Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 81 (1999)

Artikel: Properties of volcanic ash and pumice concrete

Autor: Hossain, Khandaker M.A.

DOI: https://doi.org/10.5169/seals-61426

Properties of Volcanic Ash and Pumice Concrete

Khandaker M. A. **HOSSAIN**
Lecturer in Civil Engineering
The PNG University of Technology
Lae, Papua New Guinea

Khandaker M. A. Hossain, born in 1963, received BSc and MSc in civil engineering from Bangladesh University of Engineering & Technology, Dhaka and PhD from Strathclyde University, Glasgow, UK. Previously, he worked as a Research Fellow, in the Department of Engineering, University of Aberdeen, UK and also as an assistant professor of Civil Engineering in Bangladesh. He received 1998 Ken-Francis award for his research on blended cement.

Summary

The properties of concrete using different percentages of volcanic ash (VA) and pumice (VP) as cement and aggregate replacements respectively are evaluated by conducting comprehensive series of tests. Tests were conducted by using up to 50% of VA and up to 100% of volcanic pumice aggregate (VPA) in the concrete mix. The concrete properties in both fresh and hardened states are evaluated. Results showed good potential for the manufacture of concrete using VA and VP. It is intended to develop design charts that can be used as guidelines for mix design of volcanic ash and pumice concrete.

1. Introduction

The search for cement replacement materials and new aggregates for concrete had been continuing for the last decades. This paper is focused on the use of volcanic ash and pumice in concrete production with particular preference to Papua New Guinea. The 1994 volcanic eruption that occurred in the East New Britain province devastated the province and created an environmental disaster. This research is put forward to explore the possible utilisation of this volcanic debris in concrete production that can not only provide low cost cement and concrete but also can help to decrease environmental hazard. Volcanic ash and pumice powder [1, 2,3] are pozzolanic materials and can form cementitious compounds because of their reaction with lime, liberated during the hydration of cement. These materials can also improve the durability of concrete and the rate of gain in strength and reduce the rate of liberation of heat that is beneficial for mass concrete.

Recent research [3] suggested that the production of Portland volcanic ash cement (PVAC) or Portland volcanic pumice cement (PVPC), similar as Portland fly ash cement (PVFAC), is possible by using up to 20% VA or VP with cement. On the other hand, the potential use of comparatively weaker and porous volcanic pumice as lightweight aggregate in concrete can be very useful. Nevile [4] described that satisfactory concrete which is 2 to 3 times lighter than normal concrete having good insulating characteristics with high absorption and shrinkage can be manufactured using volcanic pumice. Currently research is ongoing [5] on the use of light weight volcanic pumice concrete (VPC) in thin walled filled sections intended to be used as beams and columns for houses in volcanic areas. The light weight and enhanced ductility make this form of construction suitable and economic for earthquake prone areas especially in the context of Papua New Guinea. The optimum use of VA can improve workability [6,7] of concrete and can provide low cost volcanic ash concrete (VAC) of satisfactory strength. This paper describes the properties of VAC and VPC in connection with percentage of VA (as cement replacement) and VPA (as stone aggregate replacement) used in the concrete mix.

2. Experimental study

2.1 General Remarks

The volcanic ash (VA) and pumice (VP) used in this study were collected from the Rabaul area in the East New Britain province of Papua New Guinea and the source is a volcano called Mount Tavurvur (see Fig 1).

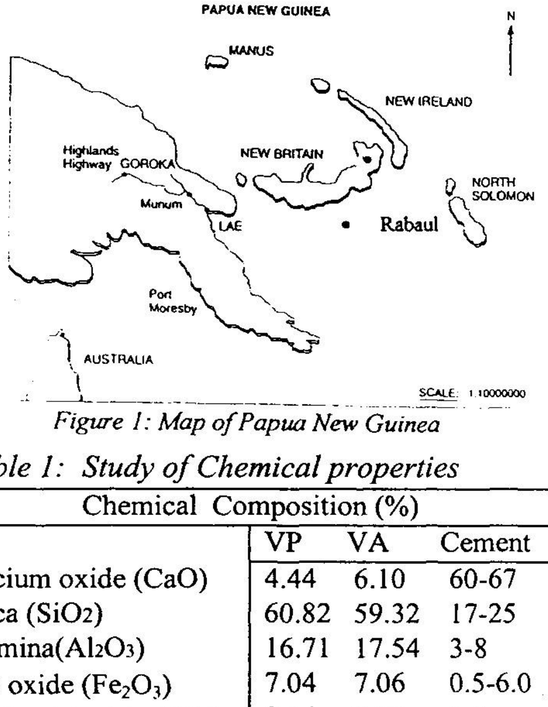

Figure 1: Map of Papua New Guinea

Chemical analysis (Table 1) indicated that the VA and VP have similar composition, composed principally of silica (about 60%) along with cementitious compounds like calcium oxide, alumina and iron oxide (total about 31%). 20 and 10mm maximum size aggregates with river sand are used for VAC while 20mm maximum size VPA with river sand are used for VPC. The cement used was locally manufactured Portland cement called 'Paradise'.

Table 1: Study of Chemical properties

Chemical Composition (%)			
	VP	VA	Cement
Calcium oxide (CaO)	4.44	6.10	60-67
Silica (SiO_2)	60.82	59.32	17-25
Alumina(Al_2O_3)	16.71	17.54	3-8
Iron oxide (Fe_2O_3)	7.04	7.06	0.5-6.0
Sulphur trioxide (SO_3)	0.14	0.71	1-3
Magnesia (MgO)	1.94	2.55	0.1-4.0
Sodium oxide (Na_2O)	5.42	3.80	0.5-1.3
Potassium oxide (K_2O)	2.25	2.03	0.5-1.3
Loss on ignition	1.52	1.03	1.22

2.2 Tests on VAC and VPC

Mix details

The particle size distribution of aggregates performed according to AS (Australian Standard) 1289.C6.1-1977 are presented in Fig 2. VPA (bulk density of 763 kg/m^3) is found to be 3.24 times lighter than normal stone aggregate (bulk density of 2470 kg/m^3). High degree of porosity in VPA leads to almost 13 times higher water absorption (37%) than normal stone aggregate (2.86%).

Volcanic ash concrete (VAC)

A series of tests was carried out to investigate the possible manufacture of concrete using volcanic ash and also to determine the variation of compressive strength with varying percentage of volcanic ash added as cement replacement. The mixes have constant water cement ratio and manufactured from same aggregates producing mixes of variable workability.

The concrete mixes are classified into six mixes according to the percentage of cement replaced by volcanic ash. All concrete mixes had the same over all ratio of 1:2:4 (cement including VA : sand: aggregate) on the volume basis. After calculation of the volume required for the cement including volcanic ash, it was transformed into weight on the basis of cement. Then from the equivalent weight of cement, the amount of volcanic ash was calculated based on % cement replacement by weight. The coarse aggregate consisted of 70% of 20 mm with 30% of 10 mm maximum size crushed gravel. River sand was used as fine aggregate. The mix parameters and some characteristics of the fresh concrete are presented in Table 1. The first numeric in the mix designations represents % of volcanic ash and the second numeric represents aggregate cement (cement including VA) ratio by weight.

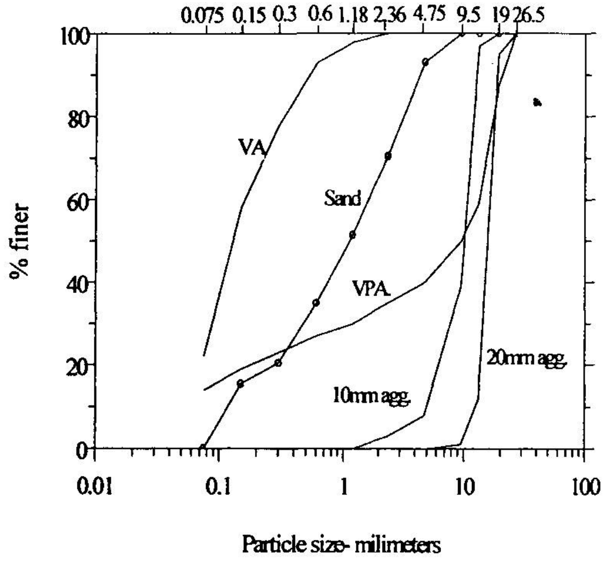

Figure 2: Particle size distribution

Table 2: VAC and VPC mix details

VAC mixes				VPC mixes			
Mix	Cement kg/m³	VA kg/m³	W/ (C+VA) ratio	Mix designation	VPA kg/m³	10mm agg. kg/m³	NW/C * by weight
Aggregate - (C+VA) ratio =4.95				VPC Mix-1: 1:2:3 , Cement =814 kg/m³			
0-4.95	438	0	0.354	100-36.9-2.38	358	0	0.465
5-5.21	416	22	0.368	90-25.6-2.55	322	119	0.44
15-5.83	372	66	0.368	75-19.4-2.80	268	297	0.39
25-6.61	328	110	0.381	50-11.3-3.22	179	594	0.376
35-7.61	285	153	0.409	0-0-4.07	0	1188	0.36
50-9.90	219	219	0.461				

W=water ; C=cement ; * Net water excluding water absorbed by VPA

Volcanic pumice concrete (VPC)

A series of tests was performed using different percentages of volcanic pumice as replacement of coarse aggregate in concrete. The concrete mixes had the over all ratio of 1:2:3 (mix 1) and 1.2:4 (mix 2) on volume basis. Each of the two mixes were classified into five sub-mixes according to the % of VPA as a replacement of normal coarse aggregate (by volume). The coarse aggregate consisted of 10 mm maximum crushed gravel and VPA with river sand as fine aggregate. The mix parameters and some characteristics of the fresh concrete for mix 1 are presented in Table 2. The first numeric in the mix designations represents % of VPA of total coarse aggregate by volume, second numeric represents % of VPA of total aggregate by weight and the third numeric represents total aggregate cement ratio by weight.

Test specimens and testing procedure

The test specimens were cast using the optimum water-cement ratio for each mix. The specimens were 100 x100x100 mm cubes and 100 x200 mm cylinders for compressive strength. Total 4 cubes were cast from each sub-mix. The samples were compacted on a vibrating table. The specimens were demoulded after 24 hours and cured under water at a temperature of 23 ±2°C until tested.

3. Results and Discussion

3.1 Properties of fresh VAC and VPC

The investigation on fresh VAC suggested that the workability of the mix increases (slump value increased from 80mm to 140mm) as the % of VA is increased from 0 to 15% and increase of VA beyond 15% (up to 75%) reduces the workability (slump value decreased from 140mm to 40mm). This confirms the possibility of using VA as water reducing admixtures and research is now ongoing on this aspect. More water is needed to get a workable mix as the % of VPA is increased from 0 to 100%. The total water requirement is much higher due to high water absorption capacity (about 37%) of VPA as well as the presence of higher quantity of fines in the VPA compared to replaced 10 mm aggregate. The high absorption of water by VPA in the initial stages of mixing, can cause balling-up of cement and a loss of slump. To avoid this, the aggregate was first mixed with at least one half of the mixing water before cement was added into the mixer. For 100% VPC, a slump of 50 to 60 mm represents satisfactory workability compared to 80-82 mm slump for 0% VPC. However, to make VPC with 50 to 100% VPA having satisfactory workability, the range of slump values should be 50 to 75 mm.

3.2 Properties of hardened VAC and VPC

The variation in compressive strength (cylinder) of VAC with different percentages of VA is shown in Fig 3. As expected, strength decreased as the VA content increased. It is possible to obtain a concrete having 28 days strength of 25 MPa with VA content of 35%. It is found that the strength of the VAC reduced sharply when the VA content is increased beyond 35%. The specimens were found to disintegrate when 50% VA was used. Higher alkali presence in the VA may have caused the disintegration of concrete due to reaction with some aggregate and also may have affected the rate of gain in strength of cement.

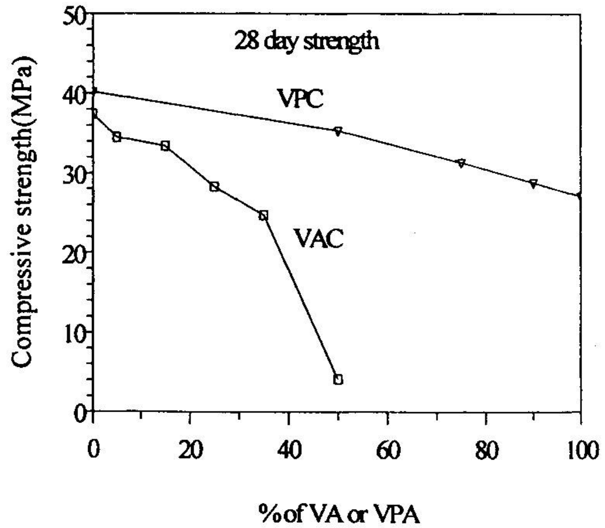

Figure 3: Compressive strength of VAC or VPC

The variation in the 28-day compressive strength (cylinder) of VPC (1:2:3) with different percentages of VPA is also shown in Fig 3. As expected, strength decreased with the increase of VPA due to the replacement of normal stone aggregate by relatively weak pumice aggregate. Results showed that by using 100% VPA, it is possible to obtain a VPC of 27 MPa (1:2:3) and 22 MPa (1:2:4). The variation of density of VAC at 28 day with percentage of VA is presented in Fig 4. The variation of density of VAC at 28 day with percentage of VA is presented in Fig 4. The density of VAC decreased with the increase of VA . This is due to the replacement of comparatively heavier cement by lighter VA. The fresh density is found to be higher than those at 7 and 28 days due to subsequent removal of water from the fresh specimen with age. The density is found to be decreased with ages. For 50% replacement of cement by volcanic ash, it is possible to produce a VAC only 5% lighter than the normal concrete. Use of 100% replacement of coarse aggregate by VPA (designated as 100% VPC) can produce a VPC 25% lighter than the normal concrete (see Fig 4).

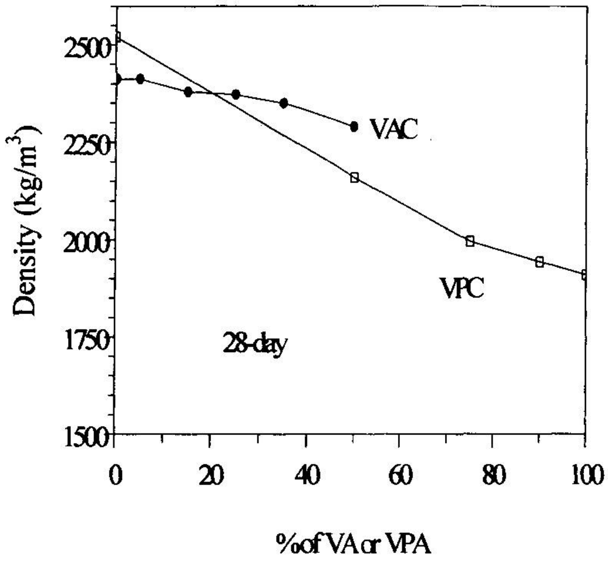

Figure 4: Variation of Density of VAC

4. Design charts

It is aimed to produce design charts for VAC and VPC relating mix design parameters. A preliminary chart showing the prediction of cylinder strength for a particular VAC mix is shown in Fig 5.

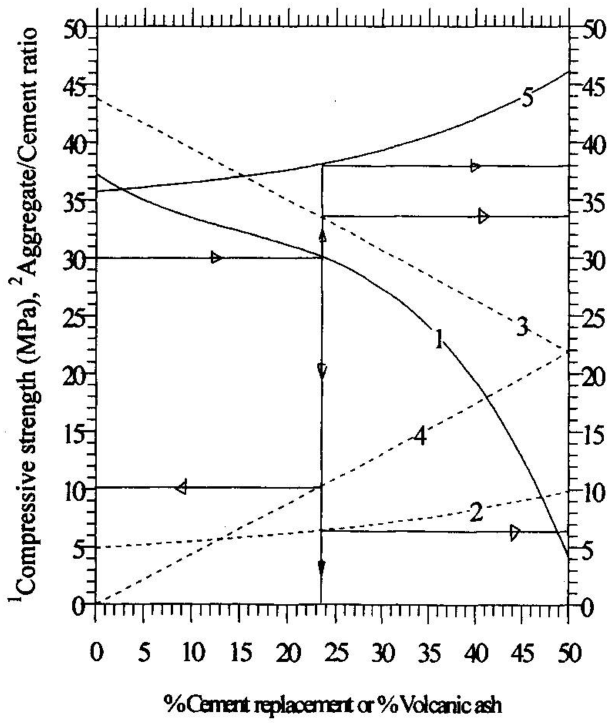

Figure 5: Typical mix design chart for VAC

The numeric superscripts in the y-axis label identify the designated curve number shown in the body of the graph. The chart illustrates through arrow diagrams, the determination of mix design parameters for a 30 MPa VAC. For 30 MPa concrete, mix design parameters are: amount of cement (curve 3) =336kg/m^3, amount of volcanic ash (curve 4)=102 kg/m^3, % of volcanic ash=23.6, aggregate cement ratio(curve 2)=6.3 and W /(C+VA) ratio (curve 5) =0.38 (38%). The design mix will also satisfy the workability requirement. This chart is valid only for similar conditions of VA and aggregate described in the paper. The reliability [6] of the charts is to be checked based on repeatability of the test results and comprehensive series of tests on mix-design procedures for various mixes is now under progress towards that objective.

5. Conclusions and future research

Results showed that by using up to 35% VA, it is possible to obtain a VAC of 25 MPa (28 day). Use of 50% VA can produce a VAC only 5% lighter than the normal concrete. It possible to obtain a VPC of strength 27 MPa and 25% lighter than the normal concrete. Design charts are developed which can be used as guidelines for mix design of VAC and VPC. It is confirmed that the volcanic ash and pumice can be used as a resource in concrete production and can be used in low cost construction especially in the post-disaster rehabilitation project in the volcanic areas of Papua New Guinea. More work is needed and currently research is in progress to investigate short and long term behaviour of VAC and VPC including shrinkage, durability, permeability, corrosion and fire resistance.

6. Acknowledgements

The author is grateful to the Papua New Guinea University of Technology for providing financial assistance in this project. The author is also grateful to the Technical staffs of the materials laboratory of the Department of Civil Engineering and National Analysis laboratory.
Sincere thanks to Mr. Jabin Basitau and Mr. Sariman of the department of Civil Engineering for their assistance.

7. References

1. Swamy, R.N.,"Cement Replacement Materials", Concrete Technology and Design, Vol.3, Surrey University Press, Great Britain,1986.

2. Swamy, R.N., "New Concrete Materials", Concrete Technology and Design, Vol.2, Surrey University Press, Great Britain, 1983.

3. Hossain, K.M.A, "Volcanic ash and pumice based blended cement", Proce. of 23rd Conference on Our world in Concrete & Structures incorporating 3rd International Seminar on blended cements, Singapore, 24 August, 1998, pp. 297-302.

4. Nevile, A.M., "Properties of Concrete", 3rd Edition, Pitman Publishing Limited, London, 1981.

5. Hossain, K.M.A., " Behaviour of thin walled composite sections as structural elements",Proce. of the Australasian Structural Engineering Conference, Auckland, 30 Sept.-2 Octo., 1998, vol. 1, pp. 175-180.

6. Hossain, KMA, "Effect of volcanic ash as cement replacement material in cement and concrete", Under preparation for possible publication in the Journal of ACI.

7. Hossain, K.M.A. " Volcanic ash as cement replacement material ", Proce. of the IEPNG International Conference, September 25-27, 1998, Rabaual, PNG, pp. 26-31.