ENGINEER - Vol. XLIX, No. 01, pp. [9-20], 2016

Influence of Fine Aggregate Types on the Performance of Self - Compacting Concrete

H.P. Sooriyaarachchi and E.D.L. Lasintha

Abstract: Self Compacting Concrete (SCC) was first developed to achieve durable concrete structures and help cast concrete into complex geometries without compromising the quality. Due to self-leveling properties, SCC is found suitable for structures with congested reinforcement and structures that are difficult for mechanical vibration. This research was carried out to understand the making of SCC using locally available fine aggregate types (river sand, quarry dust and offshore sand) and the influence of the different aggregate type on the properties of SCC. It was found that the minimum requirements of fine aggregate expressed as a percentage of the total aggregate content of the mix, were 50%, 55% and 60% for offshore sand, river sand and quarry dust respectively. Based on the above results, 60%, 70% and 80% of fine aggregate from total aggregate content was considered as common fine aggregate percentages to study the influence of fine aggregate types on the properties of SCC. As the particle size distributions of different fine aggregate types are different from one another, a separate series with aggregate sizes manipulated to confirm to a single common particle size distribution was also carried out. The influence of fine aggregate type and proportion, on the hardened properties of concrete is evaluated in terms of compressive strength and shrinkage of concrete whilst water requirement under constant dose of superplacizer is taken to evaluate the performance of the mixes in fresh state. Results of the study indicated that quarry dust as fine aggregate has the highest 28 days compressive strength for all the different water cement ratios considered in the study. All fine aggregate types have recorded higher strength when the proportion of fine aggregate to total aggregate content is 60% of the total aggregate content. Offshore sand mixes recorded the lowest water content required for making SCC whilst river sand recorded the highest. Except for changes in the water demand, SCC mixes of different fine aggregate types manipulated to common particle size distribution showed no significant variation in the strength development to that of their natural particle size distribution mixes.

Keywords: Self-compacting concrete (SCC), Compressive strength, Shrinkage, Water demand, Fine aggregate types.

1. Background

Requirements to cast concrete into intricate shapes, complex geometries and sections of highly congested reinforcement arrangements are today's common demands. Ensuring durability in complex casts is a major challenge for engineers. Use of self-compacting concrete is one solution. 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 which they termed as 'Self-Compacting Concrete'(SCC)[1][2]. SCC can be described as a high performance concrete, which flows under its own weight to fill the formworks. SCC can also be used in situations where it is difficult or impossible to use mechanical compaction of concrete, such as underwater concreting, cast in-situ pile foundations, machine bases and in columns or walls with congested reinforcement. There are numerous applications of self- compacting concrete world over. Anchorage block of the longest cable stays bridge; Akashi Kaikyo in Japan shown in Fig. 1 is one of the well documented uses of SCC. As mixing and casting for SCC has to be done in controlled environment, self-compacting concrete has become preferred choice in the precast industry in many countries [3]. However, applications of self-compacting concrete in Sri Lankan construction or precast industry are still limited. The silting chamber of the Upper Kothmale Dam is one of the limited examples of recent application of SCC mixes in Sri Lanka. Due to lack of usage of SCC, influence of locally available fine aggregate types in making SCC and their influence on fresh and hardened properties has not been comprehensively studied or understood.

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Figure 1 - Anchorage block of Akashi Kaikyo bridge.

In order to develop SCC, a delicate balance of fine aggregate to coarse aggregate is essential. Figure 2a shows the mechanism of the flow of coarse aggregate in concrete and the role of mortar in lubricating coarse aggregate[4][5]. The coarse aggregate approaching each other squashes the mortar in between. The coarse aggregate is held suspended in the mortar mix by the shear forces developed in the mortar. The consolidation of aggregate depends on the viscosity of the mortar mix and the proportion of coarse aggregate volume to mortar volume. Excessive coarse aggregate can result in segregation of aggregate or block the flow due to the formation of aggregate arch(see Figure 2b.), making it impossible for such mixes to achieve required flow characteristics of self-compacting concrete namely; passing ability, filling ability and segregation resistance . To this end, in addition to the use of superplactizer in concrete, use of higher proportion of fine aggregate than the normal becomes an essential requirement for SCC [1].

Figure 3 gives a glimpse of contrasting workability achieved by the normal and self-compacting concrete under similar testing procedure, slump test and slump flow test. As self-compacting concrete achieve extra fluidity that cannot be measured by usual devices, measuring workability of normal concrete mixes, researches have come up with different devices and measurements to explain the desired flow characteristics of self-compacting concrete [6].

Slump flow test or better known as T $_{50cm}$ measure, shown in Figure 3 which uses the same slump cone for the measurement of slump in normal concrete mixes is one such method to indicate the fluidity of SCC. In this test, time taken to empty an inverted slump cone (See Figure 3.(a)) and make a 500mm diameter film of concrete (See Fig. 3.(b)) known as t_{50} at the spread of 500mm, is considered as an indicator for fluidity of SCC.

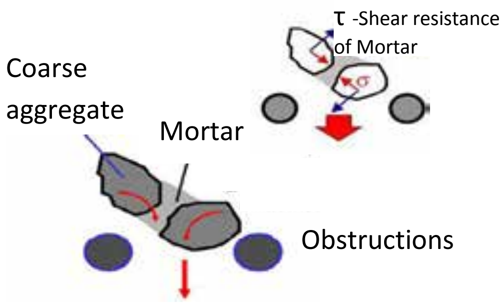


Figure 2(a) - Forces acting on the coarse aggregate

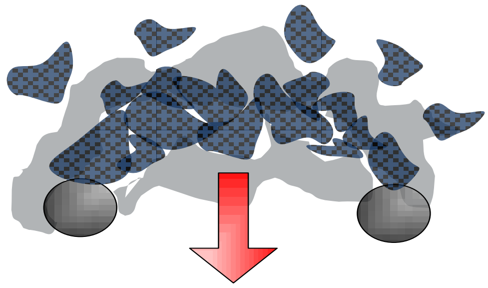


Figure 2(b) - Aggregate arch blocking the passing ability in SCC

a) Slump test for Normal concrete:	**b) Slump flow test for SCC**

Figure 3 - Measure of flow ability (filling ability) of the SCC mixes.

U-Box test, V-Funnel test and J-ring test are some of the other examples of tests devised to determine the fluidity of the self-compacting concrete. Each different test attempts to look at different workability 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 passing ability. U tube uses an obstacle in the form of equally spaced bars between the two legs, to simulate flow through congested reinforcement arrangement to give an indication of the passing ability of SCC (see Figure 4a)). Figure 4b shows the V-Funnel test which measures segregate resistance of the SCC. In the V-Funnel test, time taken to empty the funnel after being kept filled for 5 minutes (T $_{5\ minutes}$) is taken as a measurement for the segregation resistance of

SCC. L box test as seen in Figure 4(c) also employs an obstacle between its vertical and horizontal legs and measures the passing ability of SCC to fill horizontal leg as an indicator of the filling capacity of SCC.

Professional bodies like JSCE, ACI and RILEM[7],[8],[9] have come forward to recognize such testing procedures and standardize the same so that they can be adopted universally to compare the performance of self-compacting concrete. Figure 4 also shows the standard dimensions recommended by JSCE [7]. Table 1 shows standard specifications required under each of the tests to consider a concrete mix as a self-compacting concrete mix.

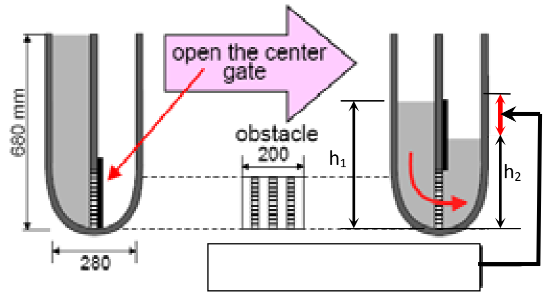


Figure 4(a) - U box test: Difference in the two legs is taken as a measure of the flow ability (passing ability) of the concrete mix

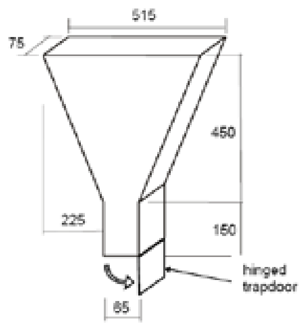


Figure 4(b) - V-Funnel test: Time taken to empty the funnel is taken as measure of flow ability (Segregation resistance) of the mix

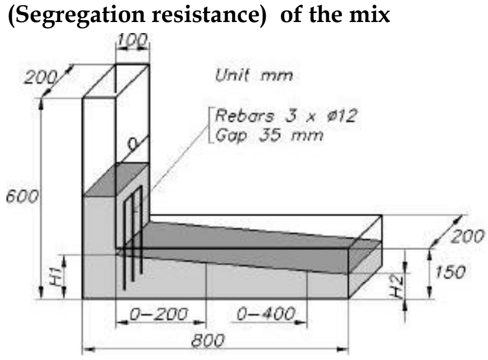


Figure 4(c) - L box test:Ratio or dif ference in the hight of the horizontal leg of the mould measurse the passing ability of SCC.

Table 1 - Typical ranges of workability for SCC

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 ($T_{5\ minutes}$)	S	6	12
J-ring	mm	0	10

2. Introduction

Gneisses and Charnockite form crushed rocks is our main source of coarse aggregate for concrete. River sand is the first choice fine aggregate type for structural concrete in Sri Lanka. However, due to the scarcity and regulations for sand mining, quarry dust and offshore sand are now being increasingly used as an alternative to fine aggregates in concrete. River sand has long been considered as an unsustainable solution for the fine aggregate requirement of the country [10][11]. Quarry dust which is a by-product of metal crushing amounts only between 20-30% of the total aggregate being crushed. With demand for lot of other uses like masonry block and paving block making, quarry dust does not seem to be providing 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 for the country's demand for fine aggregate. Figure 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) used in concrete.

Figure 6 shows the particle size distribution of different fine aggregate types; river sand, offshore sand and quarry dust compared with upper and lower bounds of BS882, requirement for particle size distribution of fine aggregate in concrete[12][13]. 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 fineness form one another. Offshore sand being the finest of all the fine aggregate types came on top of the particle size distribution curves followed by river sand (see Figure 6).

Usual coarse aggregate (Crushed stones) and fine aggregate (River sand) for concrete

Offshore sand and Quarry dust

Figure 5 - Local aggregate types

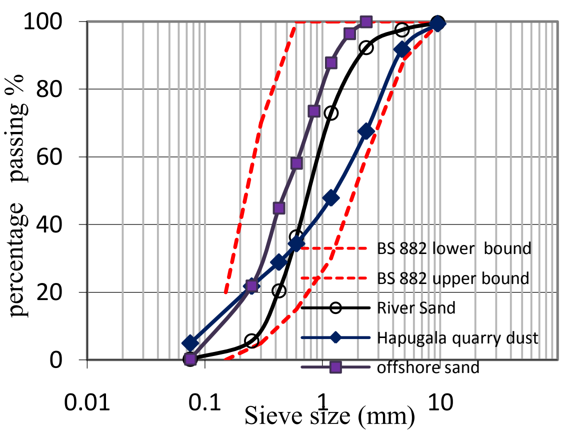


Figure 6 - Particle size distribution of different fine aggregate types compared with the upper and lower bounds of the BS882 requirement for concrete.

Quarry dust, though is in possession of higher fineness content (more than 5% passing 75 μm sieve as compared to only 0.2% passing 75 μm in the other two fine aggregate types) it has recorded equally higher percentage of coarse contents making it coarsest aggregate among the three fine aggregate types. Fines content in the fine aggregate is often employed to find the fine aggregate content required to fill the voids left by coarse aggregate in the concrete mix design. In the United Kingdom, Department of the Environment's recommendation on the method of mix selection, uses 600 μm passing fine aggregate content as a percentage of the total fine aggregate content as an indicator to determine the proportion of fine aggregate requirement for concrete mix [14].

There are several means by which fine aggregate is expected to influence the properties of concrete. Smooth spherical shape and higher fine content, like in the case of offshore sand, facilitate easy filling of the void created by coarse aggregate. The smooth round surfaces are easy to work with and require less water to lubricate. However, smooth aggregate surfaces tend to produce weak bond between aggregate and cement paste and less resistance to crack propagation. On the other hand rough surface textures and angular shape of aggregate makes the mortar made with such aggregate difficult to work with. It is clear that crushed surface texture like in the case of quarry dust can hold lot of water around its surface, and requires lot of water to overcome friction between the particles compared with particles having smooth surfaces. It is also found that angular nature of aggregate creates lot of voids, thus requiring more and more cement paste. However, rough surface texture provides better interlocking and good bond between the cement paste and aggregate. It is therefore possible that reduction of strength due to loose packing can be compensated by the better bond between the aggregate and cement paste.

There are hardly any research investigating influence of locally available fine aggregate types on properties of SCC. Research on the influence of locally available fine aggregate type on the properties of normal concrete reveals that the offshore sand as fine aggregate produces higher strength compared to other fine aggregate types. Quarry dust mixes have recorded lower strengths than offshore sand mixes but have recorded 10% higher strength compared to river sand mixes. The water demand to achieve a designated slump was found maximum in quarry dust concrete while it was found minimum for offshore sand mixes [10][11] .

Higher compressive strength of offshore sand mixes for given w/c ratio tends to suggest that, aggregate packing due to smooth surface texture and particle size distribution has over powered the possible weaker bond due to smooth aggregate surfaces [11]. Despite higher use of water content and coarse gradation of particles size distribution quarry, dust mixes have recorded higher strength over river sand. It is considered that the better bond between crushed surface textures of the quarry dust and cement paste of the mix has contributed to higher strength development in quarry dust over river sand mixes in normal concrete [10][11].Results shown in the above research show strong and significant influence of fine aggregate type on the fresh and hardened properties of normal concrete. Going by the results of normal concrete and the fact that more fine aggregate proportion are required for self-compacting concrete than normal concrete [1], one can argue that there is possibly a greater influence of fine aggregate type on the properties of self-compacting concrete. On the other hand it can also be argued that the influence of fine aggregate types will not be significant in SCC, specially, in relation to the aggregate packing, due to superplacizer induced flow. In this context it is considered extremely important to study the influence of fine aggregate type on the properties of self-compacting concrete. In the experimental program, use of locally available fine aggregate types and proportions are evaluated to find the influence of fine aggregate types on the properties of self-compacting concrete.

3. Scope & Objectives of the Research

Development of a workable self-compacted concrete mixes using different locally available fine aggregate types and to evaluate the influence of the different fine aggregate types on the fresh and hardened properties of self-compacted concrete are the main objectives of this research. In much broader sense it will also attempt to provide guidelines for the use of locally available aggregate in making self-compacting concrete.

As a minimum percentage of fine aggregate is required to achieve the required flow characteristics of SCC, finding this minimum percentage of fine aggregate to total aggregate ratio required for each of the three locally available fine aggregate types is the first step towards establishing platform to study the influence of different fine aggregate types on the properties of SCC. Three common fine aggregate proportions under three w/c ratios were considered for studying the aggregate influence. To determine the influence of particle size distribution on the properties of SCC, a separate series with particles size distribution of different aggregates manipulated and brought to a common particle size distribution (particle size distribution of offshore sand) was also investigated. Influence of fine aggregate on the properties of self-compacted concrete is mainly evaluated by the 28 day compressive strength.

To make performance of different aggregate comparable with each other, constant superplasticizer dose, 1500ml of Glenium 320 for each 100 kg of cement was used [15]. Beside the compressive strength, aggregate influence on shrinkage characteristics of SCC is the other factor that has been looked at. As the water required for achieving the desired self-compacting performance is often directly related to the subsequent strength development, shrinkage characteristics of hardened concrete and the cost of making concrete, water demand for fine aggregate types to deliver the self-compacting performance were analyzed.

4. Significance of the Study

Influence of locally available fine aggregate types on the performance of self-compacting concrete has not been studied earlier. Having investigated and reported the significant influence of fine aggregate type on the performance of normal concrete, finding the influence of fine aggregate types on SCC is considered the natural extension of the previous work[10][11]. The experimental investigation cleared many doubts of the use and performance of alternative aggregate types as fine aggregate in SCC, thus it is significant achievement of the research. The research has established the minimum fine aggregate proportions required by the different fine aggregate types to achieve flow characteristics of SCC. It is found that properties of self-compacting concrete have lesser influence from fine aggregate types used and their particle size distribution.

5. Methodology

Establishment of minimum fine aggregate proportion required for different fine aggregate types to conform to the required rheological properties of SCC was the first step in the process of selecting aggregate proportions. U Box was used as an initial investigation tool to establish the required minimum percentage of different types of fine aggregates to make SCC. Once conformity was ensured by U box, the mixes were checked for segregation resistance using the V-Funnel test ($T_{5\ minutes}$ Test)and filling capacity based on the slump flow test (t_{50cm}). Thus, the minimum fine aggregate proportion required for offshore sand was found to be 50% of total aggregate weight. This percentage was found to be 55% for river sand and 60% for quarry dust. Based on these results, fine aggregate contents of 60%, 70% and 80% of total aggregate content was considered as common proportion for all aggregate types to investigate the influence of fine aggregate type on the properties of self-compacting concrete. As one of the major parameter of study was compressive strength of concrete, testing of self-compacting concrete was conducted for 3 water/cement ratios. Figure 7 shows the different mixes studied for finding the influence of fine aggregate types on the properties of SCC. To ensure that mixes with different aggregate and mixes of same aggregate with different w/c ratios are comparable to each other and test results reflect the influence of aggregate type, same dose of superplasticizer, (1500 ml for 100kg of cement)was used in all the mixes.

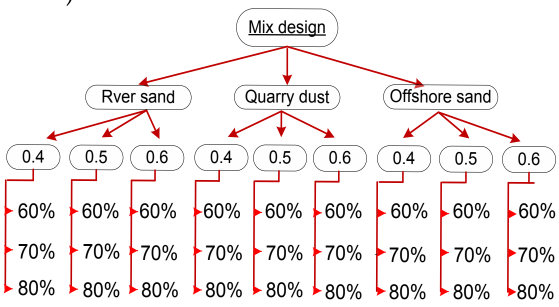


Figure 7 - Different mixes considered in the study.

All concrete mixes cast were kept under the same condition to make sure that the correct assessment of aggregate influence on the properties of concrete is done. In order to ensure the correct measurement of free water and therefore the correct free water/cement ratio in the mix, moisture absorption for saturated surface dry conditions were conducted for all the aggregate types. Table 2 shows moisture absorption for SSD conditions and the specific gravity of aggregates used in the study [16][17]. As it is the water above the SSD condition that contributes to the cement hydration, natural moisture contents of the aggregates were also determined. All aggregate were kept spread in the laboratory for at least two days before using in the mix for aggregate to reach equilibrium of moisture movement with the surrounding environment. At the same time samples were drawn from the stockpile for the determination of natural moisture content, enough aggregate quantities for mixing were drawn and kept in a sealed container to ensure that the material used for determining natural moisture content is in the same state of the material used for making concrete.

Table 2 - Properties of aggregates

Aggregate type	Moisture absorption for SSD conditions	Specific gravity of aggregates	% of Particles less than75μm
River Sand	1.41 %	2.68	0.20%
Sea Sand	0.45 %	2.64	0.21%
Quarry dust	0.43 %	2.65	4.99%
Coarse aggregate	0.34 %	2.74	-

The main comparison of the aggregate influence is done based on the compressive strength and shrinkage characteristics [20][21]. Compressive strength was determined by the cube test [18][19], while standard prisms with contact points attached to the specimen were used for shrinkage measurements.

In addition to the main study to find the aggregate influence on the properties of concrete, a separate study was conducted to find the influence of particle size distribution as well. This was done using a separate concrete mix series with particle size distribution of the different fine aggregate types manipulated and brought to single particle size distribution. Single particle size distribution is achieved by first sieving the aggregate into different aggregate sizes and then remixing to a predetermined particle size distribution. In this investigation, particle size distributions of river sand and quarry dust were brought to the natural particle size distribution of offshore sand. Aggregate size manipulated SCC mixes were limited to fine aggregate proportion of 70% of total aggregate content. Table 3 shows details of the mixes involved in this study to find the influence of fine aggregate types on the properties of SCC. Table 4 shows the details of the mixes done to establish whether it is the fine aggregate type or the particle size distribution that influences the properties of SCC.

As seen in Tables 3 and 4, each mix considered in the experimental investigation was given a unique identification code describing the main variables of the mix. In the notation, first two letters indicate the fine aggregate type (OS- Offshore sand, RS- River sand, QD-Quarry dust.). The next number indicates the actual W/C ratio used in the experimental investigation and include values;(0.4, 0.5 and

0.6). Fine aggregate proportion as a percentage of total aggregate content is indicated next and this includes percentages 60%, 70% or 80% describing the typical proportions considered in the experimental investigation. Last letter indicates whether the fine aggregates of the mix is having natural particle size distribution, denoted by "N" or manipulated particle size distribution, denoted "M".

In the mix selection, recorded water contents of mixes are arrived when the mixes achieved the conformity requirement of SCC conditions in terms of all workability parameters namely, filling capacity, segregation resistance and passing ability. All mix proportions were decided based on iterative procedure described in accordance with BS method of mix selection [14]. In each trial mix proportion, water content of the mix is successively modified until the required self-leveling properties of the mix are achieved. Under each successive time, the water content was changed, rest of the constitutive materials were recalculated keeping the w/c ratio and fine aggregate to total aggregate content constant. Picking the correct water content required for making self-compacting concrete under given constraints, that is constant dose of superplacizer, fixed w/c ratio and the constant percentage of fine aggregate to coarse aggregate, is quite a delicate task. It is found that under these constraints there exists only a narrow band-width of water contents that will satisfy the required flow characteristics to qualify mixes to be classified as SCC. Higher water contents resulted in segregation of aggregates from the cement paste, making it difficult to comply with one or more of the requirements for SCC (i.e. passing ability, segregation resistance, and filling ability). Recorded water content in the Table 3 and 4 are the water content required for any given mix designation to reach the required flow characteristics at the first instance that the mix satisfies all different flow characteristics of SCC.

Table 3 - Mixes of Natural particle distribution

Mix Code	W/C Ratio	Water Demand kg/m^3	28-day Strength (N/mm^2)
OS/0.4/60%/N	0.4	202.5	74.63
OS/0.4/70%/N	0.4	210	68.89
OS/0.4/80%/N	0.4	227.5	66.88
OS/0.5/60%/N	0.5	210	56.83
OS/0.5/70%/N	0.5	222.5	52.10
OS/0.5/80%/N	0.5	230	50.20
OS/0.6/60%/N	0.6	215	46.99
OS/0.6/70%/N	0.6	235	43.67
OS/0.6/80%/N	0.6	250	41.65
RS/0.4/60%/N	0.4	215	69.58
RS/0.4/70%/N	0.4	230	67.16
RS/0.4/80%/N	0.4	250	64.50
RS/0.5/60%/N	0.5	225	61.23
RS/0.5/70%/N	0.5	242.5	56.32
RS/0.5/80%/N	0.5	252.5	52.02
RS/0.6/60%/N	0.6	235	44.77
RS/0.6/70%/N	0.6	245	42.55
RS/0.6/80%/N	0.6	255	37.30
QD/0.4/60%/N	0.4	207.5	83.33
QD/0.4/70%/N	0.4	217.5	79.94
QD/0.4/80%/N	0.4	222.5	75.31
QD/0.5/60%/N	0.5	215	65.50
QD/0.5/70%/N	0.5	220	60.30
QD/0.5/80%/N	0.5	227.5	56.07
QD/0.6/60%/N	0.6	222.5	46.98
QD/0.6/70%/N	0.6	230	42.57

Table 4 -Mixes with manipulated particle size distribution

Mix Code	W/C Ratio	Water Demand kg/m^3	28- day Strength (N/mm^2)
QD/0.6/80%/M	0.6	242.5	37.21
OS/0.4/70%/M	0.4	212.5	70.15
OS/0.5/70%/M	0.5	222.5	54.30
OS/0.6/70%/M	0.6	230	41.68
RS/0.4/70%/M	0.4	237.5	66.59
RS/0.5/70%/M	0.5	255	57.36
RS/0.6/70%/M	0.6	260	41.28
QD/0.4/70%/M	0.4	232.5	76.19
QD/0.5/70%/M	0.5	242.5	61.32
QD/0.6/70%/M	0.6	257.5	40.69

6. Results and Discussion

6.1. Water Demand of the Mix

Water in concrete has two important functions. Facilitating the cement hydration process is one of the main functions. Providing required workability is the other. Water, acting as a lubricant to ease off the friction between the particles can help particle consolidation. The excess water can reduce the stiffness of the paste resulting segregation of aggregate. Segregated or close to segregated concrete can never satisfy the passing ability, filling ability and segregation resistance required to classify the mix as self-compacting concrete. As the coarse aggregate type, cement type, and the super plasticizer agent used in the mixes were identical, changes in water demand of the mixes are considered to be directly attributed to fine aggregate types used in the mix. Table 3 and Table 4 show the water content for different fine aggregate types and proportions. In this experimental investigation, river sand mixes recorded the highest water demand to achieve the required fluidity while offshore sand and quarry dust mixes recorded lower water requirements. Water demand can be influenced by many factors. Fineness of fine aggregate is one factor. Fineness essentially means more surface area to volume and therefore requires more water to wet the additional surface area. Shape is another factor influencing water demand. Texture or the roughness of the aggregate surfaces is another factor that influences the water demand. Rough surface texture provides more surface area to hold water around the aggregate and therefore requires additional water to overcome the surface friction. Shape is another factor influencing water demand. Round shaped natural aggregates are easy to compact while angular shapes resulted by manufactured aggregates are difficult to compact.

Figure 8 shows the increase in water demand for different fine aggregate types with the increase in fine aggregate proportions. This trend is found to be common for all w/c ratios tested. Figure 8 also shows that river sand requires higher water content to achieve the SCC status under prescribed workability tests. For a given aggregate type, it is seen that water demand increases with the increase of fine aggregate to total aggregate content proportion. Figure 9 shows the increase in water demand with the increase of W/C ratio of the mix recorded for mixes used river sand as the fine aggregate. Similar trends were observed among all other fine aggregate types.

Figure 9 shows the increase in water demand with increasing W/C ratio recorded for river sand. Figure 10 show the water demand by different aggregate types at different w/c ratios for 70% of fine aggregate proportion. Figure 11 shows the water demand for mixes with different aggregate types with common particle size distribution identical to the natural particle size distribution of offshore sand operating at the 70% fine aggregate proportion.

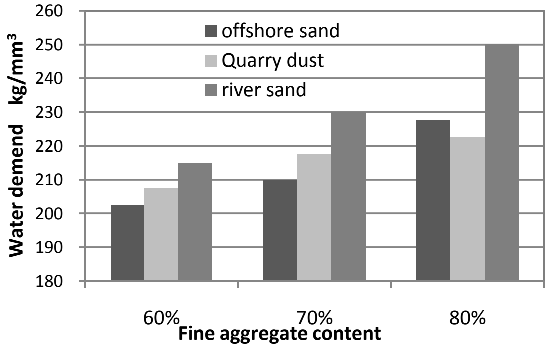


Figure 8 - Increase in water demand with the increase in aggregate proportions recorded for W/C ratio of 0.4.

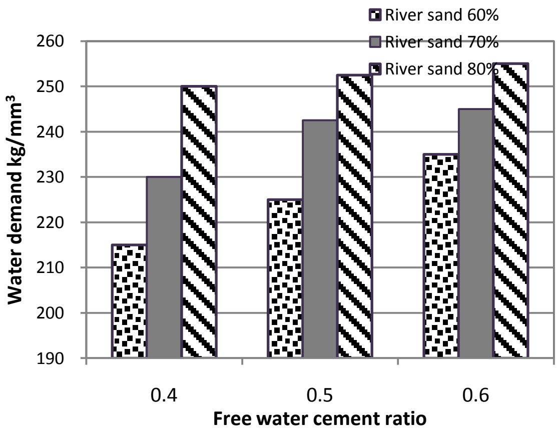


Figure 9 - water demand with the increasing water/cement ratio

According to Figure 10, it is clear that aggregate manipulated river sand and quarry dust have demanded more water than their natural particle size distributions. This is probably caused by the increase in surface area of the two aggregate types as a result of their particle size distribution manipulated into significantly finer particle size distribution that of offshore sand.

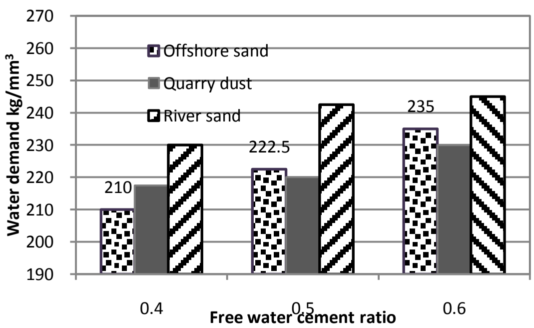


Figure 10 - Water demand by different aggregate types at different w/c ratio at 70% fine aggregate proportion

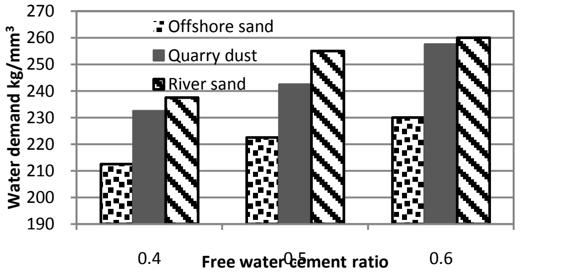


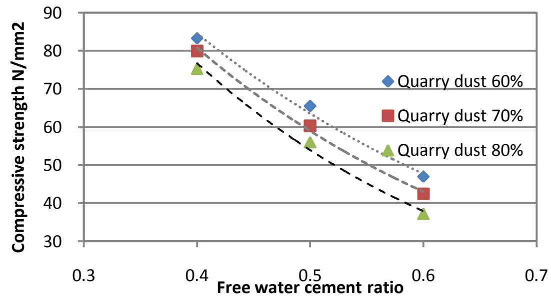
Figure 11- Water demand for different aggregate types with common particle size distribution operated at 70% of fine aggregate proportion

6.2. Compressive strength of concrete

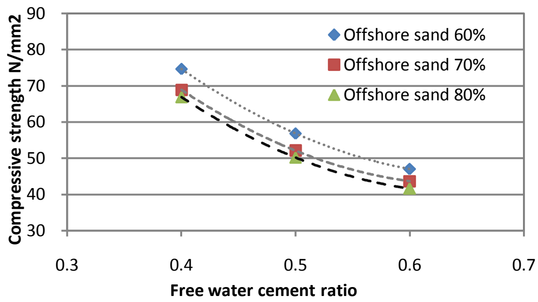
Compressive strength of concrete is one of the most important properties of concrete and accordingly, more attention was given to determine the aggregate influence on the compressive strength. Table 3 and table 4 provide 28-day compressive strength of the mixes conducted in this experimental investigation. Test results indicate that the quarry dust mixes have the highest strength under self-compacting condition. Offshore sand which had highest strength records under normal concrete, has recorded lower strength than quarry dust under self-compacting conditions [11]. Furthermore, results in Table 3 and 4 show that the Compressive strength of offshore sand and river sand are similar for all the tested W/C ratios.

Figure 12 (a),(b) and (c) show the compressive strength vs. water cement ratio for different fine aggregate types, quarry dust , offshore sand and River sand respectively, plotted for different fine aggregate proportions 60%, 70% and 80% considered in this study. Result clearly indicate, that, irrespective of the aggregate type, lowest fine aggregate proportion (60%) produces the highest strength for all the different fine aggregate types.

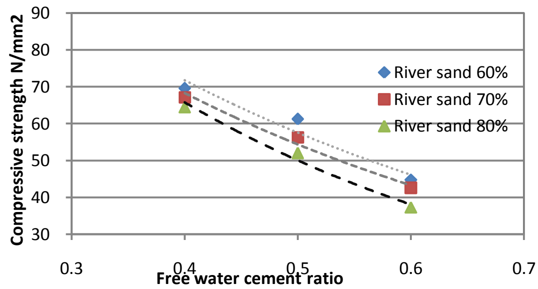
Figure 13 shows the strength Vs. water cement ratio for different aggregate types, averaged disregarding the proportion of fine aggregate to total aggregate ratio. From the average strength results, it is confirmed that quarry dust has consistently produced better results than the other two fine aggregate types for different W/C ratios considered in this investigation. Figure 14 shows strength Vs. W/C ratio for the three aggregate types for normal concrete [11] for comparison of aggregate influence under the different conditions of concrete mixing. By comparing the two graphs in Figure 13 and Figure 14, it is evident that self-compacting conditions not only have narrowed the aggregate influence but have also recorded different influence of the aggregate types on the compressive strength to that of normal concrete.



(a) Quarry dust concrete



(b) Offshore sand



(c) River sand

Figure 12 - Strength Vs. w/c ratio for different aggregate types operating at different aggregate proportions

Figure 15 combines the Compressive strength Vs. W/C ratio recorded for both normal [11] and SCC. Results show that SCC has improved the performance of all aggregate types under the tested water cement ratios. Furthermore, it can be concluded that SCC is found to have significantly improved performance of both the river sand and quarry dust mixes compared to normal mixes. However, the improvement to strength development of offshore sand is found insignificant. Overall results indicate that influence of fine aggregate types on the compressive strength has become lesser in self-compacting conditions compared to normal conditions of mixing.

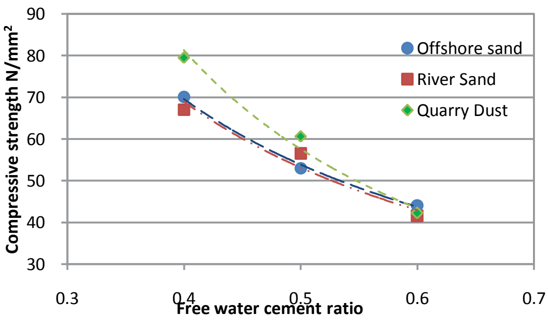


Figure 13 - Average strength vs. water cement ratio for SCC

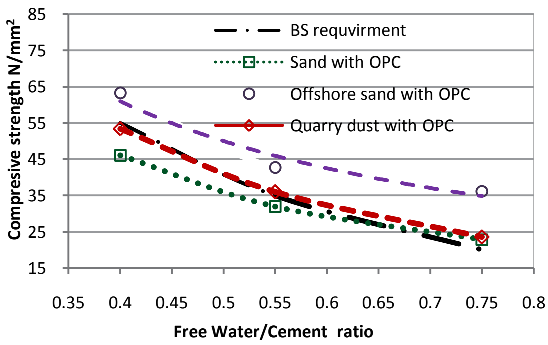


Figure 14 - Average strength vs. water cement ratio for Normal Concrete

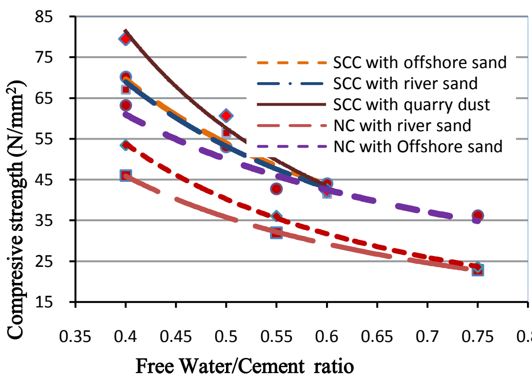


Figure 15 - Strength vs. w/c ratio for the three aggregate types for normal and self-compacting concrete.

6.3 Shrinkage of Concrete

Influence of fine aggregate on the shrinkage characteristics is another property looked at in this experimental study. Generally, SCC is expected to record higher shrinkage values due to the higher paste content and associated drying of the paste. Different absorption properties of aggregate can lead to different shrinkage characteristics of mixes. In this experimental investigation, shrinkage measurement was done using a multi-position strain gauge. Initially, when the variation of shrinkage is expected to be larger, measurements were taken at close intervals. During measurements specimens were regularly wetted and kept wrapped with cotton fabric covered by polythene sheets to eliminate drying. As all the specimens underwent same conditions, it is expected that the shrinkage measurement are comparable to one another.

Figure 16 shows the typical shrinkage measurement of SCC for various aggregate types. Although the shrinkage strain is within the acceptable limits [22] (Section 7 of BS 8110 Part 2) [23], higher shrinkage in quarry dust aggregate mixes were apparent. Offshore sand mixes reported the lowest shrinkage. It is noted that the trends of aggregate influence on shrinkage observed in SCC is very similar to normal concrete [11]. However, from the earlier discussion it was clear that water demand for quarry dust were different under self-compaction conditions. Quarry dust which had highest water demand in normal concrete recorded lesser water demand compared to river sand but yet produced highest shrinkage. Results suggest that autogenous shrinkage of quarry dust is higher than the rest of the two fine aggregate types.

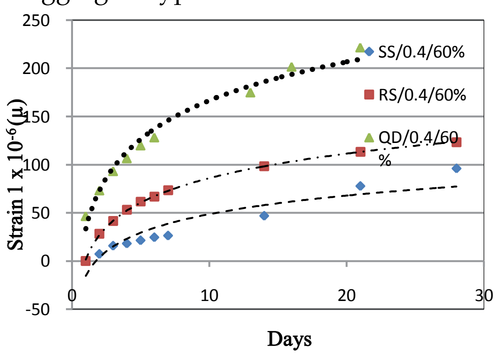


Figure 16- Typical shrinkage measurement of SCC for various aggregate types

7. Conclusions

Under the experimental program of this research study, the influence of fine aggregate on the properties of self-compacting concrete was evaluated considering different locally available fine aggregate types with a new generation superplasticizer. The minimum percentages of fine aggregate required to establish the fluidity have been found to be different from aggregate to aggregate. Offshore sand required at least 50% of total aggregate content to be fine aggregate in order to achieve required flow characteristics of SCC. This minimum requirement was reported as 55% for river sand and 60% for quarry dust mixes. The comparison of aggregate influence on the properties of SCC was done taking 60%, 70% and 80% of fine aggregate contents in the mix. From the experimental investigation, it is found that aggregate influences recorded in self-compacting concrete were different from similar aggregate influence studies conducted for normal concrete. For normal concrete, offshore sand recorded highest compressive strength while rive sand is found to be the lowest. However, in self-compacting concrete mixes, compressive strength recorded for both river sand and offshore sand is found to identical and lesser than that of quarry dust concrete. In the case of normal concrete, high compressive strength recorded by offshore sand mixes is attributed to better packing of aggregates. Lesser water required by offshore sand to achieve the designated slumps, in the normal concrete mixes, is a further confirmation that smooth fine particle size distributions have made offshore sand easy to compact. This trend has changed in SCC. It is logical to deduce that under self-compacting concrete with flow characteristics induced largely by superplacizer, there is lesser influence of aggregate shape and size characteristics on the compaction of concrete. Higher strength in Quarry dust mixes compared to the other two aggregate types is reflective of the better bond interlocking of aggregates and provides further evidence that particle size and shape induced packing of aggregates is no longer a critical factor influencing the properties of Self-compacting concrete.

Results under this investigation indicate that there is no significant change in the patterns of strength development in the mixes of different fine aggregate types with particle size distribution manipulated to single particle size distribution. Slight increase of water demand of the river sand mix and quarry dust mixes with manipulated particle size distributions seems the only notable change. As the natural particle size distribution of quarry dust and river sand are coarser than the aggregate distribution to which they were manipulated into, increase in water demand is possibly attributed to increase in the fine content and the associated increase in surface area.

From this experimental investigation, it is found that all locally available fine aggregate types of different particle size distributions can be made into self-compacting concrete when minimum percentages of fine aggregate to total aggregate contents found in this study are maintained. The minimum percentages required are found to be different from one fine aggregate type to another. It is found that finer the fine aggregate lesser the content of fine aggregate to total aggregate content required for making self-compacting concrete. This seems to be governed by the physical requirement to fill the voids created by the coarse aggregates in the mix. As quarry dust recorded the higher strength than the other fine aggregate types and demanded less water once minimum percentages of aggregates requirement to make self-compacting concrete is ensured, it is safe to conclude that aggregate packing is no longer the main criteria influencing the properties of self-compacting concrete.

Acknowledgement:

Assistance provided by Holcim Lanka (Pvt.) Ltd. to conduct the above experimental investigation and the financial support extended to the second author during the period is kindly acknowledged.

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