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Influence of Palm Oil Fuel Ash on Mechanical Properties of Ultra-High-Performance Concrete

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Abstract: The cost of producing concrete has increased, and its effects on the natural environment have become apparent. The ideal solution is to use agro-waste material instead of cement in concrete. Palm oil fuel ash (POFA) is a by-product of the burning of waste material at the palm oil power plant. Looking at the utilization of POFA in concrete research, there has been study conducted on the behaviour of properties of normal strength concrete containing POFA in terms of compressive strength performance. However, the performance of ultra-high strength concrete produced using POFA is still lack. This research aims to determine how well POFA works as a cement substitute in ultra-high-performance concrete (UHPC). It also to determine the mechanical properties of ultra-high-performance concrete (UHPC) with POFA addition. In this study, the percentage of POFA used as a cement replacement was 5%, 10% and 15% by binder weight. The results were collected from slump test and compressive strength test. Tabulation and graph illustration were the methods used to present the data. The workability test conducted showed that with the increase of POFA addition to the UHPC, the workability of fresh concrete was reduced. Meanwhile, the compressive strength at 28 days, UHPC with 5% of POFA addition showed the maximum value of compressive strength at 84.12 N/mm^2.

Keywords: Ultra-high-perfomance-concrete, palm oil fuel ash, workability, compressive strength

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1. Introduction

Rapid growth in infrastructure development demands concrete due to its versatile and durable characteristics. The characteristics of concrete have been enhanced owing to unanticipated requirements raised by society, such as high-rise buildings, long-span bridges, and high earthquake-resistant concrete structures, among others. To meet these desires, concrete should have outstanding performance in terms of its fresh, mechanical, and durability properties. Concrete consists of constituents such as cement, aggregate, and water. Cement is the potential candidate to heighten the bonding of concrete. However, emission of carbon dioxide (CO_2) is the main result of cement production. Processes involved in manufacturing cement includes the heating of limestone which releases CO_2 directly and burning of coal, natural gas or fossil fuels to heat the kiln. Therefore, in order to reach sustainable environment in construction work, research need to use renewable resources as a focal point, for instance palm oil scraps. The development of more durable and sustainable concrete in order to decrease life cycle cost of structures is an important trend in modern civil engineering. Malaysian Palm Oil Board (MPOB) (2011) informed that palm oil industry is about 4.917 million hectares of area in Malaysia. According to Hamada et al. (2018), Indonesia is the largest palm oil producer followed by Malaysia as the second-largest producer.

Recently, nano material has grabbed the researchers' attention, especially in terms of acting as an ultra-filler within the concrete microstructure to provide denser concrete (Tawfik et al., 2020). POFA is one of the aftermaths of burning palm oil industrial waste such as palm fibre, palm kernel shells and palm oil husk at temperatures about 800-100°C to generate electricity (Mo et al., 2017). Fly ash, silica fume and slag are the elements founded in the POFA. Sustainability in construction can be achieved by replacing cement with supplementary cementitious materials such as fly ash, ground granulated blast-furnace slag and silica fume (Aprianti S, 2017). POFA is widely available here in Malaysia as the industry is one of the largest agricultural industries. The high silica dioxide (SiO2) properties make POFA a good pozzolanic material (Safiuddin et al., 2011). Pozzolanic material can be described as materials containing siliceous and aluminous material by composition.

POFA are generally dispose to open fields that eventually raise the health threat to society and environmental deterioration issues. There is abundant amount of POFA in the country and it contains high pozzolanic characteristic. These cause many researchers take opportunity to evaluate its potential as a construction material. POFA is a geopolymer which considered environmentally friendly and uses minimum energy in production as to compared with the traditional materials (Hamada et al., 2018).

UHPC is a new class of concrete. UltraHigh-Performance UHPC is recognized as an example for an ultra-filler approach (Amin et al., 2020). UHPC is typically characterized by high contents of cement, silica fume, short steel fibers, special aggregates, and chemical admixtures (Benson et al., 2005), which are automatically reflected in the increase in the cost of UHPC (Fardis et al 2011) and greenhouse gas emission (Worrell et al., 2001). It has been introduced for many years for its extraordinary durability and strength characteristics. It has a very good performance under extreme condition. It also can be utilised in the structural works especially in the construction of bridge. This type of concrete has a compressive strength higher compared to the traditional concrete. There are several materials involved in the UHPC production such as Ordinary Portland Cement (OPC), fine silica sand and superplasticizer.

Literature shows that the recent utilization of POFA in concrete products is still limited and requires further investigation. The main objective of this study is to investigate the potential of POFA as a partial binder replacement for the ultimate mechanical properties of UHPC mixtures. This study may lead to the wider utilization of POFA in concrete and alleviation of both its environmental and economic impact. Ergo, the study aims to provide better and clearer arguments on using POFA in UHPC, i.e., to determine the effects of POFA addition to UHPC and come with a conclusion either the concretes produced give finer results compared to UHPC with no waste addition.

2. Literature Review

Blended cement is produced by mixing Ordinary Portland Cement (OPC) with waste materials as an alternative to partially replace cement in order to reduce cement contents in the concrete. Besides, this alternative also focuses on addition of waste materials to the effect of strength and durability of concrete. Common type of waste materials such as Fly Ash (FA), Wastepaper Sludge Ash (WPSA), Silica Fume (SF), Palm Oil Fly Ash (POFA). Fly ash is by-product of volatile power plants fired by coal, WPSA is a by-product from paper sludge mill from paper industry and POFA is a by-product from palm oil sludge.

In general, waste material is the materials that are discarded or unusable. It can be any form such as liquid, solid and gas. The evolution of technology in company with modern lifestyle has led to increment of waste production leading to a crisis in waste disposal (Batayneh et al., 2007). There is a huge amount of waste that has been produced every single year and most of it cannot be recycled. Since then, the waste materials become favorable in construction industry especially in enhancement the performance of concrete. Replacement of cement or aggregate, filler or fiber with by-product material is commonly used in the industry. In order to reduce consumption of cement, there are many waste materials or by-product have been used such as silica fume (SF), fly ash, rice husk ash (RHA) and glass (Tavakoli et al., 2018).

According to W. Kroehong et al. (2011), as the time for curing increase, the compressive strength increases too, but the strength decreases with the increase in amount of POFA replaced. POFA was grinded to a certain level of fineness that makes the compressive strength rate obtained was notably enhanced due to the hydration reaction, packing effect, pozzolanic reaction and nucleation effect. The hydration reaction takes place because of the chemical constituents in cement and water. In addition, a pozzolanic reaction occurs due to calcium hydroxide ($Ca(OH)_2$) with silicon dioxide (SIO_2) and aluminium oxide (Al_2O_3) which develop an increase in calcium silicate hydrate, C-S-H.

In addition, the compressive strength of concrete with addition of POFA at rate of 15% was the same as OPC concrete as studied by Sanawung et al. (2017). Furthermore, when both POFA concrete and OPC concrete had the same compressive strength, POFA concrete will have lower water permeability coefficient and chloride ion penetration compared to OPC concrete (Sanawung et al. 2017).

According to Shen & Xu (2019), concrete structures sometimes may be exposed to temperatures of up to 105ºC. They studied the compressive strength of concretes with different water–cement ratios during drying at 105ºC. The outcome indicates in the first instance the compressive strength decreases and increases as the water content increased. However, the link between compressive strength and moisture content was similar for concrete specimens with different porosities. As the porosity increases, a significant effect of moisture content on compressive strength increases.

Based on the study made by Salami et al. (2018), the study reports the influence of $Al(OH)_3$ as alumina source on the compressive strength of POFA alkali activated mortar (POFA AAM). A huge potential can be observed when 100% POFA is utilised in the development of POFA AAM. Furthermore, all of the POFA AAM with $Al(OH)_3$ addition were lower in compressive strength than the specimens without the addition.

Awal & Shehu (2013) did a research highlighting on the performance behaviour of palm oil fuel ash (POFA) in decreasing the heat of hydration in concrete. Four concretes were prepared which are concrete with 100% OPC as control, concrete with 50%, 60% and 70% POFA. It turned out that the total temperature rise in concrete was reduced by palm oil fuel ash. The result obtained and the observation made indicates the advantage of high cement replacement by using POFA is suitable for mass concrete where thermal cracking is a concern when excessive heat rises during hydration process.

As for workability, for OPC, 50%, 60% and 70% POFA concrete, a moderate slump of 160, 115, 90 and 80 mm were observed respectively. As conclusion, low workability is resulted from higher replacement of cement with POFA due to POFA irregular particle shape as compared to the concrete with OPC only. Furthermore, OPC concrete was observed to have the highest compressive strength. Meanwhile, sample with 50, 60 and 70% of POFA replacement made up 89%, 78% and 61% respectively of the control sample strength at 28 days (Awal and Shehu 2013).

In addition, Muthusamy et al. (2019) investigate the long-term mechanical properties of high strength palm oil clinker (POC) concrete containing partial POFA addition. Concrete mixtures containing 0% to 40% of POFA were made and up to 1 year of curing process in humid tropical environment. Concrete strength was significantly improved and the durability of palm oil clinker LWAC was enhanced with the utilization of 10% POFA. The reason of air curing in a tropical environment is it enables POC concrete with 10% POFA to achieve the desirable strength thanks to the high humidity of the surroundings (Muthusamy et al. 2019).

3. Methodology

3.1 Material Preparation

It is found that the materials needed for the experiment are those like normal concrete except with the addition of POFA. POFA was collected from the United Palm Oil Sdn. Bhd. which is located in Banting, Selangor. United Palm Oil Sdn. Bhd. is a company with integrated, eco-friendly and efficiently managed plantation and is famous for its finest agricultural practices and high-quality standards. This organization is known for its high level of social responsibility and environmental awareness and its leading role in the research and production of high-yielding palm products. This research would employ Ordinary Portland Cement (OPC) and POFA will be used as pozzolan. POFA is the by-products of burning palm fiber, shells and fruit bunches at high temperature of 700-1000 °C. Due to the contamination of foreign body and incombustible palm fibres, POFA can't be directly used. Thus, it required to be sieved through 2.12μm to retain large particles.

Using the required grading curves, the size of fine aggregates for concrete mixing can be calculated. Nevertheless, in comparison to the limit defined in BS 882, this method requires the use of fine aggregates in a small range of grading. Table 1 shows the fine aggregate grading limits. Kong et al. (1987) reported that the use of fine aggregate for the blending of a size 100 x 100 x 100 mm concrete cube specimen shall have the gradation within the M grading range. Nevertheless, given the difficulty of identifying the fine aggregates that have limited grading some researchers only suggest the use of fine aggregates which pass through the sieve test of 600 µm. Nevertheless, in this report, based on BS 410, and the natural sand that passed through 5 mm sieve and retained at 600 µm is used. To protect it from humidity, the sand is contained in a dry and airtight jar. The find aggregate's fineness component was found to be 2.75 by taking a 1000 g dry sand test. The fine aggregate is filtered into sieve sizes of 4.75xmm, 2.36 mm, 1.18xmm, 0.6 mm, 0.3 mm and 0.15 mm. Finally, by adding all the cumulative percentage values and dividing it by 100, the value of the fineness module can be obtained.

Table 1 - Grading limits for fine aggregates (BS 882: 1992)

SIEVE SIZE	Percentage by mass passing BS sieve			
	Overall Time	Additional limit of grading		
		Coarse	Medium	Fine
10.0 mm	100	-	-	-
5.00 mm	89-100	-	-	-
2.36 mm	60-100	60-100	65-100	80-100
1.18 mm	30-100	30-90	45-100	70-100
600 um	15-100	15-54	25-80	55-100
300 um	5-70	5-40	5-48	5-70
150 um	0-15	-	-	-

The coarse aggregates are separated by three nominal maximum sizes, which are 40 mm, 20 mm andx10 mm, based in the BS 882: 1992. Suitable selection of optimum coarse aggregate size is essential in concrete mix design as it affects concrete strength. In addition, the coarse aggregate should be cleaned and free of chemicals that can lead to concrete degradation. Crushed stones are typically coarse aggregates used for concrete mixing. In addition, coarse aggregate grading in compliance with BS 882 allows the percentage size of coarse aggregates to be uniform to the maximum limits as shown in Table 2. Based on the BS 882, the grading limit and total size of coarse aggregates are calculated because the aggregates could influence the water and cement needs in the concrete mix design, hence affecting the concrete strength. However, this could be avoided by choosing the water-to-cement ratio correctly, which will give a wide range of grading that can be used without affecting the concrete strength. Marsh (1988) mentioned that the maximum size of the coarse aggregate is commonly taken as 20 mmx- 5 mm.

The coarse aggregates included in this analysis are those retained on a 9 mm sieve and those passing through a 20 mm sieve which provides a range of coarse aggregate sizes fromx10 mm tox20 mm. The fineness module gained for the coarse aggregates is 7.17 by sieving 5000 g dry weight sample and sieving it through the sizes of 80xmm, 40 mm, 20xmm, 10 mm, 4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.3 mm and 0.15 mm. The value of the modulus of fineness shows that the average size of the sample of coarse aggregates falls between 10 mm and 20 mm.

Table 2 - Grading limits for coarse aggregates (BS 882: 1992)

Standard sieve (mm)	Percentage by weight passing the standard sieves		
	Nominal size of aggregate		
	40mm-5mm	20mm-5mm	14mm-5mm
20.0	100	-	-
37.5	90-100	100	-
20	35-70	90-100	100
14	-	-	90-100
10	10-40	30-60	50-85
5	0-5	0-10	0-10

3.2 Mix Design

Concrete mix design commonly uses form of dimensions or ratios such as 1:2:4, respectively representing the proportions of cement, fine aggregates, and coarse aggregates. The ratio is either determined by weight or volume. Although in terms of its simplicity of expression, this concrete mix design system has an advantage. However, it will cause a disruption when describing the effect of the mixing measurement on the concrete features. This is related to the importance in defining the amount of cement needed to cast a given concrete size. Thus, using the typical mix concrete layout sheet to measure the concrete mixing percentage is the most ideal way to specify mixing parameters for each individual material engaged in concrete mixing in terms of volume. Moreover, by measuring specifically the mixing percentages required for concrete mixing, the waste of materials typically occurring will be minimized (Marsh, 1988). The reason is that the mix design sheet can produce one meter cubic of concrete for each individual material, namely concrete, water, fine aggregate, and coarse aggregate, with designated quantities in terms of mass. The design mix proportion for this study is depicted in Table 3. Upon continuing to the casting process, the fresh concrete is then tested to assess its workability using the slump test. In addition, the vibrating table is being used to vibrate the mould to ensure that the concrete is evenly compacted while minimizing the air void produced in the concrete.

UHPC is a unique concrete with exceptional strength and durability potential. The production and implementation perform the current technology and information of concrete manufacturing. The main fields of application of UHPC are bridges, high-rise buildings, special structures such as nuclear facilities (Kamal et al., 2014). The mix design of UHPC is vary than the OPC concrete. The cement is typically content more than 850 kg/m^3 and its properties considerably influences the mechanical properties of UHPC (Janković et al. 2016; Abdul Razak et al., 2021). Superplasticizer was required to allow high reduction of water. Firstly, cement will be mixed with water, then the superplasticizer will be added and then proceeded with the mixing of POFA. POFA will be added at 5%, 10% and 15% by binder weight. A constant of 0.20 water to binder ratio was applied for all the mixtures. The mix proportions of UHPC with and without POFA are given in Table 3.

Table 3 - Mix proportion of UHPC and POFA

Mix Design	Raw materials (kg)					
	Cement	Sand	Aggregate	Water	Admixture	POFA
Control UHPC	7.92	4.29	7.92	1.58	0.16	0
UHPC+ 5% POFA	9.36	5.07	9.36	1.87	0.19	0.47
UHPC +10% POFA	9.36	5.07	9.36	1.87	0.19	0.94
UHPC+ 15% POFA	9.36	5.07	9.36	1.87	0.19	1.40

Next, sand and aggregates will be added by adding first the fine then only coarse aggregate. Four mix proportions will be made with varying rate of POFA at 0%, 5%, 10% and 15% by binder weight. Slump tests are done during the placement of concrete mix into the moulds. The following day, specimens will be demoulded and put into water for curing. The specimens shall be assessed at the age of 3, 7, 14 and 28 days. Cubes of 100mm are going to be tested for compression test. The pace rate will be set as 3.0 kN/s.

4. Testing Procedures

4.1 Slump Tests

A slump test is defined as a method to establish the consistency of the concrete. It is an evaluation of workability or fluidity of concrete. The outcome of the slump test is evaluation of the behavior of a compacted inverted concrete cone under gravity action. This test will be needing the slump cone, temping rod and scale for measurement. Workability test was performed according to procedures established by the BS 1881: Part 102: 1983.

The slump can be measured by placing the cone beside the slump concrete and the temping rod is place over the cone. The reduction of concrete height to that of mould is measured with a scale. As a precaution, before the test is conducted, the inner mould and its base shall be wetted to lessen the effect of the surface friction on the slump. The slump test is used to verify the uniformity in different batches of the same concrete. This test is convenient on site to check on the variation in materials in the mixer. A slump that with too high or too low reading will give instant warn and enables the mixer operator to take corrective actions.

4.2 Compressive Strength Tests

Compressive strength is the tendency of the component or structure to handle the load with little to no crack or deflection on its surface. Under compression, the concrete tends to reduce its size while the size elongates in tension. This test offers an understanding of the properties of concrete. When carrying out this test, it can be determined if the concreting works have been executed in a proper manner. This test was performed according to procedures established by the BS 1881: Part 102: 1983.

Load rate is vitally important for compressive strength checking. In addition, the higher the rate of loading, the greater the strength measured. It has been said that additional subcritical cracking may start happening under slow loading rates, or that slow loading causes additional creep to appear that influences the amount of strain at a specific load.

Cube test uses 100x100x100mm mould depending on the aggregate size used. Then the concrete is placed in the mould by three layers with each layer shall be compacted with the vibrating table. Top surface of the cubes shall be made smooth and even by adding cement paste and lay out smoothly on the cubes. After 24 hours the moulds will be removed, and the cubes will be place in the curing tank for curing process. After 3 days, 7 days, 14 days and 28 days of curing, the cubes will be tested by using a compression machine and will be tested at the correct angles to the casted position. Load shall be applied with increment until the cube fails. The failure load from the test shall be divided by the surface area of cube to get the compressive strength of concrete.

5. Results and Discussion

5.1 Workability

There were four concrete mixes of UHPC were made consisting of controlled sample, 5%, 10% and 15% by binder weight of POFA addition. Slump test result was measured in millimeter. Concrete mix with high slump will be sloppy while concrete mix with a low slump value will be stiff and difficult to work by hand. The slump test results for the controlled samples and for each of the concrete mix with the additional of POFA with different percentage are shown in Table 4.

Table 4 - Consistency of fresh UHPC and UHC-POFA concrete

Mix Designation	Slump Reading (mm)	Indication
Control UHPC	250	High
UHPC + 5% POFA	230	High
UHPC + 10% POFA	10	Very low
UHPC + 15% POFA	0	Zero slump

Table 4 showed the slump test result of four different concrete mixes. Results collected for Control UHPC, UHPC + 5% POFA, UHPC + 10% POFA and UHPC + 15% POFA were 250 mm, 230 mm, 10 mm and 0 mm respectively. Concrete mixes that possessed additional amount of POFA showed low slump value. The highest slump value recorded was Control UHPC with 25 0mm. The lowest slump value recorded was UHPC + 15%POFA with 0 mm. Islam et al. (2016) discovered the slump values were lowered when the palm oil fuel ash content was increased further up to 25% and if higher percentages of palm oil fuel ash are being used, a significantly higher impact of POFA water demand could have led to a reduction in concrete workability. Hence it was important to take into account strength and workability requirements for concrete work. The use of rounder shaped aggregates and the use of workability enhancing admixtures can improve the workability of concrete. Other than that, the use of admixture such as air-training admixtures improves the workability without even increasing the water cement ratio. This attempts to achieve the strength and workability required for practical concrete work. Results recorded showed higher amount of POFA replacement in concrete mix resulted to lower workability.

5.2 Strength Performance

Compressive strength test done on the concrete is a mechanical test that tests the highest level of compressive load that any material can withstand before it crashes or fractures. This test can be done on sample that has several forms such as cube, cylinder and prism. For this study concrete cubes were used for compressive strength testing and was compressed by an incrementally applied load between the platens of a compression testing machine. This test was to analyse the performance of concrete at hardened stage. Three samples were prepared for Control UHPC, UHPC + 5% POFA, UHPC + 10% POFA and UHPC + 15% POFA to carry out the compressive strength test. This test was carry out on every age of concrete which were 3 days, 7 days, 14 days and 28 days. Results were recorded and tabulated in Table 5. Comparison has been made to further analyse the outcomes.

Table 5 expressed the average compressive strength test on each sample on different age of concrete. The amount of average ultimate stress of UHPC, UHPC + 5% POFA, UHPC + 10% POFA and UHPC + 15% POFA on Day 3 were 63.60 N/mm^2, 74.08 N/mm^2, 70.67 N/mm^2 and 72.46 N/mm^2 respectively. The highest amount of average ultimate stress on Day 3 was UHPC + 5% POFA with 74.08N/mm^2. The amount of average ultimate stress of UHPC, UHPC + 5% POFA, UHPC + 10% POFA and UHPC + 15% POFA on Day 7 were 80.21 N/mm^2, 77.00 N/mm^2, 66.71 N/mm^2 and 81.42N /mm^2 respectively. The highest amount of average ultimate stress on Day 7 was UHPC + 15% POFA with 81.42N/mm^2.

Results showed that UHPC + 5% POFA has been the highest average ultimate stress for three time which are on Day 3, Day 14 and Day 28. This can be said that 5% was the optimum percentage of POFA addition to the UHPC. This can be relate with the percentage of POFA used in the concrete mix. Concrete mixes that contained POFA as cement replacement always showed higher compressive strength than control sample. Zeyad et al. (2017) in his recent study showed that ultrafine POFA as cement replacement can achieve compressive strength higher than control sample which may reach more than 90 N/mm^2 at 28 days. Sata et al. (2007) also observed that the replacement with 10% ground POFA resulted in the optimum compressive strength and yielded higher strength than control sample.

The early age increase in compressive strength which on Day 7 can be due to the void filling ability of the finer ash particles while the presence of the silicon dioxide (SiO2) in the POFA reacts with the calcium hydroxide (Ca(OH)2) and form additional calcium silicate hydrate (C-SH) that improves the interfacial bonding between the pastes and the aggregates which eventually increases the strength at the later stages. The compressive strength of the concrete mixture increased with the age of concrete but decreased with an increase in the percentage of POFA implemented as cement replacement. The POFA was ground to a reasonably high fineness. This ensured that the rate of compressive strength achieved by the concrete mixture to improve due to the hydration reaction, nucleation effect, packing effect and pozzolanic reaction.

The hydration reaction occurred due to the chemical constituents in cement and water while the pozzolanic reaction occurred due to the reaction of Ca(OH)2 with SiO2 and aluminium oxide (Al2O3) from palm oil fuel ash which produced an increase in calcium silicate hydrate (C–S–H). The pozzolanic reaction of high fineness POFA is faster than that of coarse POFA. The packing effect is exhibited as the small particles fill the voids of the paste which allow for denser packing within the material particles and the matrix phase. The nucleation effect raised when the smaller particles were dispersed in the blended cement paste which accelerated the reaction and formed a smaller cement paste product. The blended cement paste that contained POFA with high fineness was more homogeneous and denser which improved the compressive strength of the blended cement paste. Nucleation effects are most important at the early age of hydration when the microstructure was developed rapidly. The hydrates especially calcium silicate hydrate (CSH) precipitated and constituted at least 60% of the fully hydrated cement paste and form a solid network between the cement and filler grains that led to the strength development (Ouyang et al. 2017).

Table 5 - Compressive strengths of UHPC and UHPC-POF

Day	Sample	UHPC			UHPC + 5% POFA			UHPC + 10% POFA			UHPC + 15% POFA		
		Maximum Load (kN)	Ultimate Stress (N/mm^2)	Ultimate Stress Average (N/mm^2)	Maximum Load (kN)	Ultimate Stress (N/mm^2)	Ultimate Stress Average (N/mm^2)	Maximum Load (kN)	Ultimate Stress (N/mm^2)	Ultimate Stress Average (N/mm^2)	Maximum Load (kN)	Ultimate Stress (N/mm^2)	Ultimate Stress Average (N/mm^2)
3	A	636.0	63.60	63.60	691.1	69.11	74.08	753.5	75.35	70.67	703.4	70.34	72.46
	B	622.3	62.23		793.0	79.30		668.8	66.88		751.5	75.15	
	C	649.6	64.96		738.3	73.83		697.9	69.79		719.0	71.90	
7	A	848.4	84.84	80.21	742.3	74.23	77.00	720.3	72.03	66.71	845.2	84.52	81.42
	B	827.6	82.76		759.0	75.90		545.8	54.58		809.9	80.99	
	C	730.3	73.03		808.6	80.86		735.3	73.53		787.5	78.75	
14	A	697.1	69.71	73.88	680.6	68.06	76.18	820.9	82.09	74.22	789.4	78.94	75.06
	B	770.1	77.01		714.1	71.41		776.9	77.69		750.2	75.02	
	C	749.2	74.92		890.8	89.08		628.9	62.89		712.1	71.21	
28	A	820.4	82.04	80.32	805.3	80.53	84.12	787.3	78.73	81.89	732.8	73.28	82.81
	B	782.8	78.28		840.6	84.06		867.6	86.76		884.7	88.47	
	C	806.5	80.65		877.7	87.77		801.8	80.18		848.7	84.87	

5.3 Relation of Strength Performance with Slump Test

Figure 1 indicated the relationship of compressive strength and slump results. Compressive strength on day 28 was located at vertical axis while slump results was located at horizontal axis. The amount of average ultimate stress of UHPC, UHPC + 5% POFA, UHPC + 10% POFA and UHPC + 15% POFA for slump value of 250 mm, 230mm, 10 mm and 0 mm were 80.32 N/mm^2, 84.12 N/mm^2, 81.89 N/mm^2 and 82.81 N/mm^2 respectively. The maximum amount of average ultimate stress was slump value of 230mm with 84.12 N/mm^2. Compressive strength decreased as slump test value increased but the maximum compressive strength was recorded at slump value of 230 mm of 5% POFA addition.

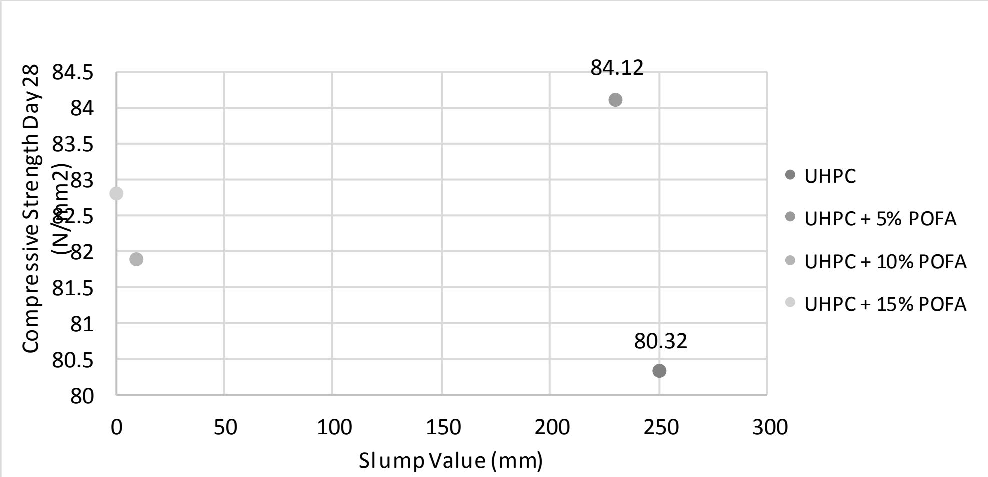

Fig. 1 - Graph of relationship of compressive strength day 28 with slump result

This was due to several factors that affected on the concrete slump test result including the material properties of the cementitious material such as chemistry, fineness, particle size distribution, moisture content and temperature. In addition, the size, texture, combined grading, cleanliness and moisture content of the aggregates also influenced the slump test results.

Concrete strength also decreased with water cement ratio increased. The raised in the water cement ratio improved concrete workability. Thus, concrete strength was inversely proportional to concrete workability. The explanation for this relationship was because water from the concrete dried up and created voids when concrete was set. The more water, the greater the number of vacuums. Number of voids increased which eventually decreased compressive strength of the concrete.

6. Conclusion

The significant conclusion that can be made from this study are:

- Compressive strength test has been conducted and the results have been tabulated properly. Based on the analysation that have been done, the highest average ultimate stress goes to UHPC with 5% POFA addition with 84.12 N/mm^2. Compressive strength recorded was higher than result recorded for UHPC without any POFA addition. This means that POFA properties helped to increase the compressive strength of the blended cement concrete.
- The average compressive strengths of UHPC with POFA addition achieved at day 3 were about at least 86 percent of the corresponding day 28 compressive strengths. A high early strength was achieved because of the low water to binder ratio. That is, in this study water to binder ratio of 0.20 was used constantly to all the four kinds of concrete mixes.
- Important material which is POFA that possessed high fineness ensured that the rate of compressive strength achieved by the concrete mixture to increase and becomes better due to the pozzolanic reaction, packing effect, nucleation effect and hydration reaction.
- Slump test has been conducted and it shown that higher percentage of Palm Oil Fuel Ash (POFA) addition to Ultra High-Performance Concrete (UHPC) will gave lower amount of slump value. At 15% POFA, the result recorded was 0mm. Lower slump value express less workability. Properties of POFA and admixtures have affected the concrete slump value for this study.
- Optimum percentage of POFA addition in this study is 5%. Based on the compressive strength results, 5% of POFA addition gives the highest strength at day 28. However, for 10% and 15% POFA addition are not considered optimum as the strength results are much closer to the controlled UHPC. Thus adding 5% of POFA into concrete mixes is more reasonable.

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