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PREDICTION OF COMPRESSIVE STRENGTH AND SOME PERMEABILITY-RELATED PROPERTIES OF CONCRETES CONTAINING VOLCANIC SCORIA AS CEMENT REPLACEMENT

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The objective of the present work is to predict the compressive strength, water permeability, chloride penetrability and porosity of concretes containing volcanic scoria as cement replacement after 2, 7, 28, 90 and 180 days curing. Concrete specimens have been produced with three different water-binder ratios of 0.5, 0.6 & 0.7 and replacement levels ranging from 10 to 35%. Test results revealed that curing time, the scoria content and the water-binder ratio had a large influence on all the examined properties of scoria-based concrete. An estimation equation has been developed by the authors to predict the studied properties depending on the water-binder ratio, the curing time and the replacement level of volcanic scoria. SEM/EDX analysis has been reported, as well.

Keywords: *Blended cement, Volcanic scoria, Concrete, Prediction of properties*

1. Introduction

Natural pozzolan is one of the oldest construction materials [1]. The Roman Empire is the most synonymous with the use of pozzolans, the name deriving from volcanic rock found near Naples [1]. After thousands of years, natural pozzolan-containing concretes are still used today owing to their ecological, economical and performance-related advantageous properties [2-9]. However, the use of natural pozzolan as cement replacement is often associated with shortcomings such as the need to moist-curing for longer time and a reduction of strength at early ages. Syria has important volcanic areas. More than 30 000 km^2 of the country is covered by Tertiary and Quaternary-age volcanic rocks [10], among which volcanic scoria occupies important volume with estimated reserves of about three-quarters billion tons [11]. However, their potential use in making concrete is not well established. The cement produced in the country is almost of CEM I, although an addition of natural pozzolan up to 5% was frequently used in most local cement plants. Hence, less than 300 000 tons of these pozzolans are only exploited annually (the annual production of Portland cement in Syria is about 6 million tons) [12].

Strength of concrete is commonly considered its most valuable property, although, in many practical cases, other characteristics, such as durability and permeability, may in fact be more important [13]. In addition, the literature shows that permeability is directly related to long-term durability [14].

The strength and permeability of concrete are dependent on many factors including the water-binder (w/b) ratio, binder type and content of the binder and the curing age. These properties in the concretes containing supplementary cementitious materials could widely differ from that of concrete with no such materials. Unfortunately, rational and easy-to-use equations are not yet available in design codes to accurately predict the compressive strength and durability properties. In addition, the current empirical equations presented in the codes and standards for estimating compressive strength are mainly based on tests of concrete without supplementary cementitious materials [15]. Thus, predicting the properties of concrete with supplementary materials (fly ash, silica fume, natural pozzolan, etc.) will be of great importance to the concrete mix designer and to the concrete structure to be built.

The aim of the study is to predict the compressive strength and some permeability-related properties of concrete containing volcanic scoria as cement replacement. In addition to the compressive strength, water permeability, porosity

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and chloride penetrability of concretes have particularly been investigated. The authors propose an equation for estimating the afore-said properties of concrete containing volcanic scoria. The variables in the estimation equation are volcanic scoria content, curing age and water-binder ratio.

The study is of particular importance not only for the country but also for other countries of similar geology, e.g. Harrat Al-Shaam, a volcanic field covering a total area of some 45 000 km^2, third of which is located in Syria. The rest covers parts of Jordan and Saudi Arabia.

2. Materials and methods

2.1 Materials

The volcanic scoria used in the experiments was quarried from Dirat-at-Tulul site, at about 70 km southeast of Damascus as shown in Figure 1. Thin sections & XRD analysis of the investigated scoria are shown in Figure 2. The chemical analysis of scoria used in the study is summarized in Table 1. Seven binder samples were prepared in accordance with EN 197-1; one plain Portland cement CEM I (control), three CEM II/A-P samples with three replacement levels (10, 15 and 20%), and three CEM II/B-P samples with three replacement levels (25, 30, 35%), respectively. 5% of gypsum was added to all these binder samples. All replacements were made by mass of cement. The clinker was obtained from Adra Cement Plant, Damascus, Syria. Chemical analysis of clinker and gypsum is shown in Table 1. All samples were interground by a laboratory grinding mill to a Blaine fineness of 3200±50 cm^2/g. CEM I (the control sample) was designated as C1/CEM I, whereas scoria-based binders were designated according to the replacement level. For instance, C2/10% and C7/35% refer to the binders containing 10% and 35% of volcanic scoria, respectively.

A total of 21 concrete mixes have been prepared using the seven binders and three different (w/b) ratios (0.5, 0.6 and 0.7). A grading of aggregate mixtures was kept constant for all concrete mixes. Aggregates used in the study were crushed dolomite with natural sand added. Coarse/total aggregate ratio was kept constant in all studied mixes. Chemical composition of the aggregates and the grading with some physical properties are illustrated in Table 1 & Figure 3, respectively.

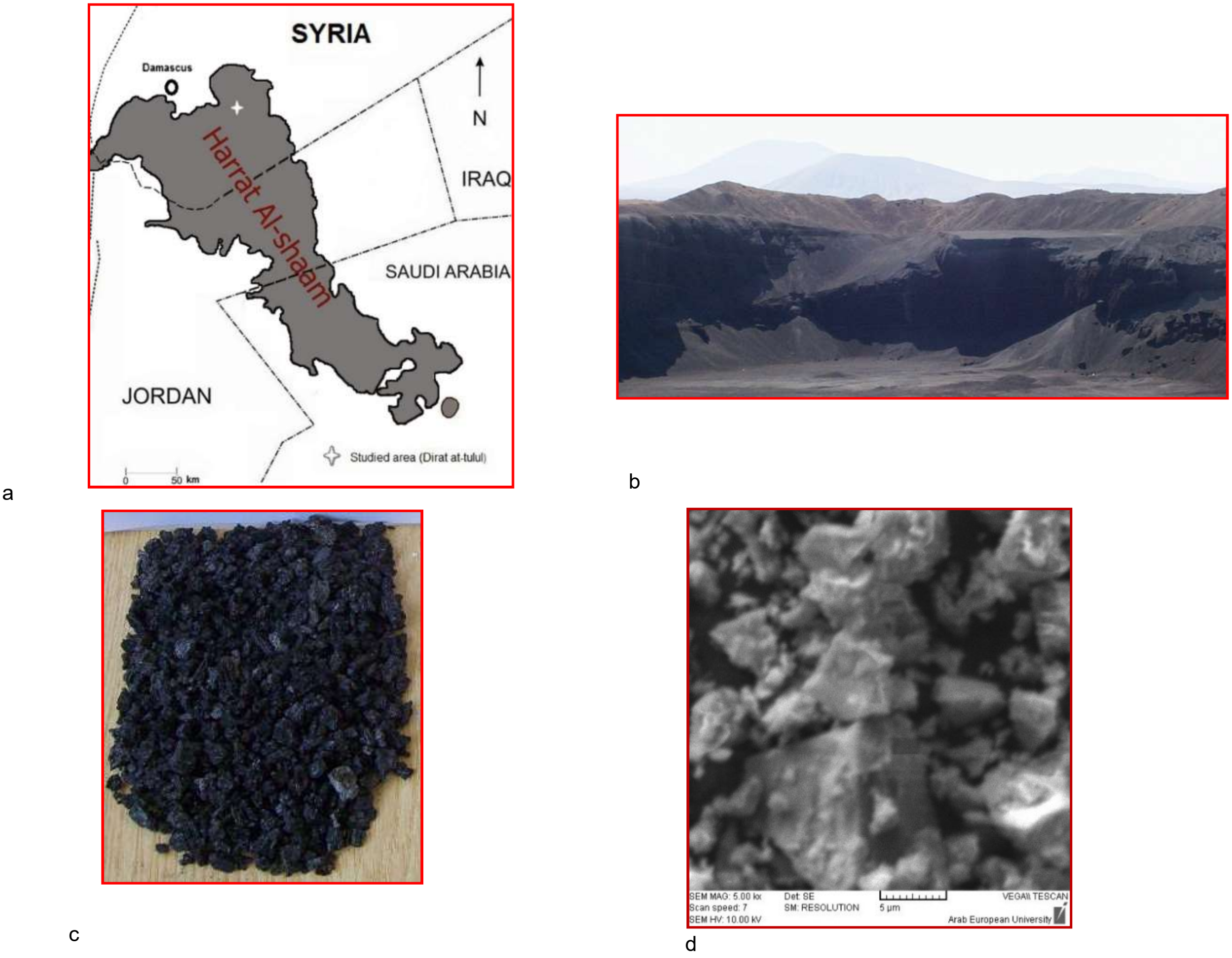


Fig. 1 - Map of Harrat al-Shaam, photo of the studied site and photo of the used scoria aggregate and the micrograph of the ground scoria. a. Map of the volcanic area “Harrat al-Shaam” and the studied site; b. The studied volcanic scoria quarry, some volcanic scoria cones are shown behind; c. the studied scoria aggregate; d. SEM micrograph of the studied ground volcanic scoria.

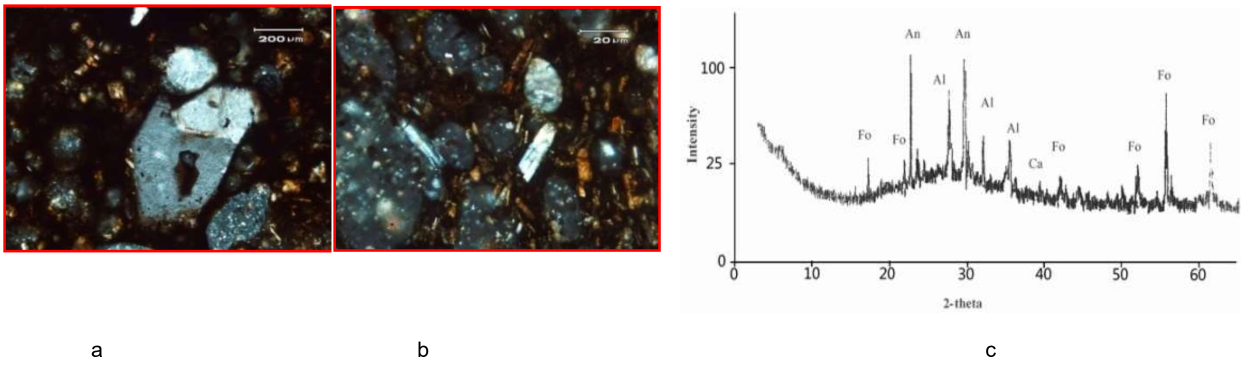


Fig. 2.- Thin sections and XRD analysis of the investigated scoria. a. Microphenocryst of Olivine in volcanic glass matrix with vesicles, some of which are filled with white minerals ; b. Microphenocrysts of elongated plagioclase in volcanic glass matrix with vesicles, some of which are filled with white minerals ; c. XRD of the scoria used (Fo : Forsterite ; Al : Albite ; An : Anortite ; Ca : Calcite).

Table 1

Chemical composition of the materials used in the concrete mixes

Chemical composition (by mass, %)	Materials				
	Scoria	Clinker	Gypsum	Dolomite aggregate	Natural sand
SiO_2	46.52	21.30	0.90	0.42	93.39
$SiO_{2(reactive)}$	42.22	-	-	-	-
Al_2O_3	13.00	4.84	0.07	0.38	0.57
Fe_2O_3	11.40	3.99	0.10	0.10	0.24
CaO	10.10	65.05	32.23	31.40	1.70
CaO_f	-	2.1	-	-	-
MgO	9.11	1.81	0.20	20.46	0.20
SO_3	0.27	0.25	45.29	0.18	1.15
Loss on ignition	2.58	-	21.15	46.48	2.52
Na_2O	2.14	0.60	-	0.06	0.06
K_2O	0.77	0.28	-	0.30	0.05
Cl^-	<0.1	0.05	-	0.021	0.017
Pozzolan activity index [ASTM C 618]	79 (at 7 days) 85 (at 28 days)				

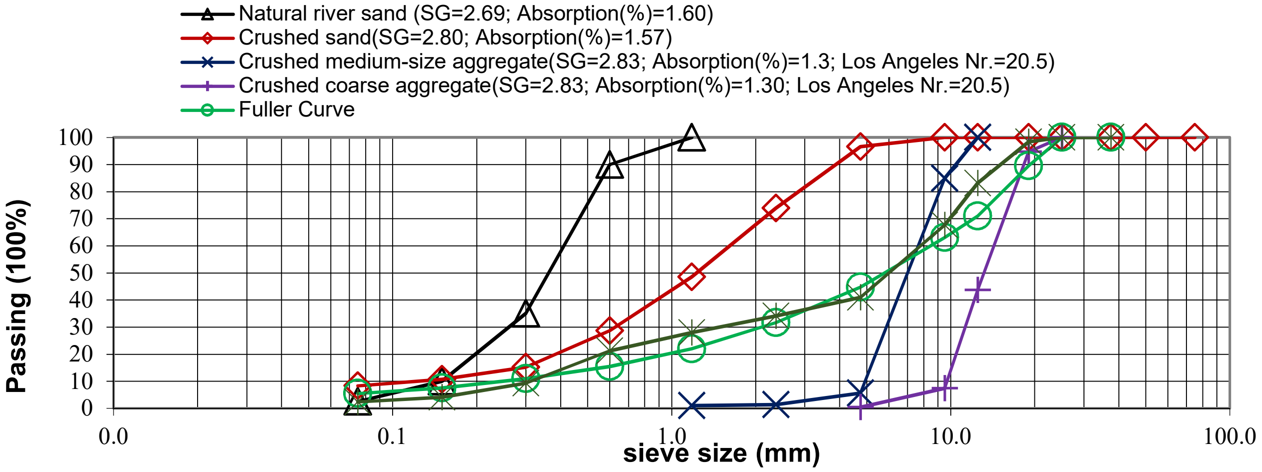
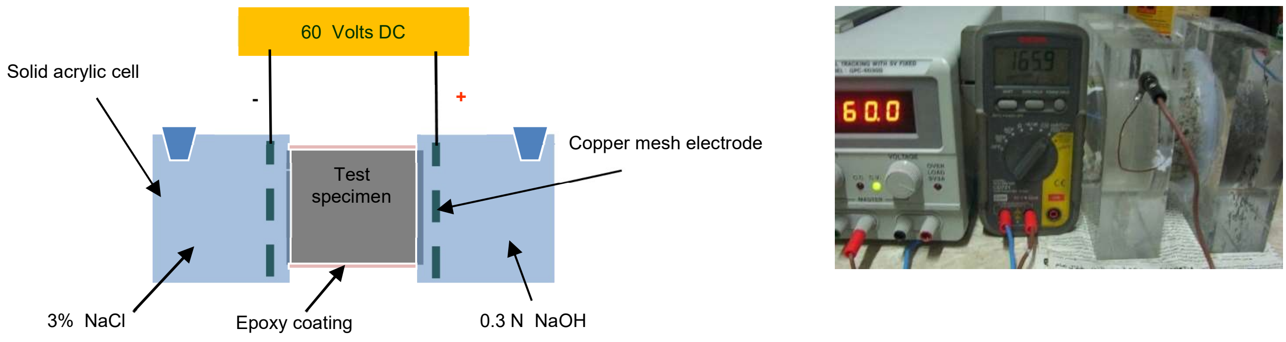


Fig. 3 - Grading curves of the concrete aggrgates with some physical properties.

The concrete mixes were designed for a workability of 150±25 mm slump. Suitable dosage of a superplasticizer was added to the concrete mixes, particularly those of w/b equal to 0.5, to obtain the required workability. Concrete cubes (150 mm) were cast for the determination of compressive strength and evaluation of the water permeability. In addition, concrete cylinders of (75 mm×150 mm) and (100 mm×200 mm) were cast for testing the concrete porosity and the penetrability of chloride ions, respectively.

2.2 Methods

The compressive strength development was determined on 150 mm cubic concrete specimens, in accordance with ISO 4012, at ages of 2, 7, 28, 90 and 180 days. Concrete permeability measured in terms of depth of water penetration was carried out as per the standard EN 12390-8. The results shown in this paper are the average penetration depth. Porosity measurements were conducted using vacuum saturation method in accordance with RILEM CPC 11.3. The average of



a

b

Fig. 4 - Experimental setup of rapid chloride penetration test. a) Schematic representation of experimental setup of rapid chloride penetration test. b) View of experimental setup (one of current readings for C6/30% specimen prepared with w/b=0.6).

three results was reported. The Rapid chloride penetrability (RCP) test was conducted in accordance with ASTM C 1202. The set-up of RCP test is illustrated in Figure 4. Three cylinder specimens of each concrete mix were tested after 2, 7, 28, 90 and 180 days curing.

3. Results and discussion

3.1. Compressive strength development

Results of compressive strength development test are plotted in Figs. 5-7. As expected, the compressive strength of the concrete increased with an increase in curing time and a decrease in volcanic scoria content for mixes with similar water-binder ratio. Plain cement concrete specimens have a high compressive strength at any age when compared to scoria-based binder concretes. This diminution of strength of scoria-based cement concretes was higher at early age and increased with the percentage of volcanic scoria. The compressive strength at 7 days decreased from 27.6 to 17.3 MPa, from 24.9 to 16.0 MPa and from 20.3 to 12.9 MPa when CEM I and CEM II/B-P with 35% of scoria were used at w/b=0.5, 0.6 and 0.7, respectively. This could be explained by i) the slowness of the pozzolanic reaction between the glassy phase in scoria and the calcium hydroxide released during cement hydration [16] and ii) the dilution effect [17]. However, due to the continuation of the pozzolanic reaction and the formation of a secondary C-S-H, a greater degree of hydration was achieved resulting in strengths after 90 days curing which were comparable to those of CEM I specimens. In addition, the effect of water-binder ratio on compressive strength has also clearly been seen from the results shown in Figs 5-7. This, which was confirmed by many researchers [13, 16], can easily be explained as the natural consequence of a progressive weakening of the matrix caused by increasing porosity with increase in the water-binder ratio [16]. Further, it was observed, from the Figs. 5-7, that the variation in compressive strength was more obvious when the w/b ratio moved from 0.6 to 0.7.

3.2 Water permeability

Water penetration depth can be considered as an indication of permeable and impermeable concrete [13]. A depth of less than 50 mm classifies the concrete as impermeable and a depth of less than 30 mm as impermeable under aggressive conditions [13]. Water penetration depth test results are presented in Table 2 for all binder types, curing age and w/b ratios. For all types of concrete mixes, the depth of water penetration increased with an increase in the w/b ratio. Further, the depth of water penetration was the least in CEM II/A-P based

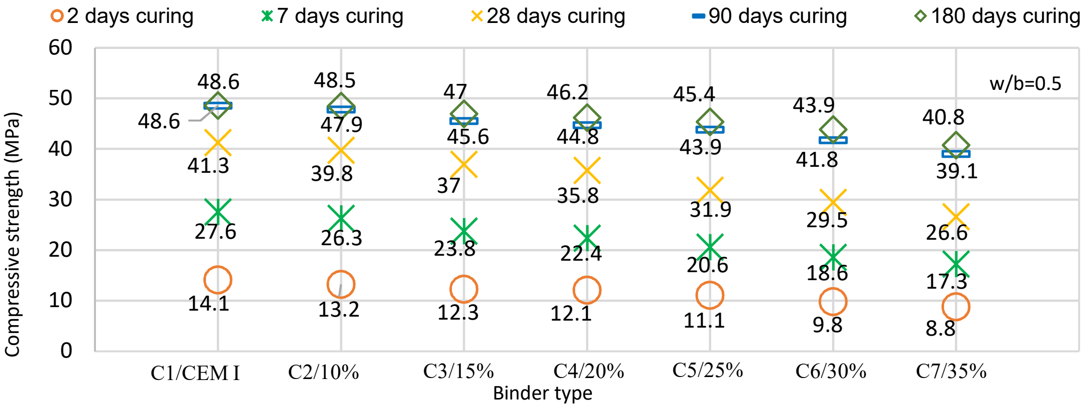


Fig. 5 - Compressive strength developments of the concretes prepared with w/b=0.5 with curing times.

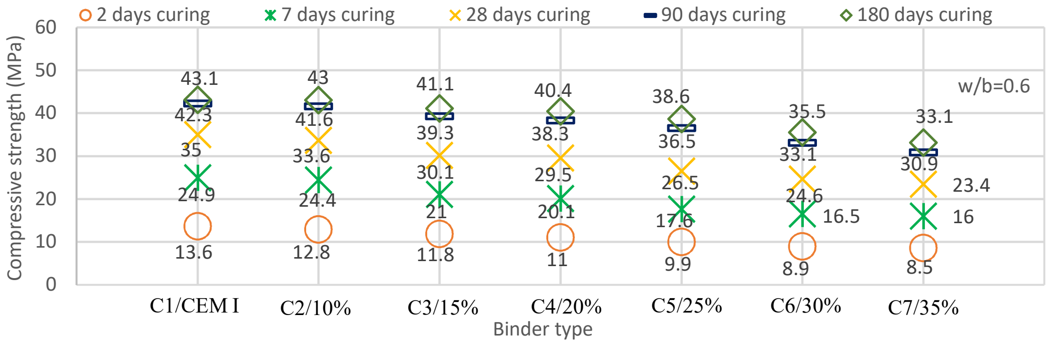


Fig. 6 - Compressive strength developments of the concretes prepared with w/b=0.6 with curing times.

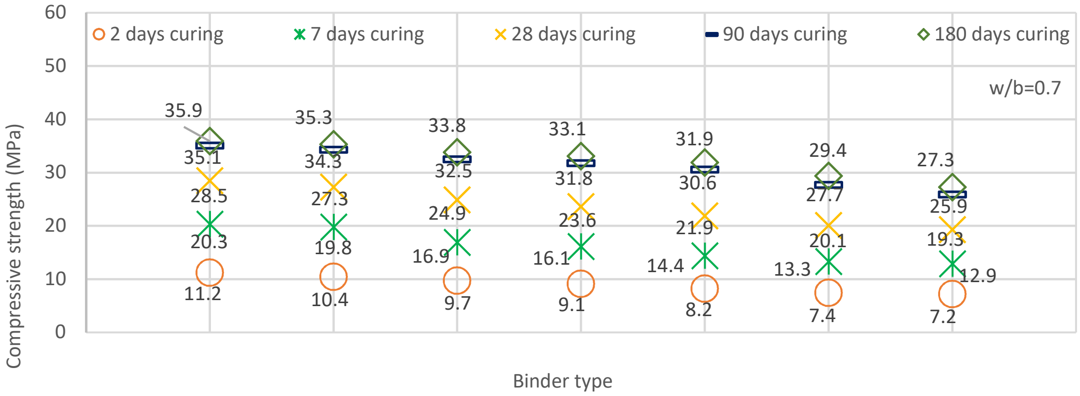


Fig. 7 - Compressive strength developments of the concretes prepared with w/b=0.7 with curing times.

Table 2

Water penetration depths, porosity and chloride penetrability of the investigated concretes

Curing time	Binder type	Water penetration depths (mm)			Porosity (%)			Chloride penetrability (Coulombs)		
		w/b=0.5	w/b=0.6	w/b=0.7	w/b=0.5	w/b=0.6	w/b=0.7	w/b=0.5	w/b=0.6	w/b=0.7
2 days	C1/CEM I	103	133	150	22.3	28.9	41.7	14000*	14000*	14000*
	C2/10%	107	139	150	21.8	29.1	43.1	14000*	14000*	14000*
	C3/15%	105	136	150	20.7	28.6	43.5	13572	14000*	14000*
	C4/20%	98	130	150	19.1	27.3	42.4	12107	14000*	14000*
	C5/25%	94	128	148	17.9	25.7	40.1	11897	13256	14000*
	C6/30%	92	132	150	17.6	25.4	40.3	11178	12987	14000*
	C7/35%	91	130	145	16.8	25.2	39.8	11267	13114	14000*
7 days	C1/CEM I	87	102	141	19.6	22.4	37.6	9845	13544	14000*
	C2/10%	83	112	144	18.4	22.6	37.9	9811	13724	14000*
	C3/15%	81	116	139	17.1	20.6	37.8	7731	11231	13876
	C4/20%	74	109	135	16.3	19.1	36.7	6114	9409	13178
	C5/25%	69	97	128	15.5	18.3	35.1	5741	8661	12789
	C6/30%	68	89	123	14.3	16.7	34.9	5128	6984	12174
	C7/35%	65	93	125	13.9	16.4	35.2	4874	6693	11987
28 days	C1/CEM I	61	97	124	16.8	18.9	32.8	6391	9245	13079
	C2/10%	57	89	121	15.4	18.9	31.3	6031	9300	12870
	C3/15%	52	91	118	14.3	17.6	29.4	5387	7859	12375
	C4/20%	47	85	109	14.1	16.5	26.5	4285	6853	11723
	C5/25%	42	76	101	11.2	14.4	23.8	3716	5014	9783
	C6/30%	40	72	96	10.1	12.3	22.3	3014	3533	8651
	C7/35%	41	56	94	10.2	12.2	22.9	2873	3441	8021
90 days	C1/CEM I	48	55	89	12.1	13.6	28.7	3419	4134	10114
	C2/10%	43	42	85	11.3	12.6	25.9	2914	3714	9261
	C3/15%	38	33	79	10.4	11	20.6	2214	2768	6784
	C4/20%	31	28	68	9.3	10.6	16.2	2013	2529	5374
	C5/25%	27	26	60	7.3	8.3	14.9	1167	1454	4378
	C6/30%	24	25	55	6.4	7.5	14.9	969	1186	4017
	C7/35%	25	23	53	6.5	7.6	13.9	938	1175	4189
180 days	C1/CEM I	37	46	85	10.9	11.7	26.4	3039	3790	9140
	C2/10%	29	35	77	10.1	10.9	22.7	2691	3411	8641
	C3/15%	24	27	67	9	10.1	16.9	1904	2389	5678
	C4/20%	18	22	55	7.9	9.4	12.9	1661	2214	4133
	C5/25%	13	19	45	5.9	7.3	12.3	908	1169	3145
	C6/30%	11	17	40	5.4	6.8	11.1	812	954	2976
	C7/35%	11	18	42	5.3	6.9	11.3	843	965	3074

*The test for these specimens was terminated because of the high temperature of the cell's solution and the highly penetrable concretes

concretes and the highest in the CEM I-based concrete. The water permeability changed from “low” to “high” due to an increase in the w/b ratio from 0.5 to 0.7. For a given w/b ratio, concretes containing scoria-based binders are supposed to have lower permeability than plain Portland cement. But in this research, it has been observed that after 7 days curing, water penetration depths of CEM II/A-P-based concrete with scoria content up to 15% were higher than that of CEM I-based concrete. Increasing the moist-curing period of concrete from 28 to 90 days reduced water penetration depths of all concretes prepared with w/b=0.6 by a factor ranging from 2.11 to 3.03 for concretes containing scoria-based cements and a lower factor of 1.74 for plain Portland cement concrete. This result is in good agreement with the findings in the literature [13].

None of concretes of $w/b \geq 0.6$ was found to be impermeable after 28 days curing. However, all concretes containing CEM II/A-P can be considered as impermeable after 28 & 90 days curing at w/b=0.5 and w/b = 0.6, respectively. Further, concretes containing binders with scoria content ranging from 20 to 35% and prepared with $w/b \leq 0.6$ can be considered -after 90 days curing- as impermeable even under aggressive conditions, according to Neville [13]. However, the concretes containing 15% & 20% volcanic scoria needed 180 days curing to achieve this kind of impermeability. It is also to be noted that the water penetration depth values in concretes containing volcanic scoria-based binders -after 90 days curing- did not significantly vary when w/b changed from 0.5 to 0.6.

3.3. Porosity

Porosity of concretes containing different levels of volcanic scoria at various curing times is presented in Table 2. Porosity of all mixes decreased with curing time and with a decrease in w/b ratio. As volcanic scoria is incorporated porosity decreased significantly. Porosity of the concretes containing CEM II/P demonstrated much lower porosity as compared to the plain concrete. The rate of decrease in porosity was faster for volcanic scoria-containing concretes as compared to the plain concrete. The reduction in the porosity could be attributed to the pozzolanic reaction between the glassy phase in volcanic scoria and the CH liberated from hydration of C_3S & C_2S [9]. Further, it should be noted that the porosity values in concretes containing scoria-based binders at w/b=0.6 were similar to that of concretes prepared with w/b=0.5. This is in well agreement to the results of water penetration depth.

3.4. Rapid chloride penetrability

From the Rapid chloride penetrability data presented in Table 2, it should be noted that the CEM I-based concrete permitted almost 2 or 3 times the coulombs charge, compared to the concrete containing CEM II/B in spite of the fact that all concretes were made with similar cementitious content and water content. It should also be noted that the rapid chloride penetrability increased with an increase in the w/b ratio in all concrete mixes. Similarly, there was a reduction in the chloride penetrability with an increase in the replacement level of volcanic scoria in the concrete mixes with all the w/b ratios. For the same w/b ratio, the chloride penetrability of CEM I-based concrete was more than that of volcanic scoria-based binder concretes

None of concretes has a total charge passed less than 2000 coulombs after 2, 7 or 28 days curing. This expected result may be due to the high w/b ratios. However, the concrete samples containing CEM II/B-P with scoria contents of 25, 30 and 35%, showed the best performance. According to ASTM C1202, these concretes can be considered- at $w/b \leq 0.6$ - as low and very low chloride permeable after 90 and 180 days curing, respectively. The improvement in resistance to chloride penetration may be related to the refined pore structure of these concretes and their reduced electrical conductivity [18]. This which was confirmed by many researches [19-21], is due to the secondary pozzolanic reaction which contributes to make the microstructure of concrete denser. Further, the significant reduction in the chloride penetrability in volcanic scoria-based binder concretes was observed more clearly in concrete samples of $w/b \leq 0.6$.

It is worth mentioning that the addition of volcanic scoria decreases the permeability of concrete even though the compressive strength of volcanic scoria-based binder concrete is less than that of CEM I-based concrete. Such a behavior has also been reported earlier by al-Swaidani & Aliyan [22].

3.5. Estimation equation

The experimental data, depicted in Fig. 5-7 and presented in Table 2 has been statistically analyzed to develop an equation to predict the investigated properties of concrete based on three variables; the curing time, the replacement level of volcanic scoria and the w/b ratio..

The equation can be expressed by the following expanded single formula:

$$Pc = a_1 + a_2 \times (w/b) + a_3 \times VS + a_4 \times \ln t + a_5 \times (w/b) \times VS + a_6 \times (w/b) \times \ln t + a_7 \times VS \times \ln t + a_8 \times (w/b) \times VS \times \ln t \quad (1)$$

Where Pc is the concrete property (i.e., compressive strength, water permeability, porosity and chloride penetrability); t is the curing time; w/b is the water-binder ratio; VS is the volcanic scoria content (%); a_1, a_2, a_3 …a_8 are constants.

The constants have been obtained through the multiple regression analysis of the data in Figs. 5-7 & Table 2. The best-fit values of constants a_1, a_2, a_3 … a_8 and the regression coefficients “R^2” of the correlation between the measured and the

Table 3

Constants a_1, a_2, a_3 … a_8 and regression coefficients (R^2) of the correlation between the measured and calculated values according to the proposed equation.

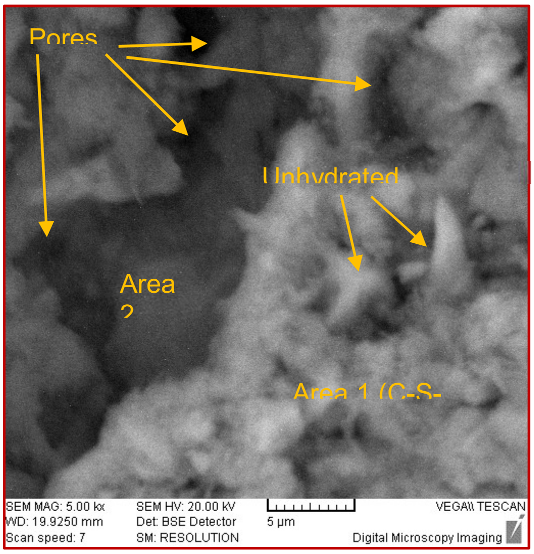
Property of concrete	Constants								Regression coefficient (R^2)
	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	
Compressive strength (MPa)	21.4	-17.9	-53.9	15.2	55	-11.2	1.2	-7.6	0.983
Water penetration depth (mm)	8.3	245	-225	-24.5	289	9.1	70.9	-136.7	0.966
Porosity (%)	-33.9	116.2	-52.1	2.4	59.6	-10.2	18.5	-35.3	0.944
Chloride penetrability (Coulumbs)	17315	-155	-64420	-6849	88970	7725	18223	-31930	0.936

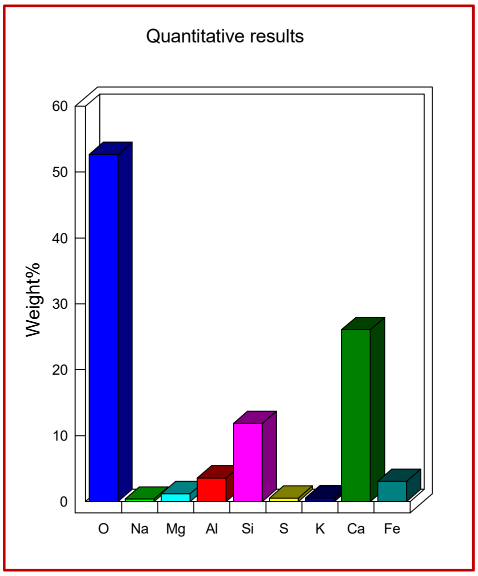
proposed values are presented in Table 3. The results indicate excellent relationships between the test results and the predicted values. According to Montgomery and Peck [23] a regression coefficient, R^2, of more than 0.85 indicates an excellent correlation between the fitted parameters.

It is to be noted that the equation developed in the present work would be helpful for concrete mix designers. However, it should be noted that the equation is applicable only to concrete mixes containing similar natural pozzolan, limestone aggregates and binder content and cured at ambient temperature. Further tests are needed in order to cover a broader range of concrete containing other types of pozzolana, aggregates and curing conditions.

From the results obtained, volcanic scoria showed significant improvement which clearly indicates that the volcanic scoria is efficient in the refinement of pore size distribution. This has been reflected in the reduction of water permeability, porosity and chloride penetrability.

The results have been confirmed using the SEM/EDX techniques, as shown in Fig. 8-10. The microstructural and EDX analysis of 7 days cured C6/30% paste, Fig. 8, reveals a non-compacted structure. On the other hand, after 28 & 90 days curing (Figs. 9 &10) the microstructural analysis of C6/30% paste shows denser and more compacted structure due to the progress of the cement hydration. In addition, the EDX analysis result clearly indicates the formation of cementitious phases, such as calcium silicate hydrate (C-S-H) and calcium alumino-silicate-hydrates (C-A-S-H). These might be formed through the continuation of cement hydration and the progress of the pozzolanic reaction between the amorphous phases in volcanic scoria and CH (calcium hydroxide) released during cement hydration [24].





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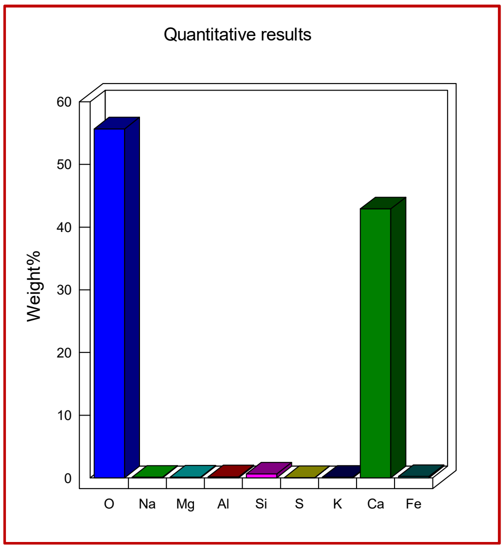

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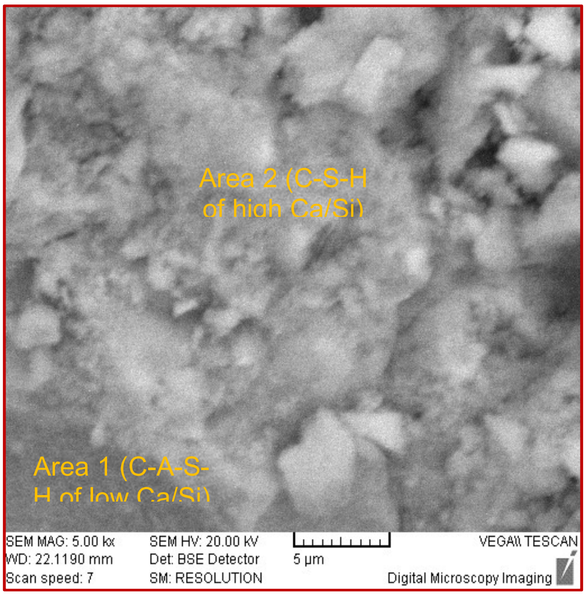
Fig. 8 - SEM/EDX analysis of 7 days cured C6/30%-based paste prepared with w/b=0.5.



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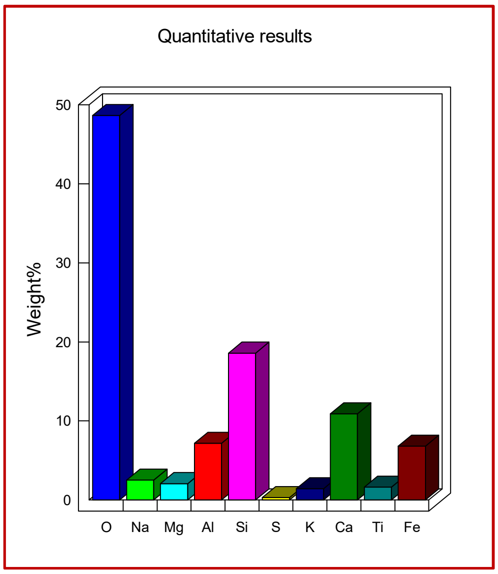

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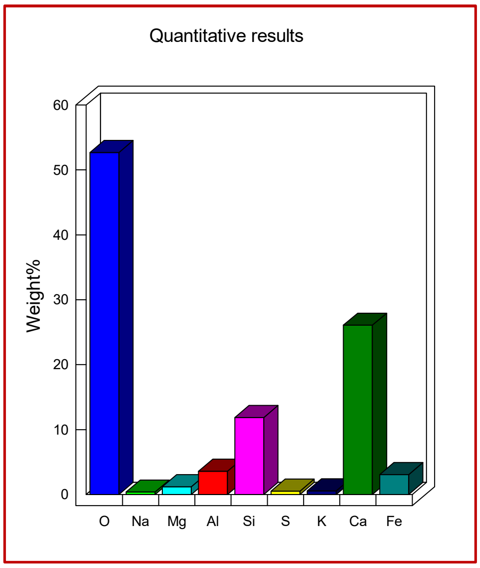
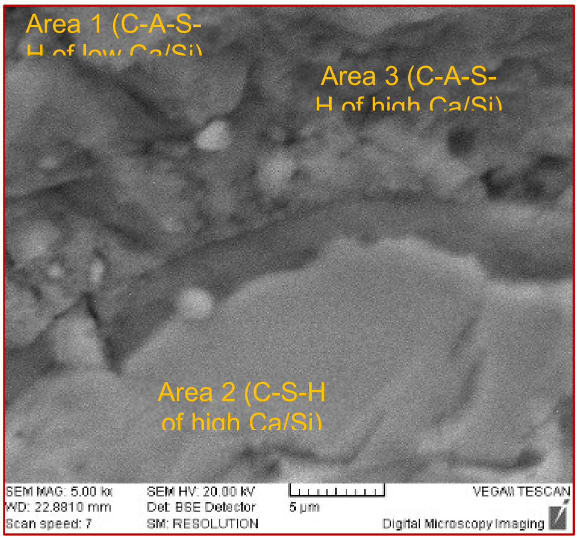


Fig. 9 - SEM/EDX analysis of 28 days cured C6/30%-based paste prepared with w/b=0.5.



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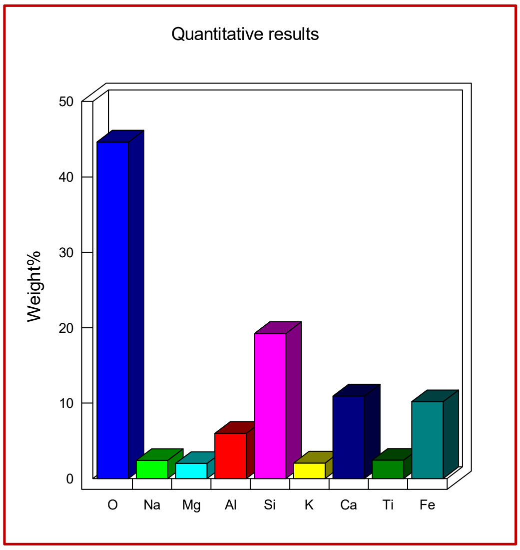

Fig. 10 continues on next page

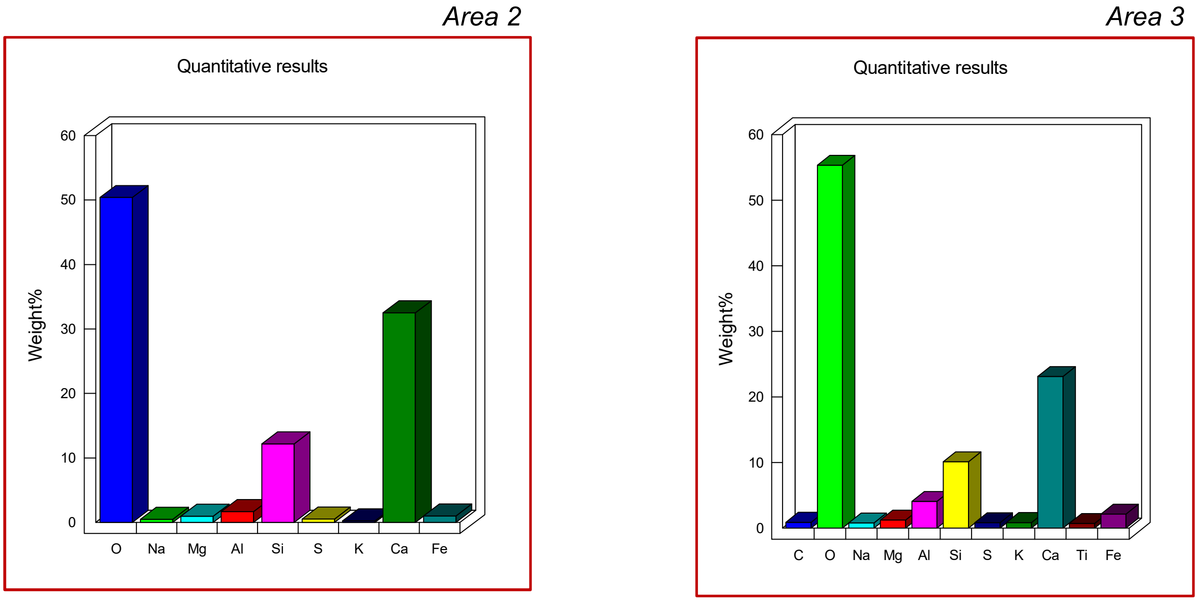

Fig. 10 - SEM/EDX analysis of 90 days cured C6/30%-based paste prepared with w/b=0.5.

4. Conclusion

From the experimental results, the following conclusions could be drawn:

-The compressive strengths of concrete containing scoria-based binders were much lower than that of plain cement concrete at all early ages of concrete. However, after 90 days curing, the compressive strengths of scoria-based binder concretes were comparable to those of plain cement concrete.

-Water permeability, porosity and chloride penetrability of scoria-based concrete mixes is much lower than that of plain concrete, especially at longer curing time and high replacement levels of scoria. This has also been confirmed by SEM/EDX analysis.

-Curing has a large influence on both compressive strengths and permeability-related properties of scoria-based binder concrete. However, the consequences of bad curing can be more serious for the latter.

-The authors derived an estimation equation for the investigated properties incorporating the effect of curing time, the replacement level of volcanic scoria and the w/b ratio. The correlation coefficient R^2 values indicate that the estimation equation is significant and the predicted results were found to be close to the experimental results. Development of such an estimation equation can be of considerable benefit to either the concrete mix designer or the concrete structure to be built.

-Based on the test results, it is suggested that volcanic scoria can be used as a partial substitute for Portland cement in production of blended cements. Depending on the replacement level, it can reduce the quantity of CO_2 released by Syrian cement plants and the consumed energy, annually. So, production of a green concrete could be promoted.

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MANIFESTĂRI ȘTIINȚIFICE / SCIENTIFIC EVENTS

11th HPC (High Performance Concrete) & 2nd CIC (Concrete Innovation Conference), Tromsø, Norway - From 06 March 2017 to 08 March 2017

The 11th HPC will actually be the 30th Anniversary since the 1st HSC conference (forerunner of HPC) was held in Stavanger, Norway. The term HPC includes more than strength and denotes concrete that perform exceptionally well ranging from rheology in fresh state to durability both as material and in construction processes/structures. Esthetics and architectural expression is also part of this.

The 2nd CIC follows the success of the 1st CIC held in Oslo, Norway, in June 2014. The future needs expressed by the industry, the society, such as energy saving, reduced CO_2-emission, and resources use, efficient construction and higher performance to lower cost, are innovation drivers. The 2nd CIC themes will be based on this. To underline the importance of innovation, a contest will be organized to highlight the best innovation in several categories.

The two conferences will be overlapping with 11th HPC running 6-7 March and 2nd CIC running 7-8 March 2017. Delegates can participate at individual conferences or both.

Contact: https://www.tekna.no/en/events/hpccic-tromso-2017-32076/

JCI-RILEM International Workshop on Control of Cracking of Mass Concrete and Related Issues Concerning Early Age Cracking of Concrete Structures (CONCRACK5), Tokyo, Japan From 24 April 2017 to 26 April 2017

JCI-RILEM international workshop “ConCrack5”, which will be held in April 2017 in Tokyo, is planned as a succeeding workshop to ConCrack3 and is composed of two keynote lectures from Japan and Europe, the introductions of “Guidelines for Control of Cracking of Mass Concrete 2017”, the results of research projects performed by IFSTTAR, the activities of CEOS.fr, COST TU 1404 project and mass concrete committee of RILEM, and the presentations of the papers including the latest research results on early age behaviors of concrete. Prevention and protection procedures of DEF, which has not become obvious in Japan, will be incorporated in “Guidelines for Control of Cracking of Mass Concrete 2017” as well as design values of physical properties of early age concrete and simple equations for thermal cracking index will be enhanced. ConCrack5 will be a helpful international workshop for the researchers and the engineers in mass concrete construction field through concentrated discussions, information exchanges and mutual understandings among the participants.

Contact:http:// *www.jci-net.or.jp/~**concrack5**/*