6th Conference on Sustainability in Civil Engineering (CSCE'24)
Department of Civil Engineering
Capital University of Science and Technology, Islamabad Pakistan

MECHANICAL AND PERMEATION PROPERTIES OF CONCRETE USING INDIGENOUS VOLCANIC ASH AS PARTIAL REPLACEMENT OF CEMENT

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Abstract- The current study aims to examine the effects of indigenous Volcanic Ash (VA) on mechanical and permeation properties of concrete upon partial substitution of Ordinary Portland Cement (OPC). The study further aims to search out the most probable benefits and the constraints of use of VA in concrete mixes as partial replacement of cement. The VA has been used as partial replacement as percentage of Binder (with ratios as 0% (the Control Mix), 5%, 10%, 15%, 20%, 25%, 30%, 35% and 40% of Binder) to examine the impacts on mechanical and permeation properties of concrete. The W/B ratio (0.5) was kept the same for all the mixes. Slump Test was also performed to determine the workability of concrete for each above-mentioned ratio of VA. It was found that increasing the ratio of VA content in concrete reduced workability. The ideal concrete mix is known to have a 10% VA component in place of cement since it meets the requirements for both the Control Mix's mechanical and permeation qualities.

Keywords- Indigenous Volcanic Ash, Workability, Compressive Strength, Splitting Tensile Strength, Water Absorption, Permeability

1. Introduction

Over the past few decades, the construction industry has significantly contributed to urbanization and industrialization. Construction activities produce approximately 30% of waste and 40% of CO_2 emissions. The manufacture of hydraulic cement alone contributes to roughly 7-9% of the total global carbon dioxide emissions [1]. Cement factories account for approximately five percent of the world's carbon dioxide emissions. We can reduce CO_2 emissions in construction by using alternative cementitious materials instead of traditional cement. To protect the environment, regulate waste, enhance air quality, and preserve ecological integrity, the construction sector needs to incorporate sustainability. Several scholars have examined the use of volcanic ash (VA) in mixed cement [2]. Across the globe, over 50 nations yield volcanic ash (VA) and its associated products, such as pumice, in significant quantities. Italy stands out as one of the foremost producers of volcanic ash materials [3][4]. Other notable producers include Chile, Canada, Spain, Turkey, and the United States. Volcanic ash has been extensively researched as a potential substitute for cement, tested at varying proportions ranging from 0% to 20% [5][6]. The findings indicate that incorporating volcanic ash as a cement alternative enhances compressive strength [7]. Volcanic Ash (VA), a natural pozzolanic material abundant in Pakistan, is a potential candidate. This research aims to assess the impact of using VA as a partial replacement for cement on the mechanical and permeability properties of concrete, while also considering the potential cost benefits. This research aims to develop an eco-friendly and cost-effective concrete by partially replacing cement with a natural pozzolanic material, Volcanic Ash (VA), readily available in Pakistan. The primary goal is to investigate the influence of VA on the mechanical properties and durability properties of the concrete.

2. Research Methodology

2.1 Materials

In the study under consideration, locally manufactured Ordinary Portland Cement has been used that met the required ASTM C-150 Type-1 (Normal) [8]. The indigenous VA has been used obtained from the source situated in Chilas (Gilgit Baltistan), Pakistan. This investigation utilized naturally sourced coarse sand from the Lawrancepur quarry as the fine aggregate (FA) in the concrete blends. Moreover, well-graded granite crushed aggregate from Margalla Hills served as the coarse aggregate. Various tests were conducted to assess different properties of the concrete. Workability was evaluated following ASTM C-143 standards [9], compressive strength was measured in accordance with ASTM C-39 [10], splitting tensile strength was assessed per ASTM C-496 guidelines [11], permeability testing followed IS-3085 standards, and water absorption testing was conducted as per ASTM C-642 [13].

2.2. Mix Proportioning

The mix proportioning for the various concrete mixes is given below in Table 1. The samples were cured for 28 days under ambient temperature.

Table 1: Concrete Mix Proportions

Mixes	**OPC (Kg/m^3)**	**VA (Kg/m^3)**	**Water (L/m^3)**	**FA (Kg/m^3)**	**CA (Kg/m^3)**
Control Mix i.e. VA-00	320	0	160	640	1280
VA-05	304	16	160	640	1280
VA-10	288	32	160	640	1280
VA-15	272	48	160	640	1280
VA-20	256	64	160	640	1280
VA-25	240	80	160	640	1280
VA-30	224	96	160	640	1280
VA-35	208	112	160	640	1280
VA-40	192	128	160	640	1280

3. Results and Discussions

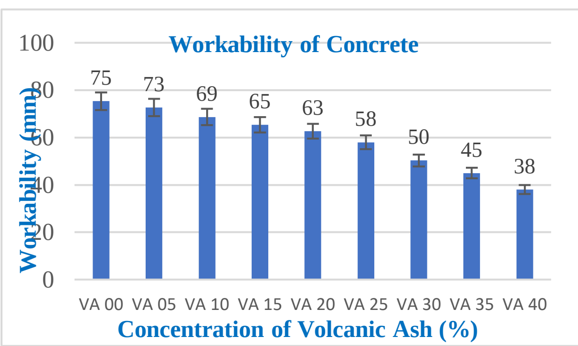

Figure 1: Workability Results of Concrete Mixes

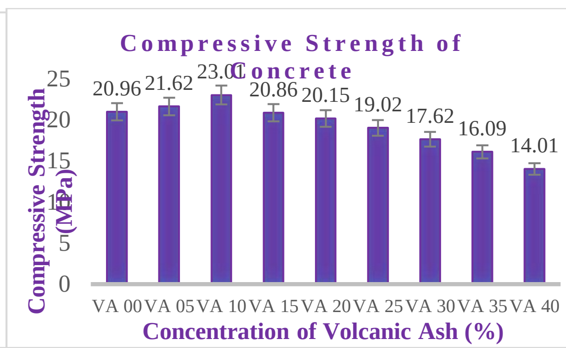

Figure 2: Compressive Strength Results of Concrete Mixes

3.1. Workability Test

It is clear from the graphical representation workability results in Figure 1 that it has decreased with the increased concentrations of the VA in the concrete. VA-40 has slump as 38 mm which is nearly 49% less than that of control mix concrete. It may be said that workability of fresh concrete decreases by increasing the concentration of the VA in the same that is most likely due to that the VA had smaller particle size and higher value of fineness making it more absorbable upon addition of water.

3.2. Compressive Strength Test

The compressive strength results have been represented in the Figure 2. Upon addition of VA, at first the compressive strength increases but then tends to decrease. The maximum compressive strength of concrete is with VA-10 (nearly 9.8% more than that of VA-00). Exothermic chemical reaction beween cement and water produces C-S-H gel, a cemetious compound and C-H, a non-cementious one. When VA is added, it reacts with C-H resulting into production of cemetious compounds in addition which ipmroves the strength upto VA-10 as compare to VA-00. Further increase in concentration of VA, will result in decrease in the strength as excessive quantity of VA beyound requirements of produced C-H will act as only a non cemetious fine agrregates like sand. It may also be because of enhanced substitution of cement with VA, lowering the cementious proportions in the mix [14].

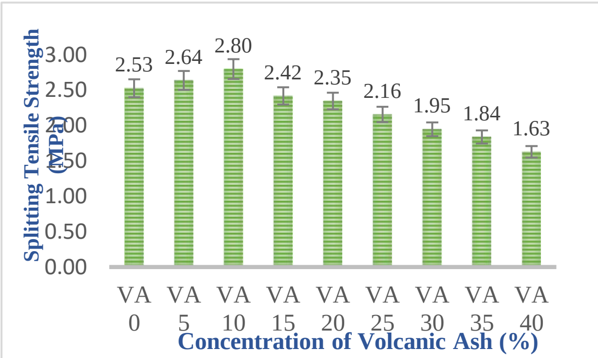

Figure 3: Spilitting Tensile Strength Results of Concrete Mixes

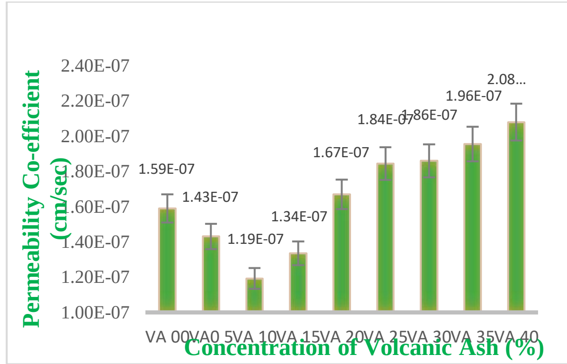

Figure 4: Permeability Test Results of Concrete Mixes

3.3 Splitting Tensile Strength Test

The obtained results for splitting tensile strength have been represented in the Figure 3. Once the VA is added to the concrete, at first the spilitting tensile strength of the concrete increases but then tends to fall down. The maximum value was obtained for the Mix VA-10 (nearly 9.6% more than that of VA-00). The values of tensile strength of concrete are more than that of VA-00 with the concentrations of VA-05 and VA-10 whereas the values of tensile strength are less than that of control mix having concentrations of VA-15 or higher. It could be due to the chemical reaction of SiO_2 in VA with C-H. As a result, the amount of C-H reduced while C-S-H increased, improving the splitting tensile strength of concrete. As IVA increases from 15% to 40%, the splitting tensile strength of concrete decreases. It could be because replacing cement with IVA decreases the cement content of the mix [15].

3.4 Permeability of Concrete

The obtained results for permeability of concrete have been represented in the Figure 4. When VA is added to the concrete, at first the permeability of the concrete decreases but then tends to rise after having the lowest value at VA-10. The minimum said preamability of concrete is with the concentration of VA-10 (nearly 25% more than that of Control Mix). However, due to further increased concentration beyond VA-15, high porosity of VA due to its fine particles results in overall porosity of the Concrete i.e., resulting into increased Permeability as compare to that of VA 10.

3.5 Water Absorption Test

Figure 5 illustrates the water absorption outcomes for various concrete blends. Upon the addition of volcanic ash to the concrete mixtures, there is initially a decline in water absorption. However, this trend shifts after reaching its minimum at VA-10, with water absorption tending to increase thereafter.The minium said water absorption is with the concentration of VA-10. However, due to further increased concentration beyond VA-15, high porosity of VA due to its fine particles results in overall porosity of the concrete.

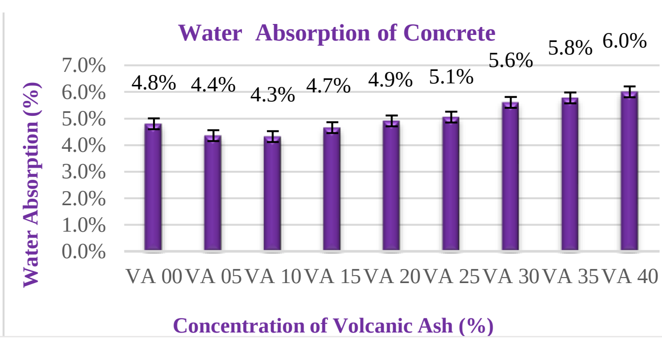

Figure 5: Water Absorption Results of Various Concrete Mixes

4. Conclusions and Recommendations

This comprehensive study on cement replacement in concrete yields several key findings:

- The slump value of Concrete VA-40 is approximately 50% lower than that of the Control Mix Concrete (VA-00).
- The compressive strength of Concrete VA-10 at 28 days exhibits the highest value, with an increase of nearly 9.8% compared to the Control Mix (VA-00).
- Similarly, the splitting tensile strength of Concrete VA-10 at 28 days achieves the maximum value, showing an improvement of approximately 10.7% over the Control Mix Concrete (VA-00).
- Concrete VA-10 demonstrates the lowest coefficient of permeability at 28 days.
- Moreover, the water absorption of Concrete VA-10 at 28 days records the lowest value among the studied mixes.

A few recommendations based on the same, are stated as under:

- It is advisable to work on other properties like Shrinkage Analysis and Toughness Testing of Concrete using VA as SCM would provide valuable insights.
- Study on Bricks made from the Concrete using VA as SCM as well as partial use of VA in making Bricks conventionally.

5. Acknowledgements

I am very much thankful to Mr. Hassan Akhtar and Chaudhary Hassan Nisar for their kind support in this research work at the Concrete Technology Lab in the Department of Civil Engineering, University of Engineering and Technology, Taxila.

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