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Enhancing Ordinary Portland Cement Mortar's Engineering Specifications using Pumice Stone

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Abstract

Recently, research efforts are being exerted to improve concrete mixture quality while lowering the cost. In this study, pumice rock powder was mixed with cement in varying proportions (10–50%) for the manufacture of concrete mortar samples. The impact of pumice powder additions was examined in terms of the initial and final settling times as well as the compressive strength of the prepared samples. The effect of water additions on the properties of pumice mortar was also investigated. Due to the increasing amounts of pumice rock powder, more water must be added compared to what is required for normal cement paste to create a high-strength concrete mixture. By combining pumice powder with Portland cement, the engineering properties of the concrete mortar samples are enhanced, resulting in a decreased porosity of the prepared samples. The ability of the resulting concrete to absorb water, moisture, and gases is subsequently reduced, providing these combinations an advantage of resistance to harsh environmental conditions. The improved compressive strength together with the decrease in concrete sample density due to pumice additions will lead to a significant reduction in construction costs.

Introduction

It has been suggested that silicate minerals combined with calcium carbonate can produce cement with usable and acceptable characteristics. This kind of cement was first discovered in the early Roman era when it was used in many different types of constructions. Pumice stone, or pumicite when in powder form, is one of these components [1, 2]. Pumice is a silicate volcanic rock with a light grey colour and a glassy texture. Due to the gases and water vapor expanding during the quick cooling that results from the fragmentation of semi-molten lava, pumice is characterized by a strong vascular structure. Pumice rock with a vascular composition has an apparent weight of less than 2 even if the constituent parts of the rock have an actual specific density of 2.5. The pumice stone has a poor permeability to liquids because it is sealed off from surrounding cells and separated from them by a vitreous barrier [1-6]. Since 1940, metal surfaces have been cleaned with pumice stone and it was used in factories in the production of soap and home detergents [7, 8].

The Romans created a form of cement containing fine volcanic ash, calcium oxide, and pumice stone that was widely utilized throughout Europe [9, 10]. The Friant tanks and Bardi in California, as well as several streams and the Altes reservoir in the state of Oklahoma, were constructed using pumice rock and pumicite along with normal Portland cement in the United States. After 1940, the use of these pumice stones in construction increased. They were used as cement ingredients with gravel and sand in concrete work after being crushed and sorted by size at quarries and mines. Pumice was also used in prefabricated walls, blocks, moulds, and concrete pours [11–13]. Pumice has been also used in different industries such as ceramics and porcelain, as a replacement for natural gravel and sand [14].

Pozzolana or pumice can be added directly to concrete or mortar with regular Portland cement or combined with limestone or clinker for usage in various types of construction projects. According to engineering standards, lime pozzolanic cement is created by combining pozzolana and lime. IS 4098-1967 white concrete, mortar, and building mortar all use pozzolan-lime cement. The Aswan reservoir's core was constructed in 1902 using this sort of cement rather than the more traditional ones. Depending on the grade of the pozzolana and the intended usage, it can also replace regular Portland cement at rates up to 50%. The weight of a unit of pumice rocks is also quite low, being between one-third and two-thirds that of comparable units of other stones including granite, basalt, dolomite, and very hard limestone. In addition, it was reported that concrete constructed from pumice rocks can act as a thermal insulator due to the lower pumice thermal conductivity coefficient that ranges from 0.98 to 2 [15-17]. Pumice is essential in enhancing the properties of concrete since standard Portland cement releases calcium hydroxide and lime milk throughout the reaction and hardening process [17, 20]. The objective of this work is to assess the possibility of adding fine ground pumice to substitute cement and produce lightweight concrete mortar with improved engineering specifications.

Materials and Methods

Characterization of mixture elements

Pumice rock samples were obtained from commercial resources. The conventional laboratory jaw crusher and ball mill were used to crush and grind the obtained samples. Ground samples were then stored in dry plastic bags until the moment they are used. A Fritsch shaker was used to measure the size distribution of the cement, sand, and pumice samples in accordance with German standards as outlined in prior publications [21, 22]. Distilled water was used for mortar preparation in all samples. The characteristics of the materials used in this study are given in Tables 1-4. Figure 1 displays the size distribution of cement, sand, and pumicite particle sizes.

Instruments and tools

1. Casting cubes (50 × 50 × 50 mm).
2. Laboratory balance with an accuracy of 0.01 g.
3. Motor cube vibrating machine.
4. Graduated cylinder, shovel, and iron rod.

Table 1 Chemical analysis of cement samples used in this work

Oxide	Value, %
SiO_2	21
Al_2O_3	5
Fe_2O_3	3.5
CaO	62
MgO	4.5
Na_2O	0.4
K_2O	0.2
Loss of ignition	3.5

Table 2 Chemical analysis of pumice samples used in this study.

Oxide	Value, %
SiO_2+ Al_2O_3+ Fe_2O_3	74
CaO	8
MgO	9
Na_2O	1.5
Loss of Ignition	7.5

Table 3 Physical characteristics of cement.

	Characteristics		Value
1	Normal consistency, %		30
2	Setting time, min.	Initial	105
		Final	156
3	Specific gravity		3.2

Table 4. Physical characteristics of sand used in this study.

	Characteristics	Value
1	Silt, %	1.3

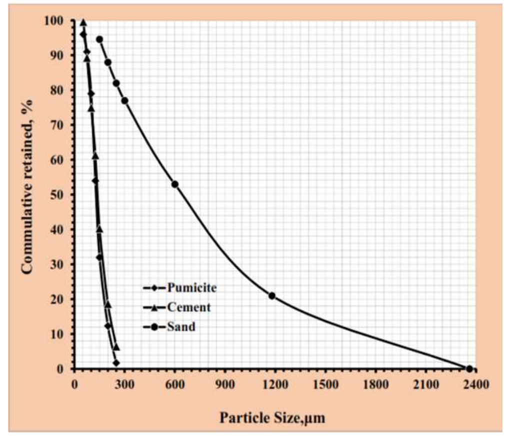

Figure 1 Analysis of cement, sand, and pumice particle sizes.

Sample preparation

To achieve uniformity amongst the sand, cement, natural pumicite, and water, the components were mixed in two steps. Sand and cement are first dry combined and then pumice is added and the whole mixture is further mixed for 30 seconds. The dry ingredients are combined with water, and the mixture is then blended for two minutes to achieve homogeneity. The casting moulds were cleaned, covered with a thin layer of oil before the moulds were mounted on the vibrating apparatus. The mortar was applied in the shape of phased layers, compacted with an iron rod with a 1 cm^2 cross-section, and then vibrated for two minutes. After the casting process, the moulds were removed, their surface was cleaned and levelled. The sample identification including the number and date was then recorded. After the shaping process, the moulds are taken off the sample so that they may be tested after 3, 7, and 28 days. The prepared samples were positioned vertically between the two loading surfaces of the compression machine and the load is gradually increased till reaching the failure load.

The porosity of the samples was calculated as the ratio of the volume of voids in the sample (V_V) to the total volume of the sample (V_T), as well as the ratio of the difference between the weights of the sample when it was dry (M_D) and when it was saturated with water (M_S) to the total volume of the sample. Three samples from each mixture were taken, and the average porosity was calculated. By dividing the fracture load by the sample's surface area and averaging the results for each of the three samples, compressive strength was obtained (MPa).

A number of cement mixtures were created utilizing pumicite and conventional Portland cement (OPC) in the following ratios: 90:10, 85:15, 80:20, 75:25, 60:40, and 50:50, with constant sand content. These combinations were made using varying amounts of water in relation to the amount of cement (50-60-70). All samples were poured into a typical cube (5x5x5 cm). Standard samples were prepared using the ratios of water, cement, and sand listed in Table 5.

Table 5. Standard sample characteristics as applied in this work.

NO	Standard Moulding of Mortar Cubes	Mixing ratios		
		Cement	Water	Sand
1	Moulding of 50 mm specimens, BS1881-131; ASTM C109	3	2	1
2	Moulding of prisms (160×50×50 mm)	3	2	1
3	Moulding of 100 mm specimens, BS1881-131; ASTM C109	3	2	1

Two standard methods were used to prepare and mould the prepared samples.

1. The jolting table method: this is a common technique that uses a mould with a prism shape of 160 mm by 50 mm and discontinues vibrations at certain intervals.
2. Vibrating machine method: this technique is conducted by applying pressure with a suitable rod to the mould surface.

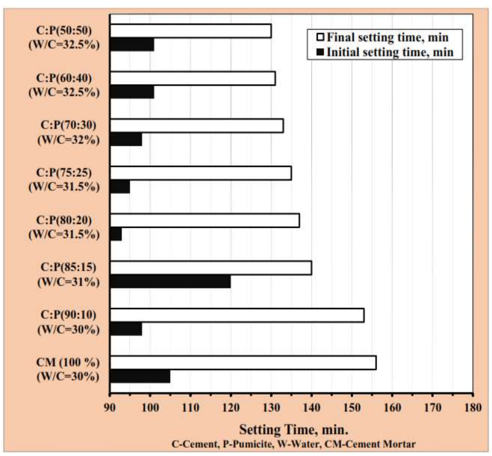

Figure 2 Effect of pumicite additions on the prepared samples' initial and ultimate setting times.

Results and Discussion

The impact of pumicite powder additions on cement mixes was investigated and evaluated in terms of setting time, porosity, and compressive strength. Figure 2 shows the impact of adding pumicite powder on the initial and final setting times of the samples that were prepared with various amounts of pumice. The first setting time of Portland cement and pumicite mixtures was within the tolerances of the normal Portland cement's setting time (30 min) [23].

When pumicite powder (30%) was added to the cement mixture, the porosity was observed to drop from 16.5% for the regular cement mixture to 15%. The proportion of pumicite added to the mixtures (10–50%) of the weight of regular Portland cement increases. The ultimate setting time is 10 to 16 percent slower than the final setting time of regular Portland cement. The quick setting time is important for the concrete working process since it makes it simple to remove the casting frame. Additionally, due to the rapid setting at the bottom of the column, the concrete is not impacted by the weights above it throughout the casting process.

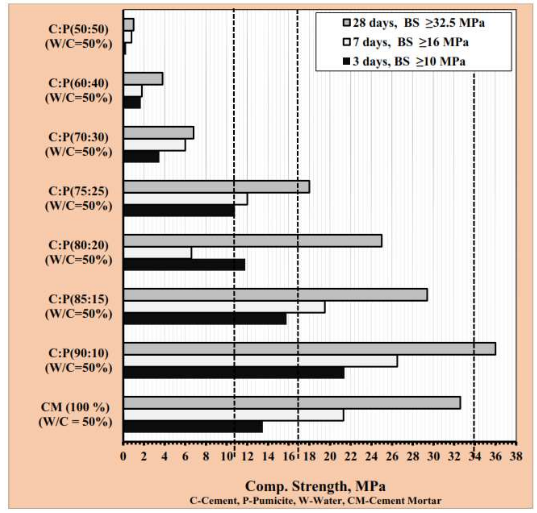

Figure 3 Effect of pumicite additions on the samples' compressive strength at 3, 7, and 28 days in comparison to the British standard at 50% water to cement.

As is common knowledge, there are three main categories of cement according to British standards specifications: the main kind of cement, the percentages of cement and clinker composition, and the index of cement strength, for instance, after 28 days. According to British Standard 196 - BS196 [16], the strength of standard cement is categorized based on cement performance. The findings of a study on the impact of pumicite addition on the sample's resistance to compressive strength are depicted in Figures 3, 4, and 5.

The compressive strength of the prepared samples is compared to the standard values of Portland cement's compressive strength according to British requirements at 3, 7, and 28 days at the water mixing ratios of 50, 60, and 70%. The samples made at water mixing ratios of 50 and 60 percent provided acceptable compressive strength. The values of the samples' strength were found to be lower (by about 75%), compared to the standard values at 28 days, as the water percentage was increased. Previous studies have shown that adding between 40 and 50 percent of water to mortar or concrete results in the highest compressive strength, proper setting time, and minimum porosity. If the water content is higher than this threshold, the resulting concrete will have a higher porosity and a lower capacity to withstand pressure. These characteristics influence the mortar's or concrete's technical requirements, strength against mechanical stresses, and resistance to the adverse effects of the environment, such as the transformation of calcium trisilicate into water-soluble calcium hydroxide [19].

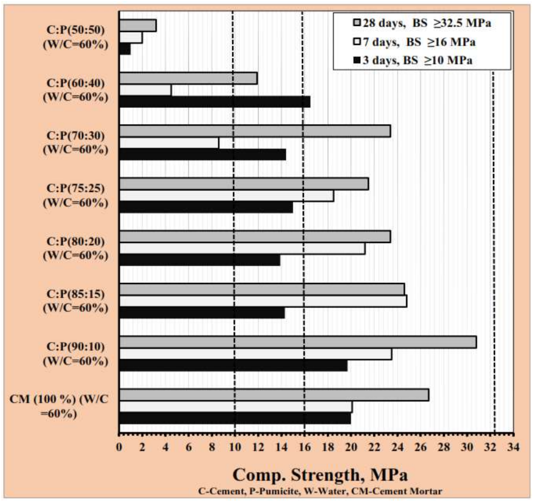

Figure 4 Effect of pumicite additions on the samples' compressive strength at 3, 7, and 28 days in comparison to the British standard at 60% water to cement.

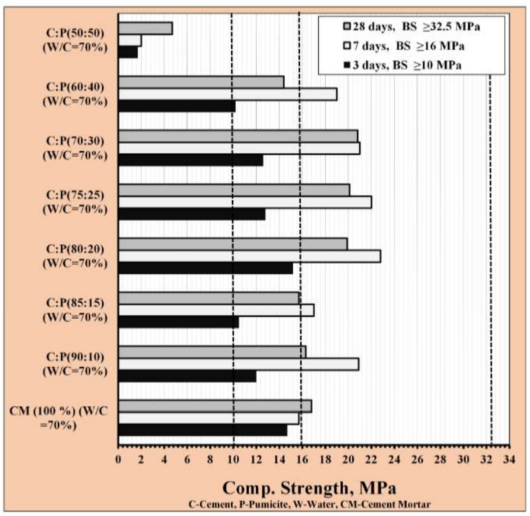

Figure 5 Effect of pumicite additions on the samples' compressive strength at 3, 7, and 28 days in comparison to the British standard at 70% water to cement.

The results also show that adding pumicite powder in amounts ranging from 10% to 50%, with the mixture containing 10% pumicite yields samples with compressive strengths higher than the benchmark values (36, 36, and 21 MPa), after intervals of 3, 7, and 28 days, respectively. 50% of the weight of the cement is made up of water. It was feasible to get results that were higher than or occasionally even equal to the standard values by increasing the amount of pumicite added to the combination (15–25%). Pumicite was added in concentrations of 30% or more, which resulted in a decline in the strength values of the mixes made with 50% water. Additionally, it was recognized that a mixture containing 30% pumicite or more requires a lot of water, thus the water percentage was raised in response.

When compared to the values obtained at 50% water, the strength of the mortar or concrete changes only slightly when the water content is increased to 60% relative to the cement weight in combinations containing 10% to 25% pumice. At a pumicite powder mixing ratio of 30%, the strength-increasing percentage reaches 25%, however at a ratio of 40%, the growth in the percentage is negligible. The results for adding water at a 70% proportion are the same as for adding water at 60% and 50%, with the exception that when pumicite powder is mixed at a 40% ratio, the strengths are twice what is indicated.

From the previous findings, we can deduce that adding pumicite powder to ordinary Portland cement improves the engineering properties of mortar or concrete because pumice contains a significant amount of silica—up to 70%—which is ground and added to cement and water to create a cement-like substance. When this silica is ground, the overall surface area increases, increasing the surface activity of the powder and the interaction between it and the free calcium oxide found in the cement during the hydration of mortar and concrete. Pumicite is added, which causes calcium hydroxide to react and create a new mineral that does not dissolve in water and hardens quickly. Cement paste is created by mixing silica and calcium hydroxide. This paste soon hardens into a solid cement that is impermeable to water [9, 19, 24]. The following chemical equation identifies the substance as a calcium hydrosilicate mineral:

$$Ca(OH)_2 + SiO_2 + (n-1)\ H_2O \longrightarrow CaSiO_2.nH_2O$$

Conclusions

Based on the results obtained in this study the addition of 20–30% pumicite to mortar mixtures leads to the production of light weigh mortar samples with decreased porosity and increased compressive strength. This, in turn, will result in a significant reduction in construction costs while providing enhanced protection against harsh environments.

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