Proportioning Self Compacting Concrete in Hot Weather Utilizing Limestone Powder

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Keywords

*Self compacting concrete (SCC),
Limestone powder (LSP),
Slump flow (SF),
Sieve segregation (SR),
V-Funnel (VF),
U-Box,
Hot weather SCC mix design.*

Abstract

Self-compacting concrete (SCC) is a special type of concrete able to flow and compact under its self-weight. The SCC requires high powder content (mainly of cement) up to 600kg/m³ to achieve its properties. This will be problematic if all cement content in the powder exceeded 400 kg/m³ used in hot weather of Sudan. This paper investigates addition of Sudanese limestone powder (LSP) to reduce cement content. The LSP dosages between 20% and 28 % (by cement weight) are used in six mixes having maximum cement content 380kg/m³. Results show that five trial mixes achieved the self-compactability tested by slump flow, sieve segregation, V-funnel and U-box tests. Compressive strength of these mixes show that the LSP increases strength with dosage. Therefore, further investigations of hardened concrete properties are recommended for the successful mixes to be applied in real projects in the Sudan. Also, it has been found that dry batching and forced-action pan mixers are the most suitable for producing SCC with high homogeneity compared to commercial tilted-drum mixers.

1. Introduction

According to BS EN 206-9:2010 [1] SCC is defined as "Concrete that is able to flow and compact under its own weight, fill the formwork with its reinforcement, ducts, box outs etc., whilst maintaining homogeneity". It was first developed inside Japan in 1986 by Professor Okamura [2]. The idea was picked up and developed in Europe around 1997-2000 [3]. There are many advantages of using SCC including: reducing the noise pollution and decrease human's hazard due to vibration, decrease of construction time and labors, increase compressive strength and improving durability caused by reducing permeability, and finishing [4]. SCC mix design has been developed based on key properties of a fresh stage defined as: flow-ability, Passing-ability, Segregation resistance and Viscosity as defined in BS EN 206-9:2010 [1].

There are two types of SCC according to mix materials such as: viscosity modifying admixture (VMA) type and/or powder type [5]. The powder type of SCC requires high cement content. This leads to increase in cost and will be problematic if used in the tropical weather Such as Sudan by increasing thermal cracks, hence reduces durability of concrete. Minerals additives, namely pozzolanic (supplementary cementation materials) such as fly ash, bagasse ash, grand granulated blast furnace slag (GGBS), silica fume, ground brick powder, metakolin, and rice husk ash have been used as partial replacement of cement [6,7]. Also filler materials such as limestone powder (LSP) up to 20% of binder by weight have been used [7]. Moreover, the addition of LSP improves consistence of SCC. It also enhances the rate of cement hydration and strength development, besides improving deformability and stability of SCC [8]. However, SCC needs more quality control and advance mix design, with more testing. Using mineral additives and fillers materials helps to improve properties of SCC. This improvement includes decreasing shrinkage, permeability, as well as increasing compressive strength [9]. In this study an empirical design method [4] has been used to obtain six concretes

mix designs in two types of mixers. These SCC mixes are tested for their properties and classified. This paper describes mix design method for the SCC limit maximum cement content to 380 kg/m³ in

order to reduce hydration heat in tropical weather of Sudan. Moreover, it has investigated the influence of LSP on fresh SCC properties and the effect of mixing procedures. This paper is composed of this section, state of art, materials and methods, results and discussions and conclusions and recommendations.

2. State of The Art

2.1 Mix Design:

There are many mix design methods of SCC. The best estimation of SCC proportions is based on trial mixes, i.e. empirical methods, and adjustment of initial mixture [4]. European guideline [3] states indicative typical range of constituents in SCC by weight and volume.

It has been reported that SCC mix design is not based on strength similar to normal concrete [9]. Okamura and Ouchi [2] stated that SCC could be achieved by achieving stability between flow-ability and viscosity of paste and mortar. A filler (powder) material is a ground material which passed 0.15 mm grounded similar to Portland cement fineness; it can be natural materials or processed mineral materials. It has uniform properties and fineness [10]. According to BS EN 197-1:1992 [11], filler or additive has been limited to 5% of cement content by weight. However, it allows the use of LSP up to 35% of cement content. The viscosity of cement-based materials can be improved by decreasing water/powder ratio (W/P) and/or using viscosity modifying admixture (VMA).

2.2 Use of LSP to Produce SCC

Nehdier *et al.* [12] stated that using of LSP improves consistence and stability of fresh SCC. Also, it reduces cost by lowering cement content. Menendez *et al.* [13] studied the effect of LSP in concrete and reported that utilizing the LSP with Portland cement increases rate of hydration at early ages and producing high early strength, except due to the dilution effect decrease of later strength. Stefania and Piotr [14] compared between effects of fly ash and LSP in fresh properties of SCC. They concluded that the SCC mixture containing LSP exhibited lower fluidity demonstrated by decreased diameter of flow and higher air content compared to fly ash-based mixes.

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On other hand, physical effect of LSP caused by small size of particles, which improves the packing density of powder and reduce the interstitial voids, thus decreasing entrapped water in the system [15]. LSP-based SCC has lower risk for bleeding, but mechanical strength is decreasing with increasing temperature [16]. Reference [8] reported that chloride ingress of SCC decreases with increasing cement replacement by LSP up to 20%. The addition of LSP reduces the initial and final setting time of SCC. LSP also acts as a viscosity enhancer, increasing the workability. Reference [17] stated that the mixing procedure has great effect on properties of SCC. However, the mixing time also affects the SCC fresh properties as well as its hardened properties such as compressive strength, splitting tensile strength and it [18].

3. Materials and Methods

3.1 Materials

Cement (C): Ordinary Portland cement (OPC) (grade 42.5 N) conforming to BS EN 197-1. The specific gravity is estimated at 3.15. The Chemical and physical properties are listed in Table 1 and 2.

Limestone powder (LSP): Locally available LSP originated from Kassala Mountains (East of Sudan) is used as filler materials. The specific gravity is measured and found to be 2.66. Table 1 and 2 show the chemical and physical properties of the LSP.

Fine aggregate (FA): local available Natural seasonal river sand from Omdurman was used. The physical properties are listed in Table 2.

Table 1: Chemical composition of OPC and LSP

Oxides in clinker (%)	OPC	LSP
CaO	61.212	39.454
Al ₂ O ₃	4.602	0.500
SiO ₂	18.872	1.669
Fe ₂ O ₃	3.29	3.971
K ₂ O	0.298	0.010
Na ₂ O	0.356	0.063
SO ₃	7.245	0.111
CL	0.018	0.027
MgO	1.074	13.363
L.O.I	2.2	40.600

Table 2: Physical properties of the concrete ingredients

Material Property	C	LSP	FA	CA	SP
Specific gravity (SG)	3.15	2.66	2.62	2.61	1.19
Water absorption (%)	NP*	NP	0.52	0.73	NP
Fineness modulus	NP	NP	3.08	7.63	NP
Dry rodded bulk density (kg/m ³)	NP	NP	NP	1600	NP

*NP= not performed

Coarse aggregate (CA): Locally available Single size natural coarse aggregate with maximum size of 19 mm having physical properties listed in Table 2.

Water (W): Tap water was used for preparing and curing of specimens.

Super plasticizer (SP): High range water reducing (manufactured by Prokem). (ASTM C494 Type F) and having relative density of 1.19 at 20°C was used in this study.

3.2 Tests methods

In this study the following tests, identified in the BS EN 206-9:2010 [1], were used, namely slump flow test, V-funnel test and sieve segregation to measure and classify the fresh SCC properties. Furthermore, U-box test [3] is used to measure the passing-ability. The principles of testing are stated in Ref. [3]. Moreover, compressive

strength measured at (7, 21 and 28) days by using by filling at once with no compaction effort triplet 100*100*100mm cubes at each age.

3.3 Mix Proportions

As mentioned previously empirical design method described in Ref [4] is used to determine the initial mix proportions. It is worth noting that this empirical method is based on detailed examples of methods reported in Refs [6, 17] and uses data and limits values stated in Ref [3]. The detailed steps for mix design are based on assuming air content by volume of concrete (not exceeding 2%), assuming CA volume (between 28 – 35%) of concrete volume, and then mortar volume is determined, assuming FA volume (between 45 – 55 %) of mortar volume. Then the paste volume is determined, hence cement content is determined assuming LSP percentage range between 0 and 35 % by cement weight. Finally, the W/P and SP dosages are adjusted to give the desired SCC properties.

3.4 Mixing procedure

The mixing procedure began by mixing of sand with powder about 1 minute. Then 2/3rds of the total water content was slowly poured while the mixer was running. Then the CA was added and followed by a 1/3d of water content intermixed with a 1/3d of SP dosage and mixed for 2 minutes. Finally, the remaining 2/3rds of the SP was slowly poured and mixed for extra 7 minutes. In this experimental work, two types of mixers were used namely forced action pan mixer (denoted as mixer 1) with 22 revolution per minute (rpm)(see Fig 10) and commercial tilted drum mixer (denoted as mixer 2) with 33 revolution per minute (rpm)(see Fig 11).

3.5 Mixes designed in this study

According to explained empirical design method, six trial mixes of SCC are mixed. Table 3 shows that the proportions of these designed SCC mixes according to the properties of ingredients listed in Table 1 and ingredient and parameter limits set in Ref. [3].

4. Results and Discussion

4.1 Fresh SCC properties

Table 4 and Fig 9 present results of fresh SCC parameters obtained from different tests carried out in this study. It also classifies the different prepared mixes, according to BS EN 206-9:2010 [1].

The effects of mixer types and LSP contents on fresh and hardened properties of SCC are depicted graphically in Fig 1 to Fig 8. However, the fresh properties of SCC mixture have been improved by increasing powder content. Moreover, according to European guideline typical range of powder (400 to 600) produces more stability for SCC. Fig 1 shows that increasing S/P ratio improves the flow-ability.

Fig 1 shows that the slump flow diameter increases with the increase of SP dosage. Increasing in water content leads to improving of slump flow diameter [14, 17].

Fig 1: Effect of SP/P ratio on SCC Flow-ability measured by Slump Flow Test.

Reducing W/P ratio has improved the SCC stability (i.e. segregation resistance)(Fig 2) and increased the Viscosity measured by slump flow

T50 (Fig 3). All these effects are due to increment of powder content in the mixture, this agrees with Ref. [12].

Regarding the effect of LSP dosage, Table 3 shows that increasing the LSP from 20% to 28% did not affect the viscosity classification, however, Figs 5 & 6 show the improvement in viscosity and passing-ability respectively. It is noteworthy that both mixes have W/C=0.49 but slightly different W/P as the 28% has less W/P than 20% (Table 3).

Fig 2: Effect of W/P on SCC segregation resistance (i.e. stability).

Fig 3: Effect of W/P on SCC flow time measured by Slump Flow Test.

Concerning the effect of mixer type on properties of SCC, mixer 1, i.e. forced action pan mixer produced more flow-ability of SCC (Fig 7), more viscosity (Fig 8) and more stability (Fig 5) compared to the commercial tilted drum mixer. This agrees well with the conclusions of Ref [18] and may be attributed to higher homogeneity of mixes produced by the forced action pan mixer compared to the commercial tilted drum mixer.

Fig 4: Effect of LSP content on V-funnel viscosity of SCC mixes.

Fig 5: Effect of LSP dosage on U –box test passing-ability of SCC mixes.

4.2 Compressive strength of SCC

The influence of W/P strength is notable (Fig 8); this may be attributed to fewer pores as the solids content increased. This agrees with the observation of Refs [8, 13, 15 and 17.], regardless of the mixer type.

Table 3: Mix proportions of SCC according to Empirical design method

Material (Unit)	Referenc e(2)	Mix Code			
		20%LS P(2)	28%LS P(2)	28%LS P(1)	25%LS P(2)
CA (kg/m ³)	783	783	783	783	783
FA (kg/m ³)	862	862	862	862	862
C (kg/m ³)	433	350	380	380	380
LSP (kg/m ³)	—	70	106	106	95
W (kg/m ³)	218	219	200	195	199
SP (kg/m ³)	6.3	5	7.4	7.3	7
Assumed Air %	2	2	1.5	2	2
W/C and W/P ratios for each mix					
W/C	0.48	0.6	0.5	0.49	0.5
W/P	0.48	0.5	0.39	0.38	0.4

**(1) mixed by the forced action pan mixer and (2) by commercial tilted drum mixer.*

*** 20% LSP (1) differs than 20%LSP (2) in many aspects notably higher FA and C contents, however, it has similar LSP%.*

Table 4: Fresh properties of SCC and Classification of mixtures according to BS EN 206:9

SCC Par. and Class	Ref.(2)	Mix Code				
		20% LSP(2)	28% LSP(2)	28% LSP(1)	25% LSP(2)	20% LSP(1)
SF (mm)	560	530	570	580	565	700
Class	SF ₁	Not SCC	SF ₁	SF ₁	SF ₁	SF ₂
VS (S)	1	1	2	3	2.5	2
Class	VS ₁	VS ₁	VS ₂	VS ₂	VS ₂	VS ₂
SR (%)	11	7	6.5	3	4	5
Class	SR ₂	SR ₂	SR ₂	SR ₂	SR ₂	SR ₂
VF (S)	NP*	NP	NP	5	NP	4
Class	—	—	—	VF ₂	—	VF ₂
U-box (mm)	NP	NP	NP	30	NP	10
Class**	—	—	—	< 30	—	< 30

**NP= Not performed Ref.=Reference Par.=Parameter*

***The BS EN 206:does not use U-box for testing passing ability; it rather uses the L-box*

Fig 6: Effect of mixer type on stability of mixes measured by segregation resistance (1- denotes forced action mixer and 2 the commercial mixer).

Fig 7: Effect of mixer type on viscosity of mixes measured by T500 of slump flow.

Fig 8: Effect of W/P on SCC Compressive Strength.

Fig 9: Effect of mixer type on compressive strength of 28%LSP SCC at 7, 21 and 28 days.

The addition of LSP in SCC produces higher early and late strength for SCC mixes. However, the addition of 20% LSP did not improve the strength in comparison to the reference mix (also prepared by mixer 2) prepared by the commercial tilted drum mixer; this may be attributed to the higher W/C and W/P as shown in Table 2.

(a) Slump flow (b) Sieve segregation

(c) V -Funnel (d) U -Box

Fig 10: Testing Fresh Properties of SCC

The impact of forced action pan mixer on improving strength is more significant than the commercial tilted drum mixer (Fig. 9).

5. Conclusions and recommendations

5.1 Conclusions

1. Empirical design method for Self-compacting concrete (SCC) design is simple and easy to be used.
2. The mixes proportions, type of mixer, powder content and mixing time have effects on properties of SCC.
3. SCC containing LSP dosages between 20% and 28% by cement weight. Takes more time to flow compared to reference mixture, i.e. they have higher viscosity as deduced from results obtained from slump flow T500 and v-funnel tests.
4. The stability of SCC can be achieved by adding LSP; this is reflected in less segregation, i.e. more stability.
5. SCC Compressive strength has increased with decreasing water/powder (W/P) ratio and increased LSP.
6. Forced pan mixers are more suitable to achieve the properties of SCC than commercial mixers.

5.2 Recommendations

We recommend

- I. Using empirical design methods for proportioning SCC, however, a link with compressive strength is required to be developed.
- II. Using LSP in the Sudan as viscosity and filler materials for producing SCC to reduce the cement content in the hot weather.
- III. Investigation of available natural pozzolanas in Sudan in SCC production as supplementary cementitious material.
- IV. Performing more laboratory tests on properties of hardened SCC incorporating LSP before any further application in real construction projects.

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