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# Suitability of Porcelain and Marble Industrial Waste Powder to Produce High Performance Concrete

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**Abstract** A siliceous or aluminous material, which possesses a little or no cementitious value but will, in a finely divided form and in the presence of moisture, chemically react with calcium hydroxide $Ca(OH)_2$ to form compounds possessing hydraulic cementitious properties. The great abundance of Porcelain and Marble waste powder industrial wastes in Gujarat (India) makes it the most suitable materials for cement-based applications. To enhance the use of Porcelain and Marble waste powder as a Supplementary Cementitious Material in Gujarat (India), a proper method to evaluate its pozzolanic activity is necessary. The pozzolanic reactivity of the Porcelain and Marble waste Powder was evaluated by conducting strength development tests according to ASTM C311. After 28 days, the strength activity index of the Porcelain and Marble waste powder with ordinary Portland cement exhibited very good performance and was higher than 90 %, therefore it is suitable to produce a high performance concrete.

***Keywords:*** *calcium hydroxide, porcelain and marble waste powder, pozzolanic reactivity, strength activity index , high performance concrete , siliceous material*

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## 1. Introduction and Literature Review

The name Pozzolan comes from the town Pozzuoli, Italy. Ancient Romans (100 B.C.) produced a hydraulic binder by mixing hydrated lime with soil (predominantly volcanic ash). Horasan mortar, mixing lime with finely divided burnt clay, is extensively used by Ottomans. Nowadays, the word pozzolan covers a broad range of natural and artificial materials. Pozzolana is a material that, when used in conjunction with Portland cement, contributes to the properties of the hardened concrete through a hydraulic or pozzolanic Activity, or both. Fig.1 shows a typical chemical composition of the natural pozzolana.

Pozzolanas are materials containing a reactive silica and / or alumina which on their own have a little or no binding property but, when mixed with lime in the presence of water, will set and harden like cement. They are an important ingredient in the production of an alternative cementing material to ordinary Portland cement (OPC).

The Greeks and the Romans were the first civilisations known to use pozzolanas in lime mortars. The Romans used not only crushed pottery, bricks and tiles which formed the first artificial pozzolanas, but also found that some volcanic soils were excellent for producing a hydraulic mortar. Nowadays, a wide variety of siliceous or aluminous materials are used for producing pozzolanas, The common pozzolanic materials are calcined clays, pulverised fly ash, volcanic ash and ash from agricultural residues such as rice husks.

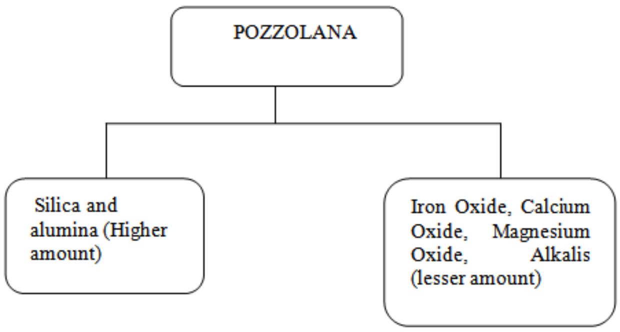


**Figure 1.** Chemical Composion of Natural Pozzolana

The pozzolanic reaction which can occur is Calcium hydroxide + silica + water → "Calcium-Silicate-Hydrate" (C-S-H), which in turn provides the hydraulic binding property of the material. There are three factors that affect the activity of Pozzolans (1) $SiO_2$ + $Al_2O_3$ + $Fe_2O_3$ contents (2) The degree of amorphousness of its structure (3) The fineness of its particles.

The pozzolanic activity of metakaolin, silica fume, coal fly ash, incinerated sewage sludge ash and sand had been compared using the Frattini test, the saturated lime test and the strength activity index test. There was a significant correlation between the strength activity index test and the Frattini test results, but the results from these tests did not correlate with the saturated lime test results. The mass ratio of $Ca(OH)_2$ to test pozzolan was an important parameter. In the Frattini and strength activity index tests, the ratio was approximately 1:1, whereas in the saturated lime test the ratio is 0.15:1 [5]. The two most simple electrical methods given by Luxan, Mccarter and Tran to evaluate the pozzolanic activity of different pozzolans were applied to RHA. The $\Delta\sigma$ method of Luxan proved to be more accurate in evaluating the pozzolanic activity at early ages, while the PI method of McCarter and Tran was more appropriate for studying the later-age pozzolanic activity [16]. The chemical test results for the natural pozzolan specimen were compared with the ASTM requirements. The natural pozzolan specimens met all requirements for fly ash but did not meet the 85 % silicon dioxide requirement for silica fume. It was worth noting that the ASTM specification for class F-fly ash requires the sum of $Fe_2O_3$, $Al_2O_3$, and $SiO_2$ to be at least 70 %. It also specified $SO_3$ less than 5 %, moisture content less than 3 %, and loss on ignition less than 6 %. Therefore, the natural pozzolan behaved more as a fly ash than a silica fume [6]. Palm Oil Fuel Ash (POFA) obtained from a palm oil mill was treated via sieving, grinding and heating at a temperature of 450 °C for 90 minutes in order to improve the pozzolanic reactivity of the POFA. The pozzolanic reactivity of the treated POFA was evaluated by conducting strength development tests according to ASTM C311 [15]. After 28 days, the strength activity index of the treated POFA with ordinary Portland cement exhibited very good performance and was higher than 100 %. At 90 days, the strength activity index increased to 101.72 %. The compressive test was performed on specimens containing varying amounts and types of pozzolan (1) Shehan (Pozzolan S), a dark black material that is the purest form found in nature, (2) Grara (Pozzolan G), very similar to Pozzolan S, but less pure (3) Ardh (Pozzolan A), occurring in the form of rocks and not well burnt during formation (4) Rsas (two types) of coarse (Pozzolan R2) and fine (Pozzolan R1) [7]. Pozzolan S was found to provide a satisfactory substitute for fly ash and other natural pozzolans when tested against ASTM C618. It was clearly found to be effective in controlling ASR. It also produced about 15 % less heat of hydration than Class F-fly ash, whereas Class F-fly ash produced about 30 % less heat of hydration than Portland cement only. Silica fume (SF) and dealuminated kaolin (DK) from Egyptian sources have been characterized chemically and mineralogically, and a comparative study of their reactivities toward lime were conducted using isothermal conduction calorimetry and an accelerated chemical method [13]. The high reactivity of DK suggested that it can be used in the production of bricks by blending with CaO at room temperature or can be used in the production of blended cement. A study of the pozzolanic activity of two types of glass clear and green coloured, with varying the particle size of the ground waste glass in the ranges: 100 and 80 µm, 80 and 40 µm and lower than 40 µm, was made [12]. By a mechanical method, it was concluded that the use of waste glass as a partial replacement of Portland cement requires the grinding of the waste glass to a particle size lower than 40 µm without regard to samples colour. The potential use of a natural raw material in the manufacture of blended cements was investigated. Mineralogical, petrographic and chemical analyses of the samples showed that the natural raw material was a porphyritic volcanic rock close to trachyandesite composition with a $SiO_2+Al_2O_3+Fe_2O_3$ content of 79.86 % [1]. These findings suggest that this material can be used in the production of blended cements. Mined pitchstone fines (PF), derived as a waste by-product from expandable perlite production in Australia, is a viable, environmentally friendly alumino silicate supplementary cementitious material (SCM) suitable for a partial Portland cement (PC) replacement, thus reducing greenhouse gas emissions resulting from PC manufacture. The pozzolanic activity exhibited at 10, 20 and 40 % replacement levels of PC, through compressive strength determinations of mortar after 1, 7 and 28 days ageing, using strength activity index (SAI) criteria [18]. The practice of using a finely powdered red ceramic brick waste as a pozzolanic additive in cement, mortar and concrete are a viable alternative to traditional materials, with the technical, economic and environmental advantages of recycling a construction waste that is often improperly discarded. The pozzolanic activity index with Portland cement for facing and structural brick samples was 78.7 % and 79.5 %, respectively. These values exceed the minimum of 75 % specified by the standard. The chemical tests also confirmed the pozzolanic activity of both samples [8]. With the increase in the amount of LUSI (Lumpur Sidoarjo) mud obtained from the mud volcano in Indonesia was used as a partial replacement for cement up to 40 %, the rate of strength development is also increasing. This exhibits that the rate of the pozzolanic activity development of LUSI mud is relatively low at early age; however it becomes faster at later ages, at least up to 56 days. Manufacturing semi high volume LUSI mud mortar, up to at least 40 % as a cement replacement, is a possibility, especially with a smaller particle size of LUSI mud, less than 63 µm [4]. Fly ash, from Mae Moh power plant, was classified by air classifier to yield fine and coarse fractions. The coarse fly ash was ground and classified again into 3 sizes. Four different sizes of fly ash from the process including the original fly ash were replaced cement 20 % by weight to make mortars [3]. More than 110 % of the strength activity index of ground coarse fly ash mortar was achieved as early as 1 to 3 days since the coarse fly ash is not in a crystalline phase. Despite the low amorphous $SiO_2$ contents, cement mortars made with 10 % Suger Cane Bagasse Ash replacement still showed satisfactory gains in compressive strength, suggesting that the amorphous $SiO_2$ content is not a primary factor contributing to strength in this system. The results helped to promote the use of industrial SCBAs as an SCM, given that their particle sizes are reduced prior to use, to increase both the filler and the pozzolanic effects and to make the effect of the amorphous $SiO_2$ content on the compressive strength gain less discriminating [17]. The strength activity index of mortar and pastes containing treated natural pozzolan (NP) as Libyan kaolin was investigated. NP obtained from south Libya was treated by a thermal method via sieving, grinding by a ball mill and calcined by heating at 800 °C for 120 minutes in order to improve the pozzolanic reactivity of the NP [14]. The result showed that after 28 days, the strength activity index of the treated NP with ordinary Portland cement exhibited a very good performance and was higher than 100 %.

## 2. Objectives

The objective of this research was to check the Strength Activity Index and to understand chemical and physical properties of industrial waste porcelain and marble powder. The results obtained were analysed to check the suitability of both pozzolanic materials to produce High Performance Concrete.

## 3. Experimental Work

### 3.1. Raw Materials

#### 3.1.1. Cement

Ordinary Portland cement (Sanghi-53 Grade) Confirming Indian Standard (IS 12269:1987) was used in the present study with properties listed in Table 1.

**Table 1. Properties of OPC 53 grade SANGHI cement**

| Sr. No. | Properties | Results |
|---|---|---|
| 1 | Loss of Ignition | 1.56 |
| 2 | %$SiO_2$ | 19.70 |
| 3 | % CaO | 63.44 |
| 4 | Specific Gravity | 3.15 |
| 5 | % Normal Consistency | 29.5 |
| 6 | Specific Surface($m^2$/kg) | 306 |
| 7 | Initial Setting Time (minutes) | 145 |
| 8 | Final Setting Time (minutes) | 185 |
| 9 | Compressive Strength(MPa)<br>3days<br>7days<br>28days | <br>37.5<br>48.5<br>63.0 |

#### 3.1.2. Fine Aggregates

River sand from local sources confirming Indian Standard (IS 383:1970) was used as fine aggregate. The fineness modulus, specific gravity and water absorption were found to be 2.64, 2.82 and 1.87 % respectively.

#### 3.1.3. Water

Fresh potable water free from acid and organic substances was used for mixing and curing the concrete. The amount of water for gauging shall be equal to that required to give a flow of 105 ± 5 percent with 25 drops in 15 seconds.

#### 3.1.4. Porcelain and Marble Powder

The porcelain waste powder shown in Figure 2 was obtained from Gopi Industries (Cera Sanitary Pvt. Ltd.) Jotana, Gujarat and Marble waste Powder shown in Figure 3 was obtained from Satyam Tiles Ltd., Dediyasan, G.I.D.C. phase IV, Mehsana, Gujarat. Table 2 shows Chemical and Physical Characteristics of both waste powders. In this test, powder samples were ground to a fine powder, but only to an upper size boundary of 75 microns.

**Figure 2.** Porcelain powder

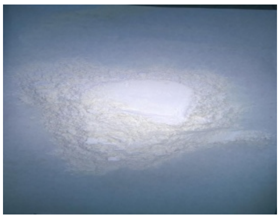

**Figure 3.** Marble powder

Porcelain and Marble Powders, by their diverse and varied nature, tend to have widely varying characteristics. The chemical composition of porcelain and marble powders varies considerably, depending on the source and the preparation technique. Generally, a porcelain and marble powders will contain silica, alumina, iron oxide and a variety of oxides and alkalis, each in varying degrees. This presents problems for small-scale manufacturers wishing to use them in a lime or OPC - pozzolana mix. Where there are no laboratory facilities available for testing the raw materials, then it is difficult to maintain standards and produce a consistent product. It is also generally agreed that although the chemical content of a raw material will determine whether or not it is pozzolanic and will react when mixed with lime or OPC, the degree of reaction and subsequent strength of the hydrated mixture cannot be accurately deduced from just the chemical composition. In most cases, no direct correlation can be found between chemical content and reactivity. Other characteristics of the porcelain and marble powders also affect its reactivity, such as the fineness and crystalline structure.

**Table 2. Chemical and Physical Characteristics of Pozzolana**

| Pozzolana | Porcelain Powder | Marble Powder |
|---|---|---|
| Chemical Composition (%) | | |
| $Fe_2O_3+Al_2O_3+SiO_2$ | 90.52 | 76.9 |
| MgO | 1.02 | 1.7 |
| $SO_3$ | 0.06 | 1.2 |
| $Na_2O$ | 2.31 | 1.4 |
| CaO | 1.87 | 0.32 |
| $K_2O$ | 2.23 | 0.05 |
| LOI | 0.48 | 2.9 |
| Physical Properties | | |
| Specific Gravity | 2.1 | 2.5 |
| Water Absorption (%) | 0.3 | 0.8 |
| Specific Surface Area($m^2$/kg) | 528 | 535 |
| Particles retained on 75 micron IS sieve | 1.41 | 1.23 |

### 3.2. Strength Index Activity Test Method

It is also argued that because pozzolanas are used for a variety of different applications, such as in mortars, concretes, block manufacture, etc., and mixed with a variety of other materials such as lime, OPC, sand, etc., (which can also radically affect the reaction of the pozzolana), then perhaps it is better to develop a test to determine the desired properties of the mixture in the context for which it is intended. This provides valuable information for specific project applications and can also help to determine the general characteristics of a pozzolana for cases where the application of the pozzolana is not specified. This approach, along with that of fineness testing, forms the basis for most field tests. In the test mixture, 20 % of the mass of Portland cement used in the test mixture was replaced by the same mass of the test waste powders.

### 3.2.1. Specimens

Mortar Cubes of size 70.6 mm × 70 6mm × 70.6 mm were prepared 3 for control mix and 3 each for both test mixtures. The dry materials used for the standard test mortar were Porcelain/Marble Powder: cement: standard sand in proportion 0.2 *N:* 0.8: 3 by weight, blended intimately (IS 1727:1967).

Where,

*N* = Specific gravity of Porcelain powder or Marble Powders/Specific gravity of cement

The amount of water for gauging used was equal to that required to give a flow of 105 ± 5 percent with 25 drops in 15 seconds.

The following quantities of materials were used for preparation of the mortar:

100 × *N g* Porcelain/Marble Powder

400 g Cement

1500 g Standard sand

Mixing of mortar was done mechanically.

### 3.2.2. Storage and Curing of Specimens

The cubes of size 70.6 mm ×70.6 mm × 70.6 mm were kept at a temperature of 27 ± 2°C in an atmosphere of at least 90 % relative humidity for 24 hours after completion of compaction. At the end of that period, they were removed from the moulds and immediately submerge in clean fresh water and kept there until taken out just prior to breaking. The water in which the cubes were submerged was renewed every seventh days and shall be maintained at a temperature of 27 ± 2°C. After they had been taken out and until they were broken, the cubes were not being allowed to become dry.

### 3.2.3. Compressive Strength Test

The Compressive Strength was determined, of three specimens of the control mixture and three specimens of the test mixture at ages 28 days.

### 3.2.4. Calculation

The Strength Activity Index with Portland cement was calculated as shown in Eqation 1.

$$\text{Strength activity index with Portland cement} = (A/B)\times 100 \quad (1)$$

Where: *A* = average compressive strength of test mixture cubes in MPa and *B* = average compressive strength of control mix cubes in MPa.

## 3.3. Results and Discussions

Table 3 shows the results of compressive strength of mortars for control mix and test mixtures at 28 days as average of three specimens. The average values are 41.96, 39.9 and 39.27 MPa for control mix, Porcelain and marble powders, respectively. The strengths for test mixtures are coming around 5 to 7 % less than control mix. Three mixes were designed with 20 % waste powder, but each used powder of a different fineness. A particle size of 75 µm or less is reported to be favourable for pozzolanic activity. Pozzolanic activity index increased because of increased fineness of the waste powders compared to Portland cement. It is worth noting that the ASTM specification for pozzolana requires the sum of $Fe_2O_3$, $Al_2O_3$, and $SiO_2$ to be at least 70 %. It also specifies $SO_3$ less than 5 %, moisture content less than 3 %, and loss on ignition less than 6 %. Both industrial waste powders satisfy these criteria and so the strength activity index is coming satisfactory. The amount of crystalline particles increased when porcelain and marble powder is increased. In addition, reducing $Ca(OH)_2$ and increasing powders lead to dilution effect. Most voids had been filled by small unreacted powder particles made it serving as an inert filler. Hence, strength increased as curing time progressed because of the consumption of $Ca(OH)_2$ by the waste powders via the pozzolanic reaction.

**Table 3. Compressive Strength results at 28 days**

| Portland Cement (Control Mix) | | Porcelain Powder (Test Mixture) | | Marble Powder (Test Mixture) | |
|---|---|---|---|---|---|
| Load | Compressive Strength (MPa) | Load | Compressive Strength (MPa) | Load | Compressive Strength (MPa) |
| 215.4 | 43.21 | 200.6 | 40.24 | 194.7 | 39.06 |
| 202 | 40.52 | 196.7 | 39.46 | 195.8 | 39.28 |
| 210.1 | 42.15 | 199.4 | 40.00 | 196.8 | 39.48 |
| Average Compressive Strength= 41.96MPa | | Average Compressive Strength= 39.9MPa | | Average Compressive Strength= 39.27MPa | |

Table 4 shows the strength activity index of porcelain and marble powders with Portland cement at 28 days. There is a marginal increase in strength activity index for porcelain powder as compared to marble powder. The large increase in the 20 % addition (porcelain and marble powders) at 28-days ageing suggests that even this blend could achieve the strength activity index requirement with further ageing. As the developing calcium-silicate-hydrate (C-S-H) gel is a phase responsible for strength development, it is likely that with increasing Porcelain and Marble Powder substitutions, formation of this phase is initially inhibited and then allowed to develop at a later stage, resulting in strength increasing with ageing.

**Table 4. Strength Activity Index of Pozzolana**

| Pozzolana | Strength Activity Index |
|---|---|
| Porcelain powder | 95.09 % |
| Marble powder | 93.59 % |

# 4. Conclusions

The following are the conclusions from the present study:-

- The summation of $SiO_2$, $Al_2O_3$ and $Fe_2O_3$ is 90.52 % for porcelain powder and 76.9 % for marble powder. According to American Standard (ASTM C618-12), Table 1 Chemical requirements, that required is minimum 70 % and therefore both industrial waste powders are suitable to produce high performance concrete by replacing them with cement.
- The Strength Activity Index with Portland cement at 28 days is 95.09 % for porcelain powder and 93.59 % for marble powder. According to American Standard (ASTM C618-12), Table 2 Physical requirements,

that required is minimum 75 % and therefore both industrial waste powders are suitable to produce high performance concrete by replacing them with Cement.

- The particles retained on 75 micron IS sieve is 1.41 % and 1.23 % for porcelain and marble powders, respectively and therefore can give a good particle packing during manufacturing of high performance concrete.
- It was observed that with marble powder being white in color, it produced mortars which were fairly normal in appearance, whereas those produced with a porcelain powder had a characteristic dark gray color.
- These findings indicated that the porcelain and marble powders are suitable materials for use in the manufacture of blended cements as they produced more C-S-H gel which led to increase the strength of concrete and decreasing porosity because of the particle packing at later ages.
- The replacement of porcelain waste powder will have major environmental benefits in terms of saving cost of cement and reducing $CO_2$ emission into the environment.

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