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Porosity and Strength of Pozzolan Modified Cement Systems

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Abstract

Porosity is one of the important properties that determine the durability of concrete and mortar. Porosity represents the amount of voids inside the concrete, which is dimensionless quantity, usually expressed as a percentage value. This aim of this study is to determine the effect of pozzolans such as pulverized fly ash (PFA) silica fume (SF) on the porosity and strength of mortars. The mix proportion with and without pulverized fly ash (PFA) and silica fume (SF) are tested with two properties such as strength and porosity in order to understand the effect against performance of the mortar. In addition, curing condition also does affect the strength and porosity of the modified mortar. The results from this study shows that the pozzolan modified mortar which is the sample with pozzolan replacement, has low in durability and higher porosity compared with non-modified mortar when it is cured under air curing, which is the method of curing that usually been applied at the construction site.

Keywords: Porosity; Strength; Pozzolan; Mortar; Air curing; Fly ash; Silica fume

1. Introduction

Durability is the capacity of concrete to resist deterioration caused by environment, human activities and also forces from loading that occupy a structure. It normally refers to the duration or life span of the concrete itself. The service life and durability of a concrete structure strongly depend on its material transport properties, such as permeability, sorptivity, and diffusivity which are controlled by the microstructural characteristics of concrete [1]. There are many properties of concrete that is related to its durability such as absorption, strength and workability. It is known that the porosity is the critical components of the microstructure of hydrated cement paste that influence durability. Porosity is the volume of voids that occupy a concrete. In order to achieve high strength,

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low permeability, and durable concrete, it is therefore necessary to reduce the porosity of cement paste [2]. Mortar are basically consists of cement, sand, water and additional material, known as an admixture added to modify certain of its properties. It is well known that the incorporation of pozzolanic materials as partial replacement of cement refines the porosity of the paste. Mortars with pozzolan replacement are known as modified cement mortar. Various types of pozzolanic materials have been used in the construction industry to produce mortar or concrete to reduce the use of OPC for a long time [3]. Pozzolanic materials are consist of either natural (Trass, zeolite, metakaolinite, burned clay) or artificial (silica fume, fly ash, blast furnace slag) types [4]. The use of additional cementitious materials due to economic, technical and environmental considerations has become common practice in modern concrete construction industry [5, 6]. The use of pozzolanic materials as a replacement addition to cement in production is useful for a number of purposes. This is reduces concrete production cost and also reduce high energy consumption as the production of OPC usually needs lots of energy [7]. One of factors that related to the strength of concrete is fundamentally a function of the volume of voids in it. Usually, the higher amount of voids in the concrete, the less strength it will exhibit. In addition, the curing condition also may affect the strength of the mortar or concrete. "Strictly speaking, strength of concrete is influenced by the volume of all voids in concrete: entrapped air, capillary pores, gel pores, and entrained air, if present [8]".

Much of the researches have been conducted on the durability and strength of concrete made with mineral admixtures [9-12]. Fly ash (FA) is waste materials from the thermal power plant. Fly ash is known to be a good pozzolanic material for use in concrete [3]. According to ASTM C618-85 [13], there are two basic types of FA: Class F (low-calcium FA) and Class C (high-calcium FA). Its physical and chemical properties depend exclusively on the quality of coal used and on technological conditions of burning. FA is added to Portland cement (PC) or directly to mortars or concretes [14]. Silica fume (SF) is a by-product resulting from the reduction of high-purity quartz with coal in electric arc furnaces [15]. It has been observed that the presence of such particles can reduce the positive effect of the SF on the microstructure and mechanical properties of the mortars [16, 17]. The use of SF decreases the permeability, thereby increasing the resistance of concrete against corrosion [18, 19], improving its strength and durability [20, 21]. The advantages of SF caused SF being the most well-known additive material for high strength concrete in recent years. Many researchers have established these effects on the physical properties and pore structure of concrete and mortar. However, the porosity and strength changes due to differences in fly ash and silica fume of cement mortars are not well established.

This paper, therefore, attempts to provide essential information on strength and porosity of modified cement mortars with fly ash and silica fume of different replacement level on the Portland cement mortar. This study also examines the effects of pozzolan addition on the porosity of modified mortar and non-modified cement. Moreover, the effects of air curing to the strength and voids development of modified and non-modified cement were investigated.

2. Materials and Methods

Materials used in this study are commercially available Ordinary Portland Cement (OPC) equivalent to ASTM Type 1 cement, a commercially available fly ash equivalent to ASTM Type F fly ash and silica fume and normal grade river sand. Mortar mixes of water-to-cement ratio (W/C) of 0.3, 0.4 and 0.5 were used throughout the investigation. In the study, a total of three different water cement ratio with three replacement of cement mortar are obtained with OPC being the reference. Fly ashes and silica fumes were used to replace ordinary Portland cement at dosage levels of 0%, 20%, and 40% by mass of binder. The dimension of mortar cubes was 100 x 100 x 100mm for this study. All mortars were removed from the moulds after 24 hours casting and cured in air dry condition in the laboratory. Compressive strength and porosity of mortars were determined at age of 7, 14 and 28 days after demoulding.

The experimental program can be summarized in the flow chart as shown in Fig. 1.

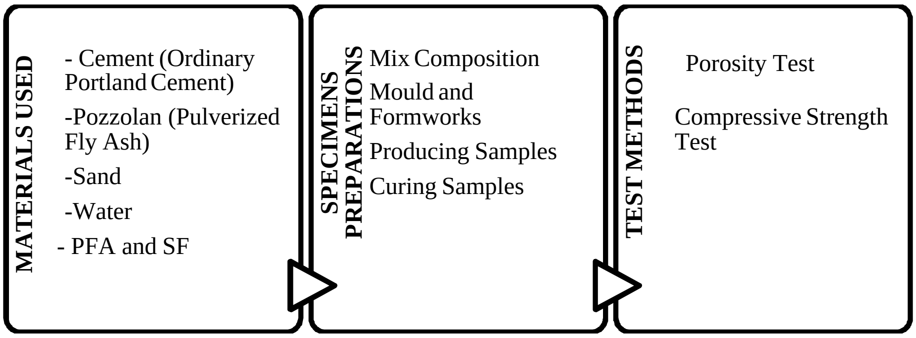

Figure 1. Experimental program

2.1 Compressive Strength Test

All mixes were subjected to compressive strength test at the end of curing period of 1, 7, 14, 21 and 28 days after demoulding. This test was carried out to determine the maximum compressive load it can carry per unit area. Since strength of mortar was directly related to the structure of hydrated cement paste, this test was important not only to determine the strength development of the mortar specimen, but also the quality of the mortar specimen. A good mortar specimen should achieve the targeted mean strength at the end of 28 days.

2.2 Porosity Test

The porosity of concrete or mortar has an effect to the durability of structures. All concrete are porous, some are more porous and some are less. Porosity define as the ratio of the volume of pores in a particle to its total volume (solid volume plus the volume of pores). The porosity of concrete can be said as the percentage of voids that occupy the solid.

$$Porosity, \% = \frac{volume\ of\ pores}{total\ volume\ of\ particles}$$

Porosity also effects the strength, permeability, and water absorption of aggregates, and it will affecting the behavior of both freshly mixed and hardened concrete. When concrete is exposed to cold temperatures and moisture, resistance to cycles of freeze-thaw is important to ensure long service life, for without adequate capacity to endure the internal movement the concrete will disintegrate. The freeze-thaw resistance of concrete also may depend on a number of factors, but mostly on the aggregate porosity, absorption, and pore structure.

3. Results and Discussion

3.1 Compressive strength test results

Comparison of compressive strength of mortar with different percentages of PFA replacement with OPC mortar is shown in Figs. (2-4). It can be seen that all modified cement with SF and PFA replacement exhibit lower strength than the non-modified cement. This is due to the curing methods, which is the sample is cure in the air with dry environment. It was stated that a silica fume is very sensitive with the curing environment than the ordinary Portland cement (OPC). Usually, when the samples is replaced with some percentage of the SF and PFA, and cured at dry environment, the strength of the samples will be lower than that of the non-modified cement's samples. Besides that, previous research also supports the same thing for the PFA replacement, which is very sensitive to dry curing environment than the OPC which is due to the microcracks in the modified mortars with silica fumes and fly ash replacement when it is cure in dry condition.

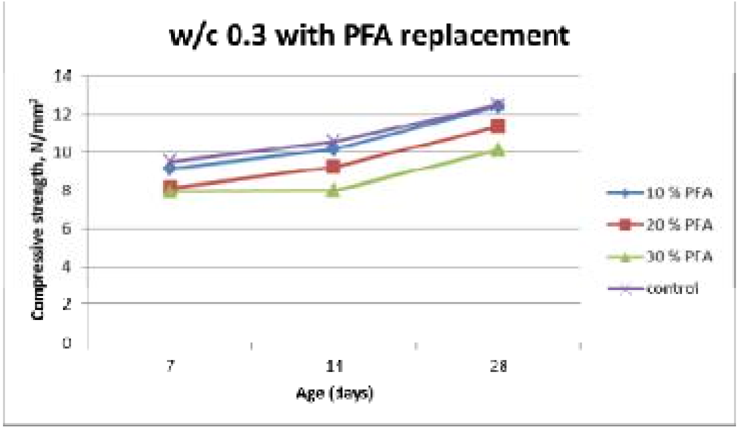

Figure 2. Comparison of compressive strength of mortar with different percentages of PFA Replacement with OPC mortar (w/c = 0.3)

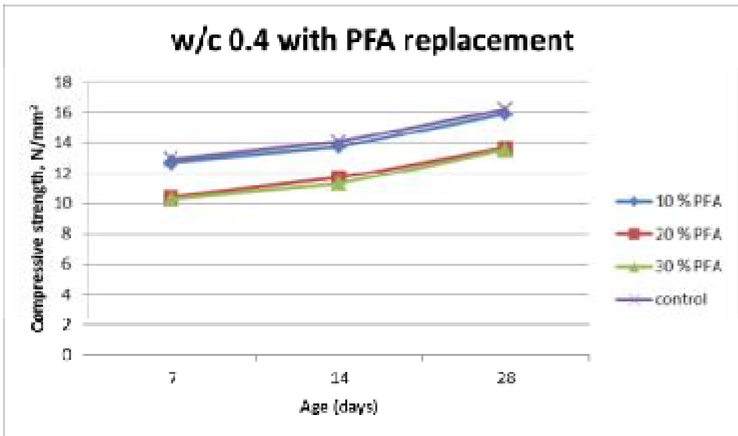

Figure 3. Comparison of compressive strength of mortar with different percentages of PFA Replacement with OPC mortar (w/c = 0.4)

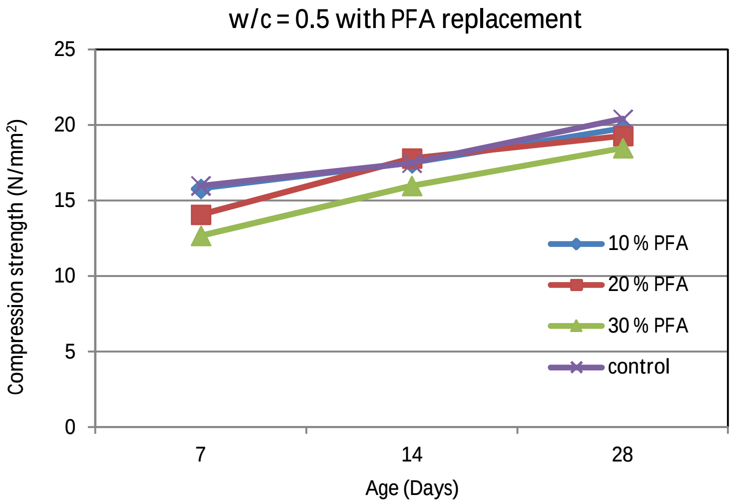

Figure 4. Comparison of compressive strength of mortar with different percentages of PFA Replacement with OPC mortar (w/c = 0.5)

Comparison of compressive strength of mortar with different percentages of SF replacement with OPC mortar is shown in Figs. (5-7). It can be observed from the test results that the more replacement of Silica Fumes and PFA is used, the weaker it is in this study. This is probably due to the more pozzolan may able to react with calcium hydroxide produced by the hydration of cement, in the dry environment. Besides that, it seems also that the strength development in samples involves in this studies developed quite slowly, which can be seen from the day 7 until the day 28, the strength didn't increase much. This is due to the dry environment that is used for the curing in this study. Usually, the sample that is cured under air curing exhibit lower increase in their strength compared to the samples that is cured under water curing.

Besides that, it seems also that the strength development in samples involves in this studies developed quite slowly, which can be seen from the day 7 until the day 28, the strength didn't increase much. This is due to the dry environment that is used for the curing in this study. Usually, the sample that is cured under air curing exhibit lower increase in their strength compared to the samples that is cured under water curing. Other than that, according to Malolepszy and Deja [22] the effect of air curing is pronounced as about 40 % strength decrease. So, that's why the strength of all samples seems to be below grade, which is below than 20 MPa. Other than that, previous research also support the same thing, which is the sample that is cured under air curing exhibit strength 19 - 50% lower than the sample cured under water curing [23, 24].

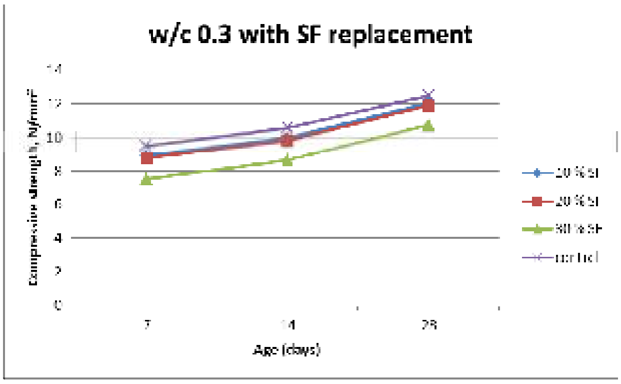

Figure 5. Comparison of compressive strength of mortar with different percentages of SF replacement with OPC mortar (w/c = 0.30).

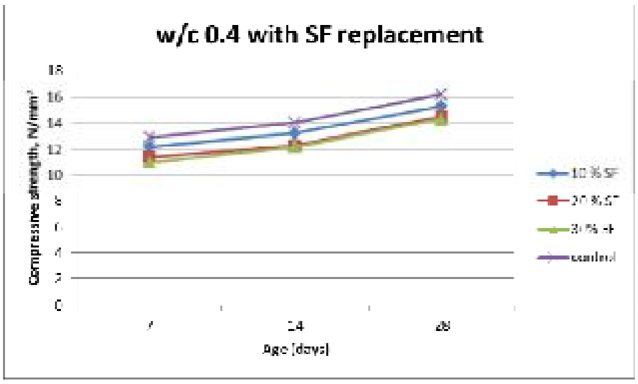

Figure 6. Comparison of compressive strength of mortar with different percentages of SF replacement with OPC mortar (w/c = 0.40).

Figure 7. Comparison of compressive strength of mortar with different percentages of SF replacement with OPC mortar (w/c = 0.50).

3.2 Porosity test results

Comparison of porosity of mortar with different percentages of PFA replacement with OPC mortar is shown in Figs. (8-10). From the result of porosity test, it can be concluded that the sample incorporation with different percentage pozzolan replacement has higher percentage of porosity at all ages compared with the sample of ordinary Portland cement (OPC). The total porosity increased with an increase in the replacement of fly ash. This is due to high air content in pozzolan sample, more amount of the water can be absorb, due to the higher volume of voids inside the mortar. The total porosity of the modified cement mortar containing finer fly ash was significantly lower than that with coarser fly ash but was still larger than that of the PC mortar at all replacements and ages. Similar finding was also reported by other investigations [22, 25, 26].

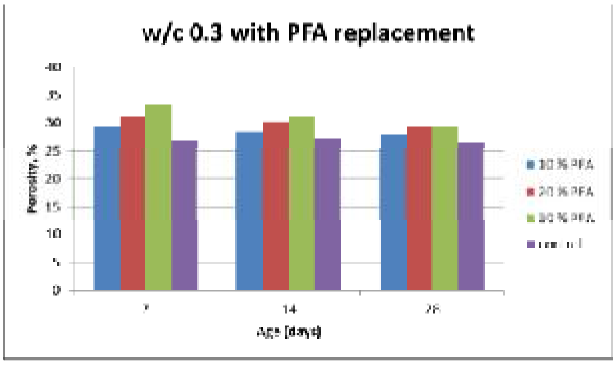

Figure 8. Comparison of porosity of mortar with different percentages of PFA replacement with OPC mortar (w/c = 0.3).

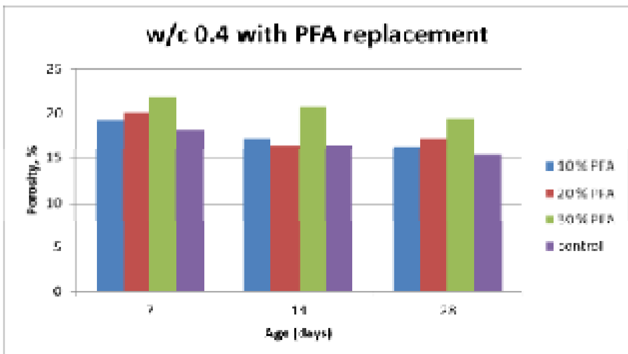

Figure 9. Comparison of porosity of mortar with different percentages of PFA replacement with OPC mortar (w/c = 0.4).

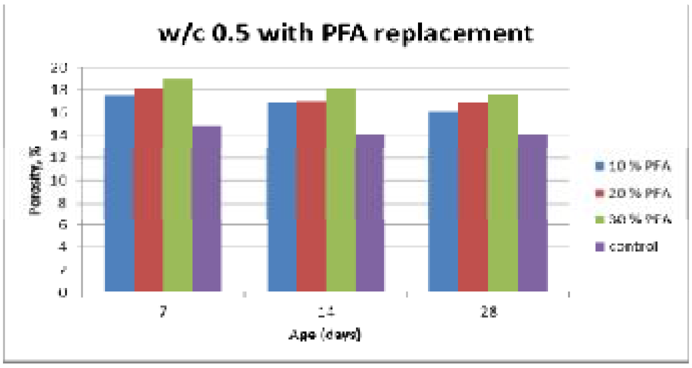

Figure 10. Comparison of porosity of mortar with different percentages of PFA replacement with OPC mortar (w/c = 0.5).

Besides that, from the result also, there is not much void development in the samples from day 7 to day 28 time duration. This is because; usually the void and pores inside the mortar do not develop so quickly, unlike the strength, which can develop faster due to the chemical attack inside the mortar itself. Besides that also, it clearly showed that, the lower the porosity, the higher the strength that can achieve by the mortar. So, usually for the amount of porosity for the mortar, the test results usually been taken once in the period of 28 days. Similar trends were noticed when using SF as a replacement at w/c ratios of 0.3, 0.4 and 0.5. Figs. (11-13) show the comparison of porosity of mortar with different percentages of SF replacement with OPC mortar.

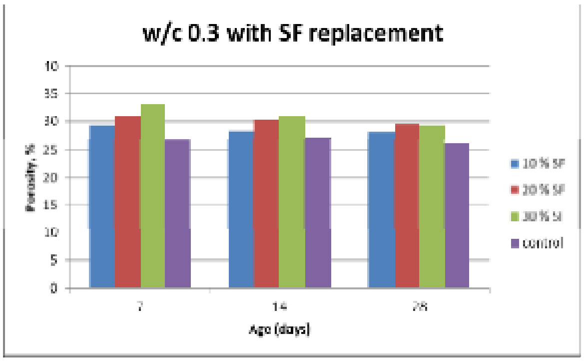

Figure 11. Comparison of porosity of mortar with different percentages of SF replacement with OPC mortar (w/c = 0.3).

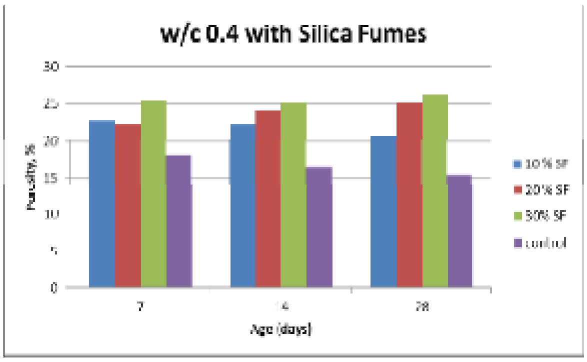

Figure 12. Comparison of porosity of mortar with different percentages of SF replacement with OPC mortar (w/c = 0.4).

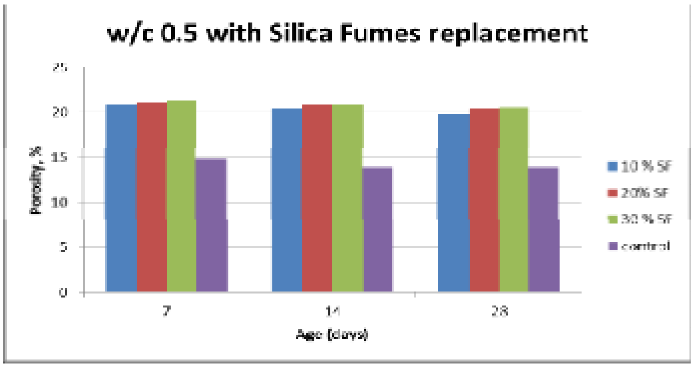

Figure 13. Comparison of porosity of mortar with different percentages of SF replacement with OPC mortar (w/c = 0.5).

Other than that, some of the test data may not be accurate due to the poor compaction of the sample. Poor compaction of samples is because of the mould that is used in this experiment in the laboratory. The polystyrene mould is very fragile and samples that occupy it can't be compacted properly. This would lead to the existence of honeycombs and more air voids in the mix due to those errors that is classified as human errors.

4. Conclusion

Based on experimental investigation the following conclusions can be drawn:

1) It can be seen that non- modified mortar seems to be more durable than the mortar that is replaced with pozzolan, in the dry air environment. Other than that, the strength of modified cement is also strongly affected by the variable conditions of curing. The more porosity of a mortar, the less strength the mortar can achieve.

2) In terms of compressive strength, test results shows that the non-modified cement mortar is shown better performance than the pozzolan replacement. So, it is clear that the construction industries in our country nowadays avoiding using too much cement replacement such as fly ash and silica fumes. This is due to condition of the site, which all the structures using concrete is cured under air curing and dry condition, and sometimes did not cured properly, and of course this condition will reduce the strength of the concrete if replace with pozzolan which is more sensitive to those environment.

3) The quality of modified cement mortar mixed with pozzolan can influenced the water need in concrete. Water, which is needed to make the cement particles to react, can cause mortar less durable or more durable, if its volume decreased or increased. In this study, it seems that the lower water cement ratio not really match with the pozzolan replacement as it need adequate water.

4) The modified cement mortars containing the original fly ash and silica fume exhibited higher total porosity than those of Portland cement mortars. The porosity and the average pore diameter of modified cement mortars containing fly ash and silica fume increased with an increase the percentage replacement level in fly ash and silica fume content on the Portland cement mortars.

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