Natural sand replacement in concrete

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Introduction

The Welsh Assembly government has identified a need for an effective method for dealing with the growing stockpiles of waste crusher dust in local quarries. The current practice in the UK is to stockpile the excess crusher dust or blend it with natural sand to produce an acceptable particle size distribution for use in concrete, but the production rate of the surplus quarry fines surpasses the rate at which they can be used due to the high percentage of blending required to produce concrete with acceptable properties [1].

A research project was commissioned to investigate the feasibility of manufacturing sand from the waste quarry fines that could be used to fully replace natural sand and sand blends in concrete applications. This was done in collaboration with Kayasand, a company which offers a dry sand manufacturing process (V7 process) which improves the shape of sand particles and controls the grading [2].

In this study manufactured sands produced with the V7 process from four quarries were considered. The resulting consistency and compressive strength of concrete when sands were used as 100% replacement for natural sand is presented.

Materials

In the study the following materials were used: CEM I 52.5 N conforming to EN 197-1, sea dredged natural sand from Bristol channel conforming to BS EN 12620:2002, 4/20 mm crushed limestone coarse aggregate, and sands produced from quarry dusts using the V7 dry manufacturing system.

Notation

Sands were manufactured from basalt, granite, limestone and sandstone quarry dusts yielding at least four gradings for each sand. These gradings differed mainly in the sub 63 micron particle or fines content. The designation for the materials used in this paper is shown in Table 1.

Table 1 Notation of materials used in the study

Material	Designation	% fines
Natural Sand	NS	-
Coarse aggregate	CA	-
Basalt crusher dust	B-Dust	-
Basalt sands	B-A	1
	B-B	2.9
	B-C	5.1
	B-D	7.4
Limestone crusher dust	L-Dust	-
Limestone sands	L-A	2.8
	L-B	4.9
	L-C	7.1
	L-D	9

Material	Designation	% fines
Granite crusher dust	G-Dust	-
Granite sands	G-A	2
	G-B	2.9
	G-C	5.1
	G-D	6.5
	G-E	9
Sandstone crusher dust	S-Dust	-
Sandstone sands	S-A	3.5
	S-B	5
	S-C	7
	S-D	9

Experimental programme

Fine aggregate tests

All sands were tested for particle size distribution according to BS EN 933-1, Particle density and water absorption according to BS EN 1097-6, Methylene blue test (MBV) according to BS EN 933-9 on the 0/2mm fraction, Sand equivalence test (SE) according to BS EN 933-8 on the 0/2mm fraction and using the New Zealand Flow cone (NZFC) according to NZS 3111-1986. Test results are shown in Figures 1-6 and Table 2.

Concrete tests

Fresh concrete was tested for slump according to BS EN 12350-2:2009, air entrainment and plastic density. Hardened concrete specimens were tested for compressive strength at 1, 7 and 28 days and flexural strength at 28 days.

Concrete mixtures

Concrete mixes were made from all sands using the mix composition reported in Table 2 with the aim of achieving an S2 (50- 90 mm) slump and using the concrete mix containing natural sand as the control. For each sand the water to cement ratio was adjusted in order to achieve an S2 slump in the –B graded sand mix. This water to cement ratio was then kept constant for the remainder of the mixes of the same sand mineralogy and the change in slump recorded.

All mix proportioning took into account the water content and absorption capacity of the coarse and fine aggregates. Nine 100 mm cubes and three 100x100x500 mm beams were made from every mix and tested at the corresponding age.

Table 2 Concrete mix composition

Cement	**Coarse aggregate**	**Fine aggregate**	**Water/cement ratio**
350 kg/m^3	1040 kg/m^3	753 kg/m^3	varies

Results and discussion

The results from the fine aggregate, fresh concrete and hardened concrete tests are presented in the following sections. The results of the crusher dust (using the 0-4mm fraction) have been included for completeness although it is recognised that a mix comprising 100% crusher dust as a replacement for natural sand in concrete is unrealistic. However, the crusher dust results do provide a useful indication of the success of the sand manufacturing process through the sand characterisation and the fresh concrete workability results.

Fine aggregate test results

Figures 1-4 show the particle size distributions for manufactured sands and the corresponding crusher dust 0-4 mm fractions used in the sand production. It can be seen that all manufactured sands irrespective of the parent material, yield similar particle size distributions with a sub 63 micron particle content ranging from 1 – 9 %. Furthermore, higher fines gradings contain more 0.3 to 1 mm particles than the feed crusher dust fractions as indicated by the steeper gradients of the particle size distribution curves in that region. The 0.3 – 1mm fraction usually is deemed to be deficient in crusher dusts, therefore requiring a blend with natural sand to comply with standards and perform adequately in concrete mixtures [1].

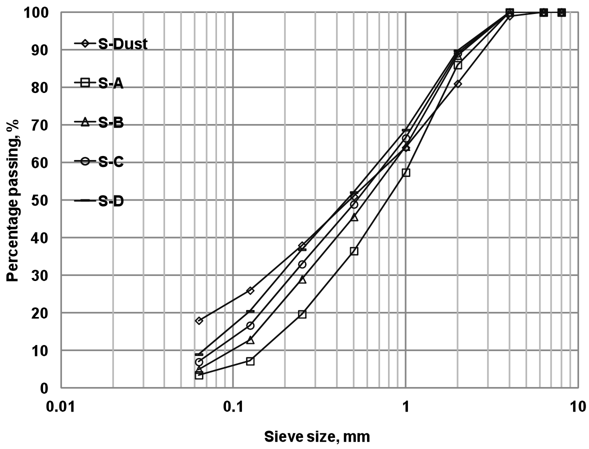

Figure 1 Sandstone sand particle size distributions

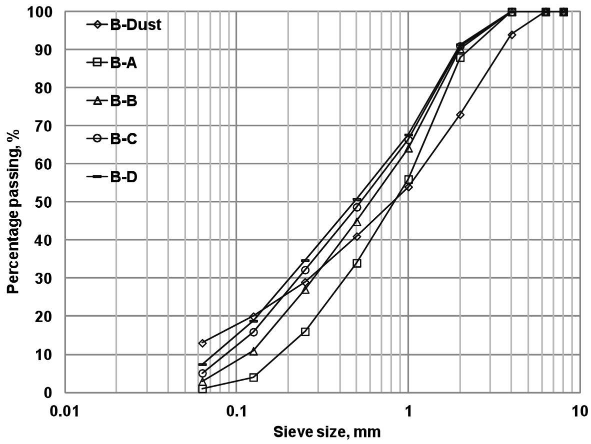

Figure 2 Basalt sand particle size distributions

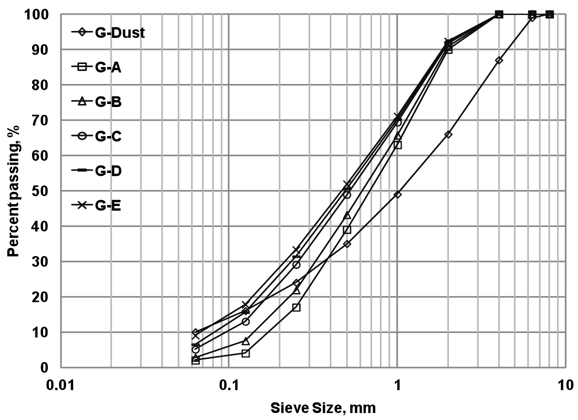

Figure 3 Granite sand particle size distributions

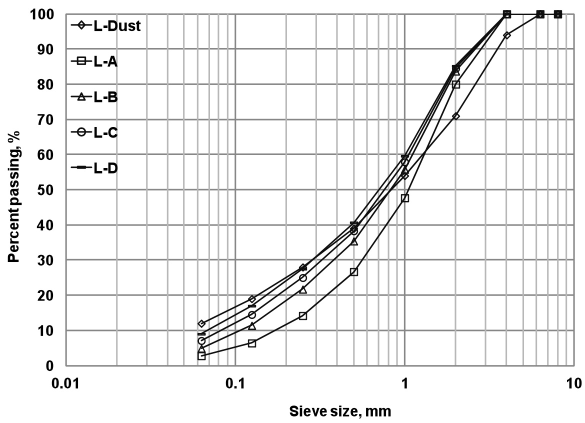

Figure 4 Limestone sand particle size distributions

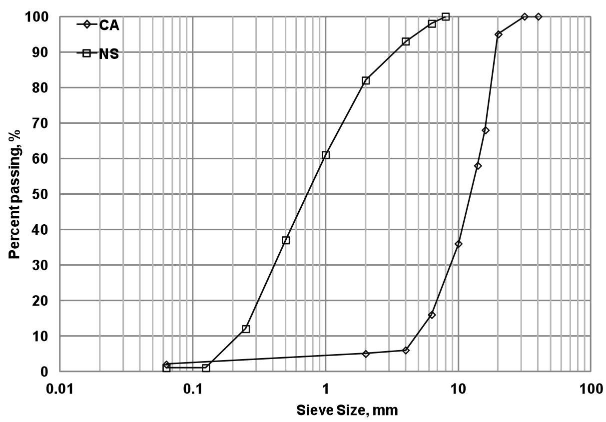

Figure 5 Natural sand and coarse aggregate particle size distributions

Table 3 shows the methylene blue value, sand equivalence and water absorption test results. Dredged natural sand has the lowest MBV and the highest SE value indicating a clean sand without deleterious particles. Such results were to be expected as natural sand from a dredged source typically has less than 1% fines as a result of additional fines being washed out in the screening process.

Table 3 Fine aggregate characterisation test results

Sample	MBV,g of MB solution per kg of 0/2mm sand	SE	WA_{24}, %
NS	0.24	94	1.04
G-Dust	0.77	50	0.58
G-A	0.39	80	0.58
G-B	0.40	74	
G-C	0.47	71	
G-D	0.50	70	
G-E	0.63	69	
B-Dust	5.36	48	1.92
B-A	2.10	73	1.67
B-B	2.29	61	
B-C	2.64	60	
B-D	2.90	58	
L-Dust	0.40	65	0.62
L-A	0.47	72	0.45
L-B	0.40	71	
L-C	0.40	71	
L-D	0.37	67	
S-Dust	3.19	27	1.53
S-A	1.40	31	0.98
S-B	1.48	30	
S-C	1.50	28	
S-D	1.63	27	

The low MBV values for granite and limestone sands indicate that the fines are mostly dust of fracture created during the processing. As such a good performance was expected and confirmed in the concrete trials discussed in the next section.

The high MBV (>1) and low SE (<70) for the sandstone and basalt sands indicate the potential presence of clays which increased the water demand of the concrete mixes as shown by the concrete trial results in Table 4.

It can be seen that all crusher dusts have higher MBV and lower SE values than manufactured sands indicating that the V7's grading and air screening process has removed some fines and possibly some of the detrimental clay particles that are known to contribute to deterioration of a concrete.

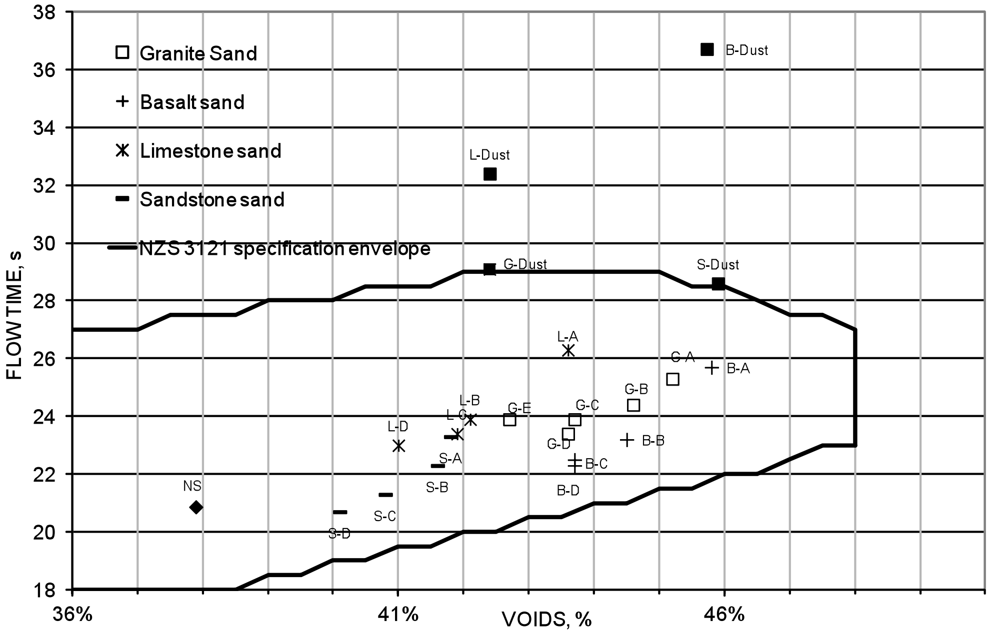

Figure 6 New Zealand flow cone plot of flow time against voids

The New Zealand flow cone test provides an indirect indication of particle shape, surface texture and grading [3]. Figure 6 shows that all sands manufactured using the V7 process fall within the prescribed specification envelope of the NZ standard whereas the crusher dusts lie just on the boundary or outside it. This suggests that the processing has optimized the grading and shape of manufactured sands and provides additional justification for their use as 100% natural sand replacement in concrete.

Concrete results

The quarry dust mixes for all of the sands required a higher w/c ratio to achieve an S2 slump than their manufactured sand counterparts. This provides clear evidence of the improved particle shape and grading of the manufactured sand as a result of the V7 process.

The basalt and sandstone sands required a higher w/c ratio (0.67) than the granite and limestone sands (0.58 and 0.55 respectively) to achieve an S2 slump. This was due to presence of clay particles in the sands as indicated by the MBV test discussed previously. Natural sand required the least water to cement ratio (0.48) to reach the S2 slump as a result of the intrinsic roundness of the sand particles and the lack of fines which, have been washed out in the dredging and screening process.

The results show a general trend of decreasing slump as the fines content increases as a result of an associated increase in the specific surface area of the sands. However, there are exceptions to this observation, in mixes S-C, L-C and B-B, in particular, where the slump values are higher than the expected trend. This might be attributed to optimum packing and the lubricating effect of the fines offsetting the negative effect of the increased specific surface area.

Table 4 Concrete mixture results

Mix	**w/c ratio**	**Slump, mm**	**Compressive strength, N/mm²**			**Flexural strength N/mm²**
			1 day	**7 day**	**28 day**	**28day**
NS	0.48	95	23.8	48.0	58.9	6.1
G-Dust	0.66	80	12.5	30.3	39.1	-
G-A	0.58	120	17.6	43.5	52.2	5.6
G-B	0.58	80	17.0	40.2	49.9	5.6
G-C	0.58	80	17.9	40.4	50.1	6.0
G-D	0.58	60	19.3	42.2	52.3	5.8
G-E	0.58	60	16.6	40.6	48.1	5.4
B-Dust	0.72	70	9.3	25.8	35.5	-
B-A	0.67	70	11.8	30.4	41.7	5.3
B-B	0.67	80	12.9	31.3	43.7	5.5
B-C	0.67	62.5	13.0	33.1	42.7	5.4
B-D	0.67	47.5	13.2	35.2	45.6	5.6
L-Dust	0.61	60	18.5	38.0	50.2	-
L-A	0.55	90	18.0	44.3	55.7	6.6
L-B	0.55	70	21.2	47.8	58.0	6.7
L-C	0.55	82.5	22.7	46.2	56.2	6.1
L-D	0.55	65	21.4	46.9	56.6	6.0
S-Dust	0.75	80	8.2	23.3	31.3	-
S-A	0.67	85	12.7	34.5	41.4	5.2
S-B	0.67	75	14.9	31.4	43.3	5.6
S-C	0.67	97.5	14.7	32.8	42.8	5.5
S-D	0.67	75	12.1	30.5	39.9	5.2

Despite the presence of clay and the w/c ratio of 0.67, the basalt and sandstone concretes produced workable concretes with 28 day compressive strengths in the range of 39.9 to 43.7 N/mm^2. Granite sand concretes at 28 days reached compressive strengths of 48.1 to 52.2 N/mm^2. Limestone sand concretes yielded compressive strengths from 55.7 to 58.0 N/mm^2, which is comparable to the dredged sand control mix with strength of 58.9 N/mm^2.These results indicate that the shape of the manufactured sand positively affects the compressive strength of concrete as the limestone sands reach approximately the same strength as natural sand but with 0.07 higher w/c ratio. This provides encouraging evidence that at the same w/c ratio and with the addition of water reducing admixtures that the compressive strength of a manufactured sand concrete mix could easily surpass that of a natural sand mix.

Conclusions

The sands produced with the V7 system had similar particle size distributions irrespective of the parent rock mineralogy. The shape and grading of the manufactured sands has been improved as demonstrated by the New Zealand flow cone results where all the manufactured sands fell within the prescribed standard envelope. The processing had reduced the amount of deleterious fines if they were present in the feed material as indicated by the methylene blue value and sand equivalence tests.

Workable concretes were produced from all manufactured sands, however higher water to cement ratios were required for the basalt and sandstone sands which contained clay to achieve the S2 slump. This in turn resulted in a reduction in the compressive strength. The limestone and granite sand concretes on the other hand yielded comparable compressive strengths to the natural sand control mix which had a lower water to cement ratio.

There was evidence that the incorporation of a water reducing admixture would allow manufactured sand concretes to surpass the compressive strength of the natural sand controls while maintaining adequate workability. Further work has since been performed to investigate this and the initial results from this study, which uses water reducing admixtures in manufactured sand concretes with fixed water to cement ratios, demonstrate that the manufactured sand compressive strength results for the four sands described in this paper exceed those of a natural sand mix at all testing ages. An overview of these results was presented at the Construction Materials Industry Conference (CMIC) [4] and the detailed results of this study will be published in 2013.

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References

1. HARRISON, D J, WILSON, D, HENNEY, P J, HUDSON, J M. *Crushed Rock Sand In South Wales, A Reconnaissance Survey*. British Geological Survey Technical Report No. WF/00/0. 2000.

2. LUSTY, A. *Sand industry leads revival of Japanese aggregates.* Quarry, 2008/10, pp 90-92.

3. CEMENT CONCRETE & AGGREGATES AUSTRALIA. *Manufactured Sand National test methods and specification values*. Research report, 2007, pp 17-18

4. LUSTY, A, PILEGIS, M. *Sand Manufacturing from Quarry Surplus*, IQA-CCAA Construction Materials Industry Conference, Melbourne, Australia, September 2012.