FIRE DURABILITY OF VOLCANIC PUMICE CONCRETE WITH SPECIAL REFERENCE TO THIN WALLED FILLED SECTIONS

Durability of volcanic pumice concrete

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Abstract

This paper concentrates on the durability of volcanic pumice concrete (VPC) subjected to fire or elevated temperature. Performance is judged based on strength and physical changes of VPC specimens as well as thin walled composite (TWC) filled sections using VPC as in-fill. Investigation suggests that it is possible to produce a VPC that is 30% lighter than normal concrete and of satisfactory strength. Both VPC and TWC specimens are subjected to fire for different durations, maximum one hour. It is found that the strength of both types of specimens decreases with the increase of the duration of fire. The fire resistance of VPC in TWC section is found to be better than its individual fire resistance. Investigation is in progress towards the development of a design specification for fire resistance of VPC and TWC sections.

Keywords: Volcanic pumice, thin walled composite, fire, strength, light weight

1 Introduction

Pumice is a natural material of volcanic origin produced by the release of gases during the solidification of lava. The cellular structures of pumice is created by the formation of bubbles or air voids when gases contained in the molten lava flowing from volcanoes become trapped on cooling. The cells are elongated and parallel to one another and are sometimes interconnected. Volcanic pumice (VP) has been used as aggregate in the production of light weight concrete in many countries of the world. So far, the use of pumice was dependent on availability and limited to countries where it is locally available or easily imported. Nevile (1981) reported 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.

Volcanic activities are a common phenomena for a country like Papua New Guinea, and due to frequent volcanic eruption, volcanic debris such as volcanic ash (VA) and pumice are found abundantly (Hossain 1998a). 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. A comprehensive programme of research is put forward with motivation from local cement and construction industries in an attempt to explore the possible utilization of VA and VP in concrete production, which can not only provide low cost cement and concrete, but also helps to decrease environmental hazard. The research is conducted based on Papua New Guinea and local structural needs, so that its benefits can be utilized in low cost construction suitable for the ordinary people.

Current research by Hossain (1998b) included investigations on the possible use of VPP (volcanic pumice powder) as cement replacement material. The results suggested that the normal consistency and setting time of Portland cement are affected by the replacement of cement by VPP. Manufacture of blended PVPC (Portland volcanic pumice cement) similar to PFAC (Portland fly ash cement) of type FC (according to Australian Standard: AS1317, 1982) is possible with maximum replacement up to 20%. A possible use of this PVPC will be in mass concrete construction, due to lower heat of hydration and higher setting time compared to Portland cement. Results also showed that by using 35% 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 Papua New Guinea.

This paper will present the properties of volcanic pumice concrete (VPC) using VP as coarse aggregate (VPA), and especially its performance in thin walled composite (TWC) filled sections. The use of TWC sections is a new idea for beams and columns (Hossain 1998c; Hossain and Mol 1998; Hossain, Mol and Wright 1998), comprising cold formed steel elements with an infill of concrete that is suitable as replacement for hot-rolled steel or reinforced concrete in small to medium sized buildings. Typical TWC beams and columns are shown in Fig. 1.

The inherent advantages of this system are derived from its structural configurations. TWC sections do not require temporary form work for infill concrete, as the steel acts as form work in the construction stage and as reinforcement in the service stage. Advantages of this system also include a very light construction weight, excellent surface finish, relatively slender dimensions, enhanced ductility and the potential for semi-rigid connections. The infill concrete in TWC sections is less likely to be affected by adverse temperature and winds as experienced in the case of reinforced concrete. The in-fill concrete is generally cured quickly, and in any case, the load capacity of the steel alone may be relied upon for most construction loads.

TWC sections are more susceptible to fire, although the thermal mass of the concrete in-fill provides reasonable protection to most fire loads. This paper will mainly focus on the fire resistance of VPC in general and in TWC sections in particular.
2 Research significance

Research is now ongoing to investigate the potential of manufacturing VPC, and its use as light weight concrete in-fill in TWC sections. The improved performance of VPC in a confined environment will allow the use of comparatively low strength VPC in this form of construction, as the main function of the concrete in-fill is to prevent local buckling of the thin sheeting. With the use of VPC, weight can be reduced by a further 35% compared to normal concrete.

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 Papua New Guinea, and TWC section can meet these requirements. The viability of this form of construction should be assessed in light of structural performance, feasibility in fabrication, and construction 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 and use of locally available VP, will provide economy. The completion of this project will provide a foundation for the use of VPC and TWC sections in the construction industry of Papua New Guinea.

3 Experimental study

A series of tests were carried out on the use of VP as a cement replacement material and as a coarse aggregate in cement and concrete. The investigation was based on VP obtained from Tavurvur and Vulcan craters located in the Rabaul area of the East New Britain province of Papua New Guinea. A brief summary of the findings will be included in this paper as a background investigation.
3.1 Background investigation

Tests were conducted (Hossain and Kaio 1998) to investigate the effect of the replacement of normal coarse aggregate by different percentages of volcanic pumice aggregate (VPA) on the strength, modulus of elasticity and density of resulting volcanic pumice concrete (VPC). Typical concrete mix designs for VPC (using 100% VPA as coarse aggregate) and representative normal concrete (NC) using 100% normal stone aggregate are presented in Table 1. The coarse aggregate consisted of 10mm maximum crushed gravel (for NC) and VPA (for VPC), with river sand as fine aggregate. The particle size distribution of aggregates performed according to AS (Australian Standard) 1289.C6.1-1977 are presented in Fig. 2. VPA was found to be 3.24 times lighter than normal stone aggregate. Higher degree of porosity in VPA lead to almost 13 times higher water absorption than normal stone aggregate. Locally manufactured Portland cement called ‘Paradise’ was used in the concrete mixes.

![Particle Size Distribution Graph](image)

**Fig. 2: Particle size distribution**

**Table 1: Concrete mix designs**

<table>
<thead>
<tr>
<th>Mix designation</th>
<th>VPA kg/m$^3$</th>
<th>Normal aggregate kg/m$^3$</th>
<th>Sand kg/m$^3$</th>
<th>Cement kg/m$^3$</th>
<th>NW/C</th>
<th>TW/C</th>
</tr>
</thead>
<tbody>
<tr>
<td>VPC</td>
<td>412</td>
<td>0</td>
<td>704</td>
<td>426</td>
<td>0.46</td>
<td>0.82</td>
</tr>
<tr>
<td>NC</td>
<td>0</td>
<td>1372</td>
<td>704</td>
<td>426</td>
<td>0.36</td>
<td>0.48</td>
</tr>
</tbody>
</table>

NW: Net water; TW: Total water including absorbed water; C: Cement
The strength, modulus of elasticity and density of VPC and NC are compared in Fig.3. Results indicated that by using 100% VPA (designated as VPC), it is possible to obtain a VPC of 18 MPa (28-day cylinder strength: mix 1:2:4) and can produce a VPC that is 25% lighter than the normal concrete (NC: 0% VPA). The strength and modulus of elasticity (E) of VPC decreased with the increase of the percentages of VPA in the mix.

3.2 Investigations

The investigation concentrated on the performance of VPC under fire loading conditions. The performance was judged based on strength and physical changes of the VPC (only concrete) and TWC test specimens. The VPC mix used in the manufacture of test specimens in this investigation was similar to that described in Table 1. Two series of tests were conducted with detailed shown in Table 2.

Series A concentrated on normal VPC specimens with standard 150 mm x 300 mm cylinders as pure concrete test specimen. A total of 21 specimens were cast and cured under water before subjected to fire.

Series B included a total of 63 specimens consisting of 42 TWC columns with VPC in-fill and 21 VPC in-fill (only concrete having same dimensions as in-fill concrete in TWC columns) column. The specimens (Fig. 4) were 75 mm diameter circular columns having a height of 300 mm. TWC columns were manufactured by using thin steel sheeting of 0.4 mm thickness.

<table>
<thead>
<tr>
<th>Type</th>
<th>Specimen Designation</th>
<th>Features</th>
<th>No. of tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Series A (150mm x 300mm)</td>
<td>Cylinder</td>
<td>only VPC</td>
<td>21</td>
</tr>
<tr>
<td>Series B Cylindrical (75mm x 300 mm)</td>
<td>TWC column TWC (VPC in-fill column) VPC column</td>
<td>Steel &amp; VPC in-fill Steel &amp; VPC in-fill only VPC</td>
<td>21* 21 21</td>
</tr>
</tbody>
</table>

* subjected to fire as TWC but steel sheet is removed before tested under axial load

3.2.1 Testing and observation

Specimens were cured in water for 60 days and then air dried before being subjected to fire in a furnace maintained at a fixed temperature of 600°C. The specimens were subjected to fire for different time duration's, ranging from 0 to 60 minutes, with an increment of 10 minutes. For each time duration, three specimens were tested to calculate mean test results with reasonable accuracy.

The test specimens were removed from the furnace after the specified duration of heating and then allowed to cool to room temperature before being tested in the compression testing machine. For VPC infill specimens, the steel sheeting was removed before they were tested. The rate of loading was kept constant for each test specimen. The specimens were loaded to failure and associated ultimate load with modes of failure was observed.
Fig. 3: Comparative study of VPC and NC

<table>
<thead>
<tr>
<th>Property</th>
<th>VPC</th>
<th>NC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength (MPa)</td>
<td>35</td>
<td>25</td>
</tr>
<tr>
<td>Tensile strength (MPa)</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>Young's modulus (kN/mm²)</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Dry density (x100 kg/m³)</td>
<td>20</td>
<td>15</td>
</tr>
</tbody>
</table>

Fig. 4: Test specimens (Series B) and failure modes

The failure of the TWC columns (not subjected to fire) were found to be due to tearing of the thin steel plate along a diametrical plane (Fig. 4). This was due to the resulting hoop stress in steel and no local buckling was formed. This confirms the fact that the steel plate should be of sufficient thickness to develop local buckling with subsequent attainment of plastic yielding in the steel plate to further enhance the strength of the columns. For the columns subjected to fire, the tearing pattern of the steel sheet changed with increasing duration in the fire. Instead of a single diametrical tearing, the sheet teared in several diametrical planes as shown in Fig. 4. This may be due to the reduction of strength of the sheeting due to heating.
The colour of the volcanic pumice aggregate was changed by the fire exposure to black, as observed from the tested VPC and TWC specimens, and no spalling of concrete was observed in VPC specimens.

4 Results and discussion

The performance of VPC under fire will be described based on test results.

4.1 Performance of cylinder VPC (Series A) specimens

The compressive strength of cylinder specimens decreases with increasing duration of fire (Fig. 5). The strength is decreased by about 53% as the duration of fire is increased from zero to one hour.

![Compressive strength vs. Duration](image)

Fig. 5: Effect of fire on compressive strength of VPC

4.2 Performance of VPC in TWC sections (Series B)

Fig. 6(a) compares the variation of axial load with duration of fire for TWC and VPC columns. As the duration of fire is increased from zero to one hour, strength of both type of specimens is found to decrease.

The strength reduction (Fig. 6(b)) in TWC column is found to be higher than that of VPC column for up to a duration of 30 minute. But as duration of fire is increased to one hour, VPC columns showed higher reduction in strength (about 52%) compared to TWC columns (about 44%).

The performance of VPC in-fill in TWC sections is much better than that of VPC columns (Fig. 6(b)). The strength reduction in VPC in-fill column is less than that of VPC columns. The lower reduction of strength in VPC in-fill columns confirms the lesser susceptibility of in-fill concrete to fire in TWC section although overall fire resistance of the sections may be lower.

The weight of both VPC and TWC columns decrease with the increase of duration of fire (Fig. 6(c)). Both of them show similar trend of variation with maximum reduction in weight of about 14% for a duration of one hour.
Fig. 6a: Variation of strength with fire duration

Fig. 6b: Strength reduction as a function fire duration

Fig. 6c: Effect of fire duration on the weight of the specimen
4.3 General discussion and ongoing research

It is required that the structural concrete should preserve good fire rating characteristics over a desired length of time. Strength of concrete decreases when exposed to a temperature in excess of 35°C and under conditions allowing loss of moisture content. On the other hand mild steel can loss one-half of the yield strength at about 600°C. The 52% strength loss in the VPC specimens can be attributed to loss of about 14% reduction in weight (may be due to loss of moisture content) and induced high temperature gradients causing hot surface layers tending to separate and spall from cooler interior concrete layer. However, light weight VPC should exhibit more fire resistance characteristics than ordinary aggregate concrete due to lesser tendency to spall and loss of lesser proportion of its original strength with the rise in temperature. The 44% reduction in strength of TWC specimens can be related to combined effect of loss of strength in concrete and steel. Lower thermal conductivity of VPC can be disadvantageous for TWC section as it can induce rapid rise in temperature in steel sheeting.

The resistance of concrete to fire and to elevated temperature depends on many factors such as: duration of fire, temperature, moisture conditions, concrete mix: leaner or richer, aggregate properties etc. More investigation is needed to fully understand the fire resistance of VPC in TWC sections. Investigation is now under progress covering all these parameters: varying duration of fire from 0 to 4 hours, temperature from 300°C-1000°C, moisture conditions from saturated surface dry to air dry, concrete mix from 1:2:3 to 1:2:4 and using ordinary and pumice aggregate. For TWC sections, thickness of steel sheeting will be another variable parameter.

5 Conclusions

The properties of volcanic pumice concrete is presented based on experimental results. Durability of VPC subjected to fire (elevated temperature of 600°C) especially in connection with TWC section is judged based on test observations and strength characteristics. The strength is found to decrease with the increase of duration of fire. The strength reduction in VPC specimens is found to be 52% compared to 44% in TWC sections when subjected to a fire of one hour duration. However, the fire resistance of VPC in TWC section is better than its individual resistance.

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7 References


