarboxylic ether. It was available in Whitish to straw coloured liquid form.

Table 1 Chemical composition of cement and Iraqi metakaolin.



Chemical characteristics (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	P_2O_5	LOI	LSF	C_3S	C_2S	C_3A	C_4AF
OPC	19.36	4.82	3.28	62.43	3.0	0.07	0.44	2.26	-	2.17	0.96	58.49	11.38	7.22	9.98
MK	53.6	36.8	1.97	0.78	0.32	0.43	0.84	0.17	0.26	4.83	-	-	-	-	-

Table 2 Physical properties of cement, and Iraqi metakaolin.



Property	Cement	MK
Fineness (Specific surface area) m^2/kg	370	1650
Median particle size (μm) (d_{50})	16.9	13.3
Specific gravity	3.12	2.61
Pozzolanic activity index 7 day (%) 28 day (%)	 100 100	 96 102
Color	Grey	Off-White

2.2. Concrete Works

Trial and error approach was used to design a reference mix, in which several trials were undertaken until the suitable mix proportions were obtained. The mix agreed with the requirement of SCC based on the applicators of specialist building products for Concrete EFNARC and the producers of the European Federation of National Associations Representing [19]. Four concrete mixes were made in this study, and the mixtures' proportions are given in Table 3. The mixes were prepared by using water-binder ratio (w/b) of 0.30 with484 kg/m^3 cementitious material on a total bases. Metakaolin was utilised to partially replace the cement in the proportion of (5%, 10%, and 15%). The mixed proportions for the SCHPCs are given in Table 3**.**

The process of mixing was undertaken using a mixer pan rotating for about nine minute based on the ASTM C192-2002 [20]. The workability of the fresh concrete mix before casting in moulds. After that, the concrete was cast in the cubes and cylinders moulds. It should be emphasized that no external aids of tamping or vibration were not used during casting of all samples.Finally, the moulds were levelled by hand trawelling and cured at laboratory temperature. After 24 hours, the specimens were demoulded carefully, so as not to be broken or chipped and then, placed in a water tank in laboratory temperature until of time test. Concrete samplesin this researchwere casted in batch cubes of 150×150×150 mm for UPV and compressive strength tests while cylinders specimens of 150×300 mm were used for porosity and water absorption tests. Demoulding of the samples was carried out after 24 h then the samples were cured using water curing tanks. Compressive strength experiments were performed at late ages (28,56 and 90 days) and according to the BS EN 12390-3 [21]. For each age, the average of three specimens was taken to represent the value of the compressive strength at that age. Moreover, the UPV tests were carried out depending on the specifications BS 1881-203 [22] and at 28, 56 and 90 curing days. An operational stage of the ultrasonic pulse velocity test is shown in Figure 1. The drying process assisted the obtaining of adequate coupling between specimen and transducers. The average path length of the specimens was determined by taking the measurement at four quaternary longitudinal locations. A PUNDIT, which stands for portable ultrasonic non-destructive digital indicating tester, was utilized for determining the ultrasonic pulse velocity. UPV was determined from path length and measured transit time and the average value of the three specimens was taken

Table 3 Mix proportions of the SCHPC mixtures.

Mix description	Replacement level (%)	Cement kg/m^3	W/B	Metakaolin kg/m^3	Coarse aggregate kg/m^3	Fine aggregate kg/m^3	SP ^{a} (%)
SCHPC-OPC	0	484	0.30	0	893	852	1.3
SCHPC5MK	5	459.8	0.30	24.2	893	852	1.3
SCHPC10MK	10	435.6	0.30	48.4	893	852	1.3
SCHPC15MK	15	411.4	0.30	72.6	893	852	1.3

SP ^{a}: Dosage Superplasticizer

Figure 1 Ultrasonic pulse velocity (UPV) test

The total porosity and water absorption of the concretes were measured at 28, 56, and 90 curing days following initial curing of 28 days to obtain the average values as shown in Figure 2. These methods were successfully used in a study by Safiuddinet al. 2005 [23]. The cylinder specimens of size Ø150×50 mm were vacuumed in water, this is followed by measuring the saturated surface-dry, buoyant, and oven-dry masses of the specimens. Vacuum saturation was used before the drying of samples by oven so as for eliminating the influence of microstructural damage by heating. Following Equations. (1) and (2), the water absorption and total porosity were measured respectively. For each test result, three specimens were made.

$$\text{Wa}= \frac{Ms-Md}{Md} \times 100 \tag{1}$$

$$\text{Pt.} = \frac{Ms-Md}{Ms-Mb} \times 100 \tag{2}$$

Where,

Wa= Water absorption (wt. %).

Pt= Total porosity (vol. %).

Ms= Saturated surface-dry mass of the sample in air.
Md= Oven dry mass of the sample in air, and,
Mb = Buoyant mass of the sample saturated in water.

Figure 2 Water absorption and porosity test

3. RESULTS AND DISCUSSION

3.1. Rheological Properties of Blended SCHPC Mixtures

In accordance with EFNARC, a mixture of concrete may only be considers as self-compacting concrete (SCC), if it achieves the requirements of passing, filling, and segregation resistivity properties. The characterizations of rheological SCHPCs manufactured by using SF were measured immediately after the mixing process by conducting L-box test (H2/H1); slump flow test (T500 and slump flow diameter), V-funnel, and segregation resistance and these results are given in Table 4. The capability of a fresh mix to flow in unconfined conditions is represented by slump-flow value. This test is sensitive and can normally be specified for all SCHPC. The influence of MK addition on the values of slump flow is given in Table 4. From the table, the satisfactory slump flow for SCHPCs containing MK are in the range of 675-720 mm. In Accordance with EFNARC, all concrete mixes can be classified as slump flow class 2 (SF2). With this class of slump flow, the concrete mixtures are considered adequate for many typical applications such as columns and walls. The results shown in Table 4indicated the reduction in the slump flow values of the concrete with the increment in the MK substitution, as the slump flow reduced from 720 mm of OPC-control to 675 mm with 15% MK substitution. This indicates an excellent filling ability of SCHPC.

The result also indicates that the increase in the amount of MK increases the requirement of water in concrete. This can be related to the quantity of substitution, the raised amount of silica in the mixture, and the large specific surface area (SSA) of the MK. The fineness of the MK particles which is governed by the specific surface area is the major factor influencing the cementitious characteristics in the binary blended mixture of cement and MK. MK led to a loss in workability since it has a smaller particle size in comparison to those of the cement. This result was also indicated by (MegatJohari et al. (2001), Wong and Razak (2005)[24, 8].The best MK replacement was determined to be 10%, and the slump value reduced with the increment in MK replacement [25]. Also, the tested mixtures satisfied the passing ability criteria regarding EFNARC limitations [19].

The viscosity of Concrete indicated by V-funnel and T500 tests was significantly increased as the content of MK in the mixtures increased which is given Table 4. The same aforementioned factors given for the slump flow reduction were thought to be responsible for increasing the viscosity of the mixes. As shown in Table 4, the slump flow had time ranging from 3-5 s to 10 s over all the mixtures. With this T500 range, the viscosity is adequate for increasing the resistance of segregation and to limit the pressure of excessive formwork [26]. Increasing the MK content in the mixtures generally increased the T500 flow time. Based on EFNARC limitations, all mixtures have viscosity classes laying within VS2/VF2 [19]. From the results of V-funnel test, it can be stated that all the SCHPC have achieved a good stability performance. The time measured by the V-funnel ranged between 8.35 to 12.15 s controlling by the mineral admixture utilised. The control concrete gave the lowest V-funnel flow time of 8.35 s , while the highest flow time of 12.15 s obtained from concrete with 15% MK. The addition of MK in the binary system generally increased the viscosity of concretes. With increasing the MK value, the value of V-funnel flow time increased. It clearly appears that MK is the reason behind the increase in the slump flow time.

Table 4 gives the results of L-box test of SCHPC containing MK. L-box tests are utilised to assess the ability of SCHPC to fill and pass. It is blocking ratios were in the range of 0.844 to 0.938 with no tendency to block. The results showed that the OPC-control have the highest blocking ratio while the lowest was given by SCHPC15MK. According to EFNARC [19], for SCC to be stable, it needs to exhibit a blocking ratio of 0.8 or higher. Based on that, all SCHPC mixtures manufactured in the study has an adequate ability to flow through the rebar of the L-box tools. However, the results of fresh properties are in conformity with previous studies conducted by (MegatJohari et al. 2001, Ahari et al. 2015) [24, 27]. Thus, the increase in the MK content, the segregation resistance index (SI) decreased noticeably (Table 4). This could result from the interesting increase in the viscosity of mixtures incorporating MK. According to the rheological characteristics, All mixes can be indicated as SCHPC.

Table 4 The results of rheological properties tested SCHPC

Mix description	**Percentage Replacement(%)**	**Workability Tests**				
		Slump flow (mm)	**T500**	**V funnel (sec)**	**Blocking Ratio in L-Box**	**Sieve Stability test (%)**
SCHPC-OPC	0	720	3.00	8.35	0.938	8.0
SCHPC5MK	5	715	4.05	9.56	0.904	6.7
SCHPC10MK	10	690	4.45	11.30	0.874	5.6
SCHPC15MK	15	675	5.10	12.15	0.844	4.2

3.2. Compressive Strength

The test was accomplished for assessing the strength of SCHPC mixtures. Figure 3 gives the average compressive strength of concrete cubes containing MK at 0%, 5%, 10% and 15% by total binder massmeasured at curing of 28, 56 and 90 days. The result indicated an increase in the compressive strength of concrete samples with the partial replacing of cement (PC) by metakaolin, with this increase being proportional with increasing the content of metakaolin. The figure also explained that the compressive strength increased with time as MK content increased. In addition, the strength of all the concrete samples incorporated MK remarkably improved in compared with the control concrete across all ages. Figure 3 also showed that SCHPC10MK gave the highest compressive strength; 69.7, 73.6 and 75.4 MPa at 28, 56 and 90 days, respectively. Thus, the addition of the MK10 produced SCHPC mixes with the best compressive strength at all ages.This result is in agreement with that reported by[11-14].The significant improvement in the strength the mixtures of concrete incorporating MK is highly attributed to the physical and chemical influence of MK. This result is very important as it indicates the significance of the pozzolanic reaction in MK concrete for enhancing the mechanical characteristics on the long term which have not reported yet, in the development of SCHPC mixtures. It is also revealed from the results obtained that the compressive strength of concrete with 10% MK is slightly more than that of concrete with 15 %MK. This can be attributed to the dilution effect which occurred due to the partial replacement of cement by the MK. In MK concrete, the dilution effects are alleviated by pozzolanic reaction of MK with calcium hydroxide, the filler effect and compounding effect (synergetic effect of mineral admixture) as they react oppositely (Parande et al. 2008) [28].

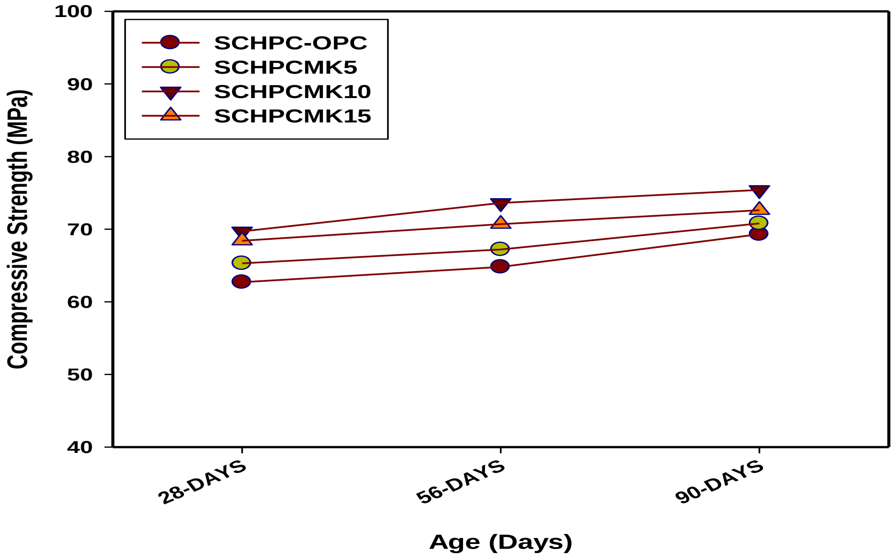


Figure 3 Compressive strength development of SCHPC mixtures containing metakaolin with respect to age

3.3. Ultrasonic Pulse Velocity

For each concrete mix, UPVwas recorded for all cubes specimens before testing of(28, 56 and 90 days). Then, the cubes were crushed to determine the compressive strengths. The results obtained from the tests on the binary mixes made from blending cement concrete with different MK proportions are evaluated and discussed below. Figure 4 illustrates the effects of the MK on the UP and explains the UPV of SCHPC containing MK for different replacements of MK at 5%, 10% and 15% by weight of cement and 28, 56 and 90 days curing periods. The UPV values changed from 4.580 to 4.810 km/s for 28 to 90 days, respectively as shown in Figure 4. At the 10 % replacement MK mixture, the UPV had the highest values for all replacement levels of the concrete cured for 90 days. Similar observations have been detected by Ulucan et al. (2008) [29].

In this study, the effect of metakaolin on quality of SCHPC through UPV values were presented to the different mixtures.UPV values for SCHPC mixes containing MK ranged from 4.580 to 4.810 km/s; with values increased with the curing ages. The assessment of the concrete quality of various ages for all the kinds of mixtures made showed an excellent SCHPC concrete quality at later ages (28, 56 and 90 days) as given and observed in Table 5. This is because the quality of concrete depends on its age in addition to its compressive strength. The UPV trend was observed to increase with the increment of the compressive strength for all the mixes. Therefore, the quality of the different concrete types produced were all considered to be excellent. Similar conclusions have been observed by Whitehurst (1951) [30], Hamidian et al. 2011 [31]. The UPV values should be more than 4.500 km/sfor excellent concrete quality; in range of 3.500-4.500 km/s for good concrete; in range of 3.000-3.500 km/s for medium concrete; while for poor concrete, it is in the range of 2.000-3.000 km/s; and less than 2.000 km/s for very poor concrete [30].

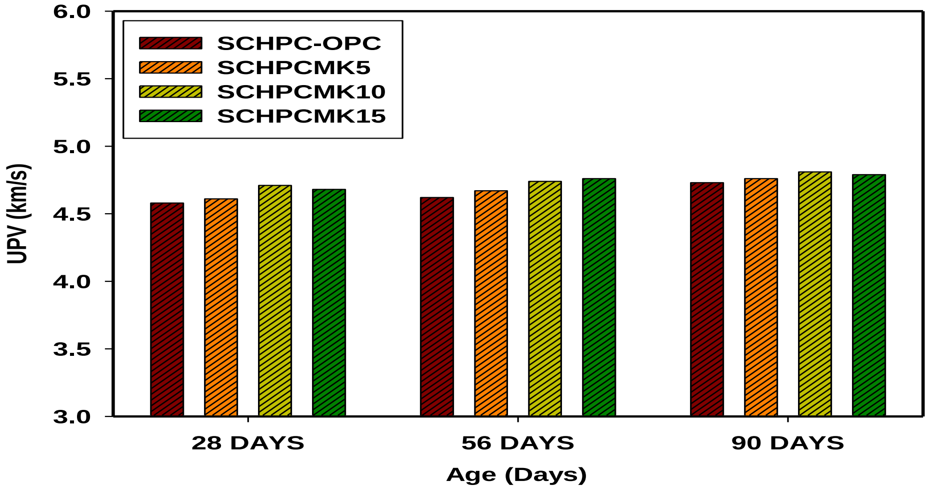


Figure 4 UPV values of SCHPC containing metakaolin with age.

Table 5 The effect of metakaolinon types of SCHPC

Mix description	Concrete quality		
	Age of concrete (days)		
	28	56	90
SCHPC-OPC	Exc.	Exc.	Exc.
SCHPC5MK	Exc.	Exc.	Exc.
SCHPC10MK	Exc.	Exc.	Exc.
SCHPC15MK	Exc.	Exc.	Exc.

Exc. = Excellent

3.4. Transport Properties

The transport properties of concrete mainly depend on its permeability that defines the penetration resistance of aggressive agents. Figs.5 and 6 show the average test results of transport properties as assessed viawater absorption and porosity of the binary blend binder SCHPC made from 5%, 10% and 15% MK as cement replacement and cured for 28, 56 and 90 days. The results revealed that water absorption varied between 2.89% and 3.82% by dry mass, as shown in Figure 5.Also, it is indicated that the water absorption of the control mix was higher than all the SCHPC mixtures containing MK. Guneyisi et al. (2008) [32], also showed this outcome in their study.This result is because of the advantage of the ultrafine MK filling impact and its pozzolanic reaction. The total porosity of all concrete mixtures ranged from 7.31 to 9.87% at 28, 56 and 90 days as presented in Figure 6. The concrete porosities decreased with the increase in age. This trend likely occurred because of the increase in the hydration of the binding materials as well as the pozzolanic reaction in addition to the filler impact participated in the porosity reduction of concrete [33,34,35].

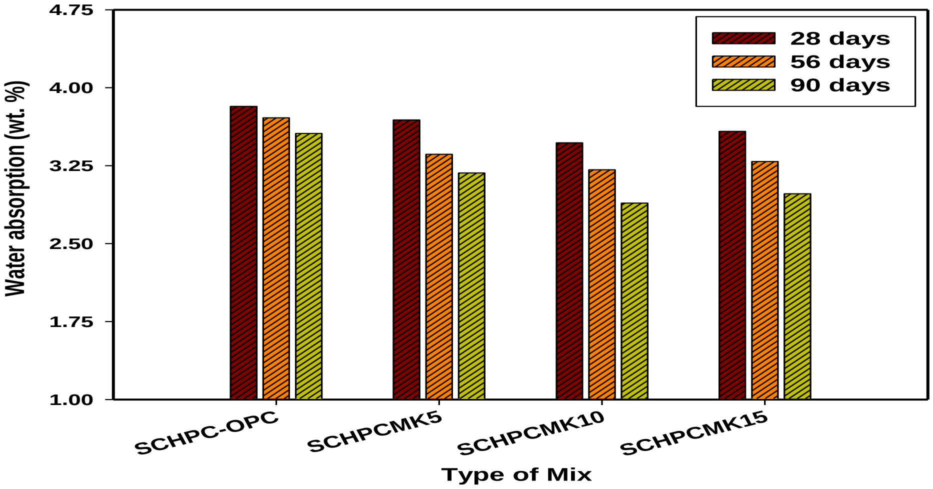


Figure 5 Water absorption of SCHPC mixtures with MK at 28, 56 and 90 days.

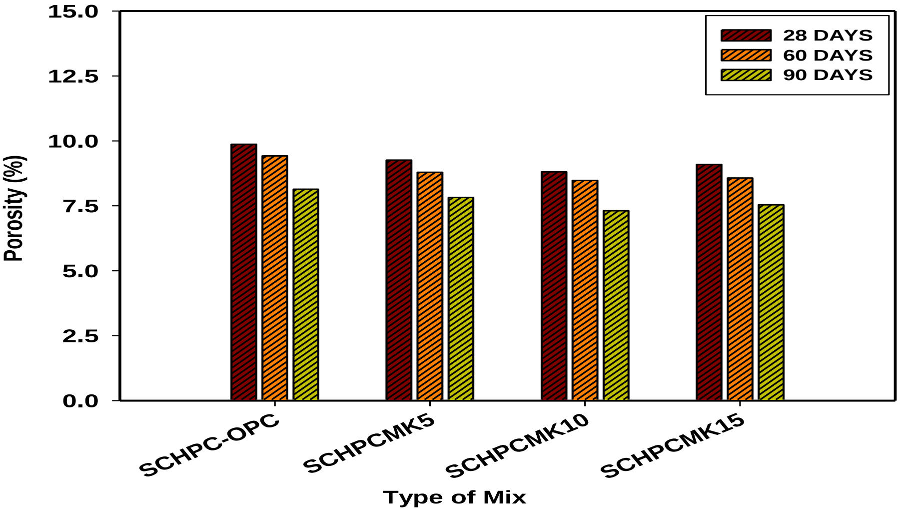


Figure 6 Porosity of SCHPC mixtures with MK at 28, 56 and 90 days.

4. CONCLUSIONS

Following conclusions are drawn from this studyare described here under:

- The criteria of passing ability and filling ability were fulfilled for all SCHPCs and a higher MK level due to the high viscosity caused by the excessive surface area of metakaolin. The increase in the substitution of cement by MKled to a significant reduction in the workability of the binary combination of MK concrete.
- The compressive strength increased with the increments in the replacement percentage of MK. SCHPC mixes with 10% MK cement replacement appeared the highest compressive strength for the all ages.
- With the increase in the MK content, The UPV values decreased for all ages. At 10% MK replacement, the UPV was the highest for all replacement levels for the concrete of all ages.
- The concrete quality is found to be excellent for all SCHPC concrete mixes at late ages.

- Water absorption varied between 2.89% and 3.82% by dry mass for the binary binder blends of concrete with MK at curing of 28, 56 and 90 days. The water absorption of MK concrete specimens decreased for the all ages compared to that of the SCHPC control mix.
- For the all concrete mixes, the decrease in porosity with the increment in age. The total porosity of all SCHPC concrete mixtures containing MK ranged from 7.31 to 9.87% for all ages.

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