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Micro Structural Study of Concrete with Indigenous Volcanic Ash †

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Abstract: Extraordinary efforts should be carried out in Pakistan to prepare green concrete from waste materials. The utilization of Volcanic Ash (VA) in concrete can make sustainable concrete that will produce less carbon dioxide (CO_2) emissions and give positive outcomes. Hence, compressive strength was tested on VA concrete with changing concentrations ranging from 0, 10, and 20% with constant W/C, and the result was evaluated by scanning electron microscopy. The analysis of results reveals that the intrusion of VA with 10% replacement gives a significant response, and enhances the strength of the overall matrix.

Keywords: compressive strength; scanning electron microscope; volcanic ash; chemical composition

1. Introduction

Possible efforts should be carried out to use waste materials in concrete for the protection of the environment by making green concrete [1]. These waste materials may be agricultural, industrial, aquaculture, waste, natural minerals, dust powder, and ashes [2]. Volcanic Ash concrete can be considered green concrete. Moreover, SCMs utilization can also improve mechanical and durability properties. The commonly used SCM includes Volcanic Ash (VA). By adding SCMs, overall mechanical and durability properties are improved. Their utilization in concrete consumes less energy for production and evolves less CO_2. Moreover, protection against freeze and thaw, alkali–silica reaction, chloride attack, and sulfate attack may also be achieved. Siddique et al. [3] revealed that the compressive strength was diminished as the proportion of Volcanic Ash (VA) replacement in cement increased. A decrease of around 40% in strength was observed when 40% of the cement was substituted with VA. Mostafa et al. [4] investigated the effect of the VA with and without magnetizing water (MW). The author used different concentrations of VA with cement replacement and revealed that the VA with 15% depicts a significant increase of about 33% in strength. Anwar et al. [5] investigated the impact of the partial replacement of cement with Volcanic Ash (VA) and pumice powder (VP) on the compressive strength of cement mortar. The replacement percentage ranged from 0 to 50%, and tests were carried out over 28 days. Based on the findings, it was observed that the compressive strength decreased as the content of VA or VP increased. This decrease in strength can be attributed to the reduction in the amount of cement in the mixture due to the higher content of VA or VP. Ekinci et al. [6] discovered that the addition of volcanic material to geopolymer concrete resulted in decreased workability, which in turn can negatively affect the compressive strength of the concrete. Moreover, a scientometric diagram, as shown in Figure 1, depicts the importance of Volcanic Ash in concrete.

There is some research on sustainable concrete using VA. However, there is minimum data related to microstructural studies available to verify exhibited mechanical properties. This research aims to use locally available Volcanic Ash as a partial replacement for cement to make sustainable concrete without compromising on compressive, and an attempt will be made to verify these results through microstructural studies of concrete with VA.

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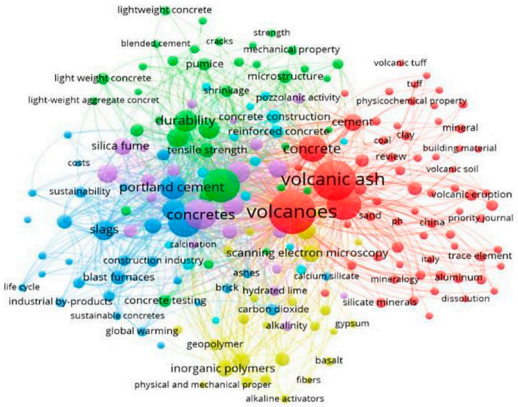


Figure 1. Scientometric diagram of Volcanic Ash.

2. Experimental Procedures

2.1. Material Used

2.1.1. Volcanic Ash

VA as a waste material was taken from the locally available place near Chilas (Pakistan), and its chemicals analysis reveals that VA has similar contents and a greater concentration of SiO_2 than OPC, as illustrated in Table 1. The SiO_2 + Al_2O_3 + Fe_2O_3 concentration is more than 70%. This depicts the pozzolanic nature of VA as per ASTM C618-01. In addition, Table 1 also demonstrates the physical composition of VA.

Table 1. The chemical composition of VA.

Chemical Composition		Physical Composition	
Oxide	**VA (%Age by Mass)**	**Characteristics**	**VA**
SiO_2	53.69	Specific Gravity	2.67%
Al_2O_3	17.43	Soundness	No Expansion
Fe_2O_3	9.52	Retain on sieve # 325 max (%)	33
CaO	7.00		
MgO	3.87		
Na_2O	3.57		
K_2O	0.86		
SO_3	0.16		
Lime saturation Factor	3.89		
Silica Modulus	1.99		
Aluminum Modulus	1.83		
L.O. I	1.3		

2.1.2. Cement

Ordinary Portland Cement (OPC) was used and had a chemical and physical composition as per ASTM C-150 type-1 (normal).

2.1.3. Coarse/Fine Aggregate

Margalla crush, with a max size equal to 3/4 ″, and Qibla Bandy sand were used for making the concrete mix.

2.2. Concrete Mix Proportion

Concrete mix proportions are shown in Table 2.

Table 2. Concrete mix proportions.

Concrete Mix Composition					
Mixes	**Cement (Kg/m^3)**	**Volcanic Ash (Kg/m^3)**	**Water (w/c = 0.5) (Kg/m^3)**	**Fine Aggregate (Kg/m^3)**	**Coarse Aggregate (Kg/m^3)**
Control Sample	320	0	160	640	1280
V10	288	32	160	640	1280
V20	256	64	160	640	1280

Sample Preparation

Mixing of concrete was performed with w/c = 0.5. Homogeneously mixed samples were cast in 4″ Ø, 8″ long cylinders in three layers of compaction. The cast samples were de-molded after 24 h and then cured with a wet hessian cloth that was maintained at room temperature of 25 °C + 3 °C. Mix proportions are included in Table 2.

2.3. Tests Performed

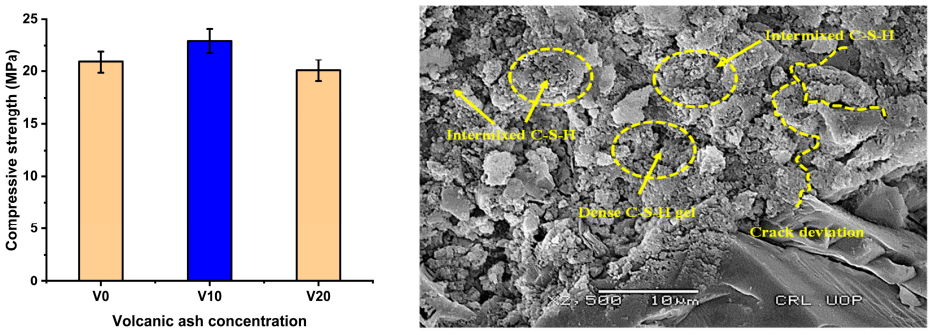
Compressive Strength and Scanning Electron Microscopy of the Concrete

Compressive strength was carried out after 28× days. The average value of the three specimens for each test was determined and recorded. Compressive strength was evaluated on the bases of ASTM C039, and SEM was performed to check the internal microscopy of the structure.

3. Results and Discussions

3.1. Compressive Strength and Microstructure of VA Concrete 1:2:4

Compressive strength values of various mixes with varying concentrations are shown in Figure 2. The best result of compressive strength was achieved for the mix VA-10 compared to that of normal concrete. Moreover, there was a decrease in strength observed with a higher concentration of VA, as demonstrated in Figure 2a. Initially, the increase in strength was due to the pozzolanic hydration process between cement and VA. The pozzolanic reaction between Volcanic Ash and CH produced additional Calcium Silicate Hydrate (C-S-H) and produced dense gel. Volcanic Ash also reacted with CH and aluminates to form C-A-S-H gel. This provided additional strength as C-A-S-H is denser than CH. Thus, it contributed to the densification of the concrete structure. The SEM analysis reveals that the volcanic ash particles, when mixed with cement, form a highly compact and dense C-S-H gel. This is the primary binding material in concrete, responsible for its strength and durability. The volcanic ash particles interact with the cement, promoting the formation of additional C-S-H gel. The denser gel structure contributes to the overall strength of the concrete, as illustrated in Figure 2b.



(**a**) (**b**)

Figure 2. (**a**) Compressive strength of VA; (**b**) scanning electron microscopy of VA with 10%.

3.2. Cost Benefit Analysis

A system process to evaluate suitability by weighing its potential benefits and cost is called cost-benefit analysis. The rate of normal PCC 1:2:4 in the foundation without shuttering for the 1 m^3 has been compared, as illustrated in Table 3. This comparison is specifically for the province of Gilgit Baltistan:

Table 3. Cost comparison of VA (20%) replacement with P.C.C.

	P.C.C Control Sample			P.C.C with 10% Replacement		
Parameters	**Quantity**	**Rates**	**Amount**	**Quantity**	**Rates**	**Amount**
Cement	6.4 Bags	Rs. 1350/Bag	Rs. 8640/-	5.12 Bags	Rs. 1350/Bag	Rs. 6912/-
VA	-	-	-	64 Kg	Rs. 3/Kg	Rs. 192/-
Sand	16 ft^3	Rs. 80/ft^3	Rs. 1280/-	16 ft^3	Rs. 80/ft^3	Rs. 1280/-
Crush	32 ft^3	Rs. 110/ft^3	Rs. 3520/-	32 ft^3	Rs. 110/ft^3	Rs. 3520/-
Labor for pouring and curing	35.311 ft^3	Rs. 30/ft^3	Rs. 1059/-	35.311 ft^3	Rs. 30/ft^3	Rs. 1059/-
Total			14,499/-			12,963/-
Cost reduction			Rs. 1536/Cum (11%)			

4. Conclusions

A comprehensive study has been carried out by replacement of cement with concrete. The following are the conclusions from this comprehensive study:

1. The compressive strength of concrete with 10% VA replacement enhances the composite strength compared to the control specimen;
2. SEM analysis reveals that VA particles react with the CH to form densified C-S-H gel. In addition, deviation of cracks is observed, which is a good sign for strength and durability;
3. Incorporating Volcanic Ash (VA) in concrete construction leads to a significant cost reduction of 11% when considering the desired compressive strength.

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