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Use of different limestone and chalk powders in self-compacting concrete

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Abstract

This paper presents a study on the use of different types of limestone and chalk powders as fillers in self-compacting concrete (SCC) and their effects on superplasticizer demand and the strength properties of concrete mixes. It was found that all the different limestone and chalk powders selected could be used successfully for producing SCC mixes, although modest adjustments of superplasticizer dosage were necessary. Generally, higher superplasticizer dosages were required for SCC using chalk powder than for that using limestone powder. The fineness of the powders had little effect on the superplasticizer demand. The compressive strength of the SCC mixes containing the limestone and chalk powders was significantly greater than that of the conventional vibrated reference concrete at the same water/cement ratio, particularly at early ages.

Keywords: Self-compacting concrete; $CaCO_3$ filler; Admixture; Strength

1. Introduction

Self-compacting concrete (SCC) removes the need for compaction when placing fresh concrete. This saves time, reduces overall cost, improves working environment and opens the way for the automation of the concrete construction. Because of these significant benefits, SCC is expected to gradually replace most of the ordinary concrete currently produced [1,2].

SCC mixes always contain a powerful superplasticizer and often use a large quantity of powder materials and/or viscosity-modifying admixtures. The superplasticizer is necessary for producing a highly fluid concrete mix, while the powder materials or viscosity agents are required to maintain sufficient stability/cohesion of the mix, hence reducing bleeding, segregation and settlement. As an increase in cement content leads to a significant rise in material cost and often has other negative effects on concrete properties (e.g., increased thermal stress and shrinkage, etc.), the requirement for increased powder content in SCC is usually met by the use of pozzolanic or less reactive filler materials. These may include pulverised fuel ash (PFA), granulated ground blastfurnace slag (GGBS), limestone powder, etc.

Limestone powder has been used to produce cement in some countries, and in the recent EN197-1 specification, up to 35% of limestone powder can be added to produce Portland limestone cement and Portland composite cement. The use of limestone powder in concrete, particularly in SCC, has been widespread in Sweden and France, where limestone powder is stored in silos alongside the cement in ready-mix concrete plants [2–4]. The addition of fine limestone powder has shown to enhance the rate of cement hydration and strength development [5], as well as to improve the deformability and stability of fresh SCC [6,7]. In Britain, the use of limestone powder in concrete has been very limited, and its potential not fully recognised.

Preliminary studies carried out as part of a major European research project on SCC suggested that fine limestone powder could be used effectively in SCC. The SCC mixes containing fine limestone powder showed good fresh properties, higher than expected compressive strength and excellent surface finish [8]. This was attributed to improved particle packing and water retention of the fresh

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mixes, as well as to possible chemical reactions involving cement hydrates and $CaCO_3$. It is not certain, however, if different types and finenesses of $CaCO_3$ powders could offer similar benefits to SCC. This paper examines the use of different types and finenesses of limestone and chalk powders as fillers in SCC and their effects on superplasticizer demand and the strength properties of the concrete mixes.

2. Experimental

2.1. Materials used

Portland cement (CEM I 42.5 according to EN197/1) with a Blaine specific surface area of 385 m^2/kg, graded crushed granite of 20-mm maximum size and natural sand (zone M of BS 882 [9]) were used throughout this study. Three types of limestone powder and two types of chalk powder, provided by OMYA UK, were chosen and used as filler to produce SCC mixes. Their chemical composition and physical characteristics are given in Table 1. Typical SEM photographs of the limestone and chalk powders are presented in Fig. 1.

The superplasticizers used were Glenium 27 and Glenium C315 with solid contents of 25% and 35%, respectively, provided by FEB-MBT. Both superplasticizers are new-generation products based on chains of modified polycarboxylic ether. Glenium 27 is primarily developed for ready-mix concrete application with enhanced slump retention, while Glenium C315 is specifically for precast application.

2.2. Study of fresh paste

It is known that the fresh paste (or mortar) phase provides lubrication between the aggregate particles and the overall stability required in SCC. Preliminary tests on fresh pastes were first carried out to assess the effect of the powders on flowability and superplasticizer demand. The paste with a fixed water to total powder (i.e., cement+filler powder total) ratio of 0.3 by mass was mixed and tested for flowability using a mini-slump flow test [10]. The limestone/chalk powders were used to replace 40% of Portland cement by mass in the paste mixes and two dosages of superplasticizers (i.e., 1.0% and 1.5% by mass of total powder for Glenium 27 and 0.3% and 0.8% for Glenium 315) recommended by the producer were studied.

2.3. Study of concrete mixes

To study the different levels of powder addition, three basic SCC mixes with limestone/chalk powder addition levels of 55%, 44% and 25% (i.e., ratio of limestone/chalk powder to total powder by mass), respectively, were chosen based on previous experience. All the SCC mixes had a total powder content (i.e., cement+limestone/chalk powder) of 540 kg/m^3 and water content of around 170 kg/m^3; thus, the water/cement ratio (w/c) for the three basic SCC mixes were 0.69, 0.57 and 0.42, respectively. These ratios represent the range of w/c ratios normally used in the construction industry in the UK. Three conventional vibrated concrete mixes with the same w/c ratios as those of the basic SCC mixes were also selected as references. The mix designs for the reference concrete were typical of those of commercial pumping mixes. These mixes cover the normal range of practical cement contents and compressive strengths for concrete. All the concrete mixes used the same type of cement and aggregates, and the superplasticizer Glenium 27 was used for all the SCC concrete mixes, as it showed a more consistent characteristics in the paste study and retains the workability of concrete longer, compared with Glenium C315. The mix proportions for the basic SCC and reference mixes are represented in Table 2.

Table 1
Main chemical compositions and physical characteristics of powders used

Powder type	L1 Limestone (ground+classified)	L2 Limestone (ground)	L3 Limestone (ground)	C1 Chalk (ground)	C2 Chalk (ground)
Chemical analysis					
$CaCO_3$ (%)	99.3	99.3	99.3	94.5	90.5
SiO_2 (%)	0.2	0.3	0.3	–	–
Fe_2O_3 (%)	0.02	0.02	0.02	0.1	0.1
Al_2O_3 (%)	0.1	0.1	0.1	0.1	0.1
MgO (%)	–	0.2	0.2	–	–
Insoluble in HCl (%)	–	0.4	0.4	4.7	9.0
Physical properties					
Residue on 45 μm sieve (%)	0.3	15	33	30	50
Top cut (d98) (μm)	30	80	200	100	250
Weight median diameter (μm)	5	17	25	n.a.	n.a.
Particles by weight <2 μm (%)	20	15	11	15	n.a.
Specific gravity	2.7	2.7	2.7	2.7	2.7

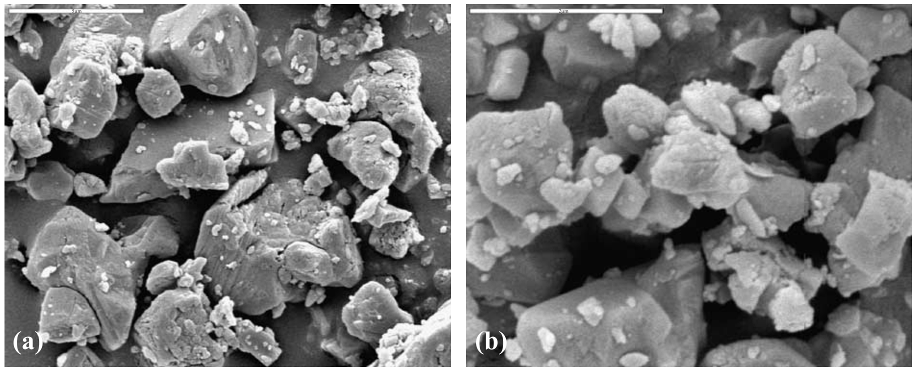

Fig. 1. Typical particle shapes of (a) limestone (L3) and (b) chalk (C2) powder.

The three basic SCC mixes were repeated five times, once each for the five different types of powder selected in this study, and the dosages of superplasticizer was adjusted in each case to achieve a suitable self-compactability. As Glenium 27 contains 75% of water, the adjustment of its dosage can lead to a variation of free water content in the SCC mixes. However, variation in water content within a small range only has a minor effect on the resulting w/c ratio and, thus, the strength of the concrete.

After mixing, the properties of the fresh SCC mixes were evaluated by the Slump Flow and the J-ring tests [11], while the Slump test was used for determine the workability of the reference mixes. The Slump Flow test is the most common method used for assessing the flowing/filling ability of SCC mixes in laboratories or on site, while the J-ring test is a simple way to check their passing ability through reinforcement without blockage. Due to the time constraint, no segregation or bleeding tests were carried out. However, visual inspections were made during the slump flow test to check if there is any noticeable segregation. Generally, a slump flow value of 600–700 mm is often targeted for normal SCC mixes.

Specimens for compressive strength testing were prepared by simply pouring the fresh concrete into standard cube or cylinder moulds without vibration for the SCC mixes, but by standard compaction method using vibration for the reference concrete mixes. The specimens were demoulded at 1 day and then placed in a water tank for standard water curing. The compressive strength tests were carried out at 7, 28 and 90 days and indirect tensile/splitting strength tests at 28 days.

3. Results and discussions

3.1. Fresh paste mixes

Results of the mini-slump flow test for different paste mixes are presented in Fig. 2. PC represented the paste mix based on pure Portland cement, while all the other mixes represent a 40% replacement of Portland cement by the different powders.

The results in Fig. 2a appear to show that when using Glenium 27 as superplasticizer, the replacement of Portland cement by the different powders leads to an increase in the mini-slump flow values of the pastes. Also, as expected, the flowability of pastes increased with an increase in superplasticizer dosage.

The results from pastes prepared with Glenium C315 were different. Here (Fig. 2b), the flowability of fresh paste seemed less sensitive to the use of different powders and to the variation of superplasticizer dosages. The absolute values of slump flow, however, were higher for the pastes using Glenium 315 than for the paste using Glenium 27 at the dosages recommended by the supplier.

3.2. Self-compacting concrete mixes

A total of 15 SCC mixes (i.e., five different Limestone/chalk powders and each with three addition levels) with similar fresh properties was successfully produced by adjusting the dosage of superplasticizer Glenium 27. All the SCC mixes achieved the target slump flow value of 600–650 mm and showed good passing ability and little sign of segregation. The reference mixes, i.e., REF 1, REF 2 and

Table 2
Mix proportions of basic SCC and reference vibrated concrete mixes

kg/m^3	Aggregate	Sand	Cement	Powder	Water	Glen. 27	W/C ratio
SCC 1	750	910	245	295	170	6.48+adj.	0.69
SCC 2	750	920	300	240	170	6.48+adj.	0.57
SCC 3	750	935	405	135	170	6.48+adj.	0.42
REF 1	840	980	295	–	205	–	0.69
REF 2	860	930	350	–	200	–	0.57
REF 3	920	745	490	–	205	–	0.42

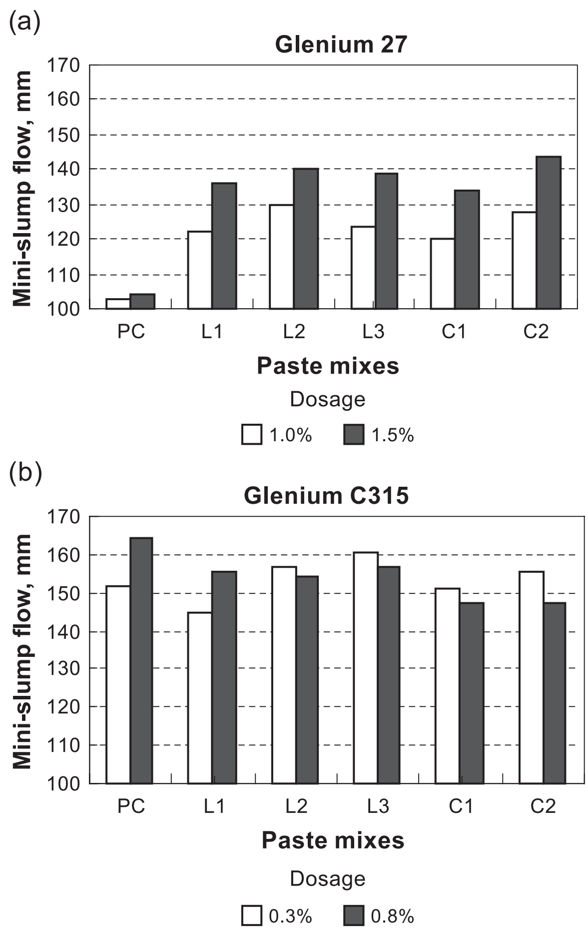

Fig. 2. Mini-slump flow values for pastes with (a) Glenium 27 and (b) Glenium C315.

REF 3, achieved slump values of 80, 100 and 140 mm, respectively, with no sign of segregation. The superplasticizer dosage required for the different SCC mixes is compared and presented in Fig. 3.

The results in Fig. 3 indicate that the dosage of superplasticizer Glenium 27 required for producing the SCC mixes depended on the type of powders and their addition levels used. SCC mixes using the limestone powders (L1, L2 and L3) appeared to require considerably smaller amounts of Glenium 27 than did the SCC using the chalk powders (C1 and C2). Such results were not consistent with those of the paste study (Fig. 2a), which showed similar superplasticizer requirement for all the pastes. This suggests that data on the flow properties of pastes may not be sufficient to predict either the self-compactability or the superplasticizer demand of the concrete mixes. The results presented in Fig. 3 also suggested that there were not significant differences in superplasticizer demand among the SCC mixes using the three different limestone powders, or between those using the two chalk powders. This seemed to suggest that it was the powder type rather than its fineness that determined the demand for superplasticizer Glenium 27 in the SCC mixes. SEM images of the limestone and chalk powders (Fig. 1) revealed that there were no significant differences in particle shape between the two powder types. It is not clear whether the difference in Glenium 27 demand might be attributed to the impurity in the powders, the difference in surface properties or the particle packing characteristics. Possible differences in absorption characteristics of the various powders may also contribute to the results discussed above. Further work is required in this aspect.

As for the effect of limestone/chalk powder addition level, the demand for Glenium 27 was found to be significantly greater at the lower addition level (i.e., lower w/c ratio). For example (Fig. 2), at the limestone powder addition of 25%, the Glenium 27 dosage required for producing the target slump flow of 600–650 mm was about 2.2%, compared with just over 1.2% at the addition of 55%. This may be explained partly by the higher demand of Glenium 27 for the Portland cement than for the different powder blends, as shown in Fig. 1a.

Results of the 28-day cube strength results of all the different mixes are plotted against the water/cement ratio in Fig. 4. This demonstrates that the SCC mixes using the selected limestone and chalk powders exhibited a considerably higher strength at a given w/c ratio than did the reference conventional vibrated concretes, and that all the SCC mixes followed a similar relationship. On average, the 28-day strength of the SCC mixes containing limestone

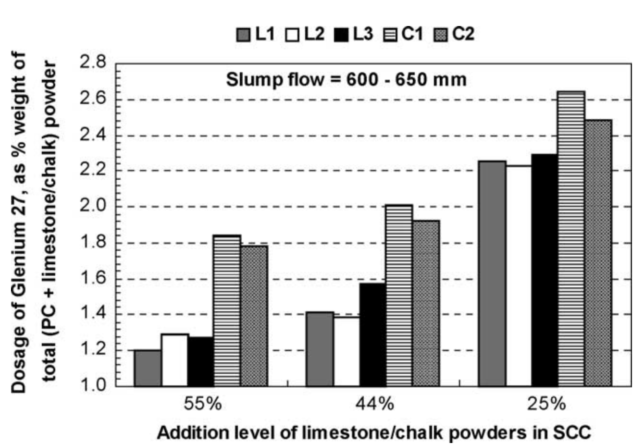

Fig. 3. Dosage of superplasticizer required for SCC to achieve the target slump flow.

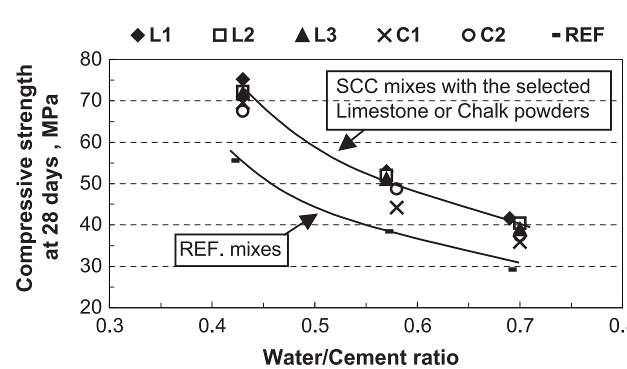

Fig. 4. Relationship of 28-day strength and water/cement ratio.

Table 3
Compressive strength of SCC mixes relative to those of the corresponding reference concretes

Powder types used	Relative compressive strength of SCC mixes (as percentage of those of REF mixes)								
	SCC 1 (W/C=0.69)			SCC 2 (W/C=0.57)			SCC 3 (W/C=0.42)		
	7 day	28 day	90 day	7 day	28 day	90 day	7 day	28 day	90 day
L1	182	142	139	168	138	132	175	135	132
L2	181	138	137	160	135	138	160	130	126
L3	175	133	130	166	133	135	153	129	121
C1	170	123	123	150	115	125	151	125	110
C2	167	128	118	155	127	128	147	121	123

and chalk powders was 10–15 MPa higher than that of the reference concrete mixes at the same w/c ratio.

As expected, from Table 2, the unit weights of the SCC mixes were 1.5–2% higher than those of the corresponding reference mixes due to the higher water content used in the reference concrete. Such differences were confirmed by measured values of saturated density of the hardened concrete cubes. Furthermore, the results of the saturated density showed only about 1% difference from those calculated from the mix proportions used. This and the visual inspection of the crushed specimens appeared to indicate that good compaction was achieved for both the SCC and the reference mixes.

Table 3 presents the compressive strengths of the various SCC mixes at different ages relative to those of the corresponding reference mixes at the same w/c ratio. The results indicate that the strength increase was much greater at the age of 7 days than at later ages. The SCC mixes using the limestone/chalk powder showed a strength increase of 50–80% over those of the reference mixes at 7 days, compared with an increase of 20–40% at 28 days. Although this was in agreement with previous findings that fine limestone powder could accelerate cement hydration and increase early strength [5,8], this degree of strength increase was not expected.

Comparing the different powders used, the results seemed to suggest that the contributions to strength gains were significantly greater for the limestone powder than for the chalk powder. Among the three limestone powders, using finer powder appeared to lead to higher strength gains in the SCC mix. This may be explained by the increased particle packing and chemical activity, with a reduction of particle size of the powder. Moreover, the results in Table 3 showed that there was no significant difference between the two chalk powders in the contribution to the strength gain of the SCC mixes.

The results of the tensile strength of SCC and reference mixes are given in Table 4. As expected, from their higher compressive strength, the SCC mixes showed significantly higher tensile strengths than did the corresponding reference concretes. Comparing the different SCC mixes at the same w/c ratios, the powder type and finenesses, however, seemed to have little effect on the tensile strengths.

4. Conclusions

The work carried out in this study demonstrated that the different limestone and chalk powders could be used for producing SCC mixes, although modest adjustments of superplasticizer dosage were necessary. For the range of the SCC mixes and materials studied, the following conclusions can be drawn:

(1) Suitable dosage of superplasticizer Glenium 27 appeared to be dependent more on the type than on the fineness of the powder used. The limestone powders used in this study showed lower demand for superplasticizer than did the chalk powders, irrespective of their fineness.
(2) Portland cement was found to have higher demand for Glenium 27 than for the limestone and chalk powders. As a result, increasing the addition levels of the limestone/chalk powder could lead to a reduction in Glenium 27 dosage and a more economic SCC mix. A different superplasticizer, such as Glenium C315, may be more efficient for producing SCC mixes with low addition level of the limestone/chalk powders.

Table 4
Indirect tensile (splitting) strength of SCC and reference mixes

Concrete mixes	28-Day tensile strength of concrete cylinders (MPa)					
	SCC mixes with different fillers					REF mixes
	L1	L2	L3	C1	C2	
Mix 1 (W/C=0.69)	3.2, 3.0	3.4, 2.8	3.2, 3.1	3.1, 2.9	2.7, 3.0	2.4, 1.6
Mix 2 (W/C=0.57)	4.1, 3.7	3.7, 4.7	3.3, 4.0	3.2, 3.8	4.2, 4.2	3.1, 2.8
Mix 3 (W/C=0.42)	5.9, 5.3	5.6, 5.2	4.9, 4.6	5.6, 6.0	5.3, 5.7	3.8, 3.0

(3) The strength of the SCC mixes containing the limestone and chalk powders was significantly greater than that of the conventional vibrated reference concrete at the same water/cement ratio. For the limestone powder mixes, the cube compressive strengths were 60–80% higher at 7 days and 30–40% higher at 28 days, compared with the corresponding reference concrete. This compares favourably with the use of PFA in the SCC mix, which usually shows no significant strength increase over the reference mix at early ages.

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