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Use of Volcanic Debris in Innovative Construction and for Sustainable Development of Volcanic Areas

K. M. A. Hossain and M. Lachemi
Department of Civil Engineering, Ryerson University, Toronto, ON, Canada

Abstract

This paper demonstrates how the cause of natural and environmental disaster can be transformed into natural resource that can be used for sustainable development. Comprehensive research has been carried on the use of volcanic debris such as: volcanic ash (VA) and pumice (VP) to manufacture blended cement, lightweight concrete and composite structural elements that are suitable for the construction of environmentally friendly low-cost houses and shelters especially for the volcanic areas. Recommendations and patents have been developed for the cement industry, ready mixed concrete companies and construction industries for the manufacture of such construction materials and building components. It is interesting to make practical applications of the developed structural elements and materials in the development works of volcanic disaster areas.

Keywords

Volcanic ash, volcanic pumice, sustainable construction, cement, concrete

1. Introduction

Volcanic activities are common for a country like Papua New Guinea (PNG). The 1994 volcanic eruption that occurred in the East New Britain province was the second destructive one in history, which devastated the province and created an environmental disaster (Blong-Aislabe 1988). In addition to economic impacts, volcanic disasters have social and environmental effects related to commerce, industry, wildlife, aesthetics and other environmental qualities, relocation and rehabilitation of people, disruption of social and cultural patterns. It is imperative that engineers, planners and builders should deeply consider the major social and environmental concerns. It has been seen that the debris of volcanic eruption are the major sources of devastation. Even the emission of volcanic ash (VA) and its subsequent down fall to the earth can destroy the social and environmental structure as seen in the past in PNG and other parts of the world.

Mount Pinatubo in the Philippines erupted in the early 1990's and a fertile beautiful valley was totally overrun by hot volcanic lava. Presently much of the valley is a wasteland and a source of volcanic pumice (VP). This VP was used as useful building materials for constructing affordable housing and also shipped to Vietnam where a 36-sq. meter model home was built. One interesting outcome of the work in Vietnam was the experimenting of a hybrid wall made of pumice-crete reinforced with bamboo- a material, which is plentiful in the area. The insulating properties of the pumice-crete were very beneficial in the hot climate of South Vietnam (Hossain 1999a). The Caribbean Island of Monseratt has recently witnessed one of its volcanoes erupting and emitting large quantities of VA and VP in the lava flows. Of course these volcanic eruptions are very dangerous catastrophes but what they leave after the danger has passed is often a very useful material. The removal of the volcanic debris is a major cause of concern for the post disaster rehabilitation and development works. One way to get rid of the debris is to use them as construction materials in the development works.

Research had been conducted to explore the possible utilisation of volcanic debris such as VA and VP in blended cement (Hossain 1998a, 1999b), concrete (Hossain 1999a) and structural element development (Hossain 1998b, 1999c) which can, not only provide low cost construction but can also help to decrease environmental hazard. The detailed presentation of the research findings is not the aim of this paper rather it will present some of the findings which will encourage the construction industry to use ash and pumice based cement, concrete and structural elements. Proposed structural elements can be used as beams, columns and walls to build houses and utility structures in volcanic areas. Fruitful utilisation of volcanic debris can lead to the sustainable development by reducing greenhouse gas (GHG) emissions, providing low cost housing, creating jobs and improving the environmental conditions.

2. Sustainable Development with Volcanic Debris

Sustainable development can be defined as economic activity that is in harmony with the earth's ecosystem. The definition of sustainability, emphasizes the importance of ensuring the satisfaction of present need without compromising the ability of future generations to meet their own requirements. Sustainable development achieves social, economic and environmental objectives in parallel (Howard 2000). For the construction industry, sustainability means: progress that meets the needs of the society, economic development, preservation of environment and efficient use of resources. Sustainable development is also related to eco-efficiency, which include the reduction of material and energy efficiency of products, reduction of toxic emissions, maximization of sustainable use of renewable resources and enhancement of material recyclability, product durability and service life. New technologies can be used to reduce the harmful effects of the concrete industry on our environment. The use of volcanic debris can reduce and control these problems and ensure sustainable development.

The manufacturing of Portland cement contributes significantly to CO_2 emissions and to the intensive use of natural resources. CO_2 is the primary gas for greenhouse effect and global warming. For the production of cement, about 50% emissions are due to the calcinations of limestone and 50% are due to the combustion of fossil fuels (Malhotra, 2000). The production of cement has increased within the last century from less than 2 million tones in 1880 to more than 1.3 billion in 1996 worldwide (Mehta 1999). The effect of Portland cement industry on our environment is evident as the production of Portland cement accounts for 7% of CO_2 produced around the world. For every tonne of cement produced, one tonne of CO_2 is released into our atmosphere including minor amounts of NO_X and CH_4. With the current trend in cement production, future damage to the world environment is very critical.

Development of new cement technologies and their implementation to the sustainable development is vital to protect the environment. The use of supplementary cementing materials (SCM) such as fly ash, slag, silica fume, etc in blended cement and concrete production, so far, remains an effective way of controlling CO_2 emissions (Malhotra 2000, Lambros et al. 2003). Likewise, the use of volcanic debris can be extremely effective in developing blended cement and concrete for the goals of sustainable development. The advantages of using volcanic debris from a conservation view point are two fold: reduction of the Portland cement content in concrete - a way of lowering GHG emissions and creation of a safe, effective and environmentally friendly means of disposal of natural hazards.

3. Volcanic Ash and Pumice in Blended Cement Production

VA and VP used in this investigation were collected from the Rabaul area in the East New Britain province of PNG and the source was a volcano called Mount Tavurvur. Chemical analysis indicated (Hossain 1998a) that both VA and VP have compounds like calcium oxide, alumina and iron oxide (total about 31%). VA (fineness of 242 m^2/kg) is found to be much coarser than Portland cement (fineness of 320 cm^2/kg), which may lead to the increase of setting time. The fineness of VPP was 285 m^2/kg and could be controlled by the user during grinding process.

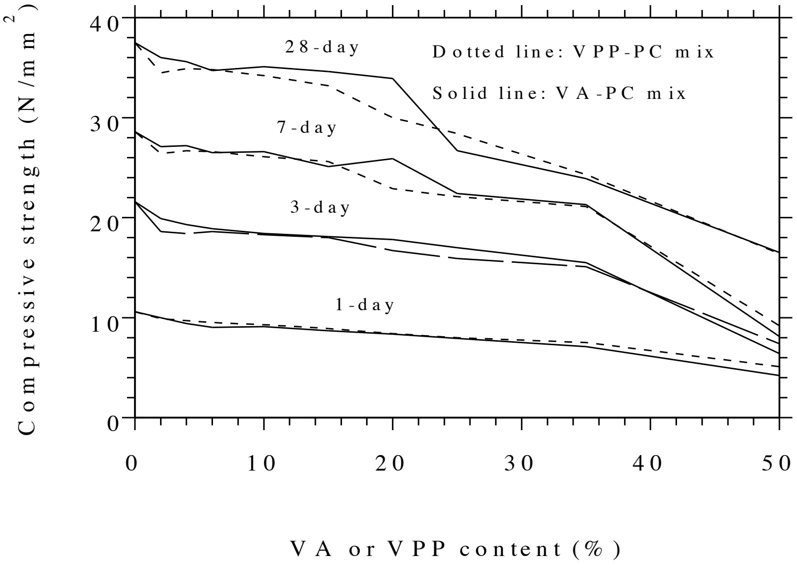


Figure 1: Compressive strength blended cements

Research included investigations on the possible use of VA and VPP (volcanic pumice powder) as cement replacement material. The results showed an increase in setting times and a decrease of compressive strength with the increase of the percentages of VA or VPP in blended cements. The typical variation of compressive strength of blended cement with different % of VA and VPP is shown in Figure 1. Manufacture (Hossain 1998a, 1999a) of blended PVAC (Portland volcanic ash cement) and PVPC (Portland volcanic pumice cement) similar to PFAC (Portland fly ash cement) of type FC (as per Australian Standard: AS1317, 1982) is possible with a maximum replacement of up to 20%. A possible use of PVAC and PVPC will be in mass concrete construction due to lower heat of hydration as a consequence of higher setting time compared to Portland cement. Results showed that by using 35% VA or VPP, it is possible to obtain a mortar having a strength of 24 MPa (28-day) using locally available sand which is acceptable for normal construction use in the context of PNG and other volcanic areas.

4. Volcanic Ash and Pumice in Concrete Production

Comprehensive series of tests were conducted (Hossain 1999a) to investigate the properties of volcanic pumice concrete (VPC) using volcanic pumice as coarse aggregate (VPA). The concrete mixtures were prepared by replacing normal coarse aggregate by VPA on volume basis (ranging from 100% to 50%). Results showed that by using 100% VPA, it was possible to obtain a VPC (28-day compressive strength ranged between 22 MPa and 27 MPa) which satisfied the criteria of structural lightweight concrete. Use of 100% replacement of normal coarse aggregate by VPA can produce a VPC of 25% lighter than the normal concrete. The strength of VPC decreased with the increase of VPA content due to comparatively weaker VPA (Figure 2). The shrinkage and permeability in VPC are found to be higher than those in the representative normal concrete (Hossain and Uy 1999).

Tests were performed (Hossain 1999a) to investigate the properties of volcanic ash concrete (VAC) using different percentages of VA (varying from 0 to 50%) as replacement of cement. The concrete mixtures were classified according to the % of cement replaced by VA. The coarse aggregate consisted of 70% of 20 mm with 30% of 10mm maximum size crushed gravel and river sand was used as fine aggregate. Strength of VAC decreased (Figure 3) with the increase of VA content. Results showed that by using 35% VA, it was possible to obtain a VAC of 25 MPa (28-day). Use of 50% VA could produce a VAC of only 5% lighter than the normal concrete. The increase in permeability with the increase of VA was prominent in the early stages but the reduction of permeability with age might have beneficial effect of improving the long-term corrosion resistance of VAC. Although the shrinkage in 20% VAC was higher than those in 35% and 50% VAC but the over all shrinkage was higher than the normal concrete (0% VA) (Hossain and Uy 1999).

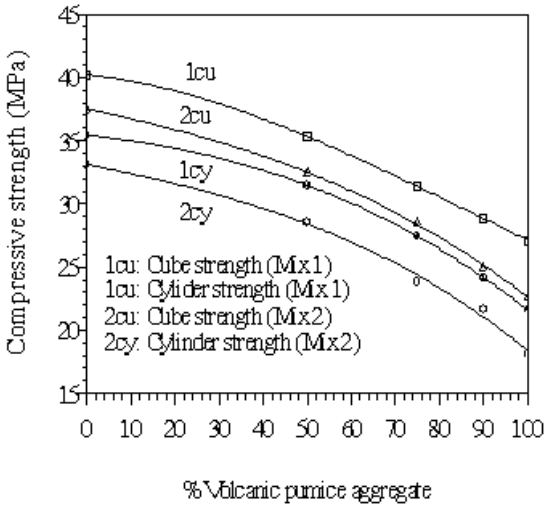


Figure 2: Effect of VPA on VPC strength

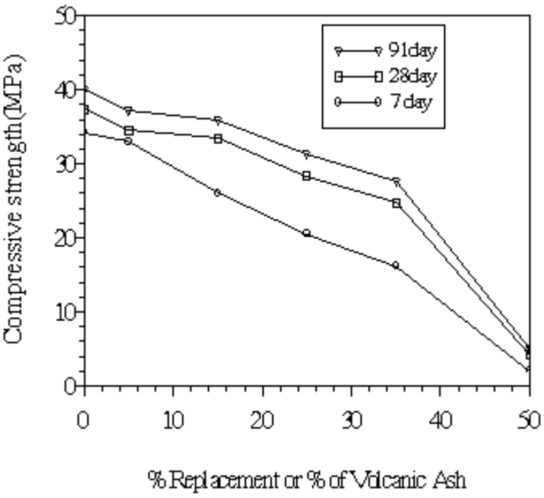
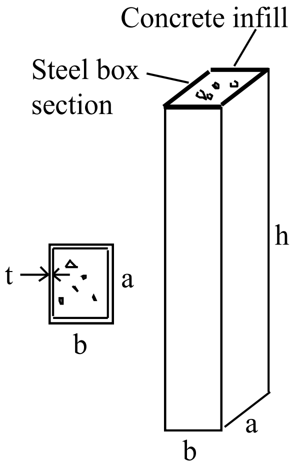


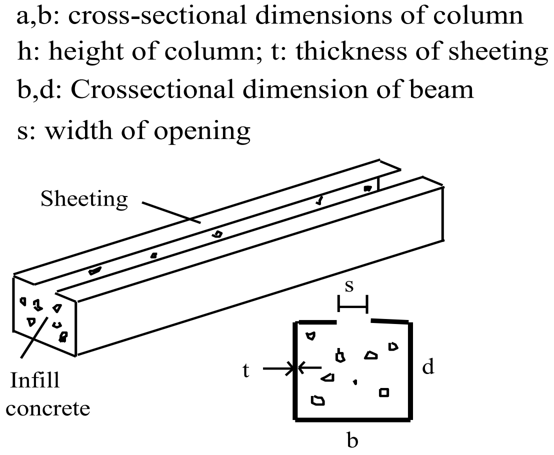
Figure 3: Effect of VA on VAC strength

5. Construction Application of VAC and VPC

VAC and VPC can be used in the construction of traditional building with thin walled composite (TWC) beams, columns and walls as shown in Figure 4. The TWC walls consist of double skins of steel sheeting with an infill of VAC or VPC. The following structural advantages can be gained from this form of construction:

- very light construction weight generally and can be reduced further by 25-35% using VPC
- ductile beam-column frame with possible semi-rigid connections; infill panel of TWC wall with frame can resist the earthquake forces in building; speedy construction due to simple fabrication and erection; excellent potential for pre-cast construction.





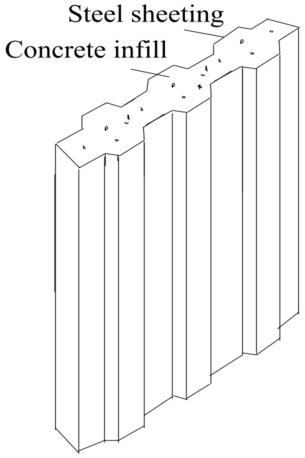


Figure 4(a): TWC columns **Figure 4(b): TWC beam** **Figure 4(c): Wall**

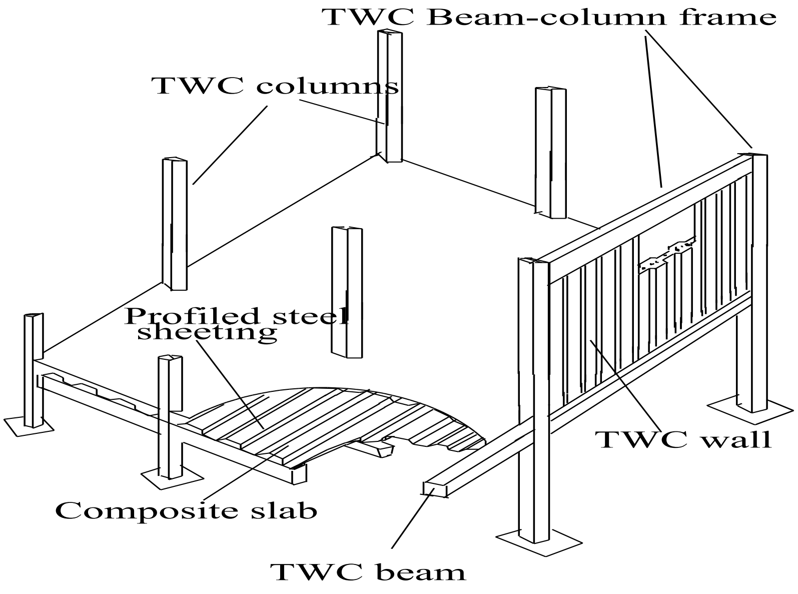


Figure 4(d): Schematic of a typical future TWC building

Comprehensive series of tests had been carried out to investigate the behaviour and potential use of TWC sections as columns, beams and walls (Figure 4). It was found that the TWC elements comparable to normal concrete (NC), could be manufactured using VAC and VPC as in-fill. The performance of VPC in TWC sections was found satisfactory and in future, VP can be used as a potential source of aggregate. The design guidelines for such elements with VAC and VPC are developed for the construction of medium to high-rise buildings in PNG.

In the context of PNG, the research was intended to answer the viability of this type of construction where the country is susceptible to earthquake. The viability of the structures in the light of structural performance, feasibility in fabrication and economy was assessed. In this regard, the TWC sections are suitable structural elements as confirmed from their advantages. However, structural performance should also be related to feasibility and economy. For feasibility assessment, the co-ordination between manufacturing and construction industry is needed. With this system the steel strip is reasonably cheap to import and the cost of setting up a rolling mill is acceptable in quite poor countries. The manufacturing of sheeting locally will provide economy. In this system, infill concrete does not need high strength as its main job is to prevent local buckling of the sheeting in addition to ensure mechanical interlock between steel and concrete. It is possible to use low strength, low cost and lightweight concrete manufactured from locally available materials such as VA and VP.

The building of an elegant structure satisfying structural (strength associated with ductility and lightness), construction (feasible and simple) and economic (low cost) requirements is vital for PNG and in the future, it is possible that TWC sections will meet those requirements and can lead to the construction of high rise buildings in PNG.

6. Conclusions

This paper demonstrates how the cause of social and environmental disaster can be transformed into a natural resource through use of appropriate technology and hence can be used in sustainable construction especially in the post-disaster rehabilitation projects in volcanic areas. It is confirmed that the volcanic ash and pumice can be used as a resource in cement and concrete production and can be used in low cost construction in Papua New Guinea.

7. Acknowledgement

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