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Research Article

Evaluation of POFA on the Mechanical Properties of Concrete

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Abstract: The abundance of POFA as an agricultural waste makes it a promising candidate to be used as supplementary cementations for palm oil-producing countries. This study investigates the effectiveness of agro-waste ash by-product Palm Oil Fuel Ash (POFA) as an alternative material to replace portland cement (OPC). Experimental work was carried out by supplementing cement by weight in concrete mixes with POFA at 2.5%, 5%, 10%, 15% and 20% The POFA as a partial replacement in aerated concrete slump test, compressive strength test and splitting tensile test strength were investigated. Portland cement (grade 42.5) was replaced by weight while 20% of POFA aluminum powder (AP) was used to make aerated concrete at 0.3% and 1%. The compressive strength of UPOFA with increase in aluminum powder and the presence of aluminum powder does not have any significant effect on portland cement for the splitting tensile test, but the presence of POFA caused decreases in its splitting tensile strength, GPOFA shows lesser tensile strength with increase in AP than that of UPOFA. This study implies that POFA is a good candidate for various applications and highlights the potential of POFA as an effective pozzolan that could enhance the sustainability and economic aspect of concrete.
Keywords: Aluminum powder, POFA, Tensile strength, Splitting test.

1. INTRODUCTION

The POFA is the original byproduct obtained through the burning of empty palm fruits bunches, shells as fuel. It is very rich in Silica as an amorphous in nature which possesses pozzolanic properties and contributes in improving the engineering properties of the soil with the low load-bearing capacity, Deepak *et al*., (2014) and Tay (1990). The potential is further strengthened and driven by the fact that the oil palm constitutes only ten percent of the palm production, while the rest of ninety percent is the residue, according to Foo and Hameed, (2009). Palm oil fuel ash (POFA) has been known to possess a pozzolanic property. The abundance of POFA as an agricultural waste in Nigeria makes it a promising candidate to be used as a supplementary cementations material in palm oil-producing states.

Similarly, the production of cement and concrete is an essential material that binds together solid bodies which equally contribute larger percentage of carbon dioxide (CO2) emission and about 10% of global CO_2 emission comes from cement production thus making the sustainability of concrete a major threat that needs immediate attention Jonida *et al*., (2018) and Hanada *et al*., (2018). The physical properties of POFA are influenced by its fineness and burning temperature according to Safiuddin *et al*., (2011) and Abdullah *et al*., (2006), that the burning temperature condition is one of the factors that significantly influence the physical properties of POFA. Several of the physical properties of unground and ground POFA used in various studies are shown in Table 1.

The utilization of pozzolanic materials in cement and concrete manufacturing has increased significantly Ettah et al., (2018).

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Table 1. Physical properties of unground and ground POFA Safiuddin *et al.*, (2011)

Properties	OPC	Unground POFA	Ground POFA
Colour	Grey	Light grey/whitish	Dark grey
Specific gravity	3.14-3.28	1.78-1.97	2.22-2.78
Median particle size, d50 (um)	10-20	54.3-183	7.2-10.1
% Passing through the 45-um sieve (% mass)		5.6-58.8	97-99
Specific surface area, Blaine (m2/kg)	314-358	796	882-1244
Strength activity index (^{0}/0)			78.6-115
Soundness, Le ChatelierExpansion (mm	0.45-1	0.5-2.6	1

1.1. LITERATURE REVIEW

According to Ahmad *et al.*, (2008), POFA is one of the potentials recycle material from palm oil industries fuel ash which contains siliceous composition and reacts as pozzolan to produce stronger and denser concrete. According to Awal and Hustin (1997), they reported that POFA additive in cement can be successfully used in soft soil stabilization if combined with lime, as the palm ash is rich in silica and low in lime (CaO).

Similarly, in the work of Awal *et al*., (2011) they carried out an investigation and concluded that a high volume of POFA with concrete, and with other pozzolanic materials, showed a slower gain in strength at an early age. This implies that the strength of the POFA is being determined and also increased by the number of days for curing. The more days of curing the higher strength will be obtained. Mohammed *et al.*, in 2009, studied concrete replacement with water to binder ratio of 0.45, were seen to develop strength exceeding the strength of almost 60 Mpa at 28 days. In 2008, Abdul *et al*. discovered that inclusion of 20 percent POFA would produce concrete having the highest strength as compared to any other replacement level.

Karim *et al.*, (2011) have found that POFA can be used in the construction industry, especially as supplement cementitious material in concrete. It can also be used as finishing in the construction of pavement structure. Abdul *et al*., (1996) and Hussin *et al*., (2009) studied the compressive strength of concrete containing POFA. The result revealed that it was possible to replace at a level of 40 percent POFA without affecting compressive strength. The maximum compressive strength gain occurred at a replacement level of 30 percent by weight of the binder. According to Abdul Awal, (1998); Abdullah *et al*., (2006) have stated that integration of POFA as a partial cement substitute enhances concrete durability towards sulfate attack.

According to Zeyad *et al*., (2018) and Sooray (2013), there are lots of additives that have been experimentally carried out on the effects to improve geotechnical properties of soil at a lower cost by replacing certain percentage of cementitious additives which are; palm kernel ash, sawdust ash, and eggshell ash.

Furthermore, Roger *et al*., (1996) discussed the relevance of calcium hydroxide in the soil water with the silicate and aluminate in clay or lateritic soil and POFA to form cementing and binders consisting of calcium silicate and aluminate hydrate; the dissolved Ca++ ion react with dissolved SiO2 and Al2O3 from lateritic or clay particles and form hydrated gels and resulting in combination of soil particles. This new compound of calcium silicate hydrates and calcium aluminate hydrate gels are formed as a result of the pozzolanic reaction and subsequently crystalize to bind the structure together.

111. RESEARCH METHOD

The cement samples were collected from Lafarge UNICHEM Mfamonsing plant, Akampka, Cross River State, Nigeria, by inter-grinding Portland cement clinker with a regulated quantity of limestone and gypsum to conform to the NIS 444- 1: 2003 and EN 197-1:2011 specifications. The compressive strength was 23-27 N/mm^2 strength at 2 days and 53-57 N/mm^2 strength at 28 days.

A. AGGREGATE

Natural Fine Quartz Sand and Natural Coarse Pebble Gravel aggregate. The coarse aggregates are crushed particles with particle size between 5mm and 20mm.

B. ALUMINUM POWDER

Fine, uniform, smooth metallic powder-free from aggregate with an atomic weight of 26.98, and a density of 0.55 g/cm^3 were used. The aluminum powder confirmed to IS 438 2006 and ASTM B 212 – 99 and is commonly used as an air-entraining agent to obtain lightweight concrete by a chemical reaction producing hydrogen gas to fresh mortar so that it contains a large number of air voids in the mortar.

C. PALM OIL FUEL ASH (POFA) ADMIXTURE

The POFA materials were obtained from the Biase Local government area of Cross River State by burning the palm bunches, kernel, fibers. After burning, it is then passed on sieve slots size of a 0.30 mm to separate coarser particles and the wreckage. The POFA is then grounded to produce ground POFA (GPOFA). To get rid of any unburned carbon, the GPOFA is further heated in a furnace at 500 ± 50 ºC for 90 minutes to produce treated POFA (TPOFA) then grounded to get the ultra-fine POFA (UPOFA).

Figure 3. 1: Sample of the POFA

D. POTABLE WATER

The potable freshwater, that is free from acid and organic substance was used in mixing the concrete.

E. CONCRETE BATCHING

Control concrete was batched by weight and mixed in the ratio of cement: sand: gravel = $1{:}1\frac{7}{10}{:}\,3\frac{9}{10}$ at a water/cement ratio of 0.50, as shown in Table 2 below. Variable concretes were then obtained by adding aluminum powder and replacing 20% of the cement by weight with POFA admixtures. The percentage replacement by weight of cementitious material with Aluminum was 0.3% and 1% respectively. The fresh concrete was tested for workability (slump test). See Table 3.1.

Table 3.1: Concrete batching

				Weight					
Mix	**Cement**	**Sand**	**Gravel**	**GPOFA**	**UPOFA**	**Aluminum**	**Water**	**W/C ration**	
	(Kg)	(Kg)	(Kg)			Powder (%)			
1	1	1 7/10	3 9/10				0.5	0.5	
2	1	1 7/10	3 9/10			0.3	0.5	0.5	
3	1	1 7/10	3 9/10			1	0.5	0.5	
4	1	1 7/10	3 9/10	20		0.3	0.5	0.5	
5	1	1 7/10	3 9/10	20		1	0.5	0.5	
6	1	1 7/10	3 9/10		20	0.3	0.5	0.5	
7	1	1 7/10	3 9/10		20	1	0.5	0.5	
	Cement =333 kgm^3 and (cement + POFA) = 333 Kgm^3								

F. CONCRETE CASTING AND TESTING

Consistency in the desired workability of fresh concrete is very important in concrete work. This can be ensured via slump testing of concrete before it sets. Slump tests were carried out in accordance with BS EN 12350-2. A slump cone specimen was cast for each concrete mixture and the slump or reduction in height of the cone is considered a measure of workability.

G. HARDENED CONCRETE TEST

The compressive strength test for the 100 mm x 100mm x 100mm concrete cube specimens was determined. The compressive test for the cubes was cured at natural temperature and crush after 28 days of curing. The compressive strength of the concrete varies from 15 MPa (2200 psi) to 30 MPa (4400 psi) and higher in commercial and industrial structures, Zeyad *et al.*, (2018). The compressive strength of concrete depends on many factors such as water-cement ratio, cement strength, quality of concrete material, and quality control during production of concrete, etc.. Various standard codes recommend concrete cylinder or concrete cube as the standard specimen for the test. American Society for Testing Materials ASTM C39/C39M provides Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.

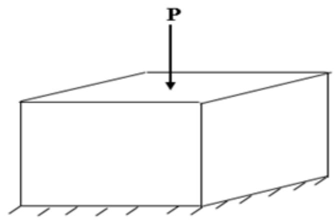

Figure 3.2: Compressive Test Specimen

Three 100x100x100mm cube specimens were cast for each concrete mixture and the strength value was calculated by the following equation: $\frac{P}{A}$

Where P= test load (KN) and A= section area normal to P

H. SPLITTING TENSILE STRENGTH TEST

The 100 mm × 200 mm high concrete cylinders for splitting tensile strength was used. The test specimens were cured at natural temperature and split after 28 days of curing. This method was used to determine the splitting tensile strength of cylindrical or cubic concrete specimens. The ages were calculated from the time of the addition of water to the dry ingredients.

Three 100 mm × 200 mm high cube specimens were cast for each concrete mixture and the spitting tensile strength value was calculated by the following equation: $\frac{2P}{\pi DL}$

Where P = test load (kN) normal to the section
D = Diameter of specimen
L = Length of specimen

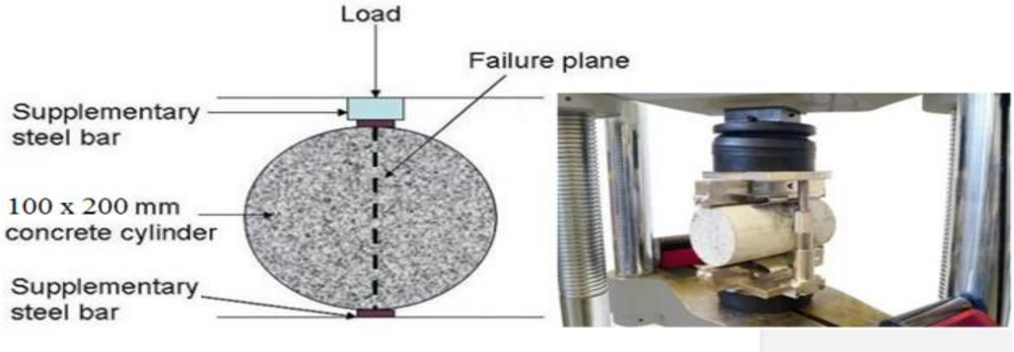

Figure 3.3: Splitting Tensile Specimen and Test Machine

IV. RESULTS AND DISCUSSION

4.1.2 The Effect of POFA on the Properties of Concrete

Several scholars have used palm oil fuel ash as a cement replacement in many quantities owing to the high present of Silica content in it, which is a good pozzolanic material for construction applications. However, the unground POFA contained coarse particles, and the grounded POFA possesses better characteristics compared to ungrounded POFA. Similarly, the compressive strength of the POFA was affected mainly with increased in the POFA content in the concrete composites, which clearly revealed that the compressive strength, decreased for concrete mixtures ranging from 10% to 50% of the unground POFA as cement replacement.

In terms of the effect of POFA on concrete properties, in the long run, the researchers noted that there is no much difference in compressive strength values between the concrete containing POFA and the control mixtures. Nevertheless concrete with POFA has lower hydration rate at an earlier age and thus decreased the compressive strength, but, the palm oil fuel ash with fine particles of 8µm range as median size replacing about 20% of cement replacement has been reported to result in compressive strength higher than the corresponding value for control concrete at 90 days of curing age. From Table 4.3 and Figure. 4.1, it clearly shows that the aluminum powder increases the compressive strength of concrete, but the presence of POFA generally decreases concrete strength. The GPOFA with higher carbon content exhibits lesser strength than UPOFA. Table 4.1 shows that all the specimens exhibit very low workability. Such concrete is suitable for mass concrete and large sections with vibration. Also, for road slabs using power-operated machines.

Table 4.1: Workability Comparison

Mix	Slump (mm)	Workability	work Type
1	1	Very low	Mass concrete and large sections with vibration. Road slabs vibrated using power-operated machines
2	1	Very low	
3	0	Very low	
4	1	Very low	
5	0	Very low	
6	0	Very low	
7	1	Very low	

4.1 And Figure 3 show the slumps of POFA replaced mixes at different replacement levels. One of the basic attributes of any cementitious material is its workability or "consistency", which is largely determined by how wet the concrete is. This is referred to as "slump". Basically, the wetter the concrete, the higher the slump. Although slump is often seen as an indication of water content, it is more reasonably interpreted as a measure of consistency.

Table 4.2: Workability Boundaries

Work type	Compacting factor	Slump (mm)	Workability
High workability concrete; for sections with congested reinforcement. Not normally suitable for vibration	0.95	100-175	High
Medium workability mixes; manually compacted flat slabs using crushed aggregates. Normal reinforced concrete manually compacted and heavily reinforced sections with vibrations.	0.92	50-100	Medium
Low workability mixes; used for foundations with light reinforcement. Roads vibrated by hand-operated Machines.	0.85	25-50	Low
Very dry mix; used in road-making. Roads vibrated by power-operated machines.	0.78	0-25	Very Low

Table 4.3 and Figure. 4.1 shows that the aluminum powder increases the compressive strength of concrete, but the presence of POFA generally decreases concrete strength. GPOFA with greater carbon content exhibits lesser strength than UPOFA.

Table 4.3: Specific Weight and Compressive Strength of Concrete Mixes at 7days

Mix	Cube	Unit Weight of Concrete (KN/m^3) Fresh	Mature	Average	Compressive strength (N/mm^2) After 7 days	Average
1	1	23.87	22.27	22.59	7.00	7.22
	2		23.33		7.77	
	3		22.17		6.88	
2	1		27.23	27.07	8.45	7.91
	2		26.19		7.83	
	3		27.78		7.46	
3	1		26.01	26.76	7.13	7.86
	2		27.75		8.10	
	3		26.53		8.34	
4	1		23.78	23.62	5.41	5.61
	2		23.75		6.11	
	3		23.33		5.31	
5	1		23.86	25.05	5.91	5.82
	2		26.23		5.63	
	3		25.07		5.91	
6	1		26.13	25.77	6.57	6.56
	2		26.67		6.59	
	3		24.50		6.52	
7	1		21.82	23.38	6.26	6.29
	2		22.66		6.50	
	3		25.65		6.10	

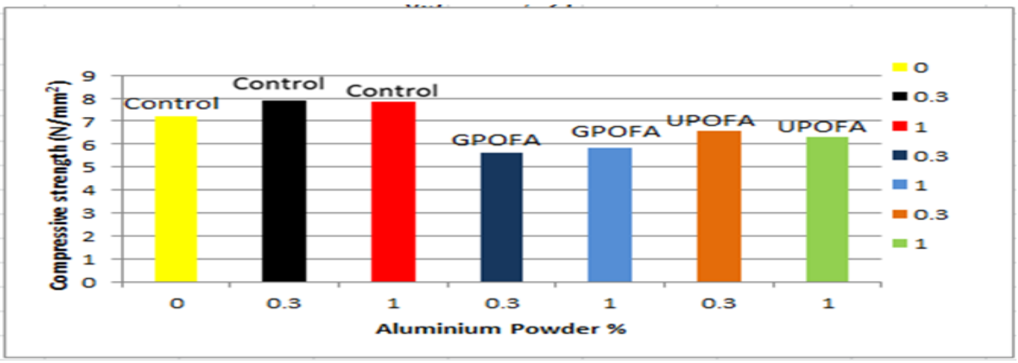

Figure 4.1: Compressive Strength and Aluminum Content after 7 days

Table 4.4 and Figure. 4.2 shows that the aluminum powder increases the compressive strength of concrete, but the presence of POFA generally decreases concrete strength. GPOFA with greater carbon content exhibits lesser strength than UPOFA.

Table 4.4: Specific Weight and Compressive Strength of Concrete Mixes at 14days

Mix	Cube	Unit Weight of Concrete (KN/m³) Fresh	Mature	Average	Compressive strength (N/mm²) After 14 days	Average
1	1	23.87	22.27		9.70	
	2		23.33	22.59	9.80	9.70
	3		22.17		9.50	
2	1		27.23		11.66	
	2		26.19	27.07	10.79	10.91
	3		27.78		10.28	
3	1		26.01		9.83	
	2		27.75	26.76	11.17	10.83
	3		26.53		11.50	
4	1		23.78		7.46	
	2		23.75	23.62	8.42	7.73
	3		23.33		7.32	
5	1		23.86		8.15	
	2		26.23	25.05	7.77	8.02
	3		25.07		8.15	
6	1		26.13		9.06	
	2		26.67	25.77	9.08	9.05
	3		24.50		9.00	
7	1		21.82		8.64	
	2		22.66	23.38	8.96	8.67
	3		25.65		8.41	

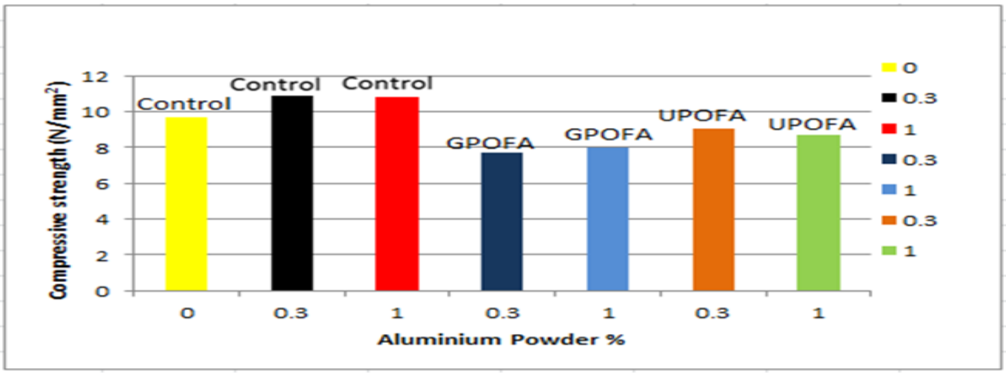

Figure 4.2: Compressive Strength VS Aluminum Content after 14 days

We deduced from Table 4.4 and Figure. 4.2, the aluminum powder increases the compressive strength of concrete, but the presence of POFA generally decreases concrete strength. GPOFA with greater carbon content exhibits lesser strength than UPOFA.

Table 4.3 - 4.5 and fig. 4.1-4.3 shows that the aluminum powder increases the compressive strength of concrete, but the presence of POFA generally decreases concrete strength. GPOFA with greater carbon content exhibits lesser strength than UPOFA.

Table 4.5: Specific Weight and Compressive Strength of Concrete Mixes at 28days

Mix	Cube	Unit Weight of Concrete (KN/m³) Fresh	Mature	Average	Compressive strength (N/mm²) After 28 days	Average
1	1	23.87	22.27		10.66	
	2		23.33	22.59	10.77	10.62
	3		22.17		10.43	
2	1		27.23		12.81	
	2		26.19	27.07	11.86	11.99
	3		27.78		11.30	
3	1		26.01		10.80	
	2		27.75	26.76	12.27	11.90
	3		26.53		12.64	
4	1		23.78		8.20	
	2		23.75	23.62	9.25	8.47
	3		23.33		8.04	
5	1		23.86		8.96	
	2		26.23	25.05	8.54	8.82
	3		25.07		8.96	
6	1		26.13		9.96	
	2		26.67	25.77	9.98	9.94
	3		24.50		9.88	
7	1		21.82		9.49	
	2		22.66	23.38	9.85	9.53
	3		25.65		9.25	

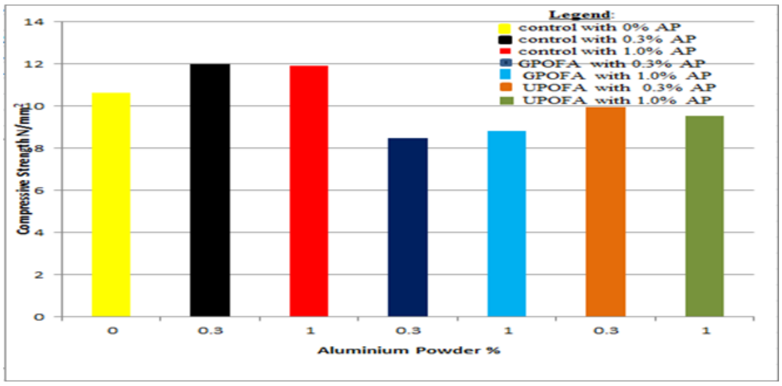

Figure 4.3: Compressive Strength and Aluminum Content after 28 days

4.1.3 SPLITTING TENSILE STRENGTH TEST

The results from Table 4.6 and Figure. 4.4 clearly depicts that the aluminum powder has no significant effect on the tensile strength of normal concrete, but the presence of POFA generally decreases the strength. GPOFA with greater carbon content exhibits lesser strength than UPOFA as aluminum powder content increases. The pozzolanic material is the function of the reaction that is produced from the ground POFA and increased alongside the fineness of POFA particles, together with the age of mortar and cement replacement as shown in Figure 4.4 respectively.

Table 4.6: Specific Weight and Spitting Tensile Strength of Concrete Mixes

Mix	Cube	Unit Weight of Concrete (KN/m³) Fresh	Mature	Average	Spitting Tensile strength (N/mm²) After 28 days	Average
	1	23.87	39.30		2.58	
1	2		36.76	38.16	2.36	2.48
	3		38.41		2.50	
	1		27.23		2.22	
2	2		26.19	27.07	2.55	2.52
	3		27.78		2.79	
	1		36.56		2.43	
3	2		36.90	36.36	2.85	2.42
	3		35.63		1.97	
	1		37.78		2.06	
4	2		38.09	37.65	2.14	2.14
	3		37.09		2.22	
	1		34.61		1.68	
5	2		31.82	33.61	1.52	1.60
	3		34.39		1.59	
	1		34.52		1.91	
6	2		36.77	34.91	2.08	1.99
	3		33.44		1.99	
	1		38.22		2.11	
7	2		35.97	36.32	2.45	2.15
	3		34.77		1.89	

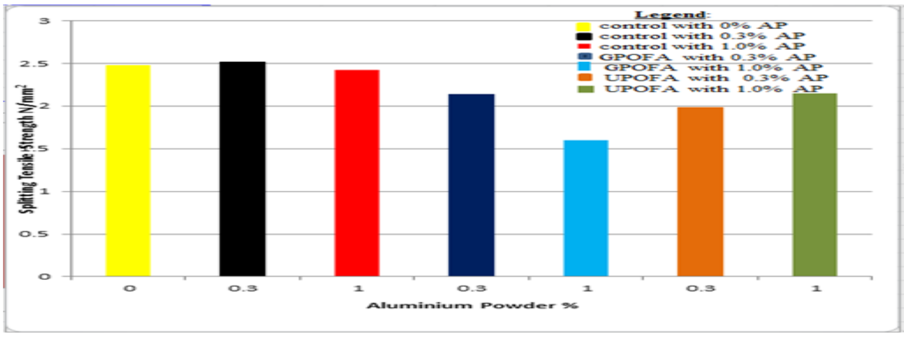

Figure 4.4: Tensile Splitting Strength VS Aluminum Content after 28 days

V. CONCLUDING REMARKS

The POFA as a pozzolana material, which contains silicon and on its own does not possess cementitious properties but will finely form in the presence of water and react with calcium hydroxide. The specimens exhibit very low workability. Such concrete is suitable for mass concrete and large sections with vibration and also, for road slabs using power-operated machines. Palm Oil Fuel Ash particle size can be compared to that of silica fume and therefore could have similar applications to silica fume especially in terms of mix design. It can be used in high-strength concrete and could include long-span bridges, mainly of precast and prestressed girders to allow for longer span in structural bridge design and high-rise skyscrapers by building smaller columns and increasing usable space.

1. The aluminum powder increases the compressive strength of normal concrete, but the presence of POFA generally decreases concrete strength. GPOFA with greater carbon content exhibits lesser strength than UPOFA. Consequently, POFA concrete produces a lower strength than OPC concrete.
2. The aluminum powder does not have any significant effect on the tensile strength of normal concrete, but the presence of POFA generally decreases the strength. GPOFA with greater carbon content exhibits lesser strength than UPOFA as aluminum powder content increases. Consequently, the aluminum powder does not have any effect on OPC and POFA on splitting tensile test.

to increase workability of POFA and if AP is to be incorporated in POFA concrete in view of UPOFA, little or no percentage is to be used, but that of GPOFA, AP percentage is to be increased and in terms of splitting tensile strength, iron reinforcement is to be incorporated in order to increase its splitting tensile strength.

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ABBREVIATIONS

POFA Palm oil fuel ash
UPOFA Unground palm oil fuel ash
GPOFA Grounded palm oil fuel ash
UPOFA Ultra-fine/treated palm oil fuel ash
HSC High strength concrete
PC Portland cement
HSC High strength concrete
HSCg High strength concrete with GPOFA
HSCu High strength concrete with UPOFA
ASTM American Society for testing and materials
AP Aluminum powder

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