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Effect of Powdered Scoria Rocks on the Fresh and Hardened Properties of High Performance Concrete

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Abstract

Traditional pozzolanic materials such as fly ash and silica fume are needed for the production of high performance concrete (HPC). In the Arabian Gulf, large amounts of these materials are imported to the region for use in HPC at high cost. The large deposits of scoria rocks (SR) covering approximately 90,000 km^2 of an area along the east of the Red Sea are proposed as alternative source for pozzolan. In this paper, the effect of different replacement levels of ground SR (by cement weight) on the fresh and hardened properties of high HPC are investigated. The results have shown that the replacement level of 20% SR can be considered as the optimum content. HPC mixes containing 20% SR have shown improved performance on the mechanical and microstructural levels. The results are very encouraging and show good potential for the use of SR as a non-traditional local source for pozzolanic material. The use of SR in HPC will reduce cement consumption and contribute to more sustainable concrete construction in the region.

Keywords: HPC, Scoria Rocks, Compressive Strength, RCPT, Microstructure Analysis

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Introduction

Concrete is the most widely used building material with an annual production rate exceeding 4.5 billion metric ton (Mehta & Monteiro, 2001). Concrete quality depends on its performance under specific environmental conditions. The concrete mixture that meets certain quality and durability requirements is defined as high performance concrete (HPC)[1] (Neville & Aitcin, 1998). HPC production requires the use of chemical and mineral admixtures. The incorporation of mineral admixtures as cement replacement materials in concrete is an effective application towards global sustainable development (Worrell et al., 2001). The waste by-products used as mineral admixtures in HPC production include fly ash, silica fume and slag etc. (Mehta & Aitcin, 1990). These mineral admixtures lower the total cost of HPC production (Hwang et al., 2013, Patil & Kumbhar, 2012, Vejmelkova et al., 2012). In the Arabian Gulf, these materials are imported to the region for the use in HPC at high cost. Therefore, there is an urgent need to explore alternative local and eco-friendly substituting cementitious materials. In this research, the large deposits of scoria rock covering approximately 90,000 km^2 of a non-urban area along the east of the Red Sea are proposed for the use as an alternative source for mineral admixtures (Moufti et al., 2000). They should provide suitable mechanical properties when incorporated in concrete (compressive strength > 50 MPa at 28 days). The use of SR in HPC will reduce cement consumption and contribute to more sustainable concrete construction in the region.

Experimental Program

Raw Materials

Fine Powders

Type I Portland Cement (PC) meets the requirements of ASTM C150 was used. Scoria Rocks (SR) were procured from western province in the Arabian Peninsula. Table 1 shows the GPS international coordinates for the procured SR sample. The site map and the actual volcanic lava field are shown in Figure 1. SR sample was ground to similar particle size distribution of cement, as shown in Figure 2. The specific gravity of SR powder is 2.78.

[1] See: Planning Committee for the Nationally-Coordinated Program on High-Performance Concrete and Steel. 1993. High-Performance Construction Materials and Systems: An essential program for america and its infrastructure, Technical Report No. Report 93-5011.http://books.google.com.sa/books/about/High_Performance_Construction_Materials.html?id=Ta9RAAAAMAAJ&redir_esc=y &
Materials for tomorrow's infrastructure. 1994. A ten-year plan for deploying high performance construction materials and systems, Technical Report CERF report # 94-5011.http://books.google.com.sa/books/about/Materials_for_Tomorrow_s_Infrastructure.html?id=0pdRAAAAMAAJ&redir_esc=y

Table 1. *Location of Collection Site of SR Sample*

Sample	GPS coordinates	
	Latitude (N)	Longitude (E)
SR	23^{o} 11.9103	39^{o} 56.9014

Figure 1. *Illustration of the Collection Site; (a) Site Map (b) Actual Volcanic Lava Field*

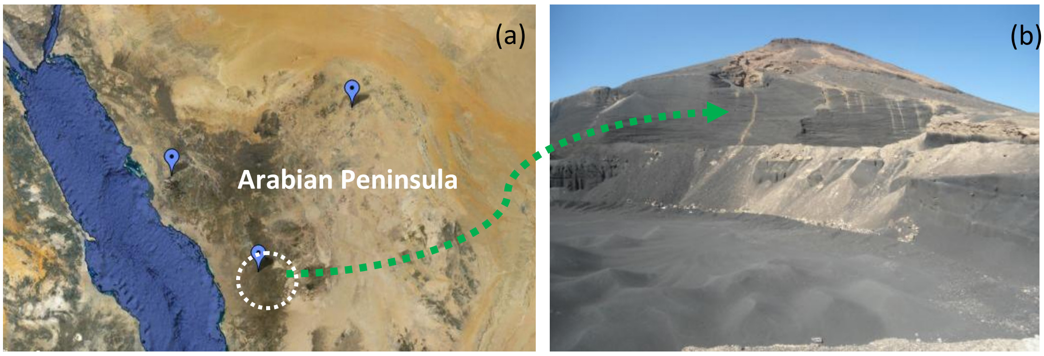
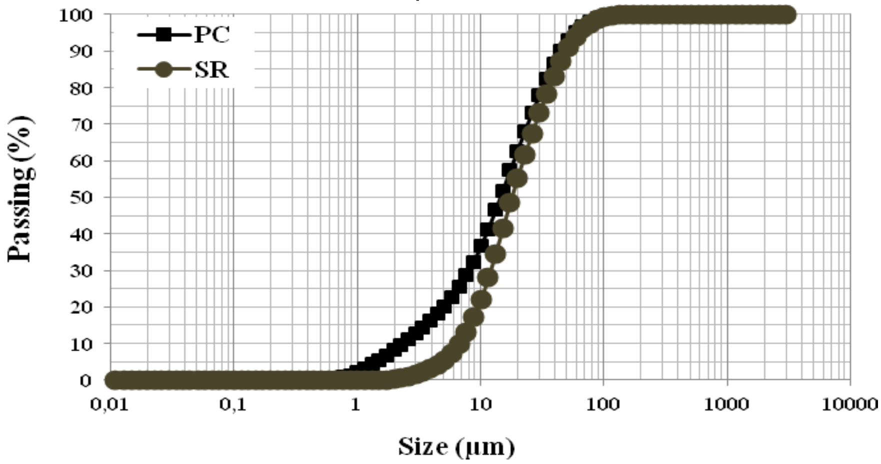


Figure 2. *Particle Size Distribution of Cement and SR Powders*



Fine and Coarse Aggregates

Natural aggregates were collected from local sources in the central region of the Arabian Peninsula. A blend of natural White and Crushed Sands (WS and CS, respectively) were used as fine aggregates while a blend of crushed aggregates of nominal grain sizes of 10 and 20 mm (CA10 and CA20, respectively) were used as coarse aggregates. The gradations of blended coarse and fine aggregates are shown in Table 2. The specific gravities at SSD state of WS, CS, CA10 and CA20 were 2.65, 2.65, 2.63 and 2.64, respectively.

Table 2. *Sieve Analysis of Blended Coarse and Fine Aggregates*

Sieve size	Coarse aggregate (70% CA20+30% CA10)	Sieve size	Fine aggregate (40% CS+60% WS)
1.5″	100	3/8″	99.91
3/4″	95.1	#4	98.74
3/8″	28.55	#8	78.25
#4	5.2	#16	66.13
#8	0.4	#30	54.70
#16	0.3	#50	46.51
		#100	23.41
		#200	19.59

Chemical Admixture (SP)

A high range water reducing, superplasticizing and slump retaining lignosulphonate-based admixture was used. The SP dosage was expressed as a percent of its dry extract (D.E.) by total binder weight. SP has a specific gravity of 1.2.

Mix Proportioning

The main HPC mix design used in this investigation is shown in Table 3. A volume of 15 L was used for the preparation of each mixture. The main idea of the mix design depends on the cement content of 520 kg/m^3 and the low water-to-cement ratio of approximately 0.26. Several trial mixtures were investigated to optimize for chemical admixture dosage and for the different replacement levels of SR. The target slump flow was in the range between 200 and 240 mm.

Table 3. *Mix Design of HPC Concrete (kg/m^3)*

	PC	Water	WS	CS	CA20	CA10
Control	520	135	463	309	749	322

Protocol of Mixing

The mixing procedures begun with addition of WS, CS, CA10 and CA20 to a 40 litre capacity tilted concrete mixer followed by the addition of calculated absorption water then the cement. Water was premixed with the selected SP dosage firstly. 50% of mixing water was added to the mixer in 30 sec during mixing. This step was followed by the addition of the rest of water which was then continued for 6 min and then by 3 min pause followed by 3 min continuous mixing. The fresh properties such as slump flow and unit weight were measured directly followed by casting samples in the prospective moulds (cubes and cylinders) on a vibrating table in approximately 15 sec for each add concrete layer to achieve good compaction.

Testing Procedure

SR sample was ground using Fritsch pulverisette 6 planetary mono Mill (320 RPM). The particle size analysis of the fine powders was determined using Horiba LA-950 laser diffraction particle size analyzer. XRD analysis was performed using Panalytical Empyrean with Cu Kα radiation of 45 kV and 40 mA with scan speed of 2θ/minutes. The X-ray patterns of samples were obtained in the 2θ-range from 5° to 60°. The chemical analysis of cement and SR samples was measured by Panalytical AXIOS XRF machine using pressed powder pellets made from approximately 12 g of sample. The main mix design of HPC mixtures is shown in Table 4. Different replacement levels of 20, 30, 40 and 50% SR were used with Water-to-Binder (W/B) ratio of 0.26. The fresh properties included concrete slump and unit weight. The hardened properties included compressive strength, chloride-ion permeability and microstructural analysis. The compressive strength was determined as per the requirements of BS 1881-116:1983 while the chloride-ion permeability results were obtained as per ASTM C1202. The hardened properties were determined at curing ages of 7 and 28 days. Small concrete pieces of freshly broken samples were taken to explore their microstructural features. Microstructural investigation was performed using field emission dual beam Versa 3D scanning electron microscope (FESEM) from FEI.

Results and Discussion

Fresh Properties

The final mix design and the fresh properties of the optimized HPC mixtures are shown in Table 4. SP dosage used with each mixture has satisfied the target slump flow without segregation, as shown in Figure 3. The addition of SR leads to a linear increase in SP dosage proportional to SR content. The unit weight did not change significantly due to the elevated specific gravity of SR powder.

Table 4. *Mix Design of the optimized SP Dosage and Fresh Properties of HPC Mixtures*

	Control	20% SR	30% SR	40% SR	50% SR
PC	520	416	364	312	260
SR	0	104	156	208	260
Water	135	135	135	135	135
WS	463	463	460	459	458
CS	309	309	305	303	301
CA20	749	747	747	746	745
CA10	322	320	316	313	311
Unit weight (kg/m^3)	2490	2470	2470	2430	2430
SP (D.E., %)	0.48	0.65	0.75	1.07	1.24

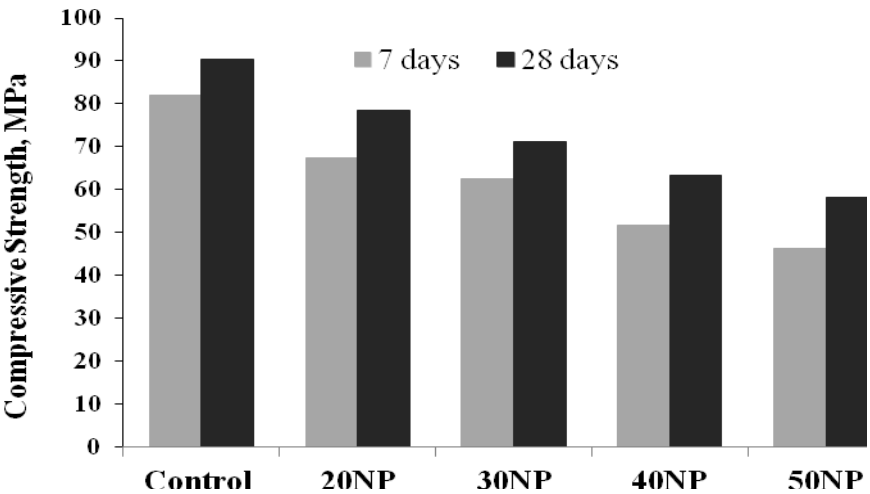
Figure 3. *Measuring Slump Flow of HPC Mixtures*

Hardened Properties

Compressive Strength

The compressive strength was measured at 7 and 28 days. The obtained results are shown in Figure 4. At 7 days, the compressive strength varied between 46 and 82 MPa while at 28 day it varied between 58 and 90 MPa. These relatively high compressive strength values are encouraging even at a high volume of SR powder (i.e. at a replacement level of 50%; the compressive strength achieved was approximately 58 MPa). These results satisfied the minimum requirement for compressive strength at 28 days even with a replacement level of 50% SR, as clearly shown in Figure 4.

Figure 4. *Development of Compressive Strength of Concrete Mixes*



Rapid Chloride Permeability Test (RCPT)

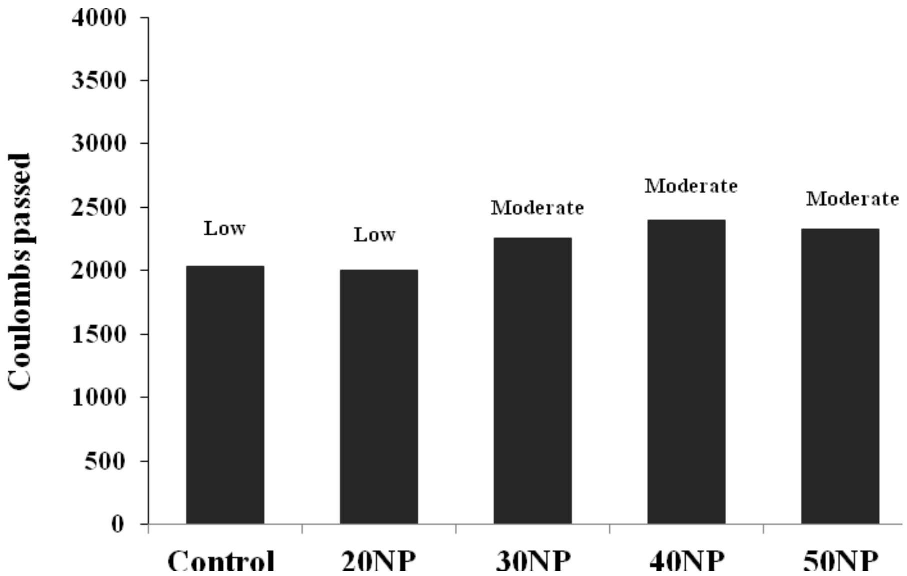
This test was conducted as per ASTM C1202 specification. ASTM C1202 classifies concrete mixtures into 5 categories dependent on the amount of the electrical charge passed through the concrete sample, as presented in Table 5.

Table 5. *RCPT Ratings as per ASTM C1202*

Charge Passed (coulombs)	Chloride ion penetrability
> 4,000	High
2,000-4,000	Moderate
1,000-2,000	Low
100-1,000	Very Low
< 100	Negligible

RCPT was conducted at 28 days. The results have shown that the control and 20% SR mixtures can be classified as low chloride ion penetrability mixtures. The other HPC mixtures with 30, 40 and 50% SR can be classified as moderate chloride ion penetrability mixtures, as indicated in Figure 5.

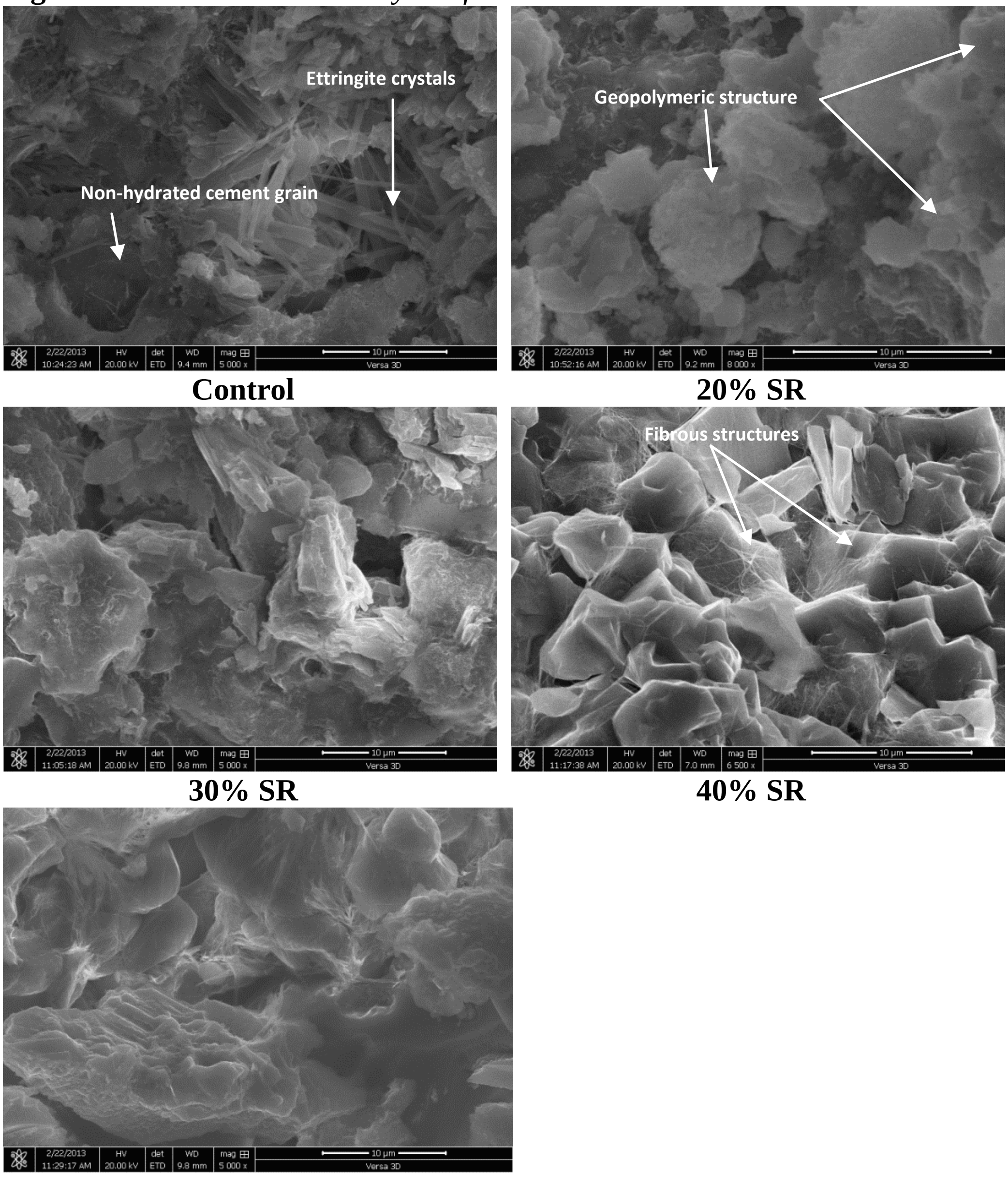
Figure 5. *RCPT of Concrete Mixes at 28 Days*



Microstructural Analysis

Pieces of concrete were taken from each sample representing HPC mixtures at a curing age of 28 days for microstructural analysis, as shown in Figure 6. The results have shown the presence of the features characteristic of control mixture such as ettringite needles, portlandite crystals and non-hydrated cement grains. On the other hand, the microstructure of HPC mixture with 20% SR has shown the presence of special types of C-S-H agglomeration of geo-polymeric structures. The microstructural analysis of HPC mixtures with 30, 40 and 50% SR shows the packing of SR gains. Large SR grains are bonded with the product of the interaction of reactive SR grains with portlandite. Moreover, the whole cementitious system seems to be held also with this type of newly formed fibrous structures, as shown in Figure 6.

Figure 6. *Microstructural Analysis of the Control- and SR-HPC Mixtures*



Conclusions

SR can be used to replace up to 50% of cement; however, SP demand increased as SR content increased. The target compressive strength of 50 MPa at 28 days was achieved with all replacement levels. HPC mixture containing 20% SR has good compressive strength and chloride ion penetrability performances. Microstructural analysis revealed that the presence of 20% SR in HPC mixture leads to the formation of advanced C-S-H of geo-polymeric structures. These results are encouraging and show good potential for the use of SR as a non-traditional local source for pozzolanic material. This will lead to a reduction in cement consumption and contribute to more sustainable concrete construction in the region.

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