Potential South African standard sand for cement mortar testing and research

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Abstract. Mortars are used extensively in accelerated methods of testing the physical properties of cementitious materials. Mortar strength is invariably used to determine cement strength grade of cements and for general evaluation of material behavior, as typically employed in research and testing. Presently, the South African (SA) cement industry imports standard from Europe for cement testing purposes. This study was conducted to formulate South African standard sand that could be used to conduct mortar strength tests for compliance to specifications and for general research purposes.

Two formulations of local South African silica sands, referenced as SA513S and SA413S, were developed to suit standard gradings. The formulated South African standard sands (SASS) where tested in comparison with European standard sand (ENSS) of EN196-1 and American graded standard sand (GSS) of ASTM C-778. Following the formulation and grading of SASS, mortar mixtures of 1:3:0.5 cement to sand to water were cast in 50 mm cubes and tested for compressive strength for ages up to 90 days. Two types of cements were employed in the tests, the ordinary Portland cement CEM 1 42.5N and pozzolanic cement CEM V 32.5N. Comparison of the 28-day compressive strength results between the four SS types showed an excellent agreement, giving standard deviations of 1.96 and 2.51 for CEM I and CEM V. The flow results for the standard sand types varied, with EN196-1 giving the highest mortar flow followed by GSS sand and SA413S. The GSS and SA513S gave precisely the same flow results. The investigation indicates the SASS may be suitable for use with SA standard specifications for mortar strength tests.

Keywords. Standard sand, compressive strength, mortars, grading

Introduction

The testing of Portland cements and various cementitious systems for strength are usually based on mortar test methods rather than concrete tests. These approaches play a crucial role in evaluating material performance and have gained universal international acceptance, through the ASTM methods, European test methods and other international standards. Specifically formulated silica sand, referred to as "standard sand" (SS) is prescribed in specifications for use in the accelerated mortar tests and is a crucial ingredient. Accordingly, the SS is required to meet specific quality and grading requirements. Internationally, SS is produced and packaged commercially for specific use in the cement industry.

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However in South Africa (SA), there is no such standard sand that is locally produced and prepackage for use by the cement industry for mortar testing and research. The standard sand (SS) used in SA is imported, usually from Europe. The importation of standard sand generally brings about difficulties associated with SS availability; it also adds to the costs of testing and research, as experienced by the local industry and academic institutions. For this reason, it is essential to investigate and develop locally available silica sand for potential use as standard sand in cement and mortar specifications, material performance evaluation, testing and research. Such SS could in future be considered for incorporation into the SANS (South African National Standards) standard specifications.

1. International specifications and requirements for Standard Sand

1.1 Standard mixtures for mortar strength testing

ASTM C 109 [1] is a standard mortar test method for determining the compressive strength grade of Portland cement. It specifies the use of graded standard sand according to the requirements of C 778 [2] and recommends mortar mixes of 1: 2.75: 0.485 cement to sand to water, for OPC and non-air entrained cement mortars. In case of non-OPC or air entrained cements, the amount of water used is determined on the basis of the water quantity required to achieve a flow of 110±5 mm. Similarly, the European method EN 196-1 [3] for strength testing of cement, specifies its grading requirements (table 1) and mix proportions of 1: 3: 0.5 cement to sand to water but does not state the chemical criteria for sand quality.

1.2 Grading requirements

The grading requirements for the standard sand for mortar strength tests, vary widely with different countries or regions, as given in Table 1 for ASTM C 778 [1-2], EN 196-1 [3] and Indian standard IS 650 [4].

Table 1. International specifications for standard sand grading

ASTM C 778		EN 196-1		IS 650 [4]	
Sieve Size (mm)	Cumulative passing (%)	Sieve Size (mm)	Cumulative passing (%)	Sieve Size (mm)	Cumulative passing (%)
1.18	100	2.00	100	2.00 -100	100
0.85	100	1.60	88-98	1.00-0.50	67
0.60	96-100	1.00	62-72	0.50 -0.09	33
0.425	65-75	0.50	28-38	<0.09	0
0.30	20-30	0.16	8-18		
0.15	0-4	0.08	0-2		

Evidently, size distribution of the sand can be vastly different but the size range of the sand is from about 80 μm for the finer particles to no more than 2 mm particle size. The predominant sizes are between 0.5-1.0 mm for EN and Indian standard, and 0.30-0.425 mm for ASTM sand. It may also be noted the minimum size for the GSS is 150 μm compared to 80-90 μm for the European and Indian standards. These size ranges and particle size distributions have significant influence on the mechanical interlock of the

grains and pore structure of the mortars; both of these factors being of impact on compressive strength [5].

1.3 Chemical requirements

ASTM C 778 [2] defines standard sand as "silica sand, composed almost entirely of naturally rounded grains of nearly pure quartz, used for preparing mortars in the testing of hydraulic cements". However, both the ASTM and EN standards [1-3] do not pay attention to the chemical composition, other than a brief mention in C 778 that the SS should be nearly pure quartz or silica. The EN 196-1 on the other hand emphasizes the verification testing of sand through a certification process. The Indian standard IS 650 [4] also is non-specific on the quartz purity level. It simply gives its chemical and physical requirements as "quartz of grey or whitish variety" and angular sand grains with small or negligible quantities of elongated, round or spherical particles. IS 650 does not state the composition or silica content requirement for SS, however, it specifies a requirement for hydrochloric acid testing of SS, which is an indicative test for purity. The acid test evaluates the amount of organic matter, which may impact setting of cement and its hydration, eventually affecting the strength development. A maximum of 0.25% mass loss under acid test is required.

1.4 Sources

It appears the standards deem it important to recommend specific deposits from which the standard sand may be obtained within particular countries or geographical regions. C 778 [2] recommends that standard sand used in North America should be obtained from Ottawa, Illinois or LeSuer, Minnesota. The Indian standard IS 650 also recommends a specific supplier while the EN 196-1 applies the use of CEN (European Committee for Standardization) certification process to verify the approval of SS producers within the European Union.

Natural sand is generally abundant and is available at various sources in most countries, yet its physical features and quartz quality can be vastly variable to the extent that perhaps much of the abundant sand may not be suitable for use as standard sand. Recommendation of verified sand sources would therefore embed uniformity of quality into the supply chain and minimize variability of test results. In testing for compliance to specification, these factors can have major implications in the industry.

2. Local South African standard sand

As mentioned earlier, South Africa presently does not have specified, commercially produced standard sand for use in mortars for cement testing, evaluation of materials or for research purposes. Instead, local cement producers import standard sand from European producers.

However, since as early as 1970s, there was recognition for the need to have a local source of sand for cement and mortar testing. The early SABS method 749:1971 [6], gave some recommendations on the quality and local source of standard sand in South Africa. The standard [6] recommended the use of naturally occurring, single size sand of 0.85 mm with not less than 10% passing 0.6 mm sieve. It also specified the acid test

similarly as the Indian standard [4]. The source of the sand was stated to be at Philippi in the Cape Province. The sand supplier was also given. Comparing these specifications with the modern standard grading requirements for standard sand (see Section 2.2), it is evident that the requirements in the old SA standard [6] are quite different and likely to give vastly different results compared to modern SS (Table 1). Lim et al. [5] found that apart from higher water demand of finer, single sized sand gradings, it may give lower strengths compared to coarser sand sizes. Similar observations are echoed by Reddy and Gupta [7]. These issues underscore the need to update or develop a suitable modern SANS specification for local standard sand. In the context of SA standard sand requirements, there would be demand for SS for use in cement testing and research in Southern Africa. Such uses are conducted by cement manufacturing companies in the region, commercial laboratories and academic institutions that are engaged in cement and concrete research. There would therefore be a sufficiently large market for locally produced standard sand, which at present is occupied by imported SS.

3. Experimental

3.1 SA sand grading formulation

Having considered the various gradings and other requirements from established international standards, the specifications in EN 196-1 were used to prepare the SASS formulation used in this investigation. Commercially available, high quality silica sand containing 98% SiO_2 was purchased as sold in different particle sizes and gradings. Following various trials, the sand sizes were divided into coarse (C), medium (M) and fine (F). Various trials of C:M:F combinations were then made to obtain gradings comparable to the EN 196-1 requirements. The two C-M-F formulations *SASS413* and *SASS513*, were found to satisfy grading requirements and were then used for mortar preparation

3.2 Mortar mixtures and physical tests

Mortar mixes of 1:3:0.5 cement to sand to water were made using the different sand types: (i) SASS4-1-3 and SASS5-1-3, (ii) GSS and (iii) ENSS. Mortar specimens consisted of 40x40x160 mm prisms, cast and cured in water until testing. Flexural strength and compressive strength were tested at ages of 3, 7, 28 and 90 days. Two types of cements, ordinary Portland cement CEM I 42.5 N and CEM V 32.5 N, were used in the mortar mixture preparations. Other tests included density and flow. During casting of the mixtures, a flow test was performed on each mix as per ASTM C 1437 [8].

4. Results and discussion

4.1 Grading of formulated standard sands

Figure 1 shows six (6) different sand gradings that were formulated during the investigation, along with the grading envelope of EN196-1 [2], plotted as CEN-LL for

the lower limit and CEM-UL for the upper limit. Also plotted is the mean grading of the reference EN sand (CEN-avrg). It can be seen that all the six sand formulations satisfied the grading requirement as they all fell within the specified envelope. However, it is notable that the locally formulated sands (SASS) had relatively less coarser fractions than the ENSS sand, as the curves tended to lie towards the upper limit especially at the mid-range fractions of 0.5 to 1.5 mm. Scrutiny of the gradings for the various trial formulations led to refinement of the combinations; the two final formulations *SASS4-1-3* and *SASS5-1-3* were then considered to be more likely to yield performance more closer to that of ENSS. The grading of the selected SASS and ENSS were compared as seen in Figure 2. The curves are generally very close all along the particle size distribution curve. However, there are some disparities in particle sizes, with the SASS showing more fine particles at the size ranges of 0.5 to 1.5 mm and more coarser fractions at higher sizes of greater than 1.5 mm.

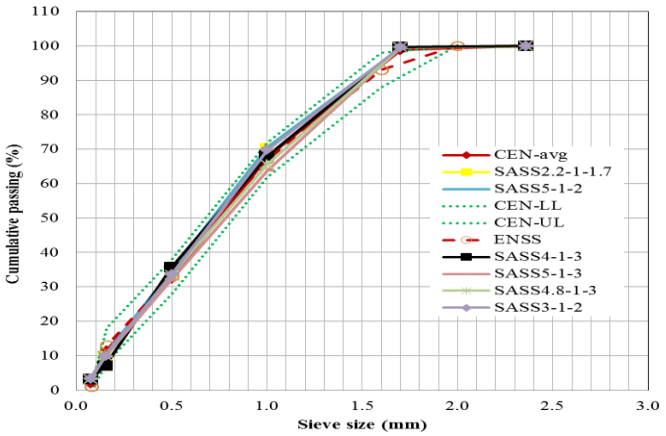

Figure 1. Various combinations of standard sand formulations (CEN-LL = lower limit of envelope, CEN-UL=upper limit of envelope, CEN-avg = mean of envelope, ENSS = EN196 standard sand, SASS = South African Standard Sand)

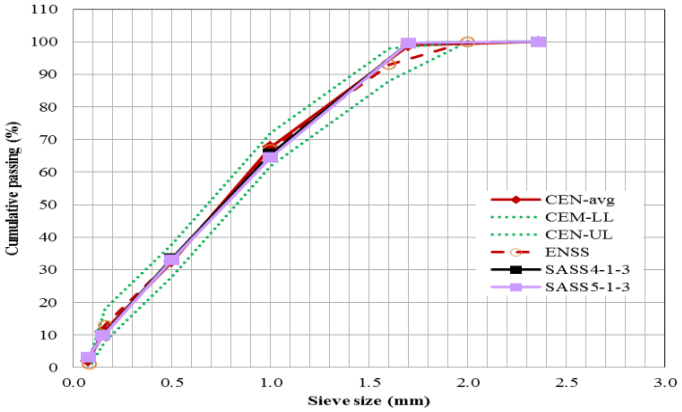

Figure 2. Comparison of SASS sands versus ENSS

4.2 Flow

A fixed water-cement ratio of 0.5 was used in all the mixes as explained in Section 4.2. Therefore the variations in the flow measurements should indicate the relative water demand of the mortar mixtures made with the different standard sand types. Figure 2 shows the flow results conducted for three batches of mortar mixtures, using CEM V 32.5 N and CEM I 42.5 N. As expected, the flow measurements for CEM V are generally higher, being in the range of 112 to 142 mm compared to the flow values of 102 to 118 mm for CEM I. The higher flow measurements in CEM V are attributed to the effect of extenders, given the high proportions of about 30% slag and 30% fly ash [9]. Incorporation of fly ash and ground granulated blast furnace slag (GGBS) is known to result in improved workability.

Regardless of the cement type, it can be seen that ENSS had the highest workability, giving flow measurements of 118 mm and 142 mm for CEM I and CEM V respectively. Among the SASS types, SASS4-1-3 gave a higher flow of 111 and 121 mm for CEM I and CEM V, compared to the respective flow values of 107 and 113 mm for SASS5-1-3. GSS had the lowest flow, measuring 102 and 112 for CEM I and CEM V respectively. As pointed out in Section 5.1, the SASS sand types had more finer fractions than ENSS which would increase the water demand of the former over the latter, leading to lower workability for the SASS types. The differences in grading may also explain, to a certain extent, the relatively low workability given by the GSS sand type.

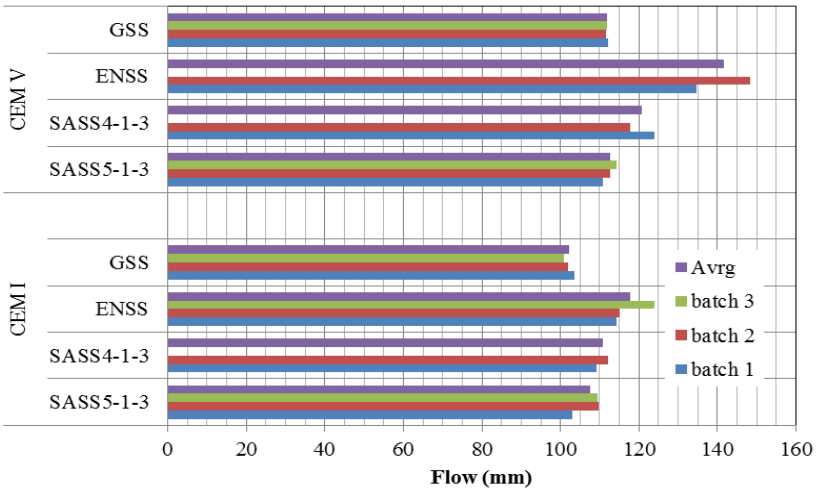

Figure 2. Flow of mortar mixes made with different standard sand types

4.3 Flexural strength

The flexural strength results of mortars made from the various standard sand types are shown in Figure 3. It can be seen that the two sand types that gave the highest results were ENSS and SASS4-1-3. The two sand types gave practically similar values of flexural strength at 28 days, as evident in both CEM I and CEM V mortar mixes. The

CEM I strength values for ENSS and SASS were 8.5 MPa and 8.9 MPa while the corresponding values for CEM V were respectively 6.0 and 6.2 MPa.

The higher flexural strengths for ENSS and SASS4-1-3 may be attributed to the good workability of these mixes over their counterparts. Unlike mixtures with lower flow, better workability allows good compaction to be achieved. The GSS sand appeared to give relatively higher early strengths but there was no sufficient data to verify this performance over the long-term.

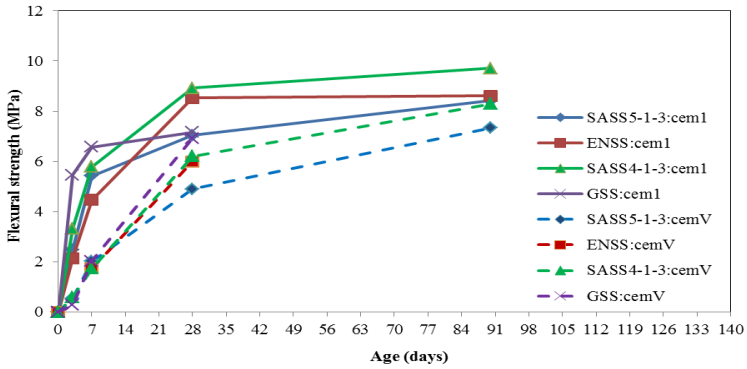

Figure 3. Flexural strength of mortar mixes made with different standard sand types

4.4 Compressive strength

Figure 4 gives a plot of the compressive strength development in the various mortar mixtures made using different standard sand types. Again, it can be seen that the two sand types ENSS and SASS4-1-3 gave higher strength growth for ages of up to 90 days. Also, the strength curves of the sand types were very close. For CEM I mortars, the ENSS sand gave compressive strengths of 29 and 32.7 MPa at 28 days and 90 days respectively, compared to the respective strength values of 29.5 and 33.8 MPa for SASS4-1-3. GSS gave lower strengths than all the other sand types (ENSS and SASS).

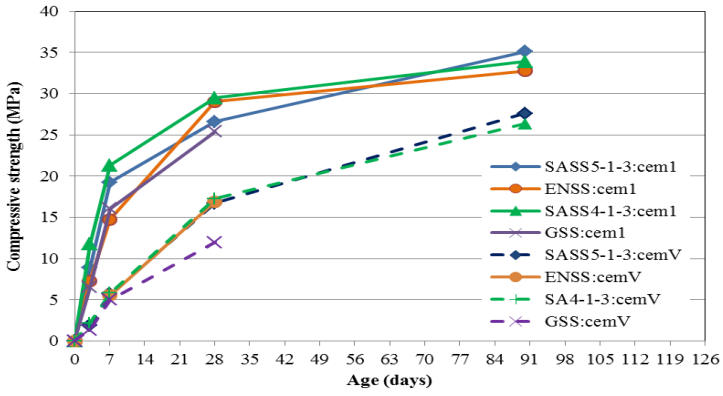

Figure 4. Compressive strength of mortar mixes made with different standard sand types

5. Conclusions

The foregone investigation was conducted to formulate potential SA standard sand for mortar strength testing. Following the formulation of six (6) sand types that satisfied the grading requirements, two refined gradings were selected for mortar strength testing. The selected SASS sand types were compared to the relevant EN standard sand and ASTM standard sand. The following conclusions have been drawn:

There is potential for developing suitable standard sand from locally available sources of silica sand in South Africa, for purposes of cement mortar testing and for research.

Whereas EN196 sand consistently gave the highest flow, the South African formulated sand types also showed good workability, better than the ASTM sand type.

It was found that the strength performance of the EN and one of the SASS sand types (SASS4-1-3) were similar, with the latter giving seemingly better flexural and compressive strength than the EN sand.

Although further investigations may be needed to exhaust this investigation, it may be postulated that the SASS formulated in this study has the full potential for use as standard sand for mortars.

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