JSACE 4/13

Received 2015/09/09

Accepted after revision 2015/11/02

Production of More Sustainable Mortar Using Finer Volcanic Scoria-based Blended Cements

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http://dx.doi.org/10.5755/j01.sace.13.4.13245

Use of natural pozzolan is growing rapidly in the construction industry due to its economical, ecological and technical benefits. However, they are often associated with shortcomings such as the need to moist-curing for longer time and a reduction of strength at early ages. Syria is relatively rich in volcanic scoria. The objective of the study is to investigate the effect of Blain fineness of cement on the strength development of scoria-based cement mortars. In the study, mortar specimens have been produced with four types of cement: one plain Portland cement (control) and three scoria-based blended cements with three replacement levels: 25, 30% and 35%, respectively. All blended cement types have been interground into four different Blaine fineness: 2400, 3200, 4200 and 5100 cm^2/g. The development of the compressive and flexural tensile strength of all mortar specimens with curing time has been investigated. The effects of the Blaine fineness of the scoria-based blended cement on the compressive and flexural strengths of mortar have been evaluated at curing ages of 2, 7, 28 and 90 days, respectively. Test results revealed that there is a decrease in strength with increasing amounts of scoria. In addition, there was found an increase in strength with increasing the Blaine fineness values. Good correlations between mechanical strengths and Blaine fineness have also been observed at different curing times. Further, based on the results obtained, an empirical equation was derived to predict the mechanical strengths of scoria-based cement mortars with curing times based on Blaine fineness. Effects of Blaine fineness on some physical properties of blended cements have been reported, as well.

KEYWORDS: mechanical strength, Blaine fineness; blended cement; natural pozzolan; volcanic scoria.

Introduction

Use of pozzolans as substitute for Portland cement is one of the most effective approaches in order to make the concrete industry more sustainable; each 1kg of substitution reduces by about 1 kg the emission of CO_2, and saves the energy required to produce 1 kg of cement. In addition, this use will lead to conservation of finite natural resources. Further, pozzolans could be used to make stronger and more durable concretes (Aitcin & Mindess, 2011).

Natural pozzolan is one of the oldest construction materials. The Roman Empire is the most synonymous with the use of pozzolans, the name deriving from volcanic rock found near Naples. (Walker & Pavia 2011). It is being widely used as cement replacement due to its ecological, economical and performance-related advantageous properties (Kouloumbi et al. 1995; Khan & Alhozaimy 2010;

Journal of Sustainable Architecture and Civil Engineering
Vol. 4 / No. 13 / 2015
pp. 49-61
DOI 10.5755/j01.sace.13.4.13245

Moufti et al. 2000; Al-Chaar et al. 2013; Senhadji et al. 2012). However, use of natural pozzolan causes longer setting times and lower early strengths compared with plain Portland cement (Shi 2001).

Strength of concrete is commonly considered its most valuable property. It is well-known that an increase in specific surface area of cement causes an increase in mechanical properties of mortars and concretes, especially at early ages. Since hydration starts at the surface of the cement particles, it is the total surface area of cement that represents the material available for early hydration. Thus the rate of hydration depends on the fineness of cement particles (Neville 2011).

To overcome the disadvantages of low early strengths of cements containing natural pozzolans, the prolonged grinding of blended cement could be therefore a solution. Day and Shi (1994), by studying the effect of grinding on the strength development of natural pozzolan from Central America, concluded that a good linear relationship existed. They showed that an increase of 1.5 MPa can be expected for every 1000 cm^2/g increase in fineness. Their study included Blaine fineness in the range of 2500 to 5500 cm^2/g. On the contrary, Rossi and Farchielli (1976) in an earlier study did not find any proportionality between the surface area of pozzolans and reactivity with lime for a given material.

Syria has important volcanic areas. More than 30 000 km^2 of the country is covered by Tertiary and Quaternary-age volcanic rocks (GEGMR, 2011), among which scoria occupies important volume with estimated reserves of about three-quarters billion tonnes (GEGMR 2007). 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 tonnes of these pozzolans are only exploited annually (the annual production of Portland cement in Syria is about 6 million tonnes) (GOCBM, 2012).

This study is part of the first detailed research in Syria to investigate the potential utilization of scoria as cement replacement in producing Portland-pozzolan cements. In the study, in order to better understand the influence of Blaine fineness on mechanical strength of scoria-based cement mortars, compressive and flexural strengths experimentally have been investigated using four Blaine fineness values of 2400, 3200, 4200 and 5100 cm^2/g, respectively. Furthermore, relationships between Blaine fineness and the development of mechanical strength of scoria-based cement mortars with different curing times have been analyzed in this paper. Some physical properties of the studied blended cements have also been reported.

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 coves parts from Jordan and Saudi Arabia.

The basic premise of the study is that producing finer blended cements containing high levels of scoria may overcome the low early strength of such cement. Further, such application would be of a great importance to both economy and ecology. An equation to estimate the mechanical strength of such kind of blended cement depending on the Blaine fineness value and the scoria content has also been derived.

Materials and Methods

Scoria

The volcanic scoria used in the experiments was quarried from Dirat-at-Tulul site, at about 70 km southeast of Damascus as shown in (Fig.1). The mineralogical analysis showed the scoria is mainly composed of amorphous glassy ground mass, vesicles, plagioclase and olivine with the following percentages (based on an optical estimate): 20%, 35%, 20% and 25%, respectively. Thin sections of the investigated scoria are shown in (Fig. 2). The chemical analysis of scoria used in the study is summarized in (Table 1).

Cement samples

Four cement samples have been prepared; one plain Portland cement CEM I (control) and three CEM II/B-P samples with three replacement levels of 25, 30 and 35% (EN 197-1). 5% of gypsum was added to all these binder samples. These replacement levels of scoria have been adopted because they improved durability-related properties of concrete significantly (al-Swaidani & Aliyan, 2015). The clinker was obtained from Adra Cement Plant, Damascus, Syria. All samples were interground by a laboratory grinding ball mill of 25 kg raw mix capacity into four Blaine fineness values: 2400, 3200, 4200 and 5100 cm^2/g. The intergrinding process has been adopted because it requires less energy than separate grinding, especially for the production of high fineness products (Binici et al. 2007). The Blaine fineness was measured using air permeability method in accordance with the European standard (EN 196-6). The principle is to measure the resistance to air flow through a compact bed of cement powder. The chemical and physical properties of the cement samples produced for this study are shown in (Table 1) and (Table 2), respectively. CEM I (the control sample) was designated as C1, whereas scoria-based cements were designated according to the replacement level. For instance, C2/25% and C4/35% refer to the blended cements containing 25% and 35% of scoria, respectively.

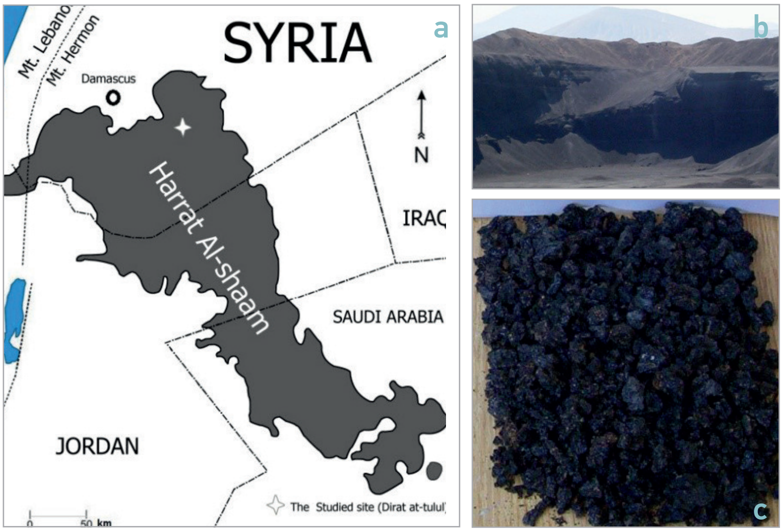


Fig. 1

Map of Harrat Al-Shaam, photos of the studied site and the used scoria aggregate:

a. Map of the volcanic area "Harrat Al-Shaam" and the studied site

b. The studied scoria quarry, some volcanic scoria cones are shown behind.

c. The studied scoria aggregate

Cement mortars

The mortar specimens of all cements used in the experiments were prepared using these cements and sand meeting the requirements of ASTM C778. The sand used is standard Ottawa sand; bulk density=1.6 g/cm^3, Fineness modulus=2.1. In all mixtures, binder: sand ratio was kept constant as 1:2.75 by weight. Mixture containing CEM I was prepared with a w/b ratio of 0.485. Mixtures containing scoria-based binder were prepared by changing the w/b ratio in order to obtain a flow within±5 of that of the CEM I mortar. After being kept in a wet cabinet for 24 hours, the mortar specimens were demolded and kept in water at 20±2 °C until the time of testing.

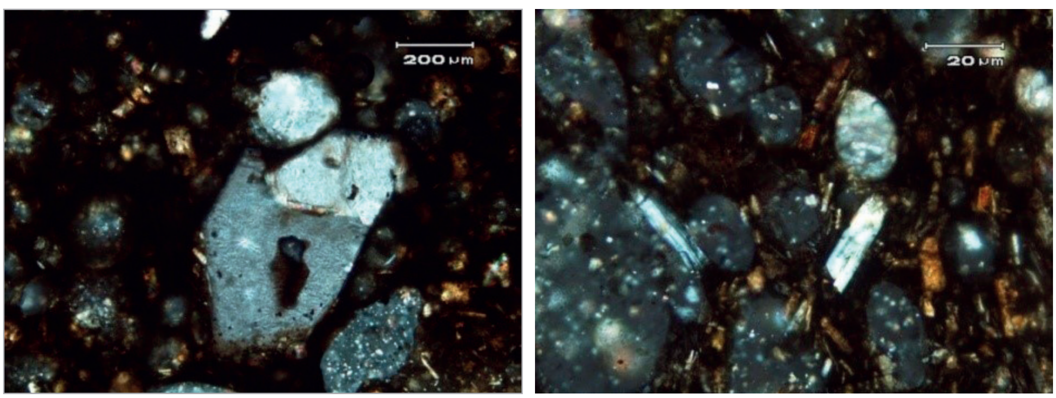


Fig. 2

Thin sections of the 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

Table 1
Chemical composition of volcanic scoria and cement types of 3200 cm^2/g Blaine fineness

Chemical composition (By mass, %)	Cementitious Materials				
	Scoria*	C1/CEM I	C2/25%	C3/30%	C4/35%
SiO_2	46.52	20.69	24.00	24.33	24.61
Al_2O_3	13.00	5.09	6.55	6.80	7.39
Fe_2O_3	11.40	4.23	5.43	5.47	6.31
CaO	10.10	60.62	50.30	48.00	44.84
MgO	9.11	2.46	3.87	4.11	4.63
SO_3	0.27	2.26	2.30	2.26	2.55
Loss on ignition	2.58	1.41	1.47	1.48	1.60
Na_2O	2.14	0.60	1.07	1.16	1.31
K_2O	0.77	0.35	0.50	0.53	0.57
Cl^-	<0.1	0.023	0.018	0.019	0.019
Insoluble Residue	3.22	1.03	3.48	4.08	5.33
Pozzolan activity index [ASTM C 618]	79 (at 7 days) 85 (at 28 days)				

* $SiO_{2(reactive)}$ = 42.22% (determined in accordance with EN 196-2).

Physical and Mechanical properties

Water requirements, setting times and volume expansion of all cement paste specimens have been determined in accordance with EN 196-3. Six halved-specimens obtained from the three mortar specimens used in the flexural strength tests, were tested for the determination of compressive strength of mortars under the same laboratory conditions as those applied in the flexural strength test. The compressive and flexural strength development was determined on 40×40×160 mm prismatic specimens, in accordance with EN 196-1, at ages of 2, 7, 28 and 90 days, respectively. The values reported in the results represent the average of six readings for compressive strength test and the average of three readings for all other tests.

Results and Discussion

Properteis of scoria and blended cements

As seen from Table 1, scoria is considered as suitable material for use as pozzolan. It satisfied the standards requirements for such a material by having a combined SiO_2, Al_2O_3 and Fe_2O_3 of more than 70%, a SO_3 content of less than 4% and a loss on ignition of less than 10% (ASTM C618). $SiO_{2reactive}$ content is more than 25%, as well (EN 197-1). In addition, it has a strength activity index with PC higher than the values specified in ASTM C618. The chemical properties of scoria-based blended cements are also in conformity with the standards requirements (ASTM C595). Their contents of MgO and SO_3 are less than 6 and 4%, respectively. The loss on ignition is also less than 5% as specified in ASTM C595.

Physical propreties of cements used

Water requirements

The results of water requirements are presented in (Table 2). Finer scoria-based blended cements have a greater water demand. The smaller the material particle size is the more water the material may absorb (due to the large surface area) (Jaya et al., 2011). This agrees with the well-known fact of finer particles requiring a greater amount of water to produce a given workability (Walker & Pavia, 2011). However, as it can been seen from (Table 2), there is no significant change in the water content even for the blended cement containing 35% of scoria content which increased only by less than 5% when compared to C1/CEM I, for the same Blaine fineness value. This could be explained by the lubricant effect of scoria on paste when finely divided (Yetgin & Cavdar, 2006).

Setting times

Knowledge of the setting characteristics of cement paste is rather important in the field of concrete construction. The setting behavior of a cement paste plays an important role in determining the time available for placement, consolidation, finishing, and form removal.

Table 2 illustrates the setting times of the control mortar and mortars containing scoria-based blended cements for all Blaine fineness values. The results showed that the setting times increased with the increase of scoria replacement level for Blaine fineness values of 2400 and 3200 cm^2/g. The effect is more pronounced when the scoria content is used at 35% as cement replacement. For example, the highest retardation of the initial & final setting times at this percentage were 177 min and 211 min for 2400 cm^2/g and 158 min and 188 min for 3200 cm^2/g, respectively. This could be due to the pozzolanic reaction between pozzolan and CH liberated during hydration of C_3S and C_2S of clinker, which is usually slower than the hydration of cement (Adesanya & Raheem 2009). Some researchers related the delay in setting times when using natural pozzolan with the increase of water requirements (Colak 2003).

On the contrary, scoria-based blended cements with 4200 and 5100 Cm^2/g Blaine fineness values showed a quit different trend. The setting times decreased with increasing the scoria replacement level. This behavior is difficult to explain by authors, but according to some authors this may be attributed to a set of reasons as follows: a) the increasing surface area of scoria content of the paste results in greater interparticle contact, thus speeds up setting (Targan et al. 1995), b) the hydration reaction of pozzolan blended cement is diffusion-controlled (Plowman & Cabrera, 1984). Blaine fineness values of 4200 and 5100 cm^2/g with scoria content of 25% up to 35% might had accelerated diffusion of water and dissolution of C_3A, and increased the transition of Ca^{2+} ion into soluble state in water, thus the crystallization rate of CSH_s increased and the setting time was shortened (Sidheswaran & Bhat, 1997). Furthermore, a similar trend has been reported by other researchers

Blaine Fineness (cm^2/g)	Cement type	Initial setting (min)	Final setting (min)	Water demand (%)	Soundness (mm)	Residue on 45 µm sieve (%)	Residue on 90 µm sieve (%)
2400	C1/CEM I	166	199	24.2	1	15.3	7.6
	C2/25%	171	198	24.8	0.8	18.2	7.9
	C3/30%	170	202	24.8	1	18.3	8.3
	C4/35%	177	211	25.1	0.9	19.7	8.1
3200	C1/CEM I	151	178	25.1	0.6	13.6	6.4
	C2/25%	152	179	25.4	0.9	16.1	6.7
	C3/30%	153	181	25.4	1.1	17.0	6.9
	C4/35%	158	188	25.5	0.9	17.9	6.8
4200	C1/CEM I	133	172	26.2	0.5	9.10	5.0
	C2/25%	126	165	26.7	0.31	9.90	5.50
	C3/30%	124	166	27.0	0.26	10.3	5.70
	C4/35%	127	162	27.5	0.29	10.5	5.80
5100	C1/CEM I	114	163	27.1	0.35	7.00	2.10
	C2/25%	106	152	27.2	0.19	7.20	2.40
	C3/30%	105	147	27.7	0.18	7.30	2.50
	C4/35%	116	147	27.9	0.15	7.5	2.60

Table 2
Physical properties of cements used in the experiments

for Blaine fineness value of 4200 cm^2/g and relatively high cement replacement levels (Ghrici et al. 2006). The natural pozzolan used in their experiments was of a chemical composition similar to that of the investigated volcanic scoria.

It is also clearly seen from the results obtained that for the same replacement level, the initial setting times were reduced with the gradual increase in Blaine fineness values. For instance, C30 with 2400 cm^2/g Blaine fineness had the initial setting time of 176 min and with 5100 cm^2/g Blaine fineness it had shorter initial setting time which was only 105 min. This seems to be in a well agreement with the literature (Uzal & Turanli, 2003; Hago et al., 2002). Further, the longer initial setting time at lower Blaine fineness values may be due to the relatively coarser clinker particles in the interground blended cements (Tsivilis et al., 1992).

It is worthwhile to mention that from the results obtained, all the scoria-based binders are seen to comply with the standard requirements (initial setting time ≥45 min and final setting time≤420 min, according to (ASTM C595) for all Blaine fineness values.

A plot of the initial setting time against the final setting time for the whole tested samples as shown in (**Fig. 3**) indicates that there is a strong correlation between the parameters as the coefficient of correlation (R^2) was calculated to be 0.94. A strong relationship exists between two variables when $R^2 \geq 0.85$ (Montogomery 1982). Thus, an estimate of the final setting time can be predicted from the Eq. (1) when the initial setting time has been obtained.

$$FST = 0.79\ IST + 64.5 \quad (R^2 = 0.94) \qquad (1)$$

where:

FST=final setting time (min); *IST*=initial setting time (min).

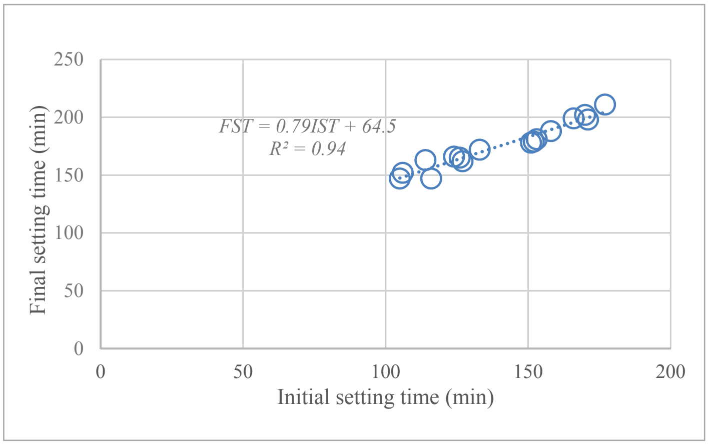


Fig. 3
Correlation between initial and final setting times of the investigated pastes

Volume expansion

CaO and MgO compounds that exist freely in cement may create a swelling effect and therefore their presence should be limited. Since the free lime ratio will decrease as the natural pozzolan addition ratio increase, a decrease in the soundness can be expected. Results of the experiments conducted to see these effects are presented in (**Table 2**).

According to the experimental results, soundness decreases as the scoria content increase. The volume expansions of samples having higher amounts of scoria show a noticeable drop compared to the control, particularly with 4200 and 5100 cm^2/g Blaine fineness, which shows that finer scoria-based cement can make an important contribution to concrete durability. Interpretation of these results needs further investigation, although all soundness results were much less than 10 mm as specified in EN 197-1.

Mechanical strengths of mortars

Compressive strength

The compressive strength results of all mortar mixes containing varying amounts of scoria are arranged in (**Table 3**). As expected, all mortars, with and without scoria show an increase in strength with curing time. Mortar specimens containing CEM I have higher compressive strengths at any age when compared to scoria-based cement mortars. Also, it is seen that as the scoria replacement level increases as the compressive strength of scoria-based cement mortars decreases for all curing times. For instance, the compressive strength of cement mortars with 3200 cm^2/g Blaine fineness at 7 days decreased from 30.57 to 19.99 MPa when CEM I and C4/35% were used, respectively. This could be explained by the slowness of the pozzolanic reaction between the glassy phase in scoria and the CH released during cement hydration. However, due to the continuation of this reaction and the formation of a secondary C-S-H, a greater degree of hydration is achieved resulting in strengths after 90 days curing which are comparable to those of CEM I specimens (al-Swaidani & Aliyan, 2015). It should also be noted that the reductions in strengths of blended cement mortars were considerable at 2, 7 and 28 days; however, the difference narrowed by the age 90 days due to progress of the pozzolanic reaction with age in blended cements. For instance, the compressive strength of C2/25% with 3200 cm^2/g Blaine fineness was found to be

Table 3

Compressive strengths development of all cement mortars with curing times

Cement type	Blaine Fineness (cm^2/g)	Compressive strength (MPa)-Normalized			
		2 days curing	7 days curing	28 days curing	90 days curing
C1/CEM I	2400	10.89-100%	23.63-100%	37.36-100%	46.85-100%
	3200	15.4-141.4%	30.57-129.4%	45.6-122.1%	54.48-116.3%
	4200	22.33-205.1	35.42-149.9%	48.23-129.1%	57.36-122.4%
	5100	25.7-236%	40.03-169.4	53.45-143.1%	61.4-131.1%
C2/25%	2400	9.09-100%	19.83-100%	30.08-100%	43.21-100%
	3200	12.54-138%	23.46-118.3%	37.03-123.1%	51.3-118.7%
	4200	20.15-221.6%	31.78-160.3%	43.67-145.2%	56.81-131.4%
	5100	22.21-244.3%	34.03-171.6%	45.33-150.7%	59.35-137.4%
C3/30%	2400	8.04-100%	16.95-100%	26.43-100%	40.54-100%
	3200	11.07-137.7%	21.26-125.4%	33.74-127.7%	49.35-121.7%
	4200	17.41-216.5%	27.57-162.7%	39.38-149%	54.56-134.6%
	5100	19.57-243.4%	29.97-176.8%	42.35-160.2%	56.91-140.4%
C4/35%	2400	7.37-100%	15.69-100%	25.88-100%	39.37-100%
	3200	10.09-136.9%	19.99-127.4%	30.56-118.1%	47.57-120.8%
	4200	16.19-219.7%	25.38-161.8%	35.96-138.9%	51.73-131.4%
	5100	18.12-245.9%	27.68-176.4%	41.08-158.7%	55.1-140%

19% lower than CEM I at 2 days curing, but this reduction was only 6% after 90 days curing.

The fineness of cement is a major factor influencing its rate of hydration, since the hydration reaction occurs at the interface with water (Hewlett 1998). Greater cement fineness increases the rate at which cement hydrates and thus accelerates strength development.

The effects of greater fineness on mortar strength are manifested principally at the early ages. Based on the results presented in (**Table 3**), prolonged grinding of the scoria-based blended cements from 2400 to 5100 cm^2/g Blaine fineness increased the compressive strength by144 %, 143% and 146% at 2 days curing and by 72 %, 77% and 76% at 7days curing but only by 37%, 40% and 40% at 90 days curing for C2/25%, C3/30% and C4/35%, respectively.

This could be explained by the effect of grinding which breaks the vitreous body and increases their surface area, resulting in higher activity (Chen, 2007). In addition, according to Shi (2001) prolonged grinding decreases the particle size and increases dissolution rate and solubility of natural pozzolan, which will accelerate pozzolanic reaction rate and strength development of mortar containing natural pozzolan. Further, when clinker and natural pozzolans are interground, the finer portion of the blended cement is mostly ground natural pozzolan whereas the coarse portion is mostly ground clinker (Binici et al., 2007). This could be confirmed by the high porosity of the studied volcanic scoria which may be an advantage for easy and economical crushing (Kelling et al. 2000).

Strong correlation coefficients of more than 0.9 were obtained if a straight line is fitted to the experimental data, as illustrated in **Fig. 4-7**. As shown in **Fig. 4-7** there is a linear increase in strength as the Blaine fineness increases irrespective of the curing time. It is clearly seen in Fig 4-7 that all blend-

Fig. 4

Correlation between compressive strength of CEM I mortar and Blaine fineness of cement at different curing times

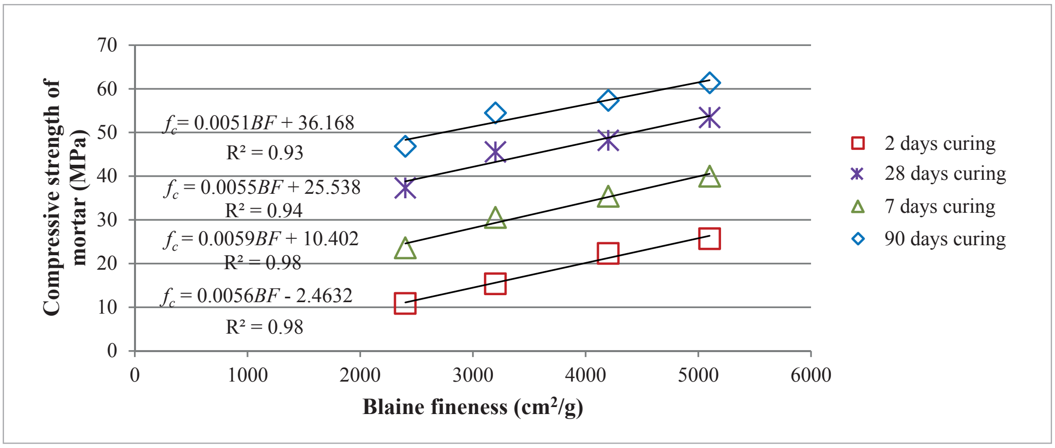


Fig. 5

Correlation between compressive strength of C2/25% mortar and Blaine fineness of cement at different curing times

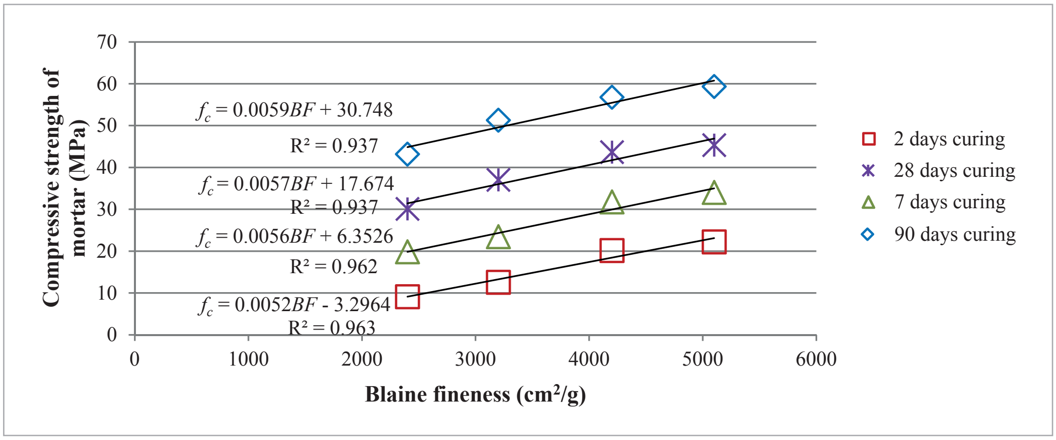
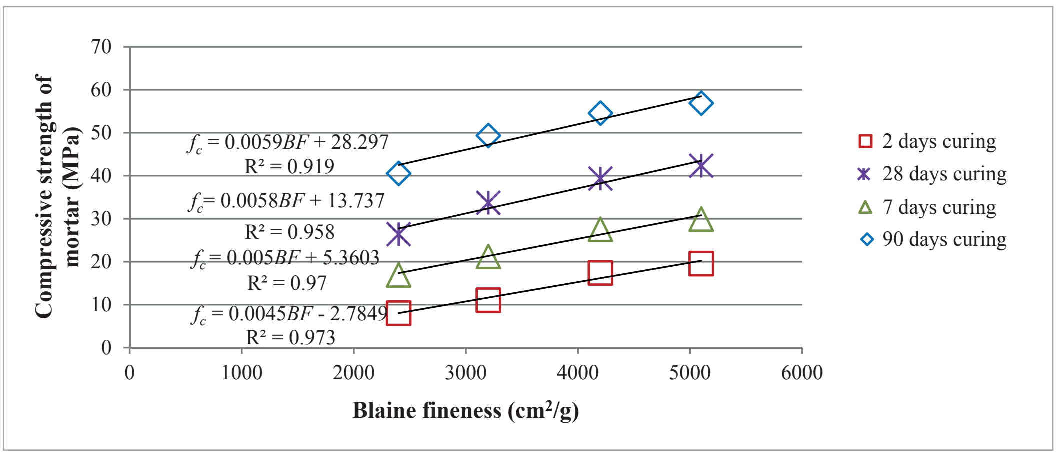


Fig. 6

Correlation between compressive strength of C3/30% mortar and Blaine fineness of cement at different curing times



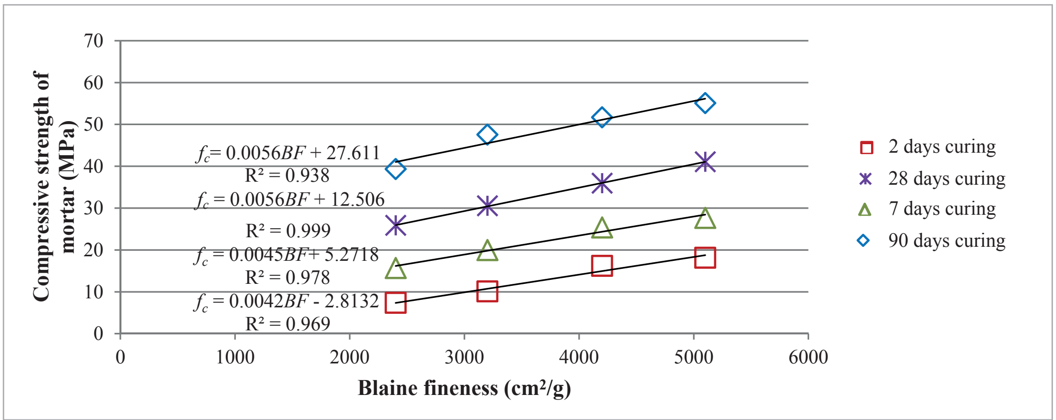


Fig. 7

Correlation between compressive strength of C4/35% mortar and Blaine fineness of cement at different curing times

ed cement mortars exhibited steeper slops with the increase in curing time. Further, it is worth noting that the significant gain in strength in blended cement mortars occurred when moving from 28 to 90 days curing times while in CEM I specimens this was noted during the first 28 days. This could be explained by the slow pozzolanic reaction and its progress with age in blended cement mortars. In addition, it is evidently seen that moving from 3200 cm^2/g (which is a customary value in cement production) to 4200 cm^2/g Blaine fineness had a very obvious influence on the results, whereas this influence was less marked when the Blaine fineness increased from 4200 to 5100 cm^2/g.

Table 4

Flexural strengths development of all cement mortars with curing times

Cement type	Blaine Fineness (cm^2/g)	Flexural strength (MPa)-Normalized			
		2 days curing	7 days curing	28 days curing	90 days curing
C1/CEM I	2400	3.65-100%	6.4-100%	7.5-100%	7.92-100%
	3200	4.27-117%	7.05-110%	7.94-106%	8.32-105%
	4200	4.73-130%	7.28-114%	8.3-111%	8.57-108%
	5100	4.92-135%	7.35-115%	8.4-112%	8.69-110%
C2/25%	2400	2.95-100%	5.66-100%	6.81-100%	7.46-100%
	3200	3.59-122%	6.08-107%	7.16-105%	7.78-104%
	4200	4.13-140%	6.43-114%	7.47-110%	7.99-107%
	5100	4.28-145%	6.45-114%	7.53-111%	8.03-108%
C3/30%	2400	2.67-100%	5.29-100%	6.51-100%	7.29-100%
	3200	3.25-122%	5.71-108%	6.91-106%	7.69-105%
	4200	3.94-148%	5.99-113%	7.31-112%	7.87-108%
	5100	4.02-150%	6.07-115%	7.38-113%	7.79-107%
C4/35%	2400	2.53-100%	4.85-100%	6.26-100%	7.04-100%
	3200	3.09-122%	5.37-111%	6.61-106%	7.42-105%
	4200	4.01-158%	5.98-123%	7.33-117%	7.81-111%
	5100	4.09-162%	5.95-123%	7.36-118%	7.85-112%

Flexural tensile strength

Results of flexural tensile strength of the prisms prepared from the produced mortars and cured in water until the test dates are arranged in (Table 4). The values given in the table show the average of flexural tensile strength for 3 samples. A similar trend to that observed for compressive strength seems to be followed by the flexural strength results. However, the results show that flexural strength is less sensitive than the compressive strength to the binder' Blaine fineness.

Correlation between compressive and flexural strength

The relationship between the compressive strength (f_c) and flexural strength (f_t) is given in (**Fig. 8**) and seems to fit well with the relation proposed by ACI 363R (1992).

$$f_t = k(f_c)^a \qquad (2)$$

The correlation between the flexural strength and the compressive strength results were calculated for the entire population of test results and hence the relation obtained is:

$$f_t = 0.90\times(f_c)^{0.56} \qquad (3)$$

With a correlation factor of 0.92. So, knowing the compressive strength f_c of mortar the flexural strength f_t can be predicted by using Eq. (3).

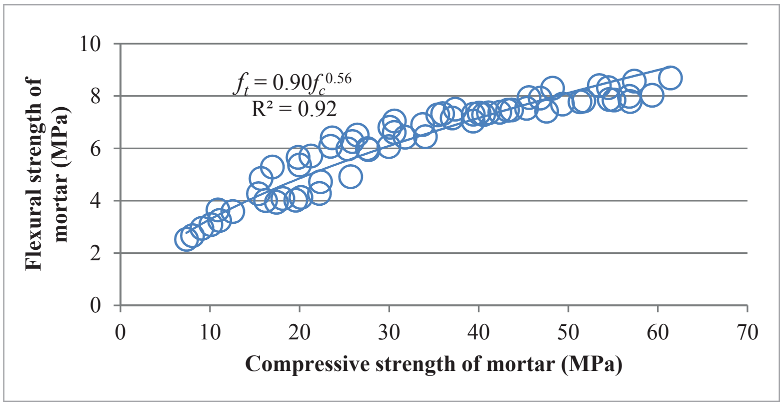


Fig. 8
Correlation between flexural and compressive strengths of the investigated mortars

Correlation between mechanical strengths and Blaine fineness

Fig. 4-7 illustrate the dependence of the compressive strength on the Blaine fineness of the cements used. Based on curve fitting by the least square method, the relationships agreed well with linear functions (**Fig. 4-7**). As shown in **Fig. 4-7** the mortar strength increases linearly with the increase in Blaine fineness for all curing times. According to the test results, the mechanical strengths of mortars containing volcanic scoria-based cements seem to have a close relationship with the binder' Blaine fineness. So, the compressive and flexural strengths of CEM II/B-P-based mortars at a given curing time can be predicted from a knowledge of the Blaine fineness.

The general correlation formulas between each compressive strength and flexural strength and Blaine fineness can be expressed as follows:

$$f_c;\ f_t = (a\times lnt + b)\times BF + c\times lnt + d \qquad (4)$$

Where f_c, f_t are compressive and flexural strength of mortars in (MPa), respectively; t is the curing time in (days); BF is the Blaine fineness of the produced cement (cm^2/g) and a, b, c and d are constants.

Table 5 presents the constants (*a*, *b*, *c* and *d*) with regression coefficients of the correlation between the experimental data and the proposed equation. However, it should be emphasized that additional factors including the type of natural pozzolan, composition and strength of clinker may also be effective on the mechanical properties of mortar. Further, it is worth noting that an increase of about 5 MPa can be expected for every 1000 cm^2/g increase in Blaine fineness for CEM II/B-P-based mortars at all curing times.

Table 5
Constants *a*, *b*, *c* and *d* and regression coefficients (R^2) of the correlation between the experimental data and the proposed equation.

Cement type		*a*	*b*	*c*	*d*	R^2
C1/CEM I	f_c	-1×10^{-4}	0.0059	10.242	-9.40	0.989
	f_t	-5×10^{-5}	0.0005	1.1773	2.5578	0.841
C2/25%	f_c	2×10^{-4}	0.0052	8.8416	-10.276	0.988
	f_t	-7×10^{-5}	0.0005	1.2989	1.6536	0.905
C3/30%	f_c	4×10^{-4}	0.0043	7.8982	-9.5233	0.982
	f_t	-7×10^{-5}	0.0005	1.3616	1.1907	0.934
C4/35%	f_c	4×10^{-4}	0.0039	7.6476	-9.3758	0.981
	f_t	-7×10^{-5}	0.0006	1.330	0.6931	0.952

Conclusions

Based on the experimental results, the following conclusions could be drawn:

- It can be said that the volcanic scoria deposits located in the studied site is a perfect potential for the cement industry. Volcanic scoria had more than of major chemical components, $SiO_2 + Al_2O_3 + Fe_2O_3$, conforming to the chemical requirements of the ASTM and EN standards. In addition, the experimental results presented in this paper showed the physical characteristics of the cement containing scoria are in conformity with the standards requirements and that the strength of scoria-based cements is lower than the plain Portland cement at early ages, but can reach the same order of strength at longer ages.
- Contrary to expectation, scoria-based blended cements with 4200 and 5100 Cm^2/g Blaine fineness values exhibited shorter setting times with the increase of scoria replacement level. This behavior is difficult to explain by authors and it needs further investigation.
- The fineness of scoria-based cement is an activating property for the mortar mechanical strength, especially during the early ages. Mechanical strengths of mortars were found to substantially increase with an increase in scoria-based cement fineness. For all curing times, it was concluded that the worst and best performance in terms of compressive strength was observed in the mortars produced with scoria-based cement with fineness of 2400 and 5100 cm^2/g, respectively.
- Prolonged grinding of the blended cements to achieve a Blaine fineness beyond 4200 cm^2/g (i. e. 5100 cm^2/g) did not show significant influence on the mechanical strengths of blended cement mortars when compared to 4200 cm^2/g. So, for reducing the costs of grinding, it is recommended as a result of this study to reach a Blaine fineness of no more than 4200 cm^2/g.
- It was evidently observed that in all mortars containing scoria, there was a noticeable gain in strength from 28 days onwards, while this was noted during the first 28 days in CEM I specimens.
- Based on the results obtained, the authors derived an estimation equation for compressive and flexural tensile strength development incorporating the effects of Blaine fineness. The mechanical strength of mortar containing scoria-based cement can reasonably be predicted using the Eq. (4). Development of such a good relationship between mechanical strengths and the binder' Blaine fineness can be of considerable benefit.
- According to the results obtained, it is suggested that volcanic scoria can be used up to 35% as a partial substitute for Portland cement in production of blended cements when interground to Blaine fineness of 4200 cm^2/g or more if the cost of grinding can be neglected. This addition ratio can provide economical and ecological benefits due to less use of cement and less CO_2 emission from production of cement. So, production of greener concrete could be promoted.

Acknowledgment

The authors gratefully acknowledge the technical and financial support of this research from the management of General Organization for Cement and Building Materials/ Adra Cement Plant. Thanks are also expressed to Eng. Amjad Bernieh (Lafarge Co.) and Prof. Tamer al-Hajeh, Vice-president of AIU for their appreciated help.

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