# SELF HEALING CONCRETE CRACK BY USING PULVERIZED FUEL ASH (PFA) AS CEMENT REPLACEMENT MATERIAL

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# ABSTRACT

Nowadays the high demand of cement is an indication of development especially for the construction industry. Therefore, it is needed an alternative way in fulfill this situation. Many researches were developed in order to find suitable material to be used as a replacement for cement such as palm oil fuel ash and pulverized fuel ash. Pulverized fuel ash can be used as a partial replacement material in cement composition and this material has pozzolana effect that can generate the self healing process. Self healing is an autogenous healing of cracks in concrete is showed by the formation of calcite in the crack. In this study, by product of coal combustion power plant from Tanjung Bin, Johore namely pulverized fuel ash (PFA), was used as the partial replacement in cement in order to study the effectiveness of PFA toward self healing in concrete crack. The ultrasonic pulse velocity (UPV) and compressive strength test were conducted to determine the ability of self healing of concrete containing PFA. The result shows that 20 % of PFA (PFA-20) is the best percentages of cement replacement and water curing was the best mechanism to heal the hairline crack in concrete.

# ABSTRAK

Pada masa kini, permintaan terhadap simen adalah tinggi terutama dalam industri pembinaan. Maka, usaha perlu dilakukan untuk mencari bahan alternatif bagi memenuhi keperluan ini. Pelbagai kajian telah dilakukan bagi mencari bahan yang sesuai untuk digunakan sebagai bahan ganti simen seperti abu kelapa sawit (POFA) dan abu serbuk bakar (PFA). Abu serbuk bakar boleh digunakan bagi menggantikan sebahagian daripada komposisi simen dalam pembuatan konkrit dan bahan ini mengandungi pozzolana yang boleh menjana pemulihan secara sendiri dalam retakan konkrit. Pemulihan diri dalam konkrit adalah proses pembaikan keretakan dimana pembentukan kalsit di dalam konkrit. Dalam kajian ini, produk daripada pembakaran arang batu dari system janakuasa di Tanjung Bin, Johor iaitu dikenali abu serbuk bakar (PFA), digunakan sebagai pengganti dalam sebahagian komposisi simen untuk mempelajari keberkesanan PFA terhadap pemulihan diri dalam retakan konkrit. Kelajuan pulsa ultrasonik (UPV) dan ujian tekanan tinggi (compressive strength test) dilakukan untuk menentukan kemampuan pemulihan diri konkrit yang mengandungi PFA. Keputusan kajian menunjukkan bahawa penggantian sebanyak 20 % PFA dalam komposisi simen (PFA-20) adalah peratusan terbaik dan pengawetan konkrti secara rendaman air adalah mekanisme terbaik untuk menyembuhkan retakan kecil dalam konkrit.

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| | | |
|---|---|---|
| ACI | - | America Concrete Institute |
| ASTM | - | American Society for Testing Method |
| DOE | - | Design of Experiment |
| FKASA | - | Fakulti Kejuruteraan Awam dan Sumber Alam |
| OPC | - | Ordinary Portland Cement |
| PFA | - | Pulverized Fuel Ash |
| UMP | - | Universiti Malaysia Pahang |
| ° C | - | Degree of Celcius |
| kg | - | Kilogram |
| kN | - | Kilo Newton |
| MPa | - | Mega Pascal |
| Mm | - | Milimeter |
| µm | - | Micrometer |
| w/c | - | Water-Cement Ratio |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Study

Malaysia has been developed successfully in structure and material construction, such as building, tunnel, damn and so on. There are a lot of mega structures develop in past year such as Kuala Lumpur City Centre (KLCC), storm-water management and road tunnel (SMART) and the latest construction is 2nd bridge of Penang. Commonly, concrete has been used as a construction material in construction industry since ancient time. It is obtained by mixing cement, water and aggregate. Concrete with no doubt is the important building material, playing a part in all building structures. Concrete have been used because it have been known for its properties, such as strength, durability and workability.

Until now, concrete is the most excellent material to be used as construction of structure. Concrete has relatively high compressive strength, but significantly lower tensile strength, and as such is usually reinforced with materials that are strong in tension. Concrete are easy to crack if less supervision on the concrete work. Concrete

crack easily due to shrinkage, overland to the structure, chemical attack and changing of temperature in the concrete.

Crack happen due to both autogenous and drying shrinkage. Nevertheless, most of types of cracks occur before 28 days. Toyoharu et al., (2007) reported that one of material that can be use to overcome hairline crack was pulversed fuel ash, because pulverized fuel ash continues to hydrate after 28 days, it is likely that hydrated products from pulverized fuel ash may modify microstructure, seal these cracks, and prolong the service life. Crack will reduce the strength and durability of the structures. Besides, cracking will make structure allowed water and for long term period can reduce the strength followed structure collapse. Cracking at the concrete structures must repair immediately before the crack become worse. This is because to prevent the crack affect entire the building. However, researchers discovered that cracked specimens under compressive testing at 28 days healed autogenously after had been stored outdoors for 8 years, many researchers have been focusing on this subject and done further studies.

The research investigate whether cracks in seal-coated cement-mortar linings in water pipe and fittings would self-heal by chemical reaction when totally immersed in potable water. Jacobsen et al., (1996) studied on self healing process of microcracks in concrete and found that in conventional concretes, micro cracks are typically induced by drying shrinkage. On the other hand, high-performance concretes such as the high-strength and the self-compacting concretes may contain cracks due to autogenous shrinkage. Many researchers have investigated and confirmed the benefits of shrinkage-reducing admixtures. Nevertheless, it is difficult to completely avoid micro cracks in concretes. Holt and Leivo (2004) reported that both drying and autogenous shrinkage could be significant in certain early age scenarios, they state about 70% of the autogenous shrinkage occurred before 28 days. This amount should be similar for drying shrinkage. If there are enough cementitious particles that can hydrate after 28 days, the self healing ability may appear. Therefore, the definition of self healing in this research

is the ability to heal the cracks without extra treatment. Meanwhile, heal ability to the crack can be found by material that have reaction of pozzolan. Pozzolan is a materia which, when combined with calcium hydroxide, exhibits cementitious properties and commonly used as an addition to Portland cement concrete mixtures to increase the long-term strength and other material properties of Portland cement concrete. Pozzolan are primarily vitreous siliceous materials which react with calcium hydroxide to form calcium silicates also to react as form to fill the void (small crack).

Pulverized Fuel Ash is a pozzolanic material that reacts with calcium hydroxide $Ca(OH)_2$ from cement hydration and produces C–S–H gel. In fact, this reaction is less influenced by the availability of free water than the hydration reaction of cementstated by Termkhajornkit et al., (2006). Pulverized Fuel Ash is also effective for improving various properties of concrete such as long term compressive strength, permeability and resistance to chloride diffusion. The C–S–H gel produced by the pozzolanic reaction of Pulverized Fuel Ash may seal micro cracks, and accordingly it is expected that the concrete made with cement and Pulverized Fuel Ash may show self healing ability.

## 1.2 Problem Statement

The major problem that occurs to the concrete structures is cracking. Concrete is susceptible to cracking due to both autogenous and drying shrinkage and it will reduce the strength and durability of the structures. Cracking in concrete can be caused by mechanical load, temperature changes in a structure, settlement, shrinkage and non proper finishing work. Shrinkages cracks are caused by hydration process and unbalance water cement ratio in the mix. The aim of this study is to analyze the chemical composition of the pulverized fuel ash and to attempt to utilize it as a cement replacement in normal concrete mixes in the construction industry. In view of the

growing use of PFA in construction industries, it is worthwhile to investigate its potential radiological hazard to the local environment.

Nowadays, industrial by products and waste materials are available in large quantities. PFA is the one of waste that technically has to use proper method to handling and economically feasible outlets. PFA might contribute to solving some of the aggregate supply problems and maybe can be use as replacement of cement composition. With the proper technical and research, PFA as waste materials can be use to solve shortages of material in the future because it can be used as partial of cement composition or as replacement of aggregate either sand depends on size, physical characteristics and chemical composition. PFA must fulfill the engineering requirements in terms of physical properties and they must not contain excessive amounts of deleterious components which might cause problems in use.

## 1.3 Objectives of Study:-

The objectives of this study are:-

i. To study the effectiveness of PFA toward self healing (cracks)
ii. To study the mechanism of self healing
iii. To study effectiveness of Pulverized Fuel Ash as partial replacement of OPC toward its strength and performance

## 1.4 Scope of Study

This study was focus on the effectiveness of pulverized fuel ash (PFA) as partial replacement of original Portland cement (OPC) toward its strength and self healing performance. The normal concrete cube is use as the control specimens and PFA-concrete concrete cube as the testing specimens. Concrete design specimens with size of 150 mm x 150 mm x 150 mm were prepared namely normal concrete cube (control specimens) and the other one is PFA-concrete concrete cube. PFA-concrete concrete was produced comprises replacement of composition cement and pulverized fuel ashes with different percentages namely 10%, 20% and 30% from total weight of cement.

There are four types of curing were conducted subjected to lab condition curing, water curing + air curing, air Curing and water Curing (Normal Curing). There were 7, 28, 60 and 90 days of PFA-concrete cube were subjected to compression test to determine the optimum percentage of PFA that can be applied to replace some of cement composition without disturbing normal concrete strength standard and also pass the requirement of environment effect. In order to study the effect of using optimum percentage of PFA obtained from compressive strength test for normal concrete and PFA-concrete cube, the ultrasonic pulse velocity (UPV) test was conducted to determine the integrity of structural concrete by measuring the speed and attenuation of an ultrasonic wave passing along a specific test path in the element and also to determine the crack healing process.

## 1.5 Significant of study

This research will be successful and can be commercialize in all over the world. From this research, PFA can heal the micro crack of concrete and maybe can solve crack problem. From the research, PFA is by its self (self healing) expected to be effective material in cement composition for repairing micro crack at structure or building. PFA can be use as substitution of cement of effective for improving various properties of concrete such as long term compressive strength, permeability and resistance to chloride diffusion. The C–S–H gel produced by the pozzolanic reaction of fly ash may seal hairline cracks, and accordingly it is expected that the concrete made with cement and fly ash may show self healing ability. This material can be widely used because it is cheap, easy, safe and also effective to solve cracking problem stated by Termkhajornkit et al., (2008).

The prospects for future use of waste materials in concrete include the potential for greater use of Pulverized Fuel Ash and granulated slag as cementitious materials, and increased production of synthetic aggregates. The potential for greater use of pulverize fuel ash (PFA) probably lies in its greater use to produce partial material in cement to meet a possible demand arising from the new higher insulation standards required in domestic housing, perhaps in expanded production of sintered aggregates, and possibly most importantly in wider use as a pozzolanic material either directly at the concrete batching plant or in the production of Portland pozzolanic cements. Some of the environmental and economic advantages to be gained by wider use of PFA, as a pozzolan recently have been considered.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

Concrete is the most widely used man-made construction material in the world and is second only to water as the most utilized substance on the planet. It is obtained by mixing cementations materials, water and aggregate in required proportions. The mixture when placed in form and allowed to cure hardens into a rock– like mass known as concrete. The hardening is caused by chemical reaction between water and cement and it continues for a long time and consequently the concrete grows stronger with the age (Sutherland et al., 2001).

The advantages of concrete are economical in the long run, have a high compressive strength, easy to handle and molded or formed into virtually any shape or size according to specifications, and fire resistant. According to the Heckroodt et al., (2002), concrete is the construction material that always expose to the environment and chemical attack that can caused damage on it structure. The major damage that usually happens is crack. Damage on concrete can reduce the durability or concrete, that why

the damage must be repair immediately before it become worse. This damage can be repair using material that have same strength to the concrete or have a better strength compare to the concrete structure. In this study, cracking on the concrete will be discussed.

## 2.2 Concrete Crack

Failure of the concrete can be valued by the cracking at the concrete structures. Cracking happen when compression and tensile load that impose to the structure exceed the compressive and tensile strength of the structures. Crack not only reduces the outer performance of the concrete, but it shows the concrete structure become weak (Alexander et al., 2004).

Cracking at the concrete structure is easy to detect and always happen. It exists like hole-lines at the concrete surface and this condition is the major effect than can reduce concrete strength. According to Susan (2003) noted that crack classification is referring to the natural condition, shape and wideness of crack. Classification of crack that based on natural on shape was stretching out diagonally, horizontal, diagonal and random, which can be classified as huge crack, normal crack or hairline crack.

Hairline crack or micro crack was the type of crack that related in this study. This crack was measured and the ranges of crack were at range 0.1 mm to 0.2 mm. According Jang et al. (2010), hairline crack of concrete for the allowable limit value is prescribed as maximum 0.2 mm in order to prevent the depassivation (corrosion process) of steel reinforcement and also for effectiveness of concrete self healing. For that reason the range of 0.1 mm to 0.2 mm width of crack was selected to be applied.

## 2.3 Pulverized Fuel Ash (PFA)

Pulverized fuel ash (PFA), is a product of pulverized fuel (typically coal) fired power stations. The fuel is pulverized into a fine powder, mixed with heated air and burned. Approximately 18% of the fuel forms fine glass spheres, the lighter of which 75 % are borne aloft by the combustion process. They are extracted from the flue gasses by cyclones and electrostatic precipitation.

The resultant material is used as engineering fill and as a component for concrete. It has been widely used, particularly in the UK, for concrete block production. The blocks are lightweight and have excellent thermal insulation properties. PFA can undergo a pozzolanic reaction and become brittle over time. PFA has a fine dust texture and is grey in color. PFA can be used for a variety of applications including structural fills (Katz and Kovler, 2004), aggregate use in concrete construction (Wainwright and Cresswell, 2001; Siddique, 2003), partial cement replacement (Man and Yeung, 1997) and production of lightweight concrete (Yasar et al., 2003). Figure 2.1 shows scanning electron microscope of the pulverized fuel ash (PFA).

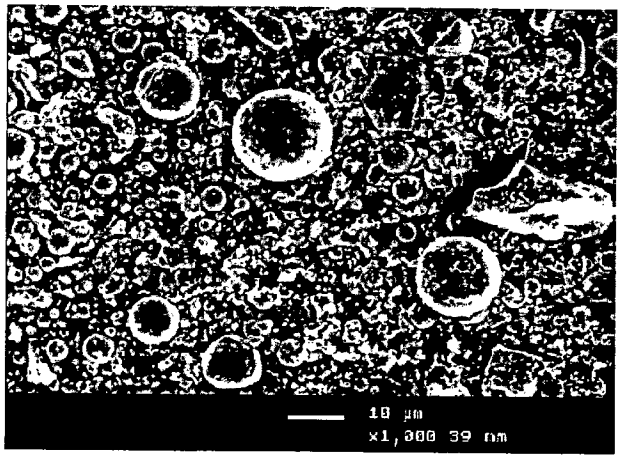


**Figure 2.1:** Scanning Electron Microscope of Pulverized Fuel Ash (PFA)

### 2.3.1 Pozzolan in Pulverized fuel ash (PFA)

As mention earlier, pulverized fuel ash (PFA) can undergo a pozzolanic reaction. Pozzolans are strictly volcanic tuffs of the type which in conjunction with lime were used by the ancient Romans in the mortars employed in many of their buildings. In concrete mix design the term Pozzolan is used to describe a powdered material, which when added to the cement in a concrete mix reacts with the lime released by the hydration of the cement to create compounds, which improve the strength or other properties of the concrete. According to american standard and testing material (ASTM) C 595 (2010), pozzolan material is siliceous and aluminous materials which on themselves posses little or no cementitious value but will in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compound possessing cementitious properties. Fly ash with high fineness exhibits high pozzolanic activity and can be used to produce high strength concrete stated by Haque (1998).

PFA has also imparts several properties to the concrete, namely pozzolanic activity (Isaia et al., 2003) where PFA reacts with the lime produced as a reaction of cement hydration and converts it into cementitious material, increase in late strength, reduction in segregation, bleeding and efflorescence, increased workability, and reduction in alkali to silica reaction. The use of PFA as a pozzolana was first reported by Davis (1937). The value of PFA as a pozzolana depends on its glass content. An effective pozzolana has to have a high specific surface area, be x-ray amorphous and have a high percentage of silica.

### 2.3.2 PFA as Replacement of Cement

Studied by Jossete et al., (2006) shows that PFA is very useful as a cement replacement and up to 20% replacement of cement by PFA produces concrete with comparable compressive strengths at 28 days and higher strengths when compared to the control after 90 days. Pulverized-fuel ash (PFA) comprises the finer fraction of the ash recovered from the gases of coal-fired power stations during the combustion of pulverized coal. The uniformity of the feed substrate and combustion conditions dictate physical properties of the PFA arising.

PFA can be taken directly from power station silos (dry ash), or with water added at source or on site to assist in handling/compaction (conditioned ash) or taken from stockpiles of previously conditioned ash located at the coal-burning power stations (stockpile ash) or recovered from storage lagoons (lagoon ash) stated by Coventry et al., (1999). Normally PFA results is lower in early strengths when compared to the control concrete, but later strengths were improved (Bianco, 1992). When used as sand replacement, irrespective of the degree of replacement, strengths comparable to control concrete were attained by 7 and 14 days, as long as the cement proportioning remained constant. Replacement of cement by PFA produced a reduction in early strength.

In this study, the percentages replacement of PFA in the cement composition is 0% as a control mix, and 10%, 20 also 30%. Studied by Psaila (1987) shows, the best proportioning to obtain strengths comparable to control concrete mix at 28 days seemed to be 10% replacement of cement and 30% if use as replacement of sand. Studied by Vanchai (2005) conclude base on Figure 2.2, illustrated that the compressive strengths of FA series of 10%, 20%, 30%, and 40% of cement replacement. At the early age (7 days) the FA concretes yielded lower compressive strengths than those of control concrete (69 MPa) with the compressive strengths. After 28 days, the compressive

strengths of FA concretes tended to increase with the curing age for all replacements and gave higher compressive strength than that of control concrete (normal concrete) up to 180 days. This can be explained by the fact that the extreme fineness of FA enhances pozzolanic properties and particle packing density. These characteristics tend to improve concrete strength as well as its density.

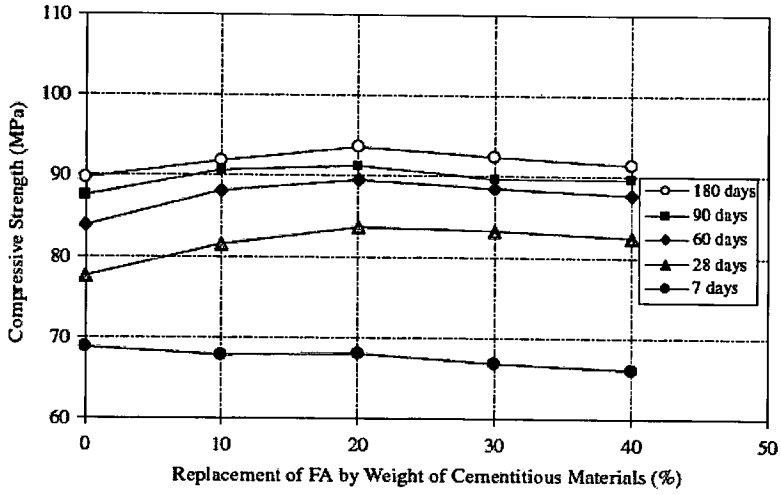


**Figure 2.2:** Relationship between Compressive Strength and Replacement PFA

### 2.3.3 Advantages of Using PFA

Pozzolan composition in the PFA makes it best material to replace some cement composition. One of the advantages is improved surface finish of the completed structure. Pulverized fuel ash or called fly ash contributes to producing a more cohesive concrete which has a reduced rate of bleeding making it easier to compact and giving the concrete better pumping properties. Reduces permeability, which reduces shrinkage, creep and gives greater resistance to chloride ingress and sulphate attack. Pozzolans material such as PFA react with lime (alkali calcium hydroxide produced by cement hydrating) to form stable calcium silicates and calcium aluminate hydrates. These fill the