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Effect Superplasticizer and Water-Binder Ratio on Freshened Properties and Compressive Strength of SCC

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Abstract: This study presents, the results of an experimental research carried out to investigate the use of tests performed in effectiveness of superplasticizer and water-binder ratio for Self-Compacting Concrete (SCC). The materials employed were cement, silica fume, sand as fine aggregate, a maximum 14 mm diameter coarse aggregate and a policarboxylate based superplasticizer. In this study, four mixtures with variation of superplasticizer, four mixtures with variation of water-binder ratio and one mixture for control were investigated. Several tests such as slump flow, slump flow time (T_{50}) and J-ring were carried out to determine freshened properties of SCC. Performance of hardened concrete was determined by classical strength test. The compressive strengths at 3, 7 and 28 days were measured. Test results indicate that the slump-flow values of the SCC mixtures were measured between 650-800 and 550-650 mm for variations of superplasticizer and water-binder ratio, respectively. The slump flow time (T_{50}) was measured when, the concrete was slumping until it reached 500 mm of flow. Flow time (T_{50}) increase with increasing of water-binder content. However, it is decrease with increasing of superplasticizer content. A lower superplasticizer and W/B ratio leads to a higher strength but lower workability and vice versa.

Key words: Freshened properties, compressive strength, self compacting concrete, superplasticizer, water-binder ratio, workability

INTRODUCTION

SCC is defined as concrete that can be placed normally by pump or skip; will flow under its own weight, maintaining its homogeneity and completely fill formwork of any shape, with high reinforcement density and with minimal bleeding or segregation. SCC is a material that meets a unique combination of performance and uniformity requirements that cannot always be achieved using conventional constituents and usual construction practices.

The common practice to obtain self-compactibility in SCC is to use superplasticizer, to limit the maximum coarse aggregate size and content and to use low water-binder ratios or use viscosity modifying admixtures (Okamura and Ozawa, 1995). Therefore, one of the disadvantages of SCC is its cost, associated with the use of chemical admixtures and use of high volumes of Portland cement. High cement content usually introduces high hydration heat, high autogenous shrinkage and high cost. To achieve high-strength and workability while, reducing creep and shrinkage Chang *et al*. (2001) suggested using superplasticizers and pozzolanic materials in the mix designs of high-performance concrete. Use of pozzolanic materials can decrease the amount of cement required, thus, reducing the occurrence of creep and shrinkage in concrete due to the high-cement content (Chang, 2004). High-volume of mineral powder is a necessity for a proper SCC design. For this purpose usually natural and/or artificial mineral additives such as; Limestone Powder (LP), Fly Ash (FA), Silica Fume (SF) and Ground Granulated Blast Furnace Slag (GGBFS) are used.

The objective of this study was to determine the effects of superplasticizer and water-binder ratio on the workability properties and compressive strength of SCC. The workability properties of SCCs were observed through, slump flow diameter, slump flow time and J-ring test. Later, hardened properties were evaluated by compressive strength test. The control mixture included only Portland Cement (PC) as a binder. For all the mixtures, the total amount of binder material (cement + silica fume) was kept constant.

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MATERIALS AND METHODS

The materials used in this study were locally available. Their properties and grading was determined in accordance with ASTM C 136 (ASTM, 2006) and the results are presented in Table 1.

The coarse aggregates are crushed gravel with a maximum size of 14 mm. Natural sand used was as fine aggregate with <50% passing through the 0.60 mm sieve. The specific gravity and water absorption properties of natural sand and crushed gravel are 2.60, 1.63% and 2.71, 0.39%, respectively.

An F type superplasticizer admixture in conformity with ASTM C 494 standard was also employed (ASTM, 2008). The solid content and the specific gravity of this superplasticizer was 39.7 and 1.10%, respectively.

All mixtures were prepared by using an Ordinary Portland Cement (CEM II/A-M) in conformity with BS EN 197-1 standard (BS, 2000).

The chemical and physical properties of cement are shown in Table 2. In order to enhance the paste content, a silica fume which conform the ASTM C 1240 standard requirements was employed (ASTM, 2005). Its specific gravity and Blaine fineness were 2.2 and 290 $m^2\ kg^{-1}$, respectively.

The chemical properties of silica fume are also shown in Table 2.

Mixture proportions and test method: Nine self-compacting concrete mixtures were prepared for this study. Mixture proportions are presented in the Table 3.

One mixture is a control mixture ID, four mixtures in Sp-series mixtures ID with vary superplasticizer; 1.15, 1.27, 1.39 and 1.59% of binder, four mixtures in W/B-series mixtures ID with variation of water-binder ratio; 0.386, 0.391, 0.396 and 0.401. Note that the total of binder content was kept constant at 581.73 $kg\ m^{-3}$.

The concrete mixtures were prepared in a horizontal axis mixer. To obtain a homogeneous SCC mix, a more complicated mixing operation was applied comparing to the conventional concrete mixing procedure. First of all, aggregates were mixed and binders (cement and SF) were added to the system. After remixing, water was added to the dry mix. Finally, superplasticizer was introduced to the wet mixture (Domone and Jin, 1999).

In the fresh state, slump flow (S), slump flow time (T50), J-ring blocking step (B_J), J-ring flow spread (S_J), J-ring flow time ($T50_J$) of the SCC mixes were measured according to the EFNARC Committee's suggestions (EFNARC, 2002). After 24 h, all specimens were submerged in water at 20°C. Compressive strength test was performed on 3, 7 and 28 days old specimens.

Table 1: Properties of aggregate

Variables	Coarse aggregate	Natural sand
Specific gravity of coarse aggregate	2.65	2.64
Bulk density of coarse aggregate	1515	1497
Water absorption (%)	-	-
Sieve, cumulative (%) passing	-	-
20.0 mm	100	-
14.0 mm	94.0	-
10.0 mm	64.0	-
5.00 mm	52.0	100
2.36 mm	8.00	98.6
1.18 mm	0.00	69.4
0.60 mm	-	32.3
0.30 mm	-	5.60
0.15 mm	-	0.50
Pan	0.00	0.00

Table 2: Properties of Portland Cement (OPC) and silica fume

Chemical composition	OPC (%)	Silica fume (%)
Calcium oxide (CaO)	65.0	<1
Silicon dioxide (SiO_2)	20.1	>90
Aluminium oxide (Al_2O_3)	4.90	<1
Ferric oxide (Fe_2O_3)	2.50	<1
Magnesium oxide (MgO)	3.10	<1
Sulphur oxide (SO_3)	2.30	<1
Potasium oxide (K_2O)	0.40	<1
Sodium oxide (Na_2O)	0.20	<1
Loss on ignition (%)	2.40	<3.0
Physical properties		
Specific gravity	3.20	2.2-2.3
Bulk density ($kg\ m^{-3}$)	-	150-700
Particle size (μm)	45-150	0.15-0.50

Table 3: Concrete mixture proportions ($kg\ m^{-3}$)

Component	C	Sp1.52	Sp1.39	Sp1.27	Sp1.15	WB0.386	WB0.391	WB0.396	WB0.401
Coarse aggregate	759.000	759.000	759.000	759.000	759.000	759.000	759.000	759.000	759.000
Fine aggregate	818.530	818.530	818.530	818.530	818.530	818.530	818.530	818.530	818.530
Cement	581.730	538.290	538.290	538.290	538.290	538.290	538.290	538.290	538.290
Silica fume	-	43.440	43.440	43.440	43.440	43.440	43.440	43.440	43.440
Water	236.040	236.040	236.040	236.040	236.040	224.390	227.260	230.140	233.090
SP	8.950	8.950	8.220	7.500	6.770	8.220	8.220	8.220	8.220
W/B	0.406	0.406	0.406	0.406	0.406	0.386	0.391	0.396	0.401
SP%B	1.52%	1.52%	1.39%	1.27%	1.15%	1.39%	1.39%	1.39%	1.39%

RESULTS AND DISCUSSION

The results of fresh concrete test, slump flow (S), slump flow time (T_{50}), J-ring blocking step (B_J), J-ring flow spread (S_J), J-ring flow time $(T_{50})_J$ with different amounts of superplasticizer and silica fume addition are discussed in the following paragraphs.

Properties of freshened concrete: It can be seen from Table 4, slump flow diameters vary between 545 and 790 mm, which refers to the mean spread diameter of concrete following the removal of slump cone as specified by JSCE (1999). The slump-flow test evaluates the capability of concrete to deform under its own weight against the friction of the surface with no external restraint present. It is well known that slump flow diameter indicates the yield stress (EFNARC, 2002). The slump flow increase with the increasing superplasticizer and water-binder content. Comparatively, Sp mixes series had improved properties, as indicated by the lesser flow time to achieve higher slump flow diameters. The effect of superplasticizer dosage, on slump flow and flow time is shown in Fig. 1.

The slump-flow time (T_{50}) was measured when the concrete was slumping until it reached 500 mm of flow. The slump flow time (T_{50}) vary between 1.59 and 7.09 sec. It may be seen that the (T_{50}) times, which provide an indication of the relative plastic viscosity of the SCC, increase with a decrease in the superplasticizer. This is an agreement with results found in previous study (Sahmaran *et al.*, 2006). The increase in viscosity will help to minimize the risk of segregation during and after placement.

The effect of water-binder ratio on slump flow and flow time is presented in Fig. 2. The optimum water-binder ratio was achieved by mixed WB0391 with higher slump flow and lesser flow time. With the reduction of free water content simultaneously, the increase in superplasticizer dosage is not sufficient to obtain the range of permissible slump-flow values (65-80 cm).

Compressive strength: The result of compressive strength development of Sp series in this study within time is presented in Table 5. Included in that Table are compressive strengths of SCC after 3, 7 and 28 days. The results show that the compressive strength decreases with the increasing superplasticizer content. It can be seen that, the compressive strength of control mix ID (0% SF) higher than all SCC mixtures in the early ages. It was proven that, SCC mixtures were good in workability. Nevertheless, the compressive strength of control mix ID and Sp1.15 mix ID were relatively equal at 28 days. It was known from that table, when compared to the control mixture, the use of SPs generally increased the strength after 28 days.

Table 4: Properties of fresh concrete

Series	Flow (S) (mm)	Time (T_{50}) (s)	J -ring (B_J) (mm)	J -spread (S_J) (mm)	J-time $(T_{50})_J$ (s)
C	722.5	1.59	4.00	720.0	2.87
Sp1.15	545.0	3.14	21.00	500.0	10.65
Sp1.27	700.0	2.29	12.75	645.0	3.02
Sp1.39	705.0	2.23	6.50	680.0	3.48
Sp1.52	790.0	2.51	12.00	700.0	3.50
WB0.386	590.0	6.21	23.00	500.0	12.48
WB0.391	635.0	3.86	16.00	590.0	13.53
WB0.396	665.0	4.95	19.25	555.0	10.50
WB0.401	575.0	5.15	23.00	535.0	8.76
Criteria	600-800	2-5	10-15	550-750	3.5-6

Table 5: Summary of compressive strength

Series	3 days (MPa)	7 days (Mpa)	28 days (Mpa)
C	45.80	50.00	54.20
Sp1.15	29.05	33.69	46.95
Sp1.27	29.49	38.07	48.90
Sp1.39	30.00	39.00	50.00
Sp1.52	30.26	41.75	54.30
WB0.386	35.13	42.15	52.25
WB0.391	38.87	47.00	55.35
WB0.396	33.48	46.95	54.80
WB0.401	30.78	43.60	52.65

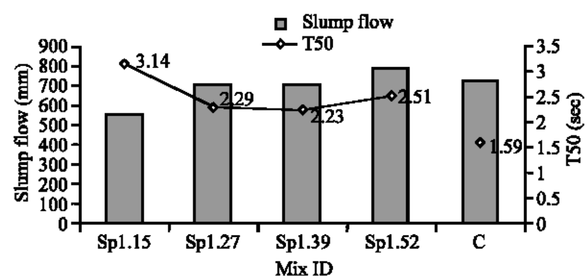

Fig. 1: The influence of superplasticizer on slump flow and flow time

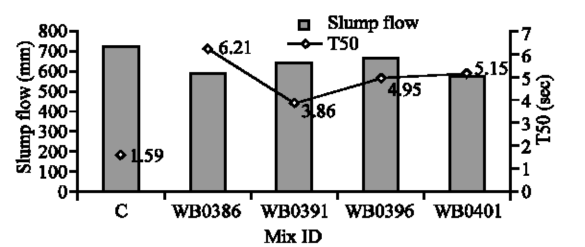

Fig. 2: The influence of W/B ratio on slump flow and flow time

Compressive strength development of W/B series up to 28 days show that compressive strength is increase with decrease of water-binder ratio. A maximum concrete strength of 54.80 MPa was achieved at a W/B ratio of 0.396 and SF content constant of 7%. It is clear that a rapid strength development can be obtained by reducing the free water content and by this means W/B ratios. When, the strength development is in issue, water reduction is more dominant than the retardation effect of

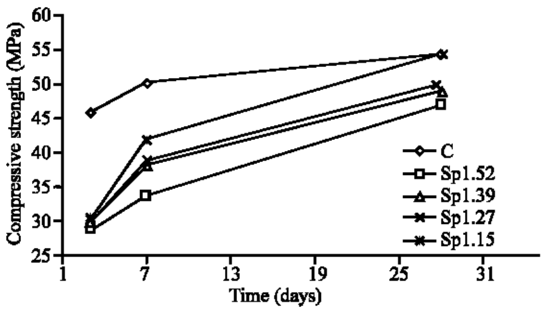

Fig. 3: Relationship between SPs content and compressive strength

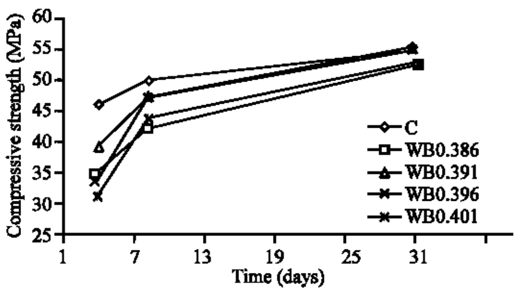

Fig. 4: Relationship between W/B ratio and compressive strength

superplasticizer. To better illustrate how the concrete strength varied with the SPs and the W/B ratio, the strength results of the compacted cubes are plotted against the SPs in Fig. 3 and against the W/B ratio in Fig. 4.

CONCLUSION

A series of trial mixing aiming to develop medium strength of self-compacting concretes has been carried out. In the total nine concrete mixes with superplasticizer content varying from 1.15-1.52% of binder, water-binder ratio ranging from 0.386-0.401 and a fixed binder content have been cast and tested. A maximum workability of 790 mm in slump flow and 2.51 sec in flow time has been achieved at a 28 days compacted cube strength of 46.95 MPa, whereas a maximum 28 days compacted cube strength of 55.35 MPa has been obtained at workability of 635 mm slum flow and 3.86 second flow time.

The effects of superplasticizer and W/B ratio on concrete strength and workability have been studied by comparing the results of the different trial mixes. As expected, a lower superplasticizer and W/B ratio leads to a higher strength but lower workability and vice versa. When, the strength development is in issue, water reduction is more dominant than the retardation effect of superplasticizer.

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