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SELF-COMPACTING CONCRETE USING AGRO-INDUSTRIAL WASTES; RELATIVE HUMIDITY EFFECT AND OPTIMUM MIXING METHOD

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This research identifies the relative humidity effect and the optimum mixing method for Self-Compacting Concrete (SCC) containing OPC mixed with agro-industrial wastes of palm oil fuel ash (POFA) and low calcium based fly ash (FA). The effects of temperature and relative humidity on the fresh state properties were assessed under three conditions; moderate humidity, H1 (RH of 70 to 80% with temperature of 32°C) and low humidity, H2 (RH of less than 70% with temperature of 36°C) and extremely high humidity, monsoon season, H3 (RH of more than 80% with ambient temperature around 23 ±2°C). Six types of mixing method were evaluated for the ternary blended mix (TNY40) with two types of super-plasticiser (SP) additions: simultaneous and delayed, in order to discover the optimum mixing time and loading sequence. Furthermore, the slump flow retention was recorded every 15 minutes after batching. In conclusion, it was found that the increased temperature with lower relative humidity accelerates the reduction of workability (up to 15%) especially in POFA SCC as compared to FA and TNY (8%) samples. From the evaluation of various mixing method, the optimum mixing method observed was using the delayed addition of SP with a total mixing time of 12 minutes. This method resulted in excellent workability properties and with mixes retaining its slump within 15 minutes of batching.

Keywords: Palm oil fuel ash, Fly ash, Binary blend and Ternary blend.

1 INTRODUCTION

SCC is a complex mixture. The more complex the concrete, the more sensitive it is to the material variations and temperature fluctuations during production (Ghafoori and Diawara 2010). Temperature and humidity is an important parameter to be considered when developing SCC. Brameshuber *et al.* (2003) reported that a temperature variation of 1^0C can lead SCC to lose its' self-compacting ability. In a tropical climate like Malaysia the temperature fluctuations does not vary as much as other countries (four seasons). However, the humidity variance can be very high (up to 100%). With high humidity, there is more moisture in the air and it will be essential to understand if this has any effect on the workability of SCC.

The loading sequence and mixing duration is an essential step in order for SCC to achieve a uniform, cohesive and homogeneous mix without segregating or bleeding (Ferraris 2001, Rahman *et al.* 2011) . This mainly depends on the type of mixer, loading sequence, and the duration and power of mixing. Irrespective of the type of mixer used, a longer mixing time than for normal concrete is necessary to fully activate the SP and to reduce frictional forces of the SCC mixes (EGSCC 2005). The use of POFA as agricultural and FA as industrial waste is not common in SCC production technology locally as there is a lack of research that comprehensively presents the effects of using these materials. The purpose of this paper is to investigate the effect of mixing method and sequence as well as humidity effect in tropical climatic conditions on the fresh properties of SCCs containing these wastes.

2 DETAILS OF MATERIALS USED

2.1 Cement

Ordinary Portland Cement (OPC) grade 42.5 based on ASTM C150 was used in the concrete as cementitious material and Its chemical composition is shown in Table 1.

2.2 Fly Ash (FA)

Low calcium FA (FA), Class F as per ASTM C618, was obtained from Sejingkat Coal Fired Power Station in Sejingkat, Kuching. The chemical composition of the FA is given in Table 1 and the particle size distribution (Figure 2) demonstrates a D50 of 13µm.

2.3 Palm Oil Fuel Ash (POFA)

Palm oil fuel ash (POFA) was obtained from a palm oil mill at Lambir, Miri, Sarawak, Malaysia. Samples were grinded in a ball mill for 8 hours. The chemical composition of POFA is given in Table 1. In addition, Figure 2 shows a D50 of 10µm.

2.4 Coarse Aggregates

10mm nominal size coarse aggregates (crushed quartzite) was used here. It is composed of particles within the range of 5mm to 10mm. Sieve analysis of 2000 gram sample showed that the entire sample (100%) passed through 9.5mm sieve while only 5% passed the 4.75mm sieve.

2.5 Fine Aggregates

The fine aggregates consisted of locally available aggregates with a maximum size of 5 mm. Two categories of fine aggregate were chosen after various bulk density tests. Type 1 was crushed quartzite that had a size range of 600 µm to 5.0 mm as per Table 2. The other category (Type 2) had a nominal size of 600 µm (uncrushed river sand as per Table 3) and a small amount of micro-fines (Table 3).

2.6 Super-plasticiser (SP)

The SP used in this research was Glenium Ace 389, supplied by BASF (Malaysia) Sdn Bhd. This SP is categorized as type F in accordance to ASTM C494 and BS EN 934-2 European Standard.

Table 1. Chemical Composition of OPC, FA and POFA (%).

Compound	FA	POFA	OPC
SiO_2	57.8	52.3	20.0
Al_2O_3	20.0	-	5.20
Fe_2O_3	11.7	6.87	3.30
SO_3	0.08	1.78	2.40
MgO	1.95	5.43	0.80
CaO	3.28	10.8	63.2
K_2O	3.88	11.4	-
TiO_2	2.02	0.61	-
Na_2O	0.30	-	-
LOI	0.32	-	2.50

Table 2. Crushed quartzite gradation.

Sieve Size	% Finer	AS 2758.1 Requirements
4.75 mm	99	90 -100
2.36 mm	50	60 -100
1.18 mm	20	30 -100
600 µm	2	15 - 80

Table 3. River sand gradation.

Sieve Size (µm)	% Finer	AS 2758.1 Requirements
600	100	15 - 100
300	58	5 - 50
150	10	0 - 20

3 MIX PROPORTIONS AND MIXING METHODS

The mix proportions of SCC are summarized in Table 4. In addition Table 5 outlines the various methods investigated. 6 batches of SCC with different mixing time and sequence were investigated in this research with SCC incorporating 40% ternary cementitious material. The mixing time was summarized as in Table 5. All the mixes were rested not less than 2.5 minutes before fresh state tests were carried out. In addition, the slump flow retention was measured every 15 minutes.

For the evaluation of relative humidity, three batches using Method 5 (M5) were evaluated as in Table 6 using a hygrometer. All mixing was done with a pan mixer in a laboratory and an average of three samples was conducted for each testing.

The three essential workability requirements for SCC are filling ability, passing ability and segregation resistance. This is measured as per specification provided by the European Guidelines for SCC (EGSCC 2005).

Table 4. Mix proportions.

	C	FA		POFA		Ternary (POFA & FA)	
Percentage Replacement (%)	0	30	40	30	40	30	40
W/P	0.38	0.38	0.38	0.44	0.44	0.38	0.38
SP Content (%)	0.86	0.66	0.66	1.2	1.4	1.1	1.1
FA(kg/m3)	0	162	216	0	0	81	108
POFA(kg/m3)	0	0	0	162	216	81	108
Cement(kg/m3)	540	378	324	378	324	378	324
0-600μm (Sand)	600	600	600	600	600	600	600
600μm-5mm (Quarry Dust)	550	550	550	550	550	550	550
Course Agg (5-10mm)	400	400	400	400	400	400	400

Table 5. Mixing methods.

Method	Procedure
M1	The aggregates were blended for 5 minutes followed by the addition of dry powders (cement, FA, and POFA) and run for another 5 minutes. 50% of water was added to about 50% of the SP in a bucket and then added into the mixer. Total running of 8 minutes. The remaining water and SP was added to the end and run for another 3 minutes before discharge.
M2	The aggregates were blended for 5 minutes followed by the addition of dry powders (cement, FA, and POFA) and run for another 5 minutes. All the required amount of water and SP was added directly into the mixer. The mixer is kept running for 8 minutes in total.
M3	All the required amount of water was added in the concrete mixer followed by addition of cement, FA and POFA. The mixer was kept running for 5 minutes after the addition of the powders. Pre-blend aggregates were added to the mixer and run for 3 minutes. SP was added at the end and run for another 2 minutes.
M4	The aggregates were blended for 5 minutes followed by the addition of dry powders and run for another 5 minutes. All the required amount of water was added to into the mixer. The mixer is kept running for 5 minutes in total. All the required amount of SP was added to the end and run for 3 minutes before discharge.
M5	The aggregates were blended for 5 minutes followed by the addition of dry powders and run for another 5 minutes. All the required amount of water was added to into the mixer. The mixer is kept running for 9 minutes in total. All the required amount of SP was added to the end for 3 minutes before discharge.
M6	The aggregates were blended for 5 minutes followed by the addition of dry powders (cement, FA, and POFA) and run for another 5 minutes. All the required amount of water was added. Total running of 15 minutes. All the required amount of SP was added to the end for another 3 minutes before discharge.

4 Results and Discussion

4.1 Mixing Method

Table 6 presents the results for mixing method. It is observed that M1 gave good workability properties, however the samples loses its' self-compacting ability within 15 minutes of batching. This was also the case for M2. With M3, when water was added to cementitious material in the beginning causes the samples to be too fluid and highly segregated. In M4, the time allocated for the addition of liquid and final mixing was not adequate which led to inefficient mix. Mixing the samples for 9 minutes in M5 gave the optimum mixing method, with highly workable sample and lower segregation ratio. In addition, Figure 5 shows that with M4 and M5, the mix could retain its slump flow within 15 minutes of mixing. However, longer mixing time after the introduction of water (M6) will result in 'balling effect' due to drying of concrete and eventually loses its workability.

4.2 Evaluation of Relative Humidity with Ambient Temperature

As seen in Table 7, increased ambient temperature, with low relative humidity, accelerated the reduction of the workability properties. A slump variance of up to 15% was seen in POFA SCC, whereas FA and TNY samples exhibited a slump variance of up to 8%, under varying temperature and relative humidity changes (Figure 1). When exposed to lower humidity in tropical weather, SCC incorporating POFA and FA, demonstrated an increase in T500 and V-funnel flow time, while the segregation ratios remained stable.

Table 6. Results for mixing methods.

Fresh State Properties			M1	M2	M3	M4	M5	M6
Filling Ability	Slump flow	T500 (s)	2.63	4.58	0.54	1.39	2.09	2.47
		Max. spread (mm)	790	800	850	820	820	820
	V-Funnel	T10 (s)	5.63	13.58	2.84	9.38	5.48	6.48
Passing Ability	J-Ring	T500J (mm)	770	710	820	800	750	780
		Step height, sh (mm)	13	10	5	7	7	7
Segregation Resistance	VSI15min	Index (0.5 - 3)	n/a-high viscosity	n/a-high viscosity	3	3	1	0.5
	Sieve Stability	Sieved portion, (%)	0.5	0.5	18	10	1.5	5

Remarks on the mixes: M1 – Mix loses consistency within 15 min, M2 – Mix loses consistency within 10 min, M3 – High amount of bleeding, M4 – Highly segregated mix, M5 – Nice & consistent mix, M6 – 'Balling Effect'.

Table 7. Fresh properties of SCC under various relative humidity.

Mix	Environmental	RH (%)	Slump Flow (mm)	T500s (sec)	J-ring Flow, (mm)	V- Funnel (sec)	Sieve Segregation (%)
Control	H3	82	800	2.54	750	9.14	12
	H2	65	740	3.71	680	11.48	9
	H1	75	790	2.02	740	9.24	11
POFA30	H3	81	770	2.00	730	6.87	7
	H2	60	670	3.39	590	16.58	4
	H1	70	750	2.48	720	7.19	6
POFA40	H3	80	770	2.64	710	8.41	10
	H2	51	650	4.09	550	17.04	3
	H1	79	760	2.28	710	7.19	10
FA30	H3	80	730	2.70	640	7.82	14
	H2	58	665	3.46	600	8.66	10
	H1	70	710	2.90	630	8.32	13

Table 7. Fresh properties of SCC under various relative humidity (Continued)

Mix	Environmental	RH (%)	Slump Flow (mm)	T500s (sec)	J-ring Flow, (mm)	V- Funnel (sec)	Sieve Segregation (%)
FA40	H3	83	780	2.01	650	5.68	18
	H2	66	700	3.00	610	7.5	15
	H1	77	760	1.49	640	5.52	18
TNY30	H3	87	780	2.27	800	8.68	12
	H2	55	700	2.66	640	10.13	6
	H1	70	755	2.19	700	8.56	10
TNY40	H3	83	755	1.81	680	9.47	5
	H2	59	700	3.15	660	12.48	2
	H1	77	745	2.39	690	10.12	6

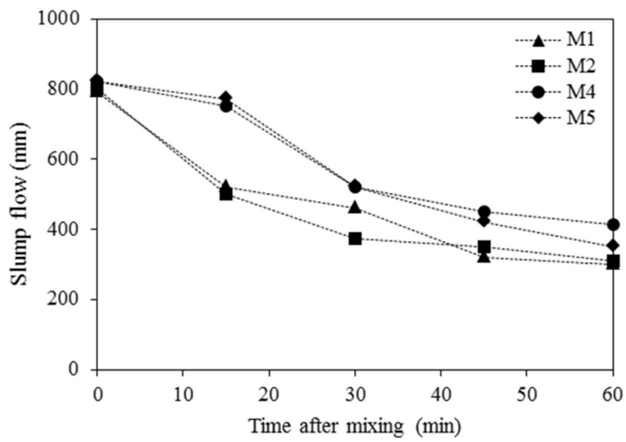

Figure 1. Slump flow retention of SCC under varying mixing methods.

5 CONCLUSION

Based on this study on SCC with agro-industrial wastes, a total mixing time of 9 min is recommended. In addition, when exposed to lower humidity in tropical weather accelerates the reduction of the workability properties of SCC especially in SCC incorporating POFA.

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