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Strength of Concrete as Influenced by Palm Oil Fuel Ash

[1]Md. Rezaul Karim; [2]M.F.M. Zain; [2]M. Jamil; [3]Md. Nazrul Islam.

[1]Ph. D Candidate, Department of Civil and Structural Engineering, Universiti Kebangsaan Malaysia, Malaysia.
[2]Department of Civil and Structural Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia.
[3]Department of Civil Engineering, Dhaka University of Engineering and Technology, Gazipur, Bangladesh.

Abstract: Concrete is a suitable and popular construction material all over the world and cement is the most important constituent for its production. Due to continuous increasing of the cost of cement, the use of supplementary cementing materials such as industrial by-product (slag, fly ash, silica fume) and biogenic wastes (palm oil fuel ash, rice husk ash, ash from timber) have become significant in concrete industry. One of these important biogenic waste is the palm oil fuel ash (POFA) - generated as by-product from palm oil mills. The production of POFA increases every year, it is disposed for landfills without any return value and now becomes a burden. It contains a non-crystalline silicon dioxide with high specific surface area and high pozzolanic reactivity. Many researches have been conducted for the use of pozzolans, especially waste pozzolans- POFA, rice husk ash, silica fume- as a replacement of ordinary Portland cement (OPC). Test results regarding compressive strength and durability of concrete from these researches confirmed the use of POFA as a pozzolanic material for cement replacement in mortar and concrete. In this paper, a review on the strength of concrete as influenced by the use of POFA as partial replacement of cement in concrete has been presented. Based on the information available in literature on the utilization of POFA in blended concrete, the compressive strength of concrete as affected by the percent replacement and fineness of POFA in concrete is mainly discussed here. Advantages and disadvantages of POFA in concrete are also mentioned. Effective consumption of POFA as pozzolanic material in concrete, would decrease the cost of concrete production, could reduce negative environmental effect, and also would solve the landfill problem for the disposal of these wastes.

Key words: Palm oil fuel ash; Concrete, and Compressive strength of concrete.

INTRODUCTION

Now, thousands of tons of ash are produced annually by operation of 200 palm oil mills in Malaysia and are simply disposed of without any commercial return (Awal, 1997). Over half of the world’s total palm oil is produced from the oil palm industry in Malaysia; the country has an aim to grow further with the global increase in vegetable oil demand. However, the nation’s pollution problem is also increased for this sector - which includes the annual production of 2.6 million tonnes of solid waste in the form of oil palm shells (Basri, 1999). A large area is required for the disposal of these POFA waste materials. The landfill of POFA is the problem for the palm oil industry when it is not reused for any work. The production of POFA is rising every year, it is disposed for landfills, now become an important environmental disposal issue. Government needs to focus for assigning more hectares of land for disposal of these huge amounts of waste; and financial losses are also increased for transporting as well as maintenance purposes of these wastes. However, reduction of dumped waste and environment sustainability can be ensured by proper consumption or recycling of these materials.

Increasing world population and life demand are continuously raising the price of raw materials and reducing the natural resources; for these reasons researches have been concentrated to use waste materials as a potential alternative in the construction industry. Waste materials, when properly processed, have shown to be effective as construction materials and readily meet the design specifications. During recent decades, many researches have been conducted for the use of agrowaste ashes - POFA, rice husk ash (Awal, 1997; Basri,

Corresponding Author: Md. Rezaul Karim, Ph. D Candidate, Department of Civil and Structural Engineering, Universiti Kebangsaan Malaysia, Malaysia.

1999; Tangchirapat, 2009; Chindaprasirt, 2007; Chindaprasirt, 2008; Tay, 1995; Jaturapitakkul, 2007; Sata, 2010; Rukzon, 2009; Tangchirapat, 2007), sawdust ash and bagasse ash -as constituents in concrete. All of these agrowaste ashes contained a high amount of silicon dioxide in amorphous form and as a result they could be used as pozzolanic materials. Pozzolans are such fine materials, with containing silica and/or alumina, that they do not exhibit any cementing properties of their own; in the presence of calcium oxide (CaO) or calcium hydroxide ($Ca(OH_2)$), silica and alumina in the pozzolans react and form cementitious materials (ASTM, 2001). POFA is an agrowaste ash that contains a large amount of silicon dioxide and has high potential to be used as a cement replacement. For producing high-strength concrete, POFA can be used as a pozzolanic material; it improves the durability, reduces cost due to less use of cement. It will also be beneficial for the environment with respect to reducing the waste disposal volume of landfills (Tangchirapat, 2009). POFA contains the silica oxide that can react with calcium hydroxide ($Ca(OH)_2$) generated from the hydration process; and the pozzolanic reactions produce more calcium silicate hydrate (C-S-H) gel compound as well as reducing the amount of calcium hydroxide (Eldagal, 2008). Thus, for the concrete production, POFA contributes to make stronger, denser and more durable concrete.

Abundant agricultural and industrial wastes are discharged from the developing countries; these wastes, including POFA, can be reutilized as potential cement replacement material in the concrete construction. Therefore, effective consumption of POFA as a replacement for cement will also encourage researchers to investigate sustainable way of saving material, especially cement. The use of POFA in concrete as cement replacement material is logical, worthy and attributable for the present situation demand in concrete industry. Finally, this reutilization of POFA will have the double advantages - reduction in the cost of construction material and minimization of waste disposal problem.

The Palm Oil Fuel Ash:

Palm oil industries can play a major role in the economic development of different tropical countries. These industries produce a large amount of solid waste by-products - fibers, nut shells, and empty fruit bunches - during the processing oil-palm fruit for oil extraction. There will be approximately 20 tonnes of nut shells, 7 tonnes of fibers, and 25 tonnes of empty bunches discharged from the mill for every 100 tonnes of fresh fruit bunches processed (Tay, 1995). Palm oil fuel ash is commonly known as POFA, which is about 5% of solid waste product, have the potentiality to be used as pozzolanic materials in concrete industry (Sata, 2010). It is the ashes produced from fiber and shell of palm oil burning for the generation of energy in palm oil mill. It is a promising pozzolanic and available material in many parts of the world. The by product from palm oil industry such as palm oil residue, palm fiber and shells, when burnt at temperatures of about 800-1000^{0}C to produce steam for electricity generation in biomass thermal power plants are known as POFA (Tangchirapat, 2009). In Thailand, more than 100,000 tons of POFA are produced annually (Chindaprasirt, 2007), and this amount increases every year because palm oil is one of the major raw materials used in the production of bio-diesel. It has recently been accepted as a pozzolanic material in concrete due to its large amounts of silica. The material is similar to other pozzolanic materials, such as silica fume and fly ash. However, due to the pozzolanic properties of POFA, it is not only used as replacement of cement but also used in making strong and durable concrete (Awal, 1997).

Physical and Chemical Properties of POFA:

Different types of agricultural wastes have separate physical and chemical properties, which can be used in concrete with proper selection. The chemical composition and physical properties of different POFA used in various research works are shown in Table-1. The major chemical composition of POFA is SiO_2, about more than 50%. Most of the ashes contained total amount of SiO_2, Al_2O_3, Fe_2O_3 less than 70% but ASTM C618 (ASTM, 2001). specified this should be minimum 70% for class N pozzolan. All these ashes have almost similar chemical composition. As seen from this table that POFA is much finer than OPC. Based on the chemical analysis, all of those POFA, in general, satisfied the requirement of pozzolana, and may be grouped in class C pozzolan as specified in ASTM C618 (ASTM, 2001). This class is also suggested by other researchers (Awal, 1997; Chindaprasirt, 2007; Tay, 1990). Particle size distribution of OPC, Fly ash (OFA), Palm oil fuel ash (GPOA), and Ground rice bark ash (GRBA) is shown in Fig. 1. From this figure, it is observed that after grinding the POFA shows similar grading curve as OPC exhibits. The grinding process increased both the fineness and the specific gravity of POFA as shown in Table-1. This was due to the crushing of porous particles, which usually have low specific gravity, into smaller particles with lower porosity (Cheerarot, 2004). This result agreed with those of other researchers who ground fly ash and bottom ash (Kiattikomol, 2001; Isaia, 2003).

Table 1: Chemical and physical properties of POFA and OPC (Wt. %)

Chemical Properties of POFA									References
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O_3	K_2O	LOI	
43.60	11.50	4.70	8.40	4.80	2.80	0.39	3.50	18.00	Awal, 1997
65.30	2.50	1.90	6.40	3.00	0.40	0.30	5.70	10.00	Tangchirapat, 2009
57.80	4.60	3.30	6.60	4.20	0.30	0.50	8.30	10.10	Chindaprasirt, 2007
63.60	1.60	1.40	7.60	3.90	0.20	0.10	6.90	9.60	Chindaprasirt, 2008
57.70	4.50	3.30	6.50	4.20	0.20	0.50	8.20	10.50	Jaturapitakul, 2007
63.60	1.50	1.50	7.60	3.90	0.20	0.10	6.90	9.60	Rukzon, 2009
48.99	3.78	4.89	11.69	1.22	---	0.73	4.01	10.51	Eldagal, 2008
Chemical Properties of OPC									
20.20	5.70	3.00	62.50	2.60	1.80	0.16	0.87	2.70	Awal, 1997
20.90	4.70	3.40	65.40	1.20	2.70	0.20	0.30	0.90	Tangchirapat, 2009
20.90	4.80	3.40	65.40	1.30	2.70	0.20	0.40	0.90	Rukzon, 2009

Physical properties of POFA			
Material Specific gravity (gm/cm^3)	Mean particle size (µm)	Fineness: passing 45µm	References
2.22	-	519 (m^2/kg)	Awal, 1997
1.97	65.60	58.80 (retained 41.2%)[a]	Tangchirapat, 2009
2.33	10.10	98.50 (retained 1.5%)[b]	Tangchirapat, 2009
2.43	8.00	99.00 (retained 1%)	Chindaprasirt, 2007
2.43	7.40	99.00 (retained 1%)	Jaturapitakkul, 2007
2.50	9.20	98.80 (retained 1.2%)	Sata, 2010
2.25	7.90	11800 (cm^2/gm)	Rukzon, 2009
Physical properties of OPC			
3.28	-	314 (m^2/kg)	Awal, 1997
3.14	14.60	--	Tangchirapat, 2009
3.14	15.00	3600 (cm^2/gm)	Rukzon, 2009

a, b - Original and Grinding POFA respectively

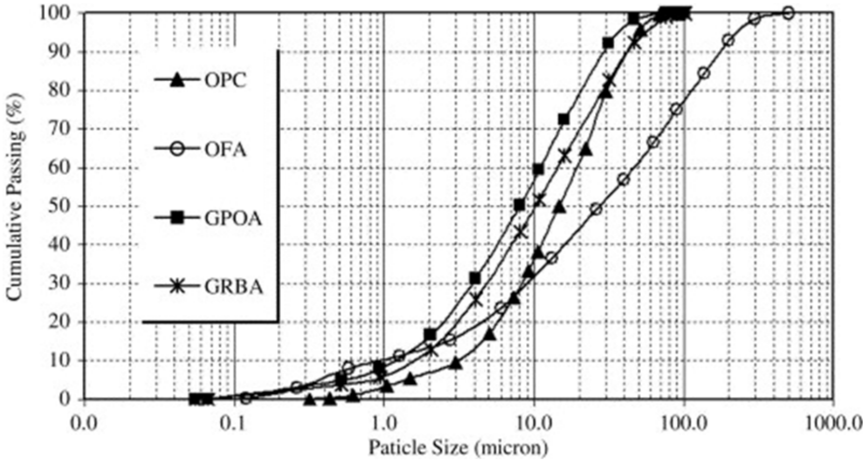

Fig. 1: Particle size distribution of different material with POFA (Chindaprasirt, 2007).

Fineness Effect of POFA on Concrete Strength:

The strength of concrete is influenced by the fineness of POFA and cement. For a same replacement of POFA in concrete with different fineness, a higher fineness of POFA can produce greater strength of concrete as well as better performance against sulfate attack (Tangchirapat, 2007). Researcher found that the depth of carbonation will be increased with decreasing the fineness of POFA i.e., the carbonation decreases when the high fineness of POFA is used (Rukzon, 2009). Fineness of POFA is a very important factor affecting the sulfate resistance of concrete. Ungrounded POFA performs low pozzolanic reaction thus it is not suitable for use as a cement replacement in concrete, in consequence results in low compressive strength and sulfate resistance of the concrete (Jaturapitakkul, 2007). Utilization of high fineness of POFA (1.0% retained on a No. 325 sieve) as a cement replacement at a level of 10% and 20% in concrete produced the compressive strength 100% and 99%, respectively, at the age of 28 days compared to that of concrete obtained from OPC type I cement (Jaturapitakkul, 2007).

The effect of fineness on the strength of concrete, as shown in Fig. 2, has been investigated by Tangchirapat *et. al* (Tangchirapat, 2007). They investigated that with 20-40% replacement of original ash (OP), the compressive strengths of concretes at 28 days were between 31% and 66% of the concrete made with OPC type I cement (Fig. 2a). The compressive strength of concrete reduced due to large particles of POFA with high porosity which causes an increase in the water-to-binder ratio of concrete. Thus, the original size of POFA is not suitable to be used as a substitute for cement in concrete. He also observed that the compressive strengths of concrete (made with median particle size 15.9µm of POFA) were 30.1 and 37.6MPa or about 94% and 101% of the OPC type I concrete (control concrete) at the ages of 28 and 90 days respectively (Fig. 2b). Contribution to improvement of compressive strength is due to pozzolanic reaction. It is seen from Fig. 2b, the concrete mixed with 20% of POFA had a compressive strength of 26.9MPa or 84% of the control concrete at 28 days, and at 90 days, it was increased to 33.4MPa or 90% of the control concrete. The highest fineness of POFA (median particle size 7.4 µm) used in that study, it was found that at 10% and 20% of cement replacement by POFA, the compressive strengths were as high as that of the control concrete at 28 days. The compressive strengths of concretes at 10% and 20% replacement of POFA at 28 and 90 days were 31.9, 31.6 and 39.0, 38.6MPa or about 100%, 99% and 105%, 104% of the control concrete, respectively (Fig. 2c).

Besides, the compressive strength of concrete with 30% replacement of POFA at 90 days was 36.8MPa or about 99% of the control concrete. It is concluded from these results that the higher fineness of POFA executes greater pozzolanic reaction and the small particles could also fill in the voids of concrete mixture, finally, improved the compressive strength of concrete. Isaia *et al*. (Isaia, 2003) and Jaturapitakkul *et al*. (Jaturapitakkul, 2007) used POFA in different particles: small, medium and the large size as replacement of Portland cement type I at a level of 10-40% by weight of binder in concrete production. They observed that large size is not suitable for use as a cement replacement in concrete because it produces low compressive strength but medium and small particle size of all POFA mixes show closer and same strength result to OPC at 28 days respectively. Therefore, all of these test results of compressive strength of concrete support that the POFA when ground to a fine particle size performs as highly potential pozzolanic material in concrete; in addition, the optimum replacement of POFA is about 20% - 30% by weight of binder, without sacrificing the compressive strength of concretes.

Supplementary Use of POFA in Cement and Concrete:

The POFA has been used as supplementary material in concrete more than a decade. The utilization of agricultural wastes like POFA as aggregate or cement replacement material in concrete has engineering significance and financial advantage. POFA with a suitable fineness, has been used as a pozzolanic material to produce high strength concrete as high as 100 MPa at 90 days (Awal, 1997; Jaturapitakkul, 2007; Sata, 2007). The mortar strength and resistance to chloride penetration of concrete can be improved by the use of blended pozzolans of equal portion of POFA and FA, and RHA and FA (Chindaprasirt, 2008). Oil palm shell (OPS) has already used in concrete as coarse aggregate and found useful as structural lightweight concrete; the compressive strengths of OPS concrete range from 20 to 24 MPa for 28 days; this satisfies the strength requirement of structural lightweight concrete (Mannan, 2001). Chindaprasirt *et al*. (Chindaprasirt, 2007) investigated that the POFA can be applied as new pozzolanic materials to concrete with an acceptable strength. The optimum cement replacement by POFA is 20%; beyond this ratio, compressive strength is reduced and tends to give higher permeability of concrete, they added. The strength development of concrete may be affected by higher replacement level of cement by 50% POFA (Awal, 1997).

Mannan and Ganapathy (Mannan, 2002). proposed that concrete made with oil palm shell as coarse aggregate can be used for the construction of low-cost houses, farm structures, tennis courts, pavements, blocks and paving drains; which results the reduction of production cost (Mannan, 2002). This ash has pozzolanic properties that not only enables the replacement of cement but also plays an important role in making strong and durable concrete (Eldagal, 2008). POFA was used to replace Portland cement, ASTM Type I, by 10, 20, and 30% by weight of cementitious materials to make high-strength concrete (Mannan, 2001). Ground POFA with high fineness can be used as a cement replacement to produce high-strength concrete. At the age of 28days, concretes containing 10-30% fine POFA exhibited higher compressive strength than concrete made from Type I Portland cement. Use of POFA in high-strength concrete resulted in a slight reduction of concrete drying shrinkage as compared to the high-strength concrete made from Type I Portland cement, depending on the amount of POFA added (Tangchirapat, 2009). Therefore, the waste material, POFA, has a good pozzolanic property, with selection of greater fineness and appropriate replacement percent, should be used as better supplementary cementing material in concrete.

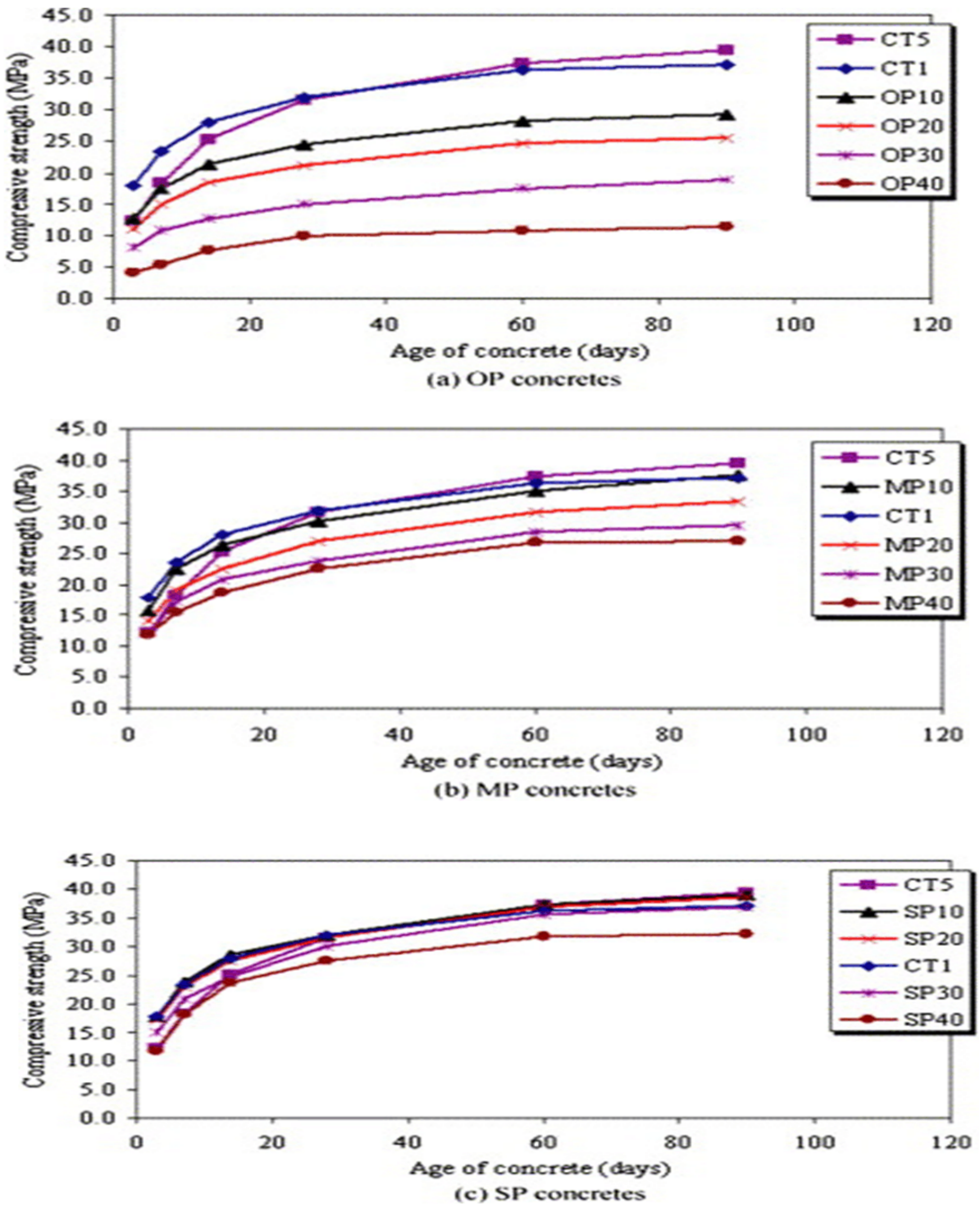

Fig. 2: Relationship between compressive strength and age of concretes (Tangchirapat, 2007).
[Note: CT1 and CT5, control concretes made from Portland cement Type I and Type V, respectively. OP, MP, and SP, are the original, medium, and small sizes of palm oil fuel ash (POFA). 10, 20, 30, and 40, percent replacement of POFA in Portland cement Type I by weight of binder].

Strength Development of Concrete with POFA:

Strength development of POFA blended concrete is pretty different from that concrete made with OPC. A slower strength gaining trend is observed of blended concrete with POFA at early ages in compare to that of OPC concrete due to the prolonged hydration process of POFA. The high fineness of POFA particles fills the voids between the cement and the aggregates. As a result the compressive strength of POFA concretes is increased at longer age. During the hydration process of cement, $Ca(OH)_2$ is generated which react with SiO_2 contained in POFA. The additional calcium silicate hydrate is formed during this process hence improves interfacial bonding between the aggregates and pastes at later ages. These characteristics have been shown to improve the compressive strength and increase the density of concrete (Isaia, 2003). The effects of POFA on the compressive strength of concretes are shown in Table-2. At an early age of 7 days, replacing Type I Portland cement with 10-30% POFA was performed by Tangchirapat *et al*. (Tangchirapat, 2009) and found the compressive strength that was comparable to concrete made with OPC Type I cement. This result shows that compressive strength of POFA mixed concrete is greater than that of OPC concrete. Chindaprasirt *et al*. (Chindaprasirt, 2007). suggested that the compressive strength of concrete containing 20% of POFA is higher than that of OPC concrete and is reduced when the replacement percent increases. The concrete strength for 40% replacement of POFA is lower than OPC concrete. Furthermore, POFA can be used as a cement replacement up to 30% in producing high-strength concrete, as shown in Fig. 2, and the compressive strength obtained is higher than that of high strength concrete made from Type I Portland cement.

It is demonstrated from Fig. 2 that 20% replacement of POFA could be the optimum level for the production of concrete because strength of concrete reduced gradually beyond this replacement level. These results suggest that ground POFA with high fineness is a reactive pozzolanic material and can be used as a mineral admixture in producing high-strength concrete up to a certain level (about 20-30%).

Table 2: Influences of POFA on the compressive strength of concrete

OPC: POFA	Compressive Strength (MPa) at							References
	3 d	7 d	14 d	28 d	90 d	180d	365d	
100:00:00	-	54.9	-	58.5	64.7	68.5	-	Tangchirapat, 2009
90:10:00	-	55.6	-	59.5	67.7	72	-	
80:20:00	-	54.6	-	60.9	69.4	73.7	-	
70:30:00	-	53.2	-	58.5	66.1	69	-	
100:00:00	-	-	-	26.1	28.2	-	-	Chindaprasirt, 2007
80:20:00	-	-	-	23.9	29.4	-	-	
60:40:00	-	-	-	20.7	23.7	-	-	
45:55:00	-	-	-	18.1	22.3			
100:00:00	-	43.5	-	57	60	-	-	Chindaprasirt, 2008
80:20:00	-	43.5	-	57.5	62	-	-	
60:40:00	-	32.5	-	53.5	61.5	-	-	
100:00:00	30.8	34	-	39.6	49.4	-	-	Sata, 2010
90:10:00	29.3	33.3	-	40	50.5	-	-	
80:20:00	28.6	32.6	-	39.6	50.1	-	-	
70:30:00	26.5	30.6	-	36.8	46.2	-	-	
100:00:00	-	44	-	58	62	-	-	Rukzon, 2009
90:10:00	-	45	-	58.5	62.5	-	-	
80:20:00	-	44.5	-	58.5	63	-	-	
60:40:00	-	33.5	-	54.5	62.5	-	-	
100:00:00	-	48.73	-	59.9	66.3	-	-	Eldagal, 2008
80 : 20 a	-	39.7	-	46.45	58.05	-	-	
70 : 30 a	-	34.55	-	46.06	46.65	-	-	
80 : 20 b	-	34.89	-	45.41	50.52	-	-	
70 : 30 b	-	29.45	-	41.37	45.1	-	-	
100:00:00	19.7	26.5	31.83	34.4	-	-	39.01	Tay, 1990
90:10:00	13.3	18.76	26.63	29.76	-	-	38.73	
80:20:00	10.76	11.63	12.93	14.23	-	-	22.36	
70:30:00	10.06	10.93	13.13	15.3	-	-	21.32	
60:40:00	6.23	7.7	8.76	10.33	-	-	16.63	
50:50:00	5.37	6.4	8.8	10.47	-	-	16.29	

a, b - POFA passing through 10 micron and 45 micron sieves respectively

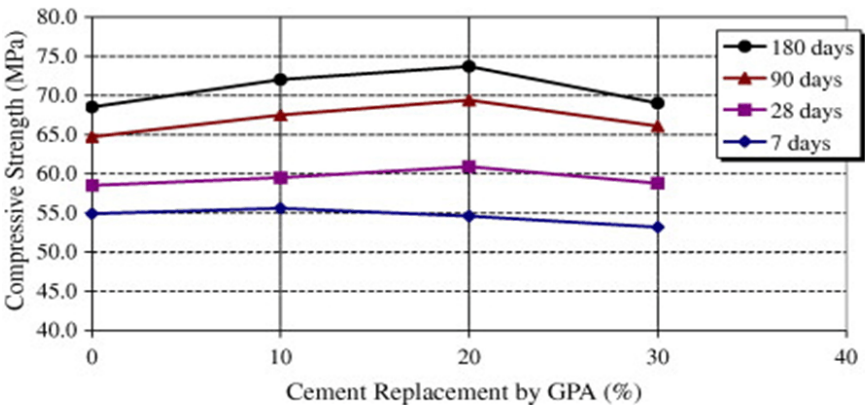

Fig. 3: Relationship between strength and cement replacement by (POFA) GPA (Tangchirapat, 2009).

Advantages of POFA in Concrete:

POFA exhibits a good pozzolanic reactivity as investigated in different literatures (Awal, 1997; Basri, 1999; Tangchirapat, 2009; Chindaprasirt, 2007; Chindaprasirt, 2008; Tay, 1995; Jaturapitakkul, 2007; Sata, 2010; Rukzon, 2009; Tangchirapat, 2007), besides that, it contributes to produce denser and durable concrete with a particular level (about 20-30%) of replacement. Based on the discussions presented in this paper, the following advantages of POFA have been found to use in cement or concrete:

Utilization of POFA in concrete could reduce the cost of concrete production due to less cement use; disposal problem can be minimized (Rukzon, 2009; Tangchirapat, 2007).

With high fineness, POFA can be used as a cement replacement to produce high-strength concrete; it also reduces the water permeability of concrete; shows smaller degree of expansion and loss in compressive strength with compare to concrete made with OPC type I cement (Tangchirapat, 2009).

POFA can be used as pozzolans to replace part of Portland cement in making mortar with relatively high strength and good resistance to chloride penetration (Chindaprasirt, 2008).

Concrete using POFA of high fineness (retained 1% on a No. 325 sieve) as a replacement of 20-30% achieved 100% strength compare to ordinary concrete (Jaturapitakkul, 2007).

Concrete made with palm oil shell can be used as structural light weight concrete (Basri, 1999; Mannan, 2001).

Awal and Hussin (Awal, 1997) suggested that POFA has a good potential in suppressing expansion due to alkali-silica reaction.

POFA can be used as a cement replacement to produce good resistance against sulfate attack (Chindaprasirt, 2008; Jaturapitakkul, 2007; Tangchirapat, 2007).

For concrete with POFA, the temperature rise of fresh concrete decreased as POFA content increased (Sata, 2010).

Disadvantages of POFA:

The utilization of POFA in either cement or concrete has great engineering, financial, and environmental benefits, that have already been described in this paper. In spite of these favorable influences of POFA in concrete, it shows a little bit bad effects that are mentioned below:

The use of POFA in concrete shows a relatively high carbonation effect in comparison with the OPC concrete (Rukzon, 2009).

The replacement of Portland cement by POFA resulted in the higher water demand in concrete mixtures as compared to OPC concrete (Chindaprasirt, 2007).

Greater percent (more than 30%) replacement reduces strength of concrete significantly; at early age strength is gained slowly (Tangchirapat, 2009; Sata, 2010).

Original coarse POFA (less fineness) does not contribute to achieve better strength in concrete (Tangchirapat, 2009; Tangchirapat, 2007).

Concluding Remarks:

The palm oil mills produce POFA as by-product which are disposed to environment without any return value. In consequence, the large area is covered or misused; so the problem can be reduced or minimized by reusing POFA during production of cement or concrete. POFA exhibits excellent pozzolanic property. So its incorporation in cement or concrete can be able to make a role in fulfillment the demand of cement. The concrete produced using a particular level of POFA replacement achieved same or more strength as compared to OPC concrete. No significant strength reduction of concrete is observed up to about 30% replacement of POFA. So, proper utilization of POFA in either cement or concrete production will be a remarkable cement and energy saving footstep for the present social demand in concrete industry. Appropriate consumption of POFA in cement or concrete is the current essential issue for disposal solution, effective environmental management as well as sustainable concrete production for the future generation in the world.

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