THE EFFECTS OF ULTI (UPOFA) TOWARDS MECHANICA MORTAR

SHARIFAH SYAZWANI BINTI SAYED HASHIM

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Faculty of Civil Engineering
UNIVERSITI MALAYSIA PAHANG

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ABSTRACT

In general, with the production of palm oil to cater for the demand of the industry, the palm oil factory itself generates an amount of waste from its production which considered as waste solids. Usage of palm oil fuel ash (POFA) is uncontrollable and minimal which contribute to solid waste in landfills that caused environmental problem. However, the growing problem of waste materials can be reduced if new recycling methods can be found for the wastage of palm oil. It has been shown that addition of pozzolan admixtures such as palm oil fuel ash and fly ash with suitable volume level can improve the strength and permeability of concrete. It was also found that using such waste materials result in positive effects on properties of Portland cement mortar and concrete. This paper presents the effects of ultrafine palm oil fuel ash (POFA) towards mechanical properties of mortar in different replacement level and compared with control mixture. In order to improve its properties, the POFA was ground until the average particle size reduced to 5.91 μm. Then, it was used to replace ordinary Portland cement (OPC) by weights of 0%, 10%, 20% and 30% in order to improve the mechanical properties and interfacial zone microstructure of mortar. It was found that mortar containing ultrafine POFA replacement between 10% and 20% can improve the workability, compressive strength, flexural strength, porosity, water absorption and modulus of elasticity. In addition, cement replacement by 20% of ultrafine POFA gave the highest compressive strength. The results, therefore, suggest that POFA with high fineness is suitable to use as cement replacement in improving the mechanical properties and microstructure of mortar.

ABSTRAK

Secara umum, kilang minyak sawit telah menghasilkan sisa daripada proses penghasilan minyak sawit yang dikenali sebagai sisa pepejal bagi memenuhi permintaan industri. Penggunaan abu kelapa sawit (POFA) adalah tidak terkawal dan boleh menyumbang kepada sisa pepejal di tapak pelupusan seterusnya menyebabkan masalah alam sekitar. Walau bagaimanapun, masalah bahan-bahan buangan yang semakin meningkat boleh dikurangkan jika kaedah kitar semula boleh diamalkan untuk mengurangkan sisa pepejal daripada proses penghasilan minyak sawit. Hal ini kerana hasil daripada beberapa kajian telah menunjukkan bahawa penambahan bahan pozolan seperti abu kelapa sawit dan abu terbang dengan jumlah yang bersesuaian boleh meningkatkan kekuatan dan kebolehtelapan konkrit. Ia juga didapati bahawa penggunaan bahan-bahan buangan tersebut boleh menghasilkan kesan positif ke atas sifat-sifat konkrit. Kertas kerja ini mengkaji kesan halus abu bahan api kelapa sawit (POFA) terhadap sifat mekanik mortar di tahap penggantian jumlah yang berbeza dan dibandingkan dengan konkrit kawalan. POFA telah dikisar sehingga saiznya dikurangkan kepada 5.91 μm dalam usaha untuk memperbaiki sifat-sifatnya. Kemudian, ia telah digunakan untuk menggantikan simen Portland biasa (OPC) dengan berat 0%, 10%, 20% dan 30% untuk memperbaiki sifat-sifat mekanikal dan zon antara permukaan mikrostruktur mortar. Ia didapati bahawa mortar yang mengandungi penggantian halus POFA di antara 10% dan 20% boleh meningkatkan kebolehkerjaan, kekuatan mampatan, kekuatan lenturan, keliangan, penyerapan air dan keanjalan modulus. Di samping itu, penggantian simen sebanyak 20% daripada POFA yang saiznya halus memberikan kekuatan mampatan yang paling tinggi. Oleh itu, berdasarkan kajian yang telah dijalankan, kami mencadangkan bahawa POFA dengan kehalusan tinggi sesuai untuk digunakan sebagai pengganti simen dalam meningkatkan sifat-sifat mekanikal dan mikrostruktur mortar.

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LIST OF SYMBOLS

μm	Micrometre
kg	Kilogram
m	Meter
g	Gram
mm	Millimetre
σ	Stress (MPa)
ε	Strain
λ	Modulus of elasticity

LIST OF ABBREVIATIONS

RMK-9	Ninth Malaysian Plan
POFA	Palm Oil Fuel Ash
UPOFA	Ultrafine Palm Oil Fuel Ash
OPC	Ordinary Portland Cement
ASTM	American Standard of Testing and Material
ANOVA	Analysis of Variance
Day 1	First day of curing
Day 3	Third day of curing
Day 7	Seventh day of curing
Day 28	Twenty-eighth day of curing
POFA 10	Contain 10% of Palm Oil Fuel Ash
POFA 20	Contain 20% of Palm Oil Fuel Ash
POFA 30	Contain 30% of Palm Oil Fuel Ash

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Malaysia is focusing on bio-technology industry aimed to produce better and quality agriculture products as framed in Ninth Malaysian Plan (RMK-9) and palm oil is listed as one of the main commodities to be exported internationally. With the production of palm oil to cater for the demand of the industry, the palm oil factory itself also generate an amount of waste from its production which considered as waste solids. Annually, more than two millions tones of waste solids such as empty fruit brunches, shells and palm fiber are produced from palm oil residue (Office of Agricultural Economic, 2002). Usage of palm oil fuel ash (POFA) is uncontrollable and minimal which contribute to solid waste in landfills that caused environmental problem. However, most of the researcher have been investigated on the use of pozzolan material as replacement in concrete such as rice husk ash (M. R., 2012), unground palm oil fuel ash (Hossein Noorvand et al., 2013), fly ash (S. A. Barbhuiya, 2009), and silica fume (M. Jamal Shannag., 2001). Most of their findings show that pozzolan material application has produced good quality concrete.

Pozzolan material should have properties complying ASTM C 618-93 standard which defines pozzolan material should be aluminous and siliceous material which possess little cementitiuos value. At normal temperature, the material will react chemically with lime (from hydrated Portland cement) in the presence of moisture in order to produce

compounds occupying cementitious properties. (M.A. Megat Johari et al., 2012) states that the smaller the particle, the larger the surface area and a lower carbon content proved to be very efficient pozzolan that produce high strength concrete by using high amount of ultrafine palm oil fuel ash. Besides that, admixing nanosilica in unground palm oil fuel ash resulted in an increase in compressive strength (Hossein Noorvand et al., 2013). However, especially in improving its early strength, the application of ultrafine palm oil fuel ash as a pozzolanic material by replacing a partial part of Portland cement has not been investigated yet.

Further study may benefit as it could minimize the agro waste material problem and obtain new material for concrete which has high strength, resistance towards corrosion, low permeability and high thermal insulation.

1.2 PROBLEM STATEMENT

In Malaysia, the growing problem of waste materials can be reduced if new recycling methods can be found for the wastage of palm oil. Besides that, concrete made of Portland cement deteriorates when exposed to environment. Cracking and corrosion have significant influence on its service behavior, design life and safety. In addition, Portland cement is often short in supply for developing countries which demands high amount of Portland cement. However, economic type of alternative cements can be produced locally which at small scale and at a lower cost. It has been shown that addition of pozzolan admixtures with suitable volume level can improve the strength and permeability of concrete. Other than strength gain, it also produces good pozzolan reaction and the filler effect through small particle size by using high volume of fine admixture. (N., 2012). It can also reduce the Portland cement content in mortar and concrete production by using this waste material as an active pozzolanic admixture. It was also found that using such waste materials result in positive effects on properties of Portland cement mortar and concrete. However, in order to improve the early strength of the concrete, many do not know the

advantages of mixing normal concrete with ultrafine POFA (UPOFA) at this state. Therefore, researchers on related topics should be carried out.

1.3 RESEARCH OBJECTIVES

The research objectives of this study are:

i. To determine the effect of ultrafine palm oil fuel ash as cement replacement material in improving its early strength.
ii. To investigate the effect of ultrafine palm oil fuel ash towards mechanical properties of mortar.
iii. To investigate the effect of ultrafine palm oil fuel ash towards interfacial zone microstructure of mortar.

1.4 SCOPE OF STUDY

This study mainly focuses on the performance such as mechanical properties changes of the cement mortar when cement mixture is mixed with different amount level of ultrafine palm oil fuel ash. Scopes of this study included the following procedures:

i. Amount level of ultrafine palm oil fuel ash as cement replacement material is 10%, 20% and 30% of the total aggregate weights.
ii. Prism specimens of 40mm×40mm×160mm and cube specimens of 50mm×50mm×50mm are used.
iii. 48 prism and 144 cube samples will be prepared for six different types of test.
iv. Tests that will be conducted are workability test, flexural test, compression test, porosity test, water absorption test and elastic modulus test. Palm oil fuel ash was ground to a median size of approximately 5μm.
v. Samples will be cured in water for 7 and 28 days after concrete mix design.

1.5 EXPECTED OUTCOMES

The early age compressive strength of the cement mortars will be increased by using ultrafine palm oil fuel ash (UPOFA) as partial replacement for ordinary Portland cement. Based on studies done by (S. A., 2009), the addition of ultrafine palm oil fuel ash was found to increase the 28 days compressive strength significantly. It is expected that the flexural strength, workability, porosity, and water absorption of cement mortars with ultrafine palm oil fuel ash as partial replacement of cement will increase compared to ordinary cement.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Nowadays the high demand for cement is an indicator of development especially for construction industry. Therefore, an alternative way is needed to fulfill this situation. Many researchers have been developed in order to find a suitable material to be used as a replacement for cement such as ultrafine palm oil fuel ash. Ultrafine palm oil fuel ash is used as a replacement in cement composition. According to (M. H. Ahmad., 2008), one of the potential recycles material from palm oil industry is palm oil fuel ash which contains siliceous compositions and reacted as pozzolans to produce a stronger and denser mortar and concrete.

There are many experimental works to be conducts to introducing recycled materials like palm oil fuel ash as a replacement of the cement with different percentages to improve the properties of mortar and concrete. In this study, the ashes produced from hush fibre and shell of palm oil burning namely ultrafine palm oil fuel ash is used as partial replacement in cement in order to investigate the early strength of cement mortar and the mechanical properties of cement mortar.

2.1.1 Modern Mortar

Mortar is a man-made material which is the most widely used building material in the construction industry. Traditional mortar is made from fine aggregate usually sand and a binding agent. When mixed with water a chemical reaction called hydration occurs and the mortar sets. Traditional mortar were usually based on lime and sand but they were very slow to set and readily absorbed water. However, modern mortar use cement as the main binding agent although hydrated lime is often introduced into the mix to give it a more plastic feel and to make it more workable. This is because lime also improves the mortar's ability to cope with thermal and moisture movement. Besides that, modern mortar consists of rationally chosen mixture of binding material such as cement, well grade fine, and water. Admixture can also be added to create a specific characteristic of cement mortar. Mortar is designed to be durable but achieves its goal through finesse.

2.1.2 Environmental Issue of Portland cement

It is known that there are several causes of global warming which including carbon dioxide from cement industry. Annual cement production of 1.6 billion tons of world covers about 7% of global carbon dioxide into the atmosphere (P. Kumar Mehta., 2001). In order to reduce the amount of carbon dioxide emission, cement manufactures can help by improving production process. Partial replacement of cement with additional cementitious materials such as iron blast-furnace slag, silica fume, and tile wastes is a common practice since they can reduce the cement content and enhance the properties of cementitious composites. These are among various by products generated by the industries that have attracted much attention by cement mortar and concrete researchers. As stated by (P. Kumar Mehta., 2001), the goal of sustainable development of the cement and concrete industries is very important. Therefore, it can be reached if we make a serious effort for complete utilization of cementitious and pozzolanic by products produce by thermal power plants industries. However, by recycling the waste material, it can reduce the dumped waste as well as to ensure environment sustainability.

2.2 PROPERTIES OF CEMENT MORTAR

Ultrafine palm oil fuel ash or common known as UPOFA will be used in this experiment. Thus, the properties of cement mortar will be observed based on the workability, flexural strength, compressive strength, porosity, water absorption and modulus of elasticity of cement mortar.

2.2.1 Workability of Cement Mortar by Using Ultrafine POFA

An investigation is carried out to evaluate the workability of concrete mixes in which UPOFA was used as an admixture during the concrete mixing. Based on the test results, (M.A. Megat Johari et al., 2012) concluded that the inclusion of the UPOFA improves the workability of the high strength green concrete, with higher workability at higher POFA content. This study observed that increase in workability could be attributed to the greater binder paste volume of the concrete especially at higher POFA content comparison to ordinary Portland cement. The excess paste volume in comparison with the ordinary Portland cement could have provided better roles of coating the particle aggregates and filling the gaps between the particles of aggregate hence increasing the workability.

Moreover, (M. A. A. Aldahdooh et al., 2013) state that the increase in workability could be a result of the replacement of ordinary Portland cement with ultrafine palm oil fuel ash. Therefore, it could be attributed to the decrease in the total binder mass of the green ultra-high performance fiber reinforced concrete especially at higher UPOFA content. The decreases in the total binder mass contribute to the increase in water-binder ratio due to the constant water contents of all concrete mixes. Thus, workability increases. From this study, it can be concluded that the inclusion of UPOFA tends to reduce the water demand of concrete which leads to a higher workability at constant water content.

2.2.2 Flexural Strength of Cement Mortar by Using Ultrafine POFA

In general, there is a relationship between compressive strength and flexural strength of concrete and cement mortar. It means when a concrete has a higher compressive strength and it will have a correspondingly higher flexural strength. This holds true for palm oil fuel ash as a cement replacement in mortar and concrete. Based on studies done by (V. M Sooraj et., 2013), it is seen that 28 days flexural strength of replacement of cement with POFA is similar to that control mix. However, when the replacement proportion is increased to 20%, the flexural strength also increases. But further increase in proportion of POFA causes a reduction of flexural strength.

(N. M., 2012) reports that the highest flexural strength of 13.51MPa was exhibited by the concrete mixture with POFA-cement ratio of 0.4 at a water binder ratio of 0.36 after 90 days. This could be explained by the growth of the porous structure because of the increase in the water-cement ratio leading to reduction in flexural strength. From the previous study, it can be concluded that flexural strength on concrete and mortar increase when water cement ratio decrease.

2.2.3 Compressive Strength of Cement Mortar by Using Ultrafine POFA

Compressive strength is the most important mechanical properties of every concrete and mortar. The study that has been done by (Awal, 1996) highlighted that POFA concrete gain maximum strength when 30% of the cement was replaced with POFA. It is reported that the maximum strength gain occurred at the replacement level of 30% but further increase in the ash content would reduce the strength of concrete gradually. Besides that, (W. Tangchirapat et al., 2003) used POFA with particle size of 7.5μm in amounts of 10% to 20% as a partial cement replacement. Test results indicate that the compressive strengths of concrete with cement replacement of 10% and 20% of POFA at 28 days and 90 days were 31.9, 31.6, and 39.0, 38.6MPa of the concrete respectively.

However, based on the research done by (M.A. Megat Johari et al., 2012), high volume of ultrafine POFA with a particle size of 2μm which is 40% substitution level exhibits the highest compressive strength of 140MPa at 28 days. The ultrafine POFA with smaller particle size, greater surface area, lower carbon content as well as high amorphous content proves to be a highly efficient pozzolan which significantly enhances the engineering and transport properties of high strength green concrete. Thus, it is possible to produce high strength concrete and cement mortar by utilizing high volume of ultrafine POFA with promisingly properties and durability performance. Besides that, added in fineness of POFA would lead to greater concrete and mortar's strength development than the coarse one.

2.2.4 Porosity of Cement Mortar by Using Ultrafine POFA

The fact that a reduction of porosity in a solid material increases its strength in general and the strength of cement-based material was recognized long ago. It has also been discovered that porosity has a role in the relationship between mechanical properties of concrete and mortar such as the compressive strength-modulus of elasticity relationship. Based on test results, (M.A. Megat Johari et al., 2012) concluded that the use of UPOFA reduces the porosity of high strength green concrete. It was observed that the reduction in porosity for all concrete mixes from 3 to 28 days indicates that the ordinary Portland cement, cement that was replaced by 20%, 40% and 60% of POFA record a reduction in porosity of 7%, 8%, 21% and 27% respectively. From these study, it shows that the higher the POFA content, the greater the reduction in porosity with longer period of water curing.

2.2.5 Water Absorption of Cement Mortar by Using Ultrafine POFA

Based on the research done by (Hossein Noorvand et al., 2013), it shows that the addition of UPOFA from 10% to 30% led to proportional increase in the water absorption and volume of permeable void ratio of mortar at 7, 28 and 90 days of curing. They found that the increasing trend in water absorption and permeable void ratio of UPOFA mixes

was consistent with reducing effect of UPOFA on compressive strength results. Admixing nanosilica on the other hand, decreased the water absorption and permeable void ratio of ultrafine POFA.

Moreover, it was found that UPOFA mixes with 0.5% and 1% nanosilica obtained lower value of water absorption capacity and permeable void ratio than those of UPOFA sample with 1.5% nanosilica at all ages. From this study, it can be concluded that the addition of UPOFA to cement mortars increased the water absorption and volume of permeable voids ratio comparing to ordinary mortar.

2.2.6 Modulus of Elasticity of Cement Mortar by Using Ultrafine POFA

The uses of pozzolans as replacement of cement have been reported to affect the static modulus of elasticity of concrete. Generally, higher strength materials have a higher modulus of elasticity. Therefore, higher strength mortar tends to crack more than lower strength mortar. For instance the use of rice husk ash in concrete as reported contributed to higher value in static modulus of elasticity when compare to ordinary concrete. On the other hand, other researchers reported that the replacement of Portland cement by slag in concrete seems to decrease the modulus of elasticity for a compressive strength below $55N/mm^2$ and slightly increase it, by about 10% for compressive strength greater than $60N/mm^2$. Modulus of elasticity is reported to be low at early age and high at later ages for palm oil fuel ash cement mortar and concrete. Therefore, the study examined the performance of UPOFA on the static modulus of elasticity when used as supplementary cementitious material in cement mortar.

2.3 CEMENT REPLACEMENT MATERIAL

2.3.1 Properties of Ultrafine Palm Oil Fuel Ash

Supply of POFA from different palm oil mill will have separate physical and chemical properties. However, silica is still the major chemical composition in UPOFA. The chemical and physical compositions of different POFA used in various works are shown in Table 2.1 and Table 2.2 respectively.

Table 2.1: Chemical Properties of OPC and POFA (M.A. Megat Johari et al., 2012)

Compositions	OPC (%)	G-POFA (%)	U-POFA (%)
SiO_2	19.01	51.18	65.01
Al_2O_3	4.68	4.61	5.72
Fe_2O_3	3.20	3.42	4.41
CaO	66.89	6.93	8.19
MgO	0.81	4.02	4.58
P_2O_5	0.08	4.1	4.69
K_2O	1.17	5.52	6.48
SO_3	3.66	0.36	0.33
TiO_2	0.22	0.19	0.25
MnO	0.19	0.09	0.11
Na_2O	0.09	0.06	0.07
C		19.05	0.09
LOI	2.48	21.6	2.53
$SiO_2 + Al_2O_3 + Fe_2O_3$		59.21	75.14

Table 2.2: Physical Properties of OPC and POFA (M.A. Megat Johari et al., 2012)

Materials	Specific gravity (kg/m^3)	Median particle size, d_{50} (μm)	Specific surface area (m^2/g)
OPC	3.1	6.79	0.785
POFA	2.42	15.76	0.435
G-POFA	2.5	2.45	1.694
T-POFA	2.5	2.99	1.438
U-POFA	2.56	2.06	1.775

According to ASTM C618 (2008), fly ash can be divided into three class, namely Class N fly ash, Class F fly ash and Class C fly ash. Based on the chemical composition of different POFA used in various research works, it shows that generally POFA is classified as Class F fly ash complied with ASTM C618 (2008). However, to achieve better strength of concrete and mortar consisting of POFA, (Awal et al., 1996) have been suggested that finer POFA is to be used.

By increasing the fineness of POFA would lead to greater strength development than the coarser one. Besides that, the use of UPOFA as pozzolanic material for partially replacing Portland cement is not well known and little research has been conducted. (M. A. A. Aldahdooh et al., 2013) used ash from palm oil waste to partially replace ordinary Portland cement and show that UPOFA possesses significant potential as an efficient pozzolanic material admixture for the production of concrete and mortar. This could lead to the greater utilization of POFA in concrete and mortar.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

In this chapter, cement mortar prisms and cubes were employed. The series of formulation of cement mortar prisms and cubes comprises cement, ultrafine palm oil fuel ash, sand and water was used. There are three different percentage of ultrafine palm oil fuel ash in cement composition were employed which are 10%, 20% and 30%. The specimens were cured in water for 1, 3, 7 and 28 days. There were 48 mortar prisms specimens with size of 40mm×40mm×160mm and 144 cube specimens with size of 50mm×50mm×50mm were prepared for compressive strength test, flexural strength test, porosity test, water absorption test and modulus of elasticity test.

3.2 SELECTION OF MATERIALS

Materials that are used for procedure the specimens in the present study were discussed in this section. Cement mortar specimens were prepared comprises of cement, sand, ultrafine palm oil fuel ash and water. However, the replacements of ultrafine palm oil fuel ash into cement composition were stated to be 10%, 20% and 30% by weight of cement.

3.2.1 Ultrafine Palm Oil Fuel Ash

Palm oil fuel ash is a by-product produced in palm oil mill. After palm oil is extracted from the palm oil fruit, both palm oil husk and palm oil shell are burned as fuel in the boiler of palm oil mill. Generally, after combustion about 5% palm oil fuel ashes by weight of solid wastes are produced (Sata et. al., 2004). The ash produced sometimes varies in tone of color from whitish grey to darker shade based on the carbon content in it. In other words, the physical characteristic of POFA is very much influenced by the operating system in palm oil factory.

Palm oil fuel ash usually is collected from palm oil factory has been dried and the ash is sieved by size of 300μm in order to remove bigger size particles and any other foreign materials. Then, it was ground in a modified Loss Angeles abrasion test machine to a median particle size of approximately 5μm in order to get ultrafine palm oil fuel ash as shown in Figure 3.1. The fineness of the POFA was then checked by using mastersizer test machine after the grinding as shown in Figure 3.2. The treated and sieved POFA were kept in an airtight container and stored in the humidity controlled room to prevent from being exposed to moisture. Figure 3.3 shows the picture of ultrafine POFA.

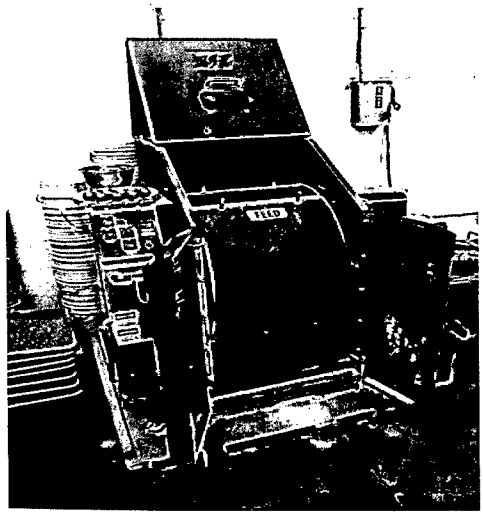

Figure 3.1: Modified loss Angeles abrasion test machine