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Structural Performance of Sustainable Waste Palm Oil Fuel Ash-Fly Ash Geo-polymer Concrete Beams

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Abstract

This study is an attempt to highlight the use of Palm Oil Fuel Ash (POFA) with Fly Ash, instead of cement, in reinforced concrete beams. POFA, a waste from Palm oil mill and Fly Ash, a waste from coal-burning power stations which are cheap and available. It is expected that millions tonnes of palm oil waste will be produced annually and a lot of money will be spent to transport and maintenance the waste. Environment is also being destroyed by the emission of CO_2 in Portland cement industries (global warming).Hence, it has become necessary that the study efforts in using of Geo-polymer concrete gain greater attention. In this study, laboratory tests were carried out to determine flexural strength, deflection and crack pattern for three kinds of materials that were used in reinforced concrete beams [POFA-Fly Ash Geo-polymer concrete, Fly Ash Geo-polymer concrete and OPC (Ordinary Portland Cement) concrete**].** The experimental result showed that the behaviour of reinforced POFA- Fly Ash concrete beams was similar to reinforced OPC concrete beams since the cracking and ultimate moments of them were close together in 90_{th} day. Regarding to durability study, POFA-Fly Ash concrete had a better resistance and performance against acidic conditions in comparison with OPC concrete due to more density and uniformity which was proved by ultrasonic pulse velocity (UPV) test.

Key words: Waste Geo-polymer Concrete Beam; Flexural Strength; Deflection; Crack Pattern; Acidic Conditions, UPV Test.

1 Introduction

Geo-polymer, a member of inorganic polymer group, can be created from Silicon (Si) and Aluminum (AL) of by-product materials [1]. The characteristic of Geo-polymer is depended on the Si to AL ratio and the most alkaline activator employed in Geo-polymerization process, Sodium silicate and Sodium hydroxide [2]. Geo-polymerization is a sustainable technique, can be suitable in the development of CO_2 reduced construction materials as an alternative to Portland-based cement [3]. According to Sobiecka (2013), Portland cement has been suggested as an effective stabilization method for hazardous waste [4]. The expression of Geo-polymer was first introduced by Davidovits in 1978. The primary difference between Geo-polymer concrete and OPC concrete is the binder that can be obtained from Ash with variable composition, [5] and alkaline activator by a certain concentration.

Previous studies on reinforced Geo-polymer concrete beams were highly limited. According to Balaguru research (1997), Geo-polymer materials have been applied to strengthen reinforced concrete beams and the result was successful. The Geo-polymer performance was also better than the organic polymer in terms of durability and fire resistance [6, 7]. Brooke et al. (2005) also reported that the Geo-polymer concrete beam–column joints performance was similar to OPC concrete joints since the crack patterns that observed in reinforced Geo-polymer concrete beams were alike to reinforced OPC concrete beams [8].

Malaysia is concentrating on bio-technology industry intended to produce good quality agricultural products such as Palm and it is expected that millions tonnes of palm oil waste will be produced annually. Hence a lot of money will be spent to transport and maintenance the waste [9]. Due to above reasons, several studies were conducted to investigate the feasibility of applying Palm Oil Fuel Ash in construction materials.

The initial research about partially replace ordinary Portland cement in concrete by Palm Oil Fuel Ash started in Malaysia since 1990. Palm Oil Fuel Ash (POFA), a waste from Palm oil mill as the partial cement replacement material was introduced in concrete to create high strength concrete and significant increase in compressive strength was resulted in comparison to OPC concrete [10]. The cost of Geo-polymer concrete was also reduced due to less cement utilization [11-13] and the mortar had a good resistance to chloride penetration [14].

In this study, the potential use of Palm Oil Fuel Ash-Fly Ash (30%-70%), instead of cement was investigated and emphasized in reinforcement concrete beams.

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2 Materials

Palm Oil Fuel Ash (POFA) and Fly Ash were obtained from burning of palm oil shell and the power station silos in Malaysia. The Ordinary Portland Cement (OPC) was also prepared from the local market that approved by the Malaysian standard. The combination of Sodium Hydroxide and Sodium Silicate solutions were applied in Geo-polymer concrete as alkaline activator to react with the Aluminium and the Silica. Fine sand and 10mm aggregates were used in Saturated Surface Dry (SSD) condition to mix with other Geo-polymer concrete ingredients. To improve the fresh concrete workability, Super plasticizer was also applied. The chemical composition of the POFA, Fly Ash and OPC are given in Table1. The mix design details regarding to the compressive strength based on Fcu=25 MPa are also given in Table2. Table3 demonstrates several ratios of materials to select appropriate mix design in relation to compressive strength.

Table1. The Chemical Composition of the POFA, Fly Ash and OPC (mass %)

	SiO_2	AL_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	$P2O_5$	LOI
POFA	53.5	1.9	1.1	8.3	4.1	1.3	6.5	2.4	18
Fly Ash	46.7	35.9	5.0	3.92	0.84	0.58	0.5	0.383	1.00
OPC	43.1	5.0	2.6	46.0	1.1	0.2	0.5	0.2	1.3

Table2. Appropriate Components Based on 25 MPa

Material	Fly Ash (100%) Geo-polymer Concrete Mass Kg/m^3	POFA-Fly Ash(30:70 %) Geo-polymer Concrete Mass Kg/m^3	OPC Concrete Mass Kg/m^3
Cement	0	0	429.31
Water	33.33	33.33	193.19
10mm Aggregates	1233.32	1233.32	965.95
Fine Sand	530	530	792.08
Fly Ash	413.33	290	0
POFA	0	123.33	0
Sodium Hydroxide	59.05	47.62	0
Sodium Silicate	147.62	119.05	0
Super Plasticizer	6.67	6.67	0

3 Methodologies

Six reinforced concrete beams (Two POFA-Fly Ash (30%-70%) reinforced concrete beams, Two Fly Ash reinforced concrete beams and Two OPC reinforced concrete beams) were manufactured based on appropriate mix design (Table3) to test at 28th and 90th days. The compressive strength, the tensile reinforcement ratio and the dimensions of specimens were the same for all of beams. The dimensions were 150mm wide by 200mm deep in cross-section and 2000mm in length (simply supported over a span of 1800mm). The clear cover to reinforcement was 30mm on all faces. The reinforcement details and geometry of beams are shown in Fig. 1.

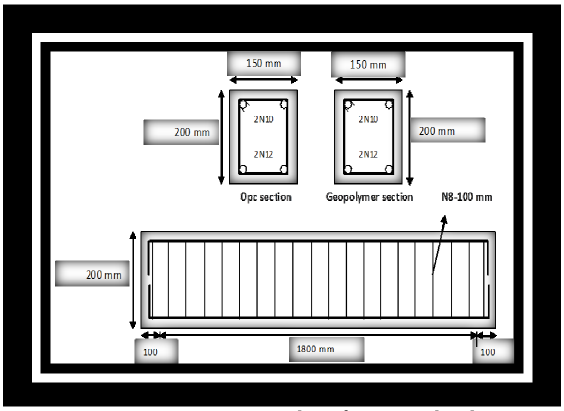

Fig. 1: Beam geometry and reinforcement details

100 mm × 100 mm × 100 mm specimens were casted for compressive strength tests at 28th, 90th days for each batch and all beams with simply supported over a span 1800mm were tested in a flexural test machine.

Two concentrated loads were placed over the span (Fig. 2) and linear variable data transformers (LVDTs) were used to measure the deflections at selected locations along the span of the beam.

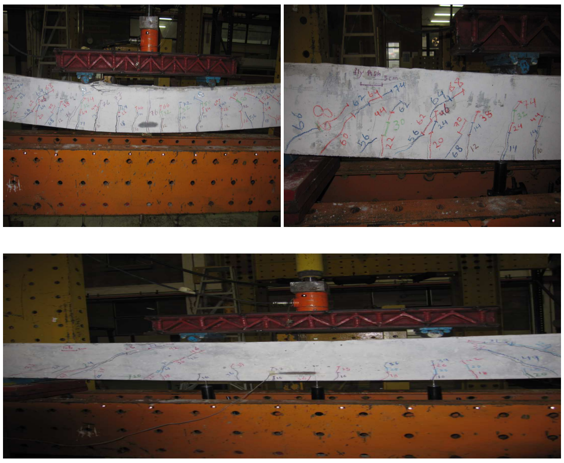

Fig.2: Two concentrated loads on reinforced concrete beams

All the specimens were white washed in order to facilitate marking of cracks. The whole procedures of specimen's preparation, curing and testing were based on previous work (Fly Ash concrete) by Hardjito, Sumajouw and Rangan [7,8]. The density and uniformity of POFA-Fly Ash concrete were also examined by ultrasonic pulse velocity (UPV) test in comparison to OPC concrete.

3.1 Acidic Conditions

The test specimens (100 mm cubes) were prepared using mixture based on Table 2. Subsequently they were immersed in 3% sulphuric acid solution for different times of exposure up to 3 month.

Table3: Concrete Mix Design Based on Different Ratio of Materials

POFA: Fly Ash	Fly Ash	POFA	Na_2SiO_3	NaOH	Sand	Aggregate	water	Plasticizer	Liquid / PFA+POFA)	Compressive Strength (MPa)
30:70	290	123.33	119.05	47.62	530	1233.32	33.33	6.67	0.403	25.20
50:50	206.67	206.67	119.05	47.62	530	1233.32	33.33	6.67	0.403	20.15
70:30	123.33	290	119.05	47.62	530	1233.32	33.33	6.67	0.403	15.10
100:0	0	413.33	119.05	47.62	530	1233.32	33.33	6.67	0.403	12.80
0:100	413.33	0	119.05	47.62	530	1233.32	33.33	6.67	0.403	35.45
0:100	413.33	0	147.62	59.05	530	1233.32	33.33	6.67	0.500	25.35
0:100	413.33	0	170.25	68.10	530	1233.32	33.33	6.67	0.576	18.15

The acid resistance was assessed based on the specimen's weight and compressive strength losses after acid exposure. OPC concrete and POFA-Fly Ash Geo-polymer concrete were compared in this experiment.

4 Results and Discussion

4.1 Cracking Moment, Flexural Capacity, Deflection

The load was recorded since the first flexural crack was visibly observed in each concrete beam. From these test data, the cracking moments were determined. The test data showed that the cracking moment increased as the compressive strength increased and the effect of age on the cracking moment was significant.

The cracking moment, the ultimate moment, and the corresponding mid-span deflection of test beams are given in Table4. Fig. 3 also demonstrates the flexural behavior of all tested beams at 28_{th} and 90_{th} days. The progressive increase of deflection at mid-span and one third-span are shown as a function of increasing load. The load-deflection curves show some occurrences that were happened during the test. These events are recognized as first cracking , yield of the tensile reinforcement, concrete crushing at the compression zone associated with concrete cover spalling , a slight drop in the load following the ultimate load and disintegration of the compression area as a result of the longitudinal steel buckling.

4.2 Acidic Conditions Results

The weight and compressive strength losses versus days in acidic conditions are shown in Fig. 4 and Fig. 5. In according to these result, POFA-Fly Ash concrete had a better resistance and performance against acidic conditions in comparison with OPC concrete. This improvement was due to more density and uniformity of POFA- Fly Ash concrete in comparison with others.

4.3 UPV Test Result

The density and uniformity of POFA-Fly ash concrete were also examined by ultrasonic pulse velocity (UPV) test in comparison to OPC concrete. In a comparative manner, higher velocity is achieved when concrete quality is high in terms of density and uniformity. **Fig6** demonstrates that the density and uniformity of POFA- Fly Ash concrete are more in comparison to normal concrete.

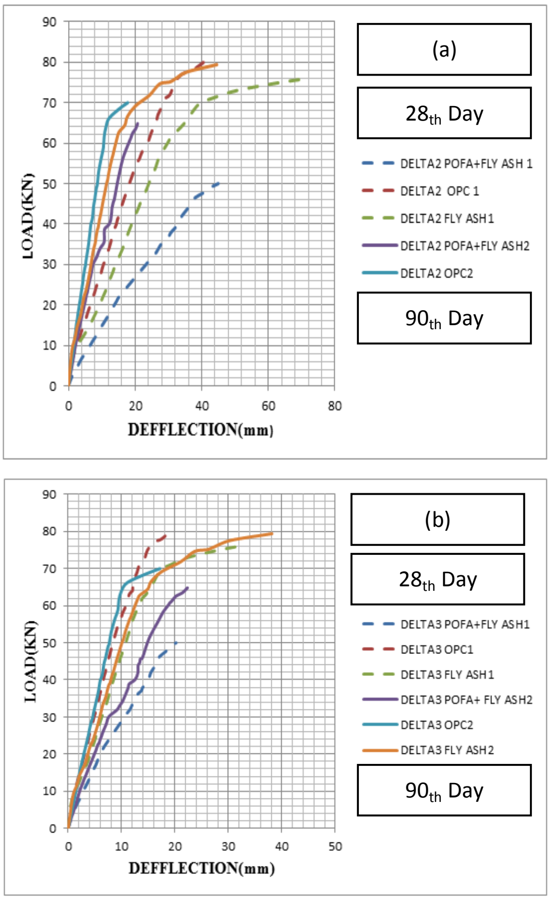

Fig. 3: Load-Deflection curve at mid-span (a) and one third-span (b) of beams at 28th and 90th days

Table 4: The Cracking Moment, Flexural Capacity and Deflection of Beams

Beam	Tensile Reinforcement ratio (%)	Cracking Moment-Mcr (KN.m)	Mid-span Deflection at Failure Load (mm)	Test Ultimate Moment (KN.m)
Fly Ash, B1-1 (28^{th} Day)	0.75	6.0	71.99	45.60
Fly Ash, B1-2 (90^{th} Day)	0.75	15.0	44.55	47.64
POFA+ Fly Ash, BII-1 (28^{th} Day)	0.75	9.6	44.95	30.00
POFA+ Fly Ash, BII-2 (90^{th} Day)	0.75	14.4	23.45	38.88
OPC, BIII-1 (28^{th} Day)	0.75	9.0	25.05	37.80
OPC, BIII-2 (90^{th} Day)	0.75	13.8	17.77	42.00

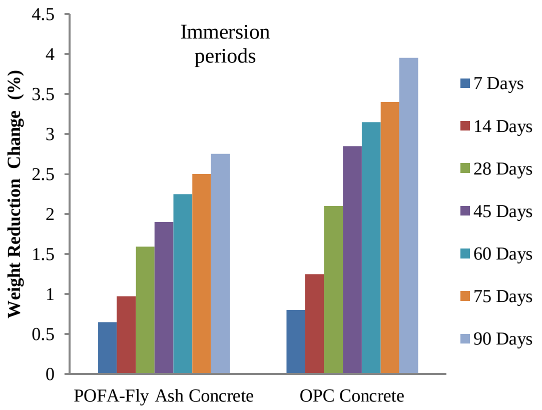

Fig .4: Weight loses of concrete specimens in Sulfuric acid for various periods

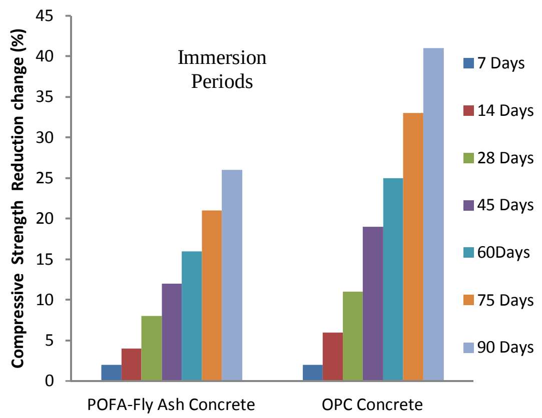

Fig .5: Compressive strength loses of concrete specimens in Sulfuric acid for various periods

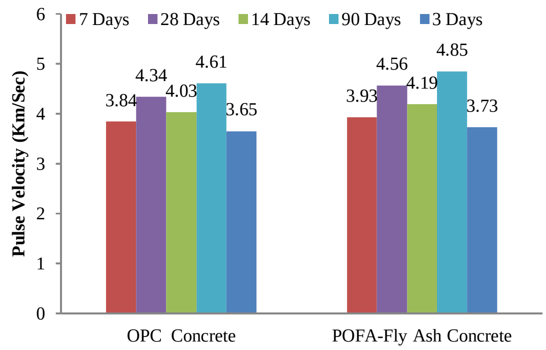

Fig 6: Ultrasonic Pulse Velocity (UPV) test result in POFA-Fly Ash concrete and OPC concrete (average)

5 Conclusions

Previous studies on reinforced Geo-polymer concrete beams are highly limited. The following conclusions were made from the experiment. The deflection amounts of POFA – Fly Ash and OPC reinforced concrete beams were reduced about 47 % and 29% respectively in mid span at 90_{th} day in comparison to similar beams at 28_{th} day. The cracking and ultimate moments of POFA–Fly Ash reinforced concrete (14.4 and 38.9KN.m) were almost close to OPC reinforced concrete (13.8 and 42KN.m) respectively at 90_{th} day. The result showed that the behaviour and crack patterns observed for POFA–Fly Ash reinforced concrete beams were almost similar to OPC reinforced concrete beams, however POFA-Fly Ash concrete had a better resistance against acidic conditions in comparison with OPC concrete. Ultrasonic pulse velocity (UPV) test also proved that the density and uniformity of POFA- Fly Ash concrete are more in comparison to others.

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