Influence of Fine Aggregate Types on the Performance Self Flowing Concrete

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Abstract: *Self-compacting concrete (SCC) was first developed to achieve durable concrete structures and help cast concrete into complex geometries without compromising the quality of the cast. This research is carried out to understand the influence of locally available fine aggregate types (river sand, quarry dust and offshore sand) on the properties of SCC concrete. As the fine aggregate proportion to coarse aggregate is considered important for the rheology, three different aggregate proportions from each of the fine aggregate type were investigated. In order to evaluate influence of aggregate proportions on the compressive strength, three w/c ratios was considered for each aggregate proportion, bringing the number of mixes for a fine aggregate type to nine and the total number of mixes in the investigation for the three different aggregate types to 27. As the particle size distributions of the different fine aggregate types are different to one another, a separate series with different aggregate types manipulated to confirm to a single particle size distribution was also carried out. This study was limited to single aggregate proportion and hence only nine additional mixes were resulted for the three aggregate types. The influence of fine aggregate type and proportion, on the harden properties of concrete is evaluated in terms of compressive strength and shrinkage of concrete. In addition, water requirement under constant doze of viscosity modifying agent is taken to evaluate the performance of mixes in fresh state. Results of the study indicated that quarry dust as fine aggregate has highest 28 days compressive strength for all the different water cement ratios. All fine aggregate types have recorded higher strength when the proportion of fine aggregate to total aggregate content is 60%. Offshore sand mixes recorded the lowest shrinkage and also lowest water content to achieve the conformity requirement of self-compacting concrete. Although quarry dust required less water compared to river sand, it had the highest shrinkage among the three aggregate types.*

Keywords: Self-compacting concrete (SCC), Concrete mix design, Offshore sand, River sand, Quarry dust.

1. BACKGROUND

Requirements to cast concrete into intricate shapes, complex geometries and sections of highly congested reinforcement arrangements are common demands in today's construction industry. Ensuring durability in complex casts is a major challenge for the engineers. Concrete mixes with self-compacting properties that allows concrete compact itself into complex geometries with minimum effort is one solution for such demanding conditions. In late 1980's and early 90's research lead by Prof. H. Okamura of the University of Tokyo pioneered in the development of such mixes of concrete with high fluidity which they coined as Self Compacting Concrete (SCC)(Okamura 2003, Oguchi M, et. al. 1996). SCC can be described as a high performance material which flows under its own weight by completely filling of formworks even when access is hindered by narrow gaps between reinforcement bars. SCC can also be used in situations where it is difficult or impossible to use mechanical compaction for fresh concrete, such as underwater concreting, cast in-situ pile foundations, machine bases and columns or walls with congested reinforcement. There are numerous applications of self- compacting concrete world over. Fig. 1, the anchorage block of the longest cable stays bridge, Akashi kaikyo, japan is one such well documented use of SCC. As mixing and casting for SCC has to be done in much control environment, which can be easily achieved in precast site, use of self-compacting concrete has become the preferred choice in the precast industry today (Brameshuber, W. et. al. (2002)). However, application of self-compacting concrete in Sri Lankan construction and precast industry are still very limited. The silting chamber of the Upper Kothmale Dam is one of limited examples of a recent application of SCC mixes in Sri Lanka. Due to lack of usage of SCC, influence of locally available aggregate types in making SCC and their influence on fresh and hardened properties of SCC has not been comprehensively studied and understood.

Figure 1 Anchorage block of Akashi Kaikyo bridge

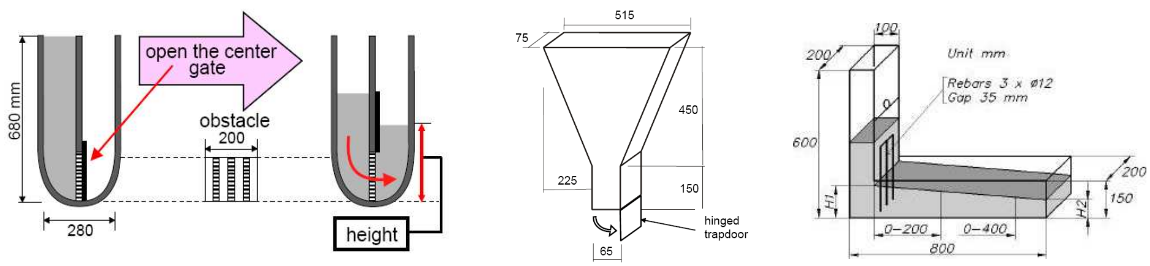
As self-compacting concrete essentially means flowing concrete, the usual devises that measure workability of normal concrete mixes like slump test, compaction factor test, and VB time test becomes unsuitable for SCC. Fig. 2 gives a glimpse of contrasting workability achieved by the normal and self-compacting concrete. To be able to measure and compare the performance of self-compacting concrete, researches have come up with different devices and measurements to explain the rheology of self-compacting concrete.

Normal concrete: Slump test	Self-compacting concrete Slump flow test	Self-Compacting concrete V Funnel test	Self-compacting concrete U-Box test

Figure 2 Measure of workability of the different concrete

U-Box test, funnel test and J-ring test are some of the other examples of test for determining the workability or fluidity of the self-compacting concrete. Each different test attempts to look into different aspects of the self-compacting concrete namely; filling capacity, passing ability and segregation resistance.

In the U box test difference in the height of concrete in the two legs of a standard U tube is taken as a measure of the workability of concrete. As it uses an obstacle in the form of equally spaced bars between the two legs, it essentially mimics the flow through congested reinforcement arrangement and measures the passing ability SCC (see Fig. 3a)). In the funnel test, time taken to empty the funnel is taken as a measurement for the workability of the concrete mix (see Fig. 3b)). Funnel test looked at the segregation resistance of the SCC mix. Similar to the U box test, L box test also employs an obstacle and measures the passing ability of SCC and uses the ratio of the concrete height in the horizontal leg as indication of the workability of the mix (see Fig. 3c)). Professional bodies like JSCE (JSCE 2005) have come forward to recognize such testing procedures and standardize the same so that they can be adopted universally to compare self-compacting concrete.



4 a) U box test   4 b)Funnel test   4 c)L box test

Figure 3 Workability measuring tests for self-compacting concrete

Table 2 standard specification

Method	Unit	Typical range of values	
		Min.	Max.
Slump Flow	mm	650	800
T_{50cm} slump flow	S	2	5
U-box (h_1-h_2)	mm	0	30
V-funnel	S	6	12
J-ring	mm	0	10

2. INTRODUCTION

Gneisses and Charnockite form crushed rocks is our main source of coarse aggregate and is available in abundance. River sand is the first choice fine aggregate type for structural concrete in Sri Lanka. However, due to scarcity and regulation in sand mining, quarry dust and offshore sand are now being increasingly used as an alternative to fine aggregate in concrete. River sand has long been considered as an unsustainable solution for the fine aggregate requirement of the country. Quarry dust which is a by-product of metal crushing amounts only between 20-30% of the total aggregate being crushed. Furthermore demand for lot of other uses like masonry block and paving block making, quarry dust doesn't provide a comprehensive solution for the fine aggregate requirement of the country. However, being an island nation with substantial offshore sand deposits, offshore sand has a great potential to cater the country's demand for fine aggregate. Fig. 5 shows the usual sources of fine aggregate (River sand) and coarse aggregate (Crushed stones) of concrete and alternative sources of fine aggregate types (Quarry dust and Offshore sand) for concrete.

Crushed stones (Coarse)   River sand (Fine)   Quarry dust   Offshore sand

Figure 4 Aggregate for concrete

The three fine aggregate types used for concrete in this study largely differ from one another in terms of the particle size distribution, shape, surface texture and moreover by its geological formation. These aggregate characteristics as well as its proportions used in concrete, have a significant impact on filling ability, segregation resistance, and passing ability of self-compacting concrete. To find the influence of these aggregate parameters on flow characteristics and hardened properties of concrete is the objective

of this research. In the experimental program usability of locally available fine aggregates (such as river sand, offshore sand, and quarry dust) in enhancing flowing characteristics are tested and compared with one another.
Fig. 6 shows the particle size distribution of the different fine aggregate types; river sand, offshore sand and quarry dust compared with upper and lower bounds of BS882 requirement of fine aggregate in concrete(British standard Institute 2002). Though it is clear that all the fine aggregate conform to the said requirement and falls between the upper and lower limits, they have different finesses to one another. Offshore sand being the finest of all the fine aggregate types came on top among the particle size distribution curves, followed by river sand. Quarry dust recorded the coarsest particle size distribution.

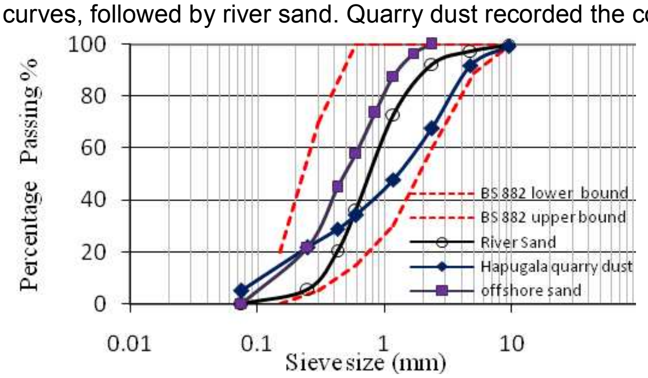


Figure 5 Particle size distribution of different fine aggregate types.

Other indicators of fineness like fineness fraction which is defined as 600 µm passing aggregate content as a percentage of the total fine aggregate content is found to be 60% for offshore sand while the value is only about 30% for the other two aggregate types. The British method of mix selection (Department of Environment (1975)), which employs the 600 µm passing measurement to find the fine aggregate proportion from the total aggregate content, suggest that higher the fineness fraction lesser the quantity of fine aggregate required to make good concrete.

3. SIGNIFICANCE OF THE STUDY

Influence of locally available fine aggregate types on the performance of self-compacting concrete has not been sufficiently studied. There is also a reluctance to use offshore sand and quarry dust as an alternative to river sand in concrete. High Cl- concentration of offshore sand seems not be the only reason not to use offshore sand for concrete. Users have no confidence in some of the important properties of concrete, like strength development and shrinkage characteristics, when alternative aggregate types are used.
Research on the influence of fine aggregate on the properties of normal concrete reveals that in term of strength both offshore sand and quarry dust perform better than river sand. It is considered that both aggregate packing and particle size distribution is the main explanation for the higher strength in the offshore sand mixes for normal concrete (Alluthwatta AGHAD et. al. 2011). Extending this study to self-compacted concrete is important as SCC uses more fine aggregate than normal concrete and therefore the influence of fine aggregate can be even more significant. From the results of normal concrete; offshore sand recorded the highest strength while quarry dust came second (Alluthwatta AGHAD et. al. 2011). However, in SCC the highest compressive strength was recorded in quarry dust mixes while offshore sand and river sand recorded almost similar compressive strengths lower than the quarry dust mixes. This is a strong suggestion that aggregate influence attributed to packing of aggregate has only secondary influences in SCC. In normal concrete quarry dust recorded the highest water demand for all workability ranges tested. However this was not to be case for SCC. In SCC river sand has recorded the highest water demand. However similar to normal concrete, quarry dust mixes recorded the highest shrinkage. Larger shrinkage under relatively lower water content suggests clear influence of quarry dust on shrinkage characteristics of concrete. Differences in the results in the normal concrete compared with SCC in many ways suggest that particle size distribution has only secondary influences on the properties of SCC. Almost similar results obtained between the mixes with natural particle distribution and particle size distribution manipulated to have identical particle size distribution provide further evidence for lesser influence of particle size distribution on the properties of SCC.

4. METHODOLOGY

Establishment of minimum fine aggregate proportion is the first step in the process of selecting aggregate proportions for the self-compacting concrete. To this end different fine aggregate proportions were tested under a constant doze of viscosity modifiers to find the minimum proportion of fine aggregate required to make SSC. U Box was used as the preferred mode to test the conformity of the self-compacting concrete. Once conformity is ensured by U box the mixes were checked for segregation resistance using the funnel test and filling capacity based on the slump flow test. With offshore sand as fine aggregate, it is found that 50% of offshore sand by total aggregate weight is the minimum fine aggregate percentage for making self-compacted concrete. This percentage is found to be 55% for river sand and 60% for the quarry dust. All these results were obtained for Glenium C320 doze of 1500 ml per 100kg of cement. With this initial results of minimum percentage of fine aggregate required under different aggregate types, common fine aggregate proportions to total aggregate proportions of 60%, 70% and 80% was considered to study the influence of fine aggregate type on the properties of self-compacting concrete. As self-compacting concrete requires only conformity to the workability requirement specified in the table 1, mixes with different workability ceases to become a variable for studying the SCC. This makes aggregate type, fine aggregate proportion to total aggregate, and the w/c ratio the only variables for the study. Fig.6 show the different mixes studied for determining the influence of fine aggregate types on the properties of SCC. To make mixes with different aggregate and mixes of same aggregate with different w/c ratio comparable to each other same doze of viscosity modifier, 1500 ml for 100kg of cement is used for all mixes. In order to achieve the desirable workability under the constant doze of viscosity modifier water content was adjusted. The results of different water quantities required to achieve the required fluidity are then used as an indicator for the performance of different aggregate types.

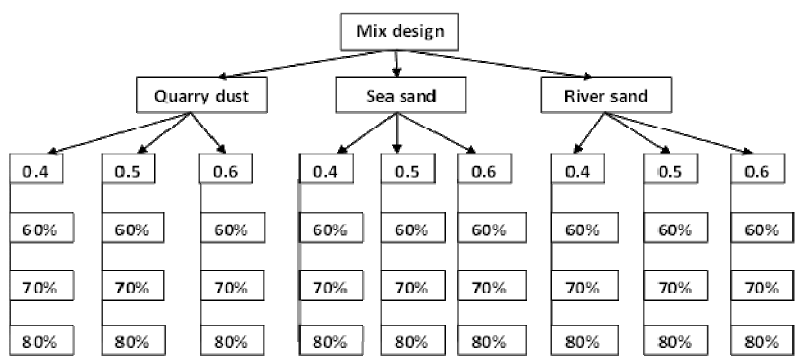


Figure 6 Different mixes considered in the study.

In addition to the main study to find the aggregate influence on the properties of concrete, a separate study to understand what might have caused it, or to understand the influence of particle size distribution on the properties of concrete, a separate mixer series with particle size distribution of the different fine aggregate manipulated to bring to a single size is also carried out. Single particle size distribution is achieved by first sieving the aggregate into different aggregate sizes and then remixing it to a predetermined aggregate distribution. In this study particle size distribution of quarry dust and river sand is manipulated to bring them to the same particles size distribution of offshore sand. Given the large quantities of fine aggregate types to be sieved in order to make them into a single particle size distribution, only 70% fine aggregate proportions to total aggregate content was considered in this series. The main comparison of the aggregate influence is done based on the compressive strength and water demand to make self compacting mixes under constant doze of viscosity modifier agent. In addition aggregate influence on shrinkage characteristics of concrete is also measured.

5. RESULTS AND DISCUSSION

5.1. Water demand of the mix

Table 2 show the different water content for all the different aggregate types. In this experimental investigation of SCC under constant dosage of viscosity modifying agent, river sand mixes recorded the highest water demand to achieve the required fluidity while offshore sand recorded the lowest. Water demand can be influenced by many factors. Fineness is one factor. Higher the fines essentially mean more surface area to volume and therefore require more water to wet the additional surface area. Texture or the roughness of the aggregate surfaces is another factor that influences the water demand. Rough surface textures provide more surface area to hold water around the aggregate and requires addition water to overcome the surface friction created by the roughness of the aggregate.

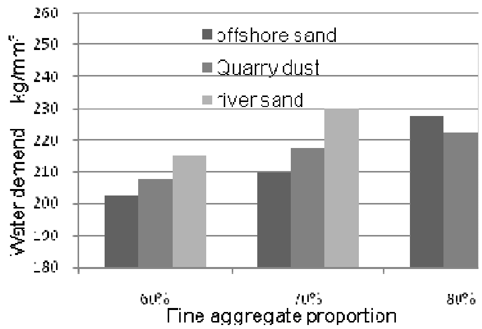


Figure 7 The increase in water demand with the increase in aggregate proportions (w/c =0.7)

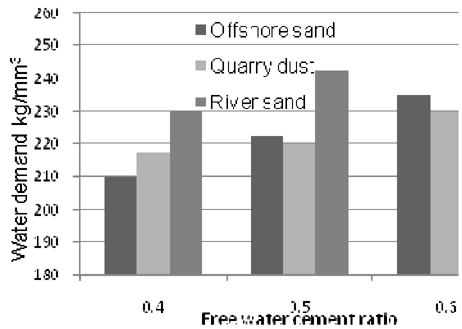


Figure 8 The increasing water demand with the increasing w/c ratio for 80% fine proportion.

Table 2. Results of the concrete mixes series

Mix name	W/C	Water demand kg/m^3	28 days kN/mm^2	increment % compared to River sand
OS/0.4/60%	0.4	202.5	74.63	7.25%
OS/0.4/70%	0.4	210	68.89	2.57%
OS/0.4/80%	0.4	227.5	66.88	3.69%
OS/0.5/60%	0.5	210	56.83	-7.18%
OS/0.5/70%	0.5	222.5	52.10	-7.51%
OS/0.5/80%	0.5	230	50.20	-3.50%
OS/0.6/60%	0.6	215	46.99	4.95%
OS/0.6/70%	0.6	235	43.67	2.63%
OS/0.6/80%	0.6	250	41.65	11.66%
RS/0.4/60%	0.4	215	69.58	0.00%
RS/0.4/70%	0.4	230	67.16	0.00%
RS/0.4/80%	0.4	250	64.50	0.00%
RS/0.5/60%	0.5	225	61.23	0.00%
RS/0.5/70%	0.5	242.5	56.32	0.00%
RS/0.5/80%	0.5	252.5	52.02	0.00%
RS/0.6/60%	0.6	235	44.77	0.00%
RS/0.6/70%	0.6	245	42.55	0.00%
RS/0.6/80%	0.6	255	37.30	0.00%
QD/0.4/60%	0.4	207.5	83.33	19.76%
QD/0.4/70%	0.4	217.5	79.94	19.01%
QD/0.4/80%	0.4	222.5	75.31	16.75%
QD/0.5/60%	0.5	215	65.50	6.97%
QD/0.5/70%	0.5	220	60.30	7.06%
QD/0.5/80%	0.5	227.5	56.07	7.78%
QD/0.6/60%	0.6	222.5	46.98	4.93%
QD/0.6/70%	0.6	230	42.57	0.05%
QD/0.6/80%	0.6	242.5	37.21	-2.40%

Fig. 7 shows the increase in water demand for the different fine aggregate types with the increase in aggregate proportions recorded at 0.6 w/c ratio. This trend is found to be true for all the w/c ratio tested. Fig. 7 also shows that the river sand requires higher water content for all the aggregate proportions. Fig. 8 shows the water demands for different w/c ratios recorded for 60%fine aggregate proportion to total aggregate content. With the increase in w/c ratio cement content and therefore the admixture dosage in the mix is expected to be dropped. As earlier mentioned, fluidity in SCC is effected by both water content & admixture dosage. Therefore this higher water demand for the higher w/c ratio is attributable to regain the effect of admixture dosage.

5.2 Compressive strength of concrete

Compressive strength of aggregate is one of the most important properties of concrete and accordingly more attention was given to determine the aggregate influence on the compressive strength of concrete. Along with the water demand Table 2 provides 28 days compressive strength of all the mixes conducted in this experimental investigation. For all SCC mixes cast at different aggregate proportions and water cement ratio, quarry dust mixes have recorded the highest strength. Offshore sand has come next while river sand has recorded the lowest 28 day compressive strength. Fig. 9 shows the strength vs. w/c ratio for quarry dust conducted for different fine aggregate proportions 60%, 70% and 80%. Results clearly indicate that lower fine aggregate proportion (60% of fine aggregate content to total aggregate content) have resulted higher strength. It is also found that same relationship is true for the other aggregate type. Fig. 10 shows the strength vs. w/c ratio of the mixes with 70% fine aggregate proportion, with natural particles size distribution and particles size distribution manipulated to match offshore sand distribution. Similar results obtained by the two particles size distribution of the single aggregate type indicate that particles size distribution has only secondary influence on strength of SCC.

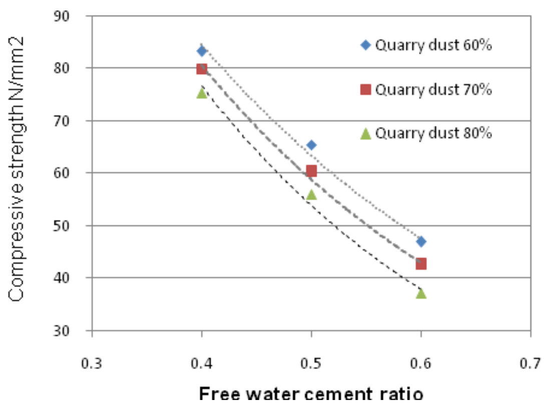


Figure 9 Strength vs. water cement ratio for different proportions of quarry dust

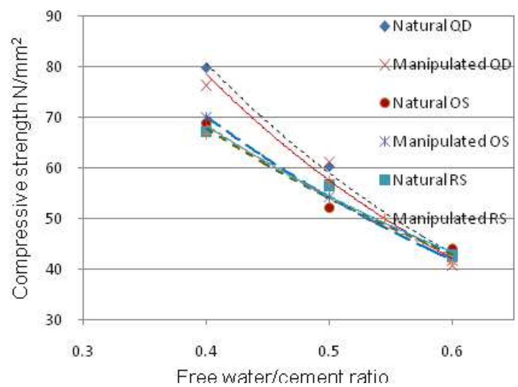


Figure 10 Strength vs. water cement ratio for different particle size distributions

Fig. 11 shows the average strength vs. water cement ratio for the different aggregate types, collated and averaged disregarding the proportion of fine aggregate to total aggregate content. From the average results of strength vs. water cement ratio for different aggregate type it is clear that quarry dust record higher strength compared to other aggregate types. Quarry dust recording higher strength than all other aggregate types is further confirmation of the less sensitivity of particle size distribution and packing on the properties of SCC. Fig. 12 shows strength vs. w/c ratio for the three aggregate types for normal concrete and self-compacting concrete (Alluthwatta AGHD et. al (2011)). Results indicate that SCC has always produced higher strength than normal concrete.

It is also seen that, unlike in the case of normal concrete where offshore sand produced higher strength, in SCC, quarry dust has produced the highest strength. It is also seen the margins of differences of the recorded strength between different aggregate types have narrowed down considerably for the SCC. For normal concrete, it is evident from the higher water demand that mixes with quarry dust as fine aggregate is most difficult to workwith (Rajapaksha RWCN et.al (2009). However, there is marked contrast of its performance as fine aggregate of SCC. Lower water demand for quarry dust compared with river sand mixes and the highest recorded compressive strength for quarry dust mixes are indications that viscosity modified self-compacting concrete have largely eliminated the influence of fine aggregate due to particle size distribution and aggregate packing.

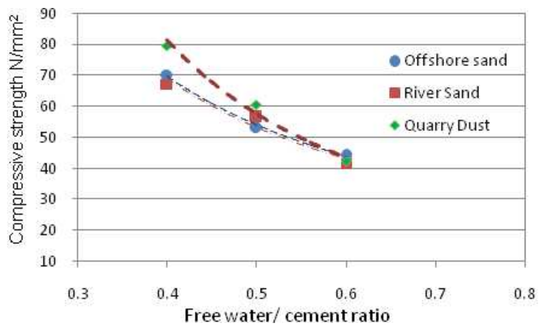


Figure 11 Average strength vs. w/c ratio for Self-compacting concrete.

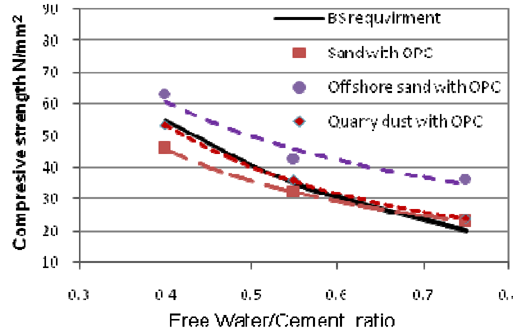


Figure 12 Ave. strength vs. w/c ratio for normal concrete (Alluthwatta AGHD et. al 2011)

6. CONCLUSIONS

Overall results of the experimental study indicate that both offshore sand and quarry dust is a viable alternative for river sand as fine aggregate of self-compacting concrete. Based on strength quarry dust is found to be the better fine aggregate type for self-compacting concrete. Reason for higher strength in quarry dust can be attributed to the possible better bond between the aggregate and cement paste. SCC mixes has recorded different trend for the water required under the constant doze of viscosity modifying agent and compressive strength compare to normal concrete mixes. Study with particle size distribution of the different aggregate manipulated to a single particle size distribution reveals no significant change in strength between the mixes with natural particle distribution and single particle distribution. This means that the particle size distribution has only secondary influences on the SCC.

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