

# Production of High-Strength Concrete by Utilizing Volcanic Pumice Waste in KSA, Jazan Region: Particle Size Effect

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**Abstract** - Volcanic areas are scattered in several areas of Saudi Arabia. This spread contributes to the diversity of the sources of volcanic substances and their chemical structures. This study assesses the use of volcanic pumice powder (VPP) obtained from volcanic residues in the western region of Saudi Arabia to produce high-strength concrete (HSC). Chemical analysis reveals that these volcanic residues consist of 76.01% pozzolanic materials. The VPP was used to replace part of the cement content of HSC, and the effects of replacing 10% and 20% of the cement mass with VPP on HSC properties were studied. In particular, the effects of granules measuring 4.96  $\mu\text{m}$  (4VPP) and 63.6  $\mu\text{m}$  (60VPP) in size were observed. The compressive strength, flexural strength, indirect tensile strength, porosity, and water absorption rate of the samples were determined after 7, 28, and 90 days of curing. The compressive strength of HSC samples containing 10% (4HSC10) and 20% (4HSC20) 4VPP improved by 12.0% and 16.6% compared with those of 60HSC10 and 60HSC20, respectively, after 28 days of aging. Water absorption decreased when the main particle size was 4 mm compared with that when the main particle size was 60 mm. The water absorption rate decreased by 12% after 28 days of curing when 20% of the cement mass was replaced with 4VPP.

**Keywords** - volcanic pumice, water absorption, porosity, compressive strength, pozzolanic, particle size.

## I. INTRODUCTION

Concrete is a crucial material in the construction industry because it possesses high compressive strength and is inexpensive. Concrete can be cast into various structural configurations and requires minimal maintenance during service.

The need for additional structures in developing countries and rapid economic expansion has increased the demand for cement and concrete. In 2009, nearly 2.65 billion metric tons of cement was consumed by the concrete industry (Portland Cement Association). Replacing up to 40% of the cement mass with volcanic wastes, such as natural pozzolanic materials (NPs), can reduce cement consumption and CO<sub>2</sub> emissions at the same rate of replacement by NPs (Ulus, Aruntas et al., 2016). The use of pozzolanic materials in the concrete industry is important, but the industrial wastes of these materials, such as fuel ash, fly ash, zeolite, and waste glass, must be disposed properly to avoid environmental damage. Utilizing NPs from volcanic activity in concrete applications is appropriate, especially in HSC, which consumes large amounts of cement (at least 500 kg/m<sup>3</sup>; Alves, Cremonini et al., 2004). Previous studies

on the hydration and strength of mortar and concrete containing volcanic ash (VA) based on global standards are limited (Siddique, 2012; Al-Fadala, Chakkamalayath et al., 2017). However, NPs can be used in any region depending on the data sources of VA and VT. Several factors, such as origin region, mineralogical components, particle size characteristics, and manner of formation, may change the properties of cement (Çolak, 2003; Pekmezci and Akyüz, 2004). Volcanic wastes that are classified as NPs, such as VA, VT, and VP, are abundant in the southwestern region of the Arabian Peninsula. Jazan Region, in particular, features many inactive volcanoes containing large amounts of VP.

The aggregate industry produces waste materials (dust) from the grinding of lightweight aggregates; this waste material is called VP powder (VPP). VPP is extremely fine and floats in the air; thus, it is harmful to humans and the environment. A number of studies have shown that grinding improves the reactive properties of VPP with Ca(OH)<sub>2</sub> for secondary gel production, thereby improving the efficiency of cement paste by increasing the active strength index to 111% of the reference mix (Binici, Temiz et al. 2007, Karataş, Benli et al. 2017). In the western region of Saudi Arabia, a chain of volcanic ranges forms spreads over 2000 km of land (Moufti and

Németh 2016). In the present study, the effect of the particle size of VPP (4 and 60  $\mu\text{m}$ ) used as a cement replacement (10% and 20%) on the fresh concrete properties, strength, and permeability of high-strength concrete (HSC) was determined after curing for 7, 14, and 28 days.

## II. EXPERIMENTAL

### 1. Material and mixture proportions

The VPP used in this investigation was obtained from a quarry of lightweight aggregates in Jazan Region, KSA. VPP was collected from the floating dust produced by the crushing of VP and passed through a 150  $\mu\text{m}$  sieve (60VPP). Some of the sieved powder was ground by a ball milling machine to produce extremely fine powder with an average diameter of 4.96  $\mu\text{m}$  (4VPP). The physical and chemical properties of VPP and Portland cement, which is compatible with ASTM standards, are displayed in Table 1.



Fig.1. Volcanic area in the southwestern region of KSA.



Fig.2. Volcanic pumice powder (60VPP).



Fig.3. Volcanic pumice powder (4VPP).

Table I: Chemical composition of volcanic pumice powder (VPP) and OPC.

Property	VPP (%)	OPC (%)
SiO <sub>2</sub>	47.40	20.05
Al <sub>2</sub> O <sub>3</sub>	18.57	4.93
Fe <sub>2</sub> O <sub>3</sub>	10.04	3.90
CaO	7.90	61.57
MgO	6.04	0.81
Na <sub>2</sub> O	2.58	0.08
TiO <sub>2</sub>	1.62	0.24
K <sub>2</sub> O	1.07	1.33
P <sub>2</sub> O <sub>5</sub>	0.64	0.08
SO <sub>3</sub>	0.34	3.06
MnO	0.133	0.19
Cl	0.01	-
LOI	2.21	2.10
SiO <sub>2</sub> +Al <sub>2</sub> O <sub>3</sub> +Fe <sub>2</sub> O <sub>3</sub>	76.01	-

Table II: Physical properties of VPP and OPC.

Specific gravity (g/cm <sup>3</sup> )	2610	3100
Surface area (cm <sup>2</sup> /g)	4298	3410
Average D <sub>50</sub> ( $\mu\text{m}$ )	4.96	7.60

Mixture proportion (kg/m <sup>3</sup> )						
Mix	C	VPP	FA	Ca	W	SP
HSC	500	0	789	1070	150	7.5
4HSC10	450	50	757	1070	150	7.5
4HSC20	400	100	741	1070	150	7.5
60HSC10	450	50	757	1070	150	7.5
60HSC20	400	100	741	1070	150	7.5

### 2. Slump test

The slump test was conducted to measure the workability of different cement mixtures according to ASTM C143.

Hardened concrete tests

Tests on hardened concrete were conducted to assess the compressive, indirect tensile and flexural strengths of the samples in accordance with ASTM C39, ASTM C496, and ASTM C78, respectively. Here, 100 mm × 100 mm × 100 mm standard cubes, 100 mm (diameter) × 200 mm (height) standard cylinders, and 100 mm × 100 mm × 400 mm standard prisms were respectively used for the compressive, indirect tensile, and flexural strength tests. All tests were recorded using three samples on days 7, 28, and 90 after initiation of curing.

#### • Water absorption and porosity

The vacuum saturation method was used to determine the water absorption characteristics of the concrete samples according to the method of RILEM (1984). The test was performed using cube samples measuring 70 mm × 70 mm × 70 mm. Water absorption (A) and porosity (P) were determined using Equations (1) and (2), respectively (RILEM 1984).

$$A(\%) = \frac{(W_1 - W_3)}{W_3} \times 100, \text{ Eq. (1)}$$

$$P(\%) = \frac{(W_1 - W_2)}{W_1 - W_3} \times 100, \text{ Eq. (2)}$$

where W1 is the weight of specimen in saturated and surface dry condition in air (g), W2 is the weight of the saturated specimen in water (g), and W3 is the weight of oven-dried specimen in air (g).

### III. RESULTS AND DISCUSSION

#### 1. Slump test

Table 4 shows the results of the slump test. Addition of VPP improved the properties of fresh concrete. A high VPP content resulted in high workability under the condition of a constant water/binder ratio and super plasticizer dosage. Inclusion of VPP reduced the cement content and, in turn, the water demand of the mixtures. HSC containing 60VPP (60HSCx) revealed higher workability than HSC containing 4VPP (4HSCx), possibly due to effect of the surface area of VPP. The low surface area of 60HSC reduces the amount of water necessary to wet the surface of cement. Moreover, replacement rates of 10 % and 20% of cement mass content contributed to increase slump test results of 3%, 11%, 11% and 14% of 4HSC10, 4HSC20, 60HSC10 and 60HSC20 compared to HSC.

Table IV: Slump test results of different mixtures

Mix	Slump (mm)
HSC	180
4HSC10	185

4HSC20	200
60HSC10	200
60HSC20	205

#### 2. High-strength concrete test

##### 2.1 Compressive Strength

Figure 3 shows the effect of particle size and VPP content on the strength of the HSC samples. Addition of VPP decreased the compressive strength of HSC after 7 days of aging; longer aging periods of 28 and 90 days led to improvements in the compressive strength when 10% of the cement content of HSC was replaced with 4VPP. The difference in compressive strength among samples was evident when the average particle size of VPP was reduced from 60 μm to 4 μm.

The results shown in Figure 3 confirm that the use of 4 μm VPP improves the compressive strength of HSC when compared with that of samples containing 60 μm VPP. The compressive strengths of HSC, 4HSC10, 4HSC20, 60HSC10, and 60HSC20 after aging for 7 days were 45.3, 43.3, 42.9, 41.9, and 40.0 MPa, respectively. By comparison, the compressive strengths of HSC, 4HSC10, 4HSC20, 60HSC10, and 60HSC20 after aging for 90 days increased to 62.5, 65.1, 64.2, 55.1, and 53.5 MPa, respectively. The respective compressive strengths of 4HSC10 and 4HSC20 increased by 2% and 3% after aging for 28 days. The observed increase in compression strength over longer aging periods may be attributed to the fact that pozzolanic materials need time to complete their reaction with Ca(OH)<sub>2</sub> and produce secondary gel (calcium silicate hydrate). Improvements in the compressive strength of 4HSCx may be attributed to the large surface area of the VPP particles, which accelerates the reaction process. These findings coincide with the results of previous researchers (Çetin, Erdoğan et al. 2016).

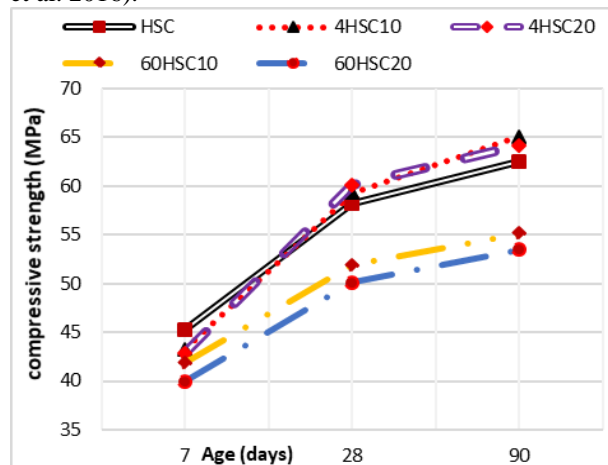


Fig.3. Compressive strength results.

## 2.2 Flexural Strength

Figure 4 shows the effects of VPP particle size and content on the flexural strength of the HSC samples. Addition of VPP decreased the flexural strength of the HSC samples after 7 days of aging. After 28 and 90 days, however, the flexural strength of the samples improved when 10% of the cement mass was replaced with 4VPP. The difference in flexural strength was evident when the average particle size of VPP was reduced from 60  $\mu\text{m}$  to 4  $\mu\text{m}$ . The results in Figure 3 confirm that the use of 4  $\mu\text{m}$  VPP improves the flexural strength of HSC when compared with that of samples containing 60  $\mu\text{m}$  VPP. These results are consistent with the findings of previous researchers (Givi, Rashid et al. 2010, Zeyad, Johari et al. 2016).

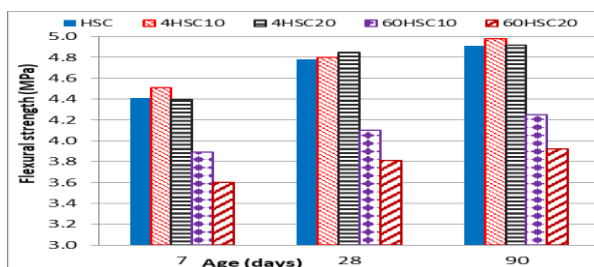


Fig.4. Flexural strength results.

## 2.3 Indirect Tensile Strength

Figure 5 shows the indirect tensile strength of the HSC samples. Addition of VPP decreased the indirect tensile strength of the HSC after 7 days of aging; however, after aging for 28 and 90 days, the indirect tensile strength of the samples improved when 10% of the cement mass was replaced with 4VPP. The difference in indirect tensile strength was evident when the average particle size of VPP was reduced from 60  $\mu\text{m}$  to 4  $\mu\text{m}$ . The results in Figure 3 demonstrate that the use of 4  $\mu\text{m}$  VPP improves the indirect tensile strength of HSC when compared with that of samples containing 60  $\mu\text{m}$  VPP. These findings coincide with the results of previous researchers (Zeyad, Megat Johari et al. 2016, Zeyad, Johari et al. 2017).

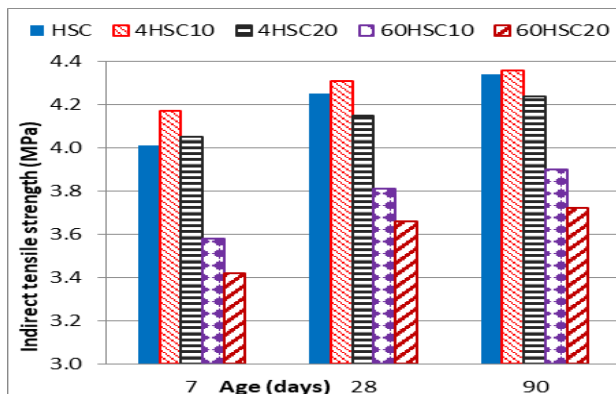


Fig.5. Indirect tensile strength results.

Figures 6 and 7 show the porosity and water absorption results of the HSC samples. Addition of VPP generally decreased the porosity and water absorption rate of the samples. Improvements in porosity and water absorption of HSC were evident when the average particle size of VPP was reduced from 60  $\mu\text{m}$  to 4  $\mu\text{m}$ . Figure 6 shows that the use of 4  $\mu\text{m}$  VPP improves the porosity and water absorption properties of HSC when compared with those of samples containing 60  $\mu\text{m}$  VPP. These results are consistent with the findings of previous researchers (Supit, Shaikh et al. 2014).

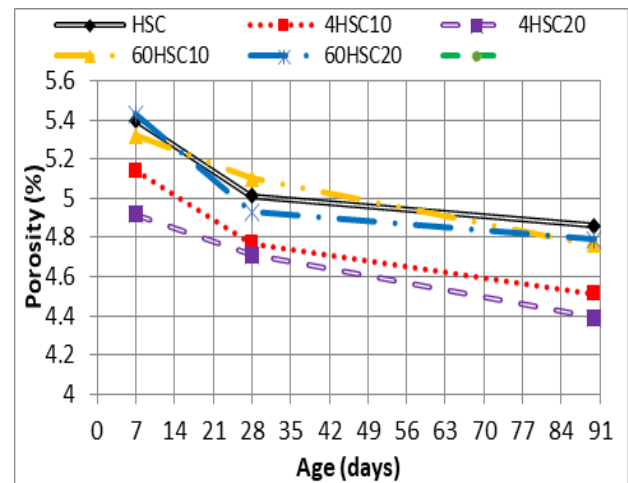


Fig.6. Porosity results.

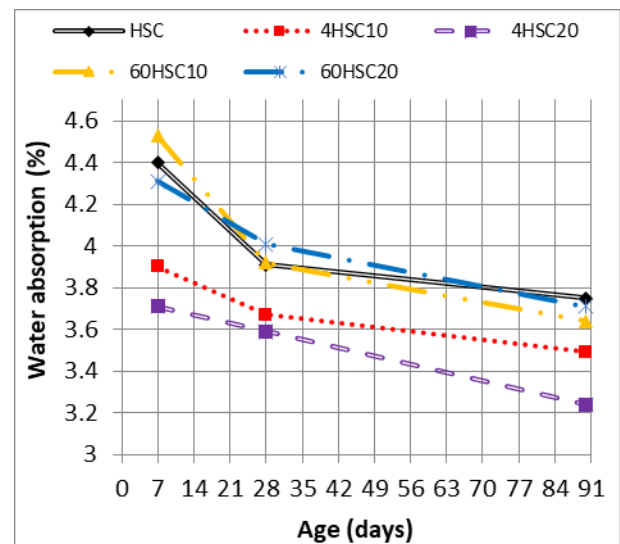


Fig.7. Water absorption results.

## IV. CONCLUSION

- The use of VPP improved the fresh concrete properties of HSC. The slump results increased with increasing rate of replacement.
- VPP with a particle size of 4  $\mu\text{m}$  negatively affected the properties of fresh concrete by increasing the

water demand of the samples to maintain workability similar to that of samples containing VPP with a larger particle size.

- The compressive, indirect tensile, and flexural strengths of the samples improved when 10% and 20% of the cement mass of HSC was replaced with 4VPP.
- The compressive, indirect tensile, and flexural strengths of the samples decreased when 10% and 20% of the cement mass of HSC was replaced with 60VPP.
- VPP exerted a positive effect on concrete permeability, water absorption, and porosity.
- HSC with a compressive strength of >60 MPa can be produced from local materials with up to 20% 4VPP.

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