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Effects of Paste Content on Flow Characteristics of SCC Containing Local Natural Pozzolan

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Abstract**—**Natural pozzolan (NP) is one of the potential prehistoric alternative binders in the construction industry. It has been investigated as cement replacement in ordinary concrete by several researchers for many purposes. Various supplementary cementitious materials (SCMs) such as fly ash, limestone dust and silica fume are widely used in the production of SCC; however, limited studies to address the effect of NP on the properties of SCC are documented. The current research is composed of different SCC paste and concrete mixtures containing different replacement levels of local NP as an alternative SCM. The effect of volume of paste containing different amounts of local NP related to W/B ratio and cement content on SCC fresh properties was assessed. The variations in the fresh properties of SCC paste and concrete represented by slump flow (flowability) and the flow rate were determined and discussed. The results indicated that the flow properties of SCC paste and concrete mixtures, at their optimized superplasticizer dosages, were affected by the binder content of local NP and the total volume fraction of SCC paste.

Keywords**—**Binder, fresh properties, natural pozzolan, paste, SCC.

I. Introduction

ENVIRONMENTAL aspects have nowadays become a major concern of many in the field of construction industry. A substantial amount of CO_2 pertained to cement industry contaminates the environment. To minimize the amount of CO_2 introduced to environment, it is essential to control the entire process of cement production. Currently, it has been successfully achieved by the ~~use~~ introduction of supplementary cementitious materials (SCMs). The demand and the subsequent added-cost for the SCMs increase from one day to another and from one application to another. Self-compacting concrete is considered as relatively recent concrete technology which requires much amount of SCMs as fine materials [1].

SCC is different from normally vibrated concrete (NVC in the proportions of its constituents and performance in fresh and hardened states [2, 3]. In SCC a much higher quantity of binder (powder), a higher fine aggregate content, and relatively lesser amount of coarse aggregate content are used than those used in NVC. To form SCC, it is essential to incorporate chemical admixtures such as superplasticizers to keep proper workability and viscosity aspects into consideration.

To achieve higher flowability, elevated quantities of finer particles are added. Consequently, additional volume ~~of~~ is added to paste in concrete mass. The increased paste volume has a significant effect on the fresh as well as hardened properties of SCC [4]. Therefore it is necessary to study the variations imparted on SCC characteristics by the change in this paste volume and its characteristics at different replacement levels of local fine materials such as natural pozzolan (NP). Few methods are presented as guidelines to design different SCC mixes [2, 7, 8, 9-11]. The increased paste volume leads to lower yield stress value dependent upon W/C ratio compared to NVC with higher yield stress values. Yet, the powered content or the paste volume cannot be obtained beyond a certain level of paste volume (Vp) [4]; as it may adhere to difficulty in flow. Optimized flowability can be defined within optimized range of Vp which not only provides the cover to the aggregates but also plays as a lubricant between the matrix particles to smooth the mix flow. This approach is explained by the excess paste theory which defines for a given fine aggregate content a given fraction of paste volume to control as the main parameter the SCC fresh properties [12]. For regular shape aggregates, the mean value of Vp was found approximately at 0.38 while in the angular shape aggregate it was found between 0.4 to 0.46 [4]. In this study the effect of NP on the SCC paste flow properties and the effect of V_p on the fresh properties of SCC mixes are presented.

II. Experimentation and Materials

A. Materials

One of the objectives of this study was to investigate the effects of locally available natural pozzolan (NP) on the properties of paste comprising of water, cement, NP (as SCM) and PCE. Type I Portland cement meeting the requirements of ASTM C150 was used as the available binder to which other cementitious materials are added as partial cement replacements. Cement has a median grain size of 13.5µm and

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Blaine fineness of 307m^2/kg. Local NP with a median grain size of 19 µm was sourced and ground from Jeddah, the western area of Saudi Arabia. Local NP powder is complying to the ASTM C 618 requirements.

TABLE I
CHEMICAL COMPOSITIONS OF LOCAL NATURAL POZZOLAN AND CEMENT

Oxide Composition, % by weight	CEM	NP
SiO_2	19.91	42.17
Al_2O_3	5.79	16.53
Fe_2O_3	3.55	15.38
CaO	62.37	10.04
MgO	0.62	2.83
SO_3	2.72	0.22
K_2O	0.09	0.73
Na_2O	0.11	0.15
Loss Of Ignition	1.26	2.85

TABLE II
SIEVE ANALYSIS OF AGGREGATES USED

	Passing (%)		
Sieve size (mm)	Red sand	Crushed sand	Coarse aggregate 10 mm
19	100	100	100
9.5	100	100	100
4.75	100	99.1	91.5
2.36	99.98	43.3	16.6
1.18	99.96	8.1	3.4
0.60	99.78	4.3	2.2
0.30	84.3	2.8	0
0.15	24.3	1.2	0
0.075	1.46	0.24	0

The sieve analysis and optimized proportions of fine and coarse aggregate are given in Table II. The optimized proportions of fine and coarse aggregate are proved to provide the best rheological properties. The optimized proportions are detailed in SCC mixes. The physical properties of fine and coarse aggregates used during this study are shown in Table III.

TABLE III
PROPERTIES OF AGGREGATES USED

Aggregate	Specific Gravity (SSD)	Unit Weight (kg/m3)	Absorption (%)
10 mm	2.63	1608	1.17
Crushed Sand	2.65	1597	1.98
Red Sand	2.59	1769	0.36
10 mm	2.63	1608	1.17

Polycarboxylic ether (PCE) polymers and potable water were used to cast the pastes and SCC mixes. PCE has a specific gravity of 1.1 and dry extract of 36%. PCE dosage was calculated based on the binder content expressed as a percent of the dry extract (D.E.) with respect to the binder content (cement alone or cement and NP).

III. RESULTS AND DISCUSSION

A. Optimization of Pastes

In order to optimize the SCC pastes, a series of tests using modified marsh cone test (MMCT) was conducted. The MMCT apparatus is a very simple tool constructed from local materials in the lab by the research team. It comprises of a graduated funnel of a total capacity of 500 ml containing a controller gage to adjust the output flow rate. The funnel is held on a stand over a graduated measuring cylinder where the time needed by a fixed volume of 300 ml paste to flow under gravity is recorded (Fig. 1). A stop watch to record the flow time was used. The flow rate of paste mixes with W/B ratios of 0.3, 0.4 and 0.5 at different replacement levels of 0, 10, 2, 30 and 40% NP was evaluated. The optimum PCE dosage for each replacement level of NP at different W/B ratios was to be selected from the flow time recorded for tested pastes at different PCE dosages. Fig. 1 shows the flow time values of the SCC paste mixes of control, 10, 20, 30 and 40% NP. The optimum dosage of CPE content is found at approximately 0.18% in the control, 10 and 20% NP mixes. Whereas

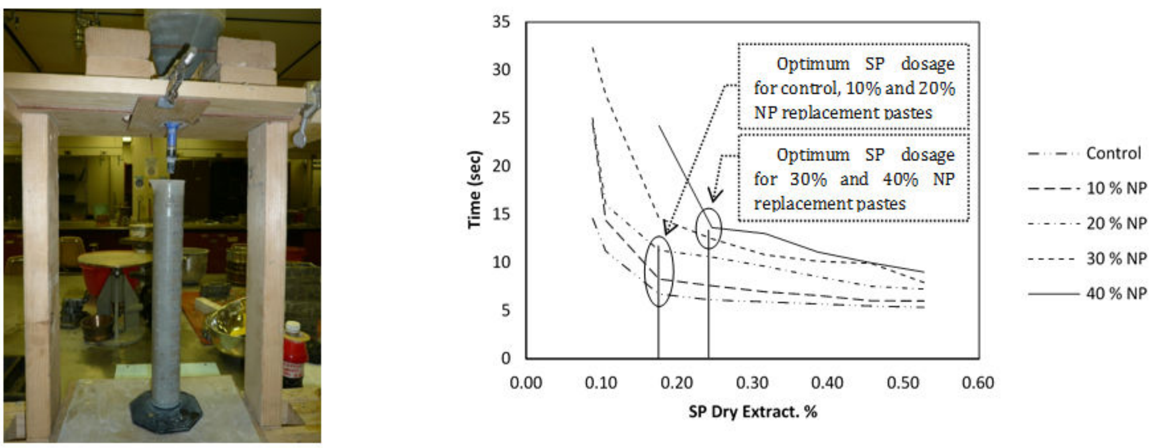

Fig. 1 Modified marsh cone test (MMCT) apparatus and the results of the paste mixes made of W/B ratio of 0.3

optimum PCE value tends to shift to higher values of 0.23% and 0.27% at higher replacement levels of 30 and 40%, respectively. The physical nature of NP particle seems to have neutral effect on the reactivity of cement.

The PCE dosage after which there was insignificant change in flow time value was considered as the optimum dosage. At the optimum PCE dosage, the average flow spread value from mini slump of same pastes was also recorded, as shown in Fig. 2.

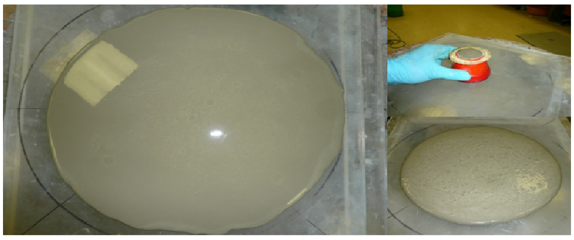

Fig. 2 Mini-slump and flow spread for a paste in mini-slump test

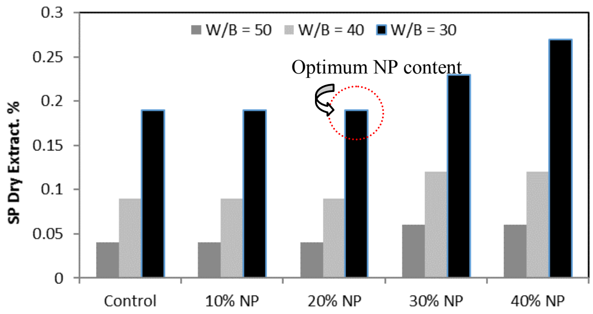

Fig. 3 Optimum SP dosages at different w/b ratios and various NP replacement level for pastes

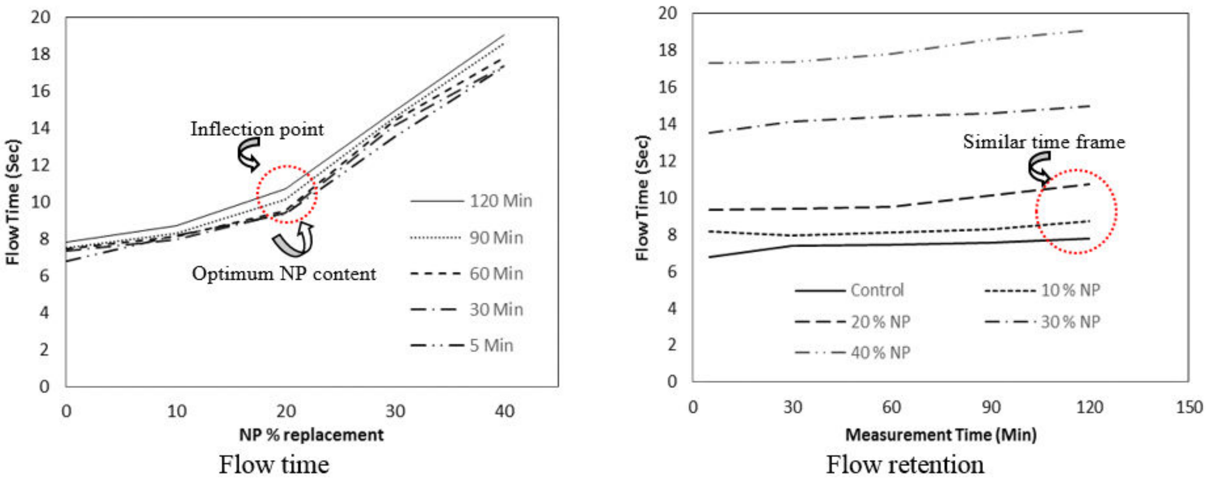

Fig. 4 Test results of paste mixes prepared at W/B ratio of 0.3 using MMCT test set up under different NP replacement level and testing time intervals

The summarized optimum PCE values at all replacement levels of NP and W/B ratios are given in Fig. 3. The results have shown that the replacement level of 20% NP did not require additional PCE dosage in comparison to the control mix. However, the mixes with higher replacement levels of 30 and 40% NP show an incremental requirement for additional PCE dosage.

In the following, various results from flow properties such as flow time, flow retention and the mini slump flow of the selected W/B ratio of 0.3 required for domestic high performance concrete. The optimum PCE dosage corresponding to each replacement level of 0, 10, 20, 30 and 40% NP shown in Fig. 2 was applied. The flow time with replacement level and flow retention with testing time were evaluated and presented in different ways, as shown in Fig. 3. The results show the flow time is not significantly affected by different elapsed times of 5, 30, 60, 90 and 120 minutes. It can be also noted that there a gradual increase in flow time with NP replacement level up to 20% NP which is then followed by a significant increase with replacement levels of 30 and 40% NP. The flow retention at different NP replacement levels shows that the mixes with 0, 10 and 20% NP have similar time frame which is nearly stable with time. The mixes with 30 and 40% NP are located at two different time frames of higher flow time values, respectively. Therefore, at the optimum PCE dosage, there remarkable stability in the fresh properties of NP mixes with time. It can be concluded that NP particle are non-reactive and their

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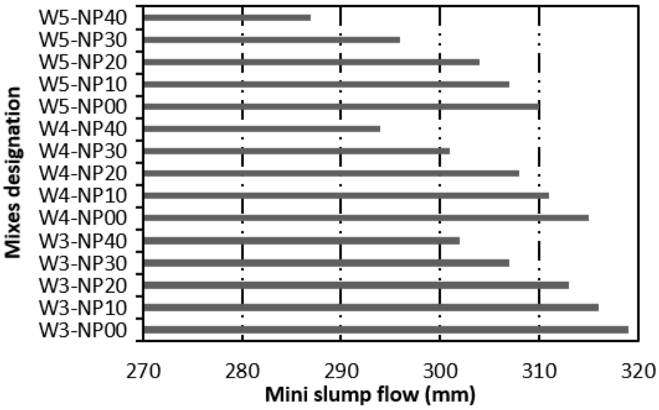

Mix designation	NP %	W/B ratio
W3-NP00 to W3-NP40	0, 10, 20, 30 and 40	0.3
W4-NP00 to W4-NP40		0.4
W5-NP00 to W5-NP40		0.5

Fig. 5 Mini-slump flow values for the pastes of several NP % on their optimized SP dosages

presence positively affects the rheological properties.

The mini slump flows for all paste mixes using the test set up shown in Fig. 2 were recorded. It can be observed that the flow value tends to drop with the increase in W/B ratio and NP replacement level, as clearly depicted in Fig. 4. Moreover, the difference in the flow spreads with the replacement level of NP was most evident at W/B ratio of 0.5. Therefore, the water content composing the paste plays an important role by affecting the end spread diameter. With increased replacement level of NP, the flow spread tends to decrease as confirmed in similar studies [4, 7] and presented in Fig. 5.

B. SCC Mixes

SCC mixes containing the optimum NP content of 20% obtained from paste optimization test were designed as per the guidelines provided by EFNARC [16] shown in Table IV. The mixing procedure for SCC was performed in accordance with ASTM C192. After mixing, the fresh properties of SCC mixes were verified by the slump flow range defined in EFNARC specifications. The demand for PCE was found within approximately 1.5 to 2 times what was found in paste due to the effect of surface area of natural fine aggregate. Moreover, the results of slump flow and T_{500} for SCC mixes containing 20% NP are presented to describe the effects of paste content and paste constituents on the fresh properties.

TABLE IV
TYPICAL RANGES OF SCC MIX COMPOSITION EFNARC [16]

Constituent	Typical range by mass (kg/m^3)	Typical range by volume (liters/m^3)
Powder	380-600	
Paste		300-380
Water	150-210	150-210
Coarse Aggregates	750-1000	270-360
Fine Aggregates (sand)	Content balances the volume of the other constituents, typically 48-55% of total aggregate weight.	
Water/powder by vol.		0.85-1.10

The volumetric mix design of the tested SCC mixes with different W/B ratios of 0.3, 0.4 and 0.5 is shown in Table V. The mixes made with W/B ratio of 0.5 are under development to prepare cost effective SCC containing local materials such as NP. In this study, NP was proven to improve the plastic viscosity in a way that provides stable SCC mixes at W/B ratio of 0.5. The control mixes were prepared using the same mix design except for the total amount of cement was represented by the sum of cement and NP shown in Fig. 4 at each W/B ratio. The range of constituents used in Table V complies with the requirements set by EFNARC shown in Table IV.

Being a major constituent ingredient of paste, the effect of binder is significant on both i.e. slump as well as the T_{500} value for all SCC mixes containing 20% NP. The higher content of binder provides stability to the mix; yet it needs to be kept within certain limits as set by EFNARC i.e. 380-600 kg/m^3 of SCC mix. Passing beyond these limits is expected to require higher dosage of PCE at lower W/B ratio of 0.3 with elevated risk of segregation honeycombing and bleeding.

TABLE V
MIX DESIGNS OF THE 20% NP-BASED SCC MIXES WITH W/B RATIOS OF 0.3, 0.4 AND 0.5

Constituent (L/m^3)	W/B Ratio		
	0.3	0.4	0.5
Cement	148.57	118.73	99.37
NP	43.17	34.69	28.78
Fine Aggregates	322.05	355.89	363.12
Coarse Aggregates	300.38	291.25	296.96
Water	176.00	187.00	195.00
PCE (%, D.E.)	0.34	0.24	0.16
Air Content (%)	1-2 %		

The effect of NP replacement level on the fresh properties of pastes was investigated, as shown in Table VI. It is depicted that the usage of NP as cement replacement up to 20% has minor impact with insignificant effect on the fresh properties of paste. Similar trend was observed for the concrete mixes. It is observed that there no substantial difference would be recorded in the flow spread and the T_{500} values if the NP is used as an alternative binder up to 20%. The W/B ratio greatly affects the end flow value. At W/B ratio of 0.3 and 20% NP, the maximum flow value shall be recorded with respect to the flow values exhibited by the mixes of lower W/B ratios of 0.4 and 0.5 under same replacement level of NP.

TABLE VI
EFFECT OF NP REPLACEMENT LEVEL ON SLUMP FLOW AND SLUMP FLOW TIME OF SCC MIXES OF VARIOUS W/B RATIOS

Test/NP content		**W/B ratio**		
		0.3	0.4	0.5
Slump flow (mm)	0% NP	820	795	760
	20% NP	800	775	745
T500	0% NP	2.71	2.35	0.60
	20% NP	2.68	2.27	0.66

Similarly the flow time T_{500} required to flow to a certain distance is also inversely proportional to the W/B ratio, i.e. the higher the w/b ratio the lower is the flow time. From Table VI, the effect of NP on slump flow and T_{500} at a given W/B ratio with respect to the control mix is limited, as observed previously in case of pasts. The SCC mix prepared with 20% NP and W/B ratio of 0.5 shows low T_{500} value which however, did not show signs of segregation and aggregate settlement.

IV. CONCLUSIONS

On the basis of the results described in this paper regarding the fresh properties of SCC pastes and concrete mixes containing natural pozzolan as an alternative binder, the following conclusions can be drawn.

1. Effect of NP replacement up to 20% on PCE demand can be negligible. Beyond the replacement levels of 30% and 40%; the requirement additional PCE increases and there is an apparent reduction in the slump flow value. This leads to define a limit in the application of NP as an alternative binder in SCC mixes i.e. up to 20% shall provide flowable mix without limited precautions;
2. The use of modified marsh cone test (MMCT) helped in determination of the optimum PCE dosage for various pastes. It was also observed that the flow-ability of the pastes and mixes increases progressively with the increase in PCE dosage; beyond that dosage there was no change in the flow, though the segregation started to occur i.e. optimum PCE dosage;
3. The slump flow tends to increase with the increase in the volume fraction of paste of higher binder content. At higher water volume, there is a risk of segregation and settlement of aggregate.
4. For a given W/B ratio, the value of T_{500} decreases with the increase in the paste volume fraction. In addition to the aforementioned parameters, the effect of cement type and temperature is significant and needs to be determined on the SCC mixes containing NP as SCM. The effect of NP on the hardened properties of short, medium and long age can represent a good area of investigation.

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