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Practical Application of Natural Pozzolans and Lime for Cost Optimisation in Low Cost Housing

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Abstract. Portland cement is considered one of the costly construction materials. It is sometimes used in applications where its strength levels are not necessary. This study optimized the use of OPC by considering its substitution with pozzolanic materials to reduce construction cost. The pozzolnic material used was volcanic ash which is abundant in many parts of Uganda. The ash was mixed with lime and water. The study examined the pozzolan-lime system to determine its optimum performance for a given pozzolan with known mineral composition. The work was experimental involving testing trial mortar cubes of different pozzolan-lime blends and varying pozzolan particle sizes. The results yielded second order polynomial relationships between the achieved compressive strength and the pozzolan-lime content. The optimum blend was determined from the first derivative of the functions. The blends that would yield the highest possible compressive strength values were derived from the absolute critical points of the polynomials, which when substituted into the functions yielded the actual peak values. Using the best fitting polynomial models, the maximum possible compressive strength values were generated. The blends containing pozzolans of 125microns particle size yielded consistently high peak values for all the experiments. The optimum blend was determined using the 125micron function, and the pozzolan-lime content that yielded consistent results was between 54% and 60%. The achieved compressive strength was 0.9MPa, which is expected to increase for pozzolans with finer particles. The values attained are adequate for a number of low-strength construction applications. The use of OPC can be restricted to only structurally-sensitive elements like beams and columns. This would serve to reduce the demand for OPC in housing construction and also reduce the cost of construction.

Keywords: Pozzolans, Volcanic Ash, Low-Strength Construction Applications

1 Introduction

Portland cements are the most widely used binders in construction. However, cement-based binders are costly mainly due to high energy requirements for Portland cement production [1]. In spite of its cost, the high demand for Portland cement has been attributed to the little confidence the users have in alternative binders [2]. When used for small buildings and low-strength applications, Portland cement makes construction unnecessarily more expensive than it ought to be. Habitat [3] estimates that up to 80% of the world-wide use of cement does not require strength levels of Portland cement. This can only change if the fitness of purpose of cheaper alternatives is explored to reduce the cost of construction. One such alternative is the use of natural pozzolans with lime.

A pozzolan is a material which when finely ground and mixed with lime in the presence of water, reacts to form a cement-like product [4]. Addition of natural pozzolans to lime was found to increase the density and reduce porosity of mortar, which increases its strength and durability [5]. Significant increases in compressive strength of concrete were also registered by various researchers [6] [7].

There are vast deposits of natural pozzolans in Uganda especially in form of volcanic soils and other natural earth deposits of similar origin in rift valley areas [8]. Their extensive use in construction has been hindered by the suspect quality of their products and lack of adequate information about their performance.

The use of lime binders in construction has become prominent due to its sustainability credentials [9]. Pozzolans have over the years been used to enhance the properties of lime as a binder [10].

2 Objectives, Materials and Methodology

This study was carried out to examine the pozzolan-lime system to determine its optimum performance for a given pozzolan with know mineral composition. The work was experimental involving trial mortar cubes of different pozzolan-lime blends and varying pozzolan particle size, and tested after 7 days, 28 days, and 90 days of curing.

A fixed effects model was used with 5 different blending levels selected over a uniform range from 10% to 90%. Each grade of the pozzolan defined by the dominant particle size was divided into five proportionate portions and treated to the lime blends of 10%, 30%, 50%, 70%, and 90%. Each treated portion was mixed thoroughly with a motorised mixer, and the same quantity of water added to each. All the cubes were subjected to the same curing environment, and tested for compressive strength. The procedure used ensured pre-treatment equality of the sample portions by random assignment. The compressive tests were guided by the test procedure prescribed in ASTM311 detailed under Test Method C109/C109M.

The experiments focussed on two parameters that were found to have significant influence on engineering performance and cost. These include the pozzolan content (blend) and particle size (grade). The investigation assessed each of the parameters independent of the other, and also considered the likely combined effect on compressive strength development of pozzolans lime mortar. The aim was to establish the nature of the effect of each of these parameters, independently and in combination, on engineering performance in terms of compressive strength development, and the extent and significance of such an effect.

3 Results

The variations of trends revealed from the assessment of one factor at a time pointed to the possibility that the observed effect of one factor could actually be dependent on the level of the other factor at which it occurred. Therefore, examination of the interaction between the two factors, pozzolan content and particle size, to influence the observed compressive strength values was conducted. The cross-tabulation of the findings for 90 days is given in Table 1.

Table 1 Compressive strength variation with pozzolan grade and content

					7-Day Tests				
	45μm	***63μm***	***75μm***	***90μm***	***106μm***	***125μm***	***150μm***	***180μm***	***212μm***
10%	0.2968	0.2650	0.2120	0.2014	0.1802	0.1696	0.1484	0.1272	0.1166
30%	0.3604	0.3604	0.2650	0.2332	0.2332	0.2014	0.2014	0.1696	0.1590
50%	0.4240	0.3392	0.3074	0.2014	0.2014	0.2014	0.1590	0.1484	0.1166
70%	0.2544	0.2226	0.2226	0.2226	0.1590	0.1590	0.1484	0.1378	0.0064
90%	0.2544	0.2332	0.2014	0.1802	0.1802	0.1590	0.1166	0.0636	0.0424
					28-Day Tests				
	45μm	***63μm***	***75μm***	***90μm***	***106μm***	***125μm***	***150μm***	***180μm***	***212μm***
10%	0.4134	0.4134	0.3922	0.3604	0.3074	0.2862	0.2650	0.2120	0.0000
30%	0.7950	0.5194	0.4452	0.4240	0.3922	0.3710	0.3710	0.3604	0.2756
50%	0.5512	0.5194	0.4770	0.4452	0.4452	0.3922	0.3074	0.2438	0.2438
70%	0.6360	0.4134	0.4028	0.3286	0.2650	0.2120	0.2120	0.1696	0.1272
90%	0.4558	0.2544	0.2226	0.1272	0.1060	0.0954	0.0636	0.0551	0.0000
					90-Day Tests				
	45μm	***63μm***	***75μm***	***90μm***	***106μm***	***125μm***	***150μm***	***180μm***	***212μm***
10%	0.5194	0.4664	0.4664	0.4400	0.4240	0.3900	0.3816	0.3500	0.3180
30%	0.8480	0.5830	0.5300	0.5088	0.4770	0.4400	0.4240	0.4000	0.3900
50%	0.6200	0.5600	0.5300	0.5000	0.4982	0.4770	0.4558	0.2120	0.2120
70%	0.6890	0.6800	0.6000	0.5500	0.3710	0.2120	0.1908	0.1590	0.1484
90%	0.3816	0.3816	0.3100	0.2400	0.2120	0.1696	0.1590	0.1378	0.0530

This examination established that not only did each factor have an effect on the observed values, but there was also an influence from interaction between the two factors. There was no single blend or grade that produced consistently high or low compressive strength values. As such, the combined effect was found to be more relevant in determining the behavior of pozzolan-lime mortars.

Further examination aimed at optimising the contribution from both. The 50% and 70% blends exhibited the highest interaction between the two factors at 7 days. The 28-day experiments exhibited clear interaction between the two factors for all the blends except for the 10% and 90% experiments. Observations from long-term experiments after 90 days showed virtually no interaction for the 10% and 90% blends. Figure 1 presents the findings for the two-factor interactions.

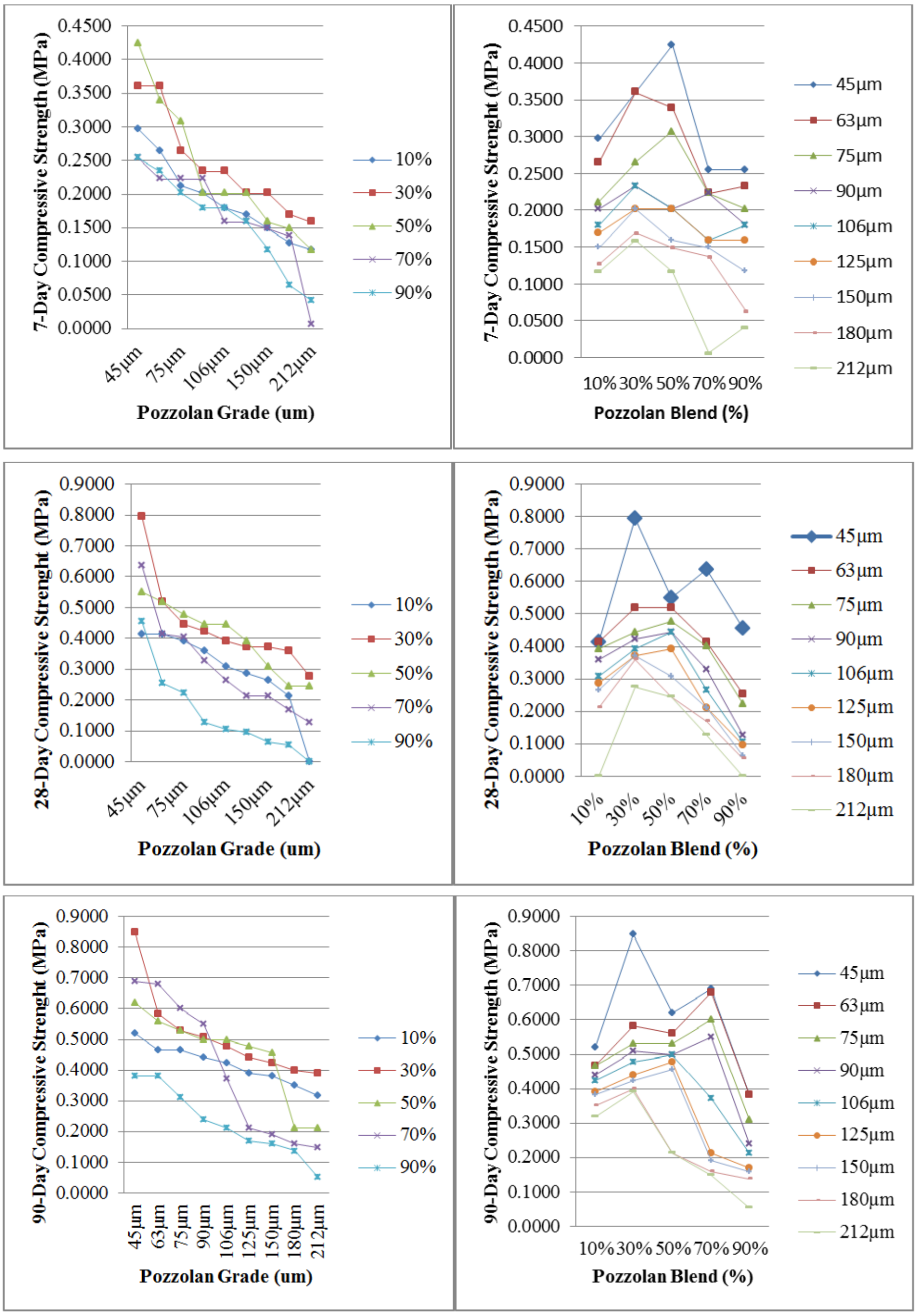

Figure 1 The two-factor interaction for 7-day, 28-day and 90-day experiments

The high interaction exhibited by the 50% and 70% blends at 7 days indicates the need to have both lime and pozzolans in comparable proportions skewed towards more pozzolans. On the other hand, the improved interaction at 28 days can be attributed to prolonged contact between pozzolans and lime that allowed more of the reactive compounds to contribute to the compressive strength development. The 90-day findings affirmed the inference that for higher quantities of either constituent, there is little or no interaction of the dependent variables, and any observations made could be a result of the filler effect of the excess material.

4 Discussion

The interchange in performance between 50% and 70% mixes with respect to maximum attainable compressive strength and stability against changes in grade over time, implies that in between the two mixes lies the mix that would yield optimum performance. This mix was established by examining the variation of compressive strength with respect to the pozzolan content in the mix. The observations revealed significant interaction of the pozzolan content and pozzolan grade in influencing compressive strength for the 50% and 70% blends. This interaction was consistent for the entire duration of the experiments as opposed to other blends that exhibited interaction only for ultimate strength tests. Interaction was also observed for the fine grades up to 125μm. This upper limit of pozzolan grade would enable effective reaction of the pozzolan and lime. Any finer grades would be more expensive to produce, while less fine grades would be less effective in compressive strength development.

The experiments generally confirmed that the compressive strength of the pozzolan-lime system increases up to a certain point beyond which it begins to reduce. The peak points for early age compressive strength are skewed to the right. This implies a bigger influence by pozzolans on the early peak compressive strength attainable than lime. However, the peaks are closer to the 50% pozzolan content level than the 90% content, which implies the need for pozzolans and lime in comparable proportions.

The pozzolan blends that registered peak early age compressive strength for all pozzolan grades were above 50%. However, these followed no particular trend. This is an indication of no clear link between the blend that gives peak strength and the pozzolan grade. While the compressive strength generally increases with finer grades, it was not the case with the critical blends producing peak compressive strength values. This suggests greater stability for pozzolan content with respect to compressive strength variability. Hence, irrespective of the pozzolan grade, the range of the pozzolan content that gives peak strength varied less.

Where two factors are contributing to the observed effect, the effect of each factor depends on which level of the other factor it occurs [11]. This is a result of the interaction of the two factors in contributing to the observed effect. It was therefore important to establish the level or range of each of the factors within which the observed effect is optimised sustainably and consistently. The derived polynomial expressions were used to predict the range within which interaction consistence is maintained. The pozzolan content was varied between 0% and 100% in the 7-day, 28-day, and 90-day experiments with the 125µm grade to obtain the resultant illustrations given in Figure 2.

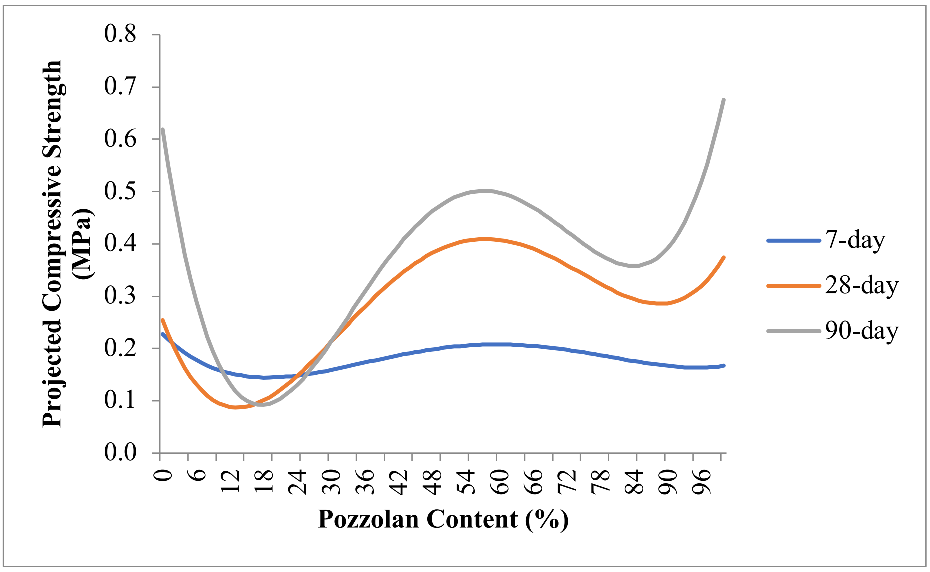

Figure 2 Prediction of optimal strength development in the pozzolan - lime system

It can observed that the range of pozzolan content that gives the same strength values for the same duration irrespective of the pozzolan content is 47% to 68%. It is in this region that there is noticeable increase in compressive strength values between 7-day, 28-day, and 90-day experiments, irrespective of the pozzolan content. The best results are however obtained in the range of 54% to 60% pozzolan content.

5 Conclusions

It can be deduced from the findings that the best compressive strength performance values can be obtained in the pozzolan-lime system if the predominant pozzolan particle size is in the range of 125µm, and the pozzolan content between 54% and 60%.

The maximum strength attainable for any grade is less sensitive to pozzolan content, provided adequate pozzolans are available to react with the available lime. This is important in practice as it may not be practical to have strict content guidelines for a craftsperson using the material. This should provide confidence in application because the less sensitivity of attainable strength values over a wide range of pozzolan content values allows for greater flexibility when using the material.

The registered peak value for compressive strength was 0.9MPa. This is much more inferior to that attained with Portland cement, but would pass for a number of low-grade mortars and low-strength construction applications like mortars and soil stabilization.

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