

EVALUATION OF THE POTENTIAL OF SEA SAND AS AN ALTERNATIVE TO RIVER SAND FOR CONCRETE PRODUCTION IN SRI LANKA

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ABSTRACT

We investigated the suitability of sea sand for concrete production. Our aim is to compare compressive strength, textural properties and salt contents with respect to grade 30 concrete produced by quarry dust and river sand. Crushing strength of concrete blocks constructed with sea sand was investigated where the sand was obtained from Muthurajawela stock piles. Concrete cubes were casted using different fine aggregates while keeping the other admixtures as constant. The crushing strength was measured after curing the concrete blocks for 7 and 28 days. We further investigated the chloride contents in the sea sand to assess whether the contents are within the permissible level for concrete production. Results show that the concrete produced using sea sand has the compressive strength of 30-40 N/mm² falls within the limits of conventional concrete. This study also confirmed that stronger concrete could be produced using fine aggregates with higher quartile ratio. Chloride in older sea sand stocks exposed to monsoon rains of 1-2 years show acceptable amounts.

Keywords: Sri Lanka, Construction, Concrete, Sea-sand, Crushing strength, Chloride content

INTRODUCTION

With the new freedom enjoyed after twenty five years of the civil war, the construction sector in Sri Lanka has boomed with increasing demand for raw materials. Large scale concrete structures are building in many parts of Sri Lanka where demand for fine aggregates was increased by several orders. Such increase can even be identified in the Gross National Product from mining and quarrying sector, which has almost doubled during the period from 2005 to 2010 (Central Bank of Sri Lanka, 2011). River sand has been widely used in the production of concrete in Sri Lanka, since the fine aggregate with its mineralogy, texture and the absence of salts, leading to produce stronger and durable concrete. However, river sand is expensive. The

cost of transportation to construction sites and excessive erosion associated with excavation from the natural sources are additional burdens. Large-scale depletion and over consumption of naturally occurring building material have also indirectly created numerous environmental problems. The most common problems are salt water intrusion due to lowering river beds close to the river mouth, river bank erosion along with flood plains and island wide coastal erosion (Ratnayake et al., 2011). Therefore, it is an immediate requirement to seek an alternative to river sand, not only as fine aggregate for concrete, but also for other requirements in the construction industry. Although the fine aggregates are commonly known to be inert filler, diverse properties associated with aggregates have a wide range of impacts on

impacts on strength, durability, workability, and economy of concrete (Dias et al., 2008). Such diversified properties of aggregates allow designers and contractors achieve necessary flexibility on meeting their design and construction requirements. Mineralogy, shape, specific gravity, reactivity, soundness and bulk unit weight along with the water/cement ratio determine the strength, workability, and durability of concrete (Yaqub and Bukhari, 2006; Neville and Brooks, 1993). Therefore, we are facing with finding new sources of alternative fine aggregates, considering variables as given above, to be used in the concrete production.

Table 1 Mix Ratios of Grade 30 Concrete

Materials	Cement	Fine Aggregates	Coarse Aggregate	Maximum Water
Volume Ratio	1	1	2	0.55

Available alternative fine aggregate resources for producing concrete in Sri Lanka are coastal dune sand, paleo river or flood plain sand, quarry dust, manufactured sand, and sea sand. Due to large scale availability, ease of extraction and low cost, sea sand has the greatest potential to replace river sand as an alternative. Nevertheless, the chloride ion presents in the sea sand, make its application, potentially threatening to the durability of concrete structures (Dias et al., 2008; Kayali and Zhu, 2005; Matsunaga et al., 1999; Watanabe and Koga, 2006). Therefore, it's important to remove chloride ions from the sea-sand by washing them either natural rainfall or artificial washing plants prior to use for the concretes. Besides the chloride problem, Sri Lankan consumers are much concerned about shell contents and textural suitability of sea sand. Therefore, sea sand usage in Sri Lanka is limited and only rarely used for concrete work.

Moreover, in a global context, sea sand usage has increased especially in developed countries such as Japan, and UK. Therefore, mining sea sand has not been developed in Sri Lanka despite large scale sea sand deposits are available in the shallow continental shelf in Sri Lanka. Instead, river sand mining has been accelerated in every

possible area in Sri Lanka creating an environmental disaster. This study examines the suitability of sea sand as an alternative fine aggregate for the river sand in concrete production.

METHODOLOGY

SAMPLING

Sampling of fine aggregates (sea sand, quarry dust and river sand) and coarse aggregates (approximately 20 mm size) were carried out during 2007 August. Sand samples of 40-50 kg were collected from the sea sand stock piles that

were mined from the nearby offshore area in 2002 May, 2005 May, 2006 April and 2007 March and then piled up to 25 to 30 m high stacks in Muthurajawela area belonged to the Land Reclamation Department of Sri Lanka. During the present sampling period in 2007 August, sea sand was available for sale to the public for construction purposes from the stock piles of 2002 May. Sampling was carried out using an excavator from selected stock piles representing each sampling year and from different levels.

Required coarse aggregates (consist of well graded crushed gneissic material of 20 mm maximum aggregate size) and quarry dust was obtained from ICC quarry located at Thudugala. The host rock at this quarry site is made up of hornblende biotite gneiss. River sand used as fine aggregates was obtained from Kaluganga River Estuary.

TESTING OF SAND SAMPLES

SIEVE ANALYSIS

Sieve analysis was carried out according to BS 812: Part 1(1995) for each sea sand sample taken from Muthurajawela stock piles. The

taken from Muthurajawela stock piles. The standard sieve sizes used were 2 mm, 1.7 mm, 1.4 mm, 1.18 mm, 0.85 mm, 0.5 mm, 0.425 mm, 0.3 mm, 0.25 mm, 0.106 mm, and the 0.075 mm (BS 1377: Part 3, 1990). All the sand samples were oven dried prior to sieving and sieve analysis was carried out to find the grain size distribution of sediment collected using a sieve and a shaker for 10 minutes. The cumulative mass passing each sieve as a percentage of the total sample mass was calculated and grading curves of each sample were plotted between passing percentage and the aperture size. Finally, mean grain average (D_{50}), quartile ratio (D_{75}/D_{25}) and sorting index $((D_{84} - D_{16}) / 4 + (D_{95} - D_5) / 6.6)$ of each grading curve were calculated.

MINERALOGICAL AND TEXTURAL STUDY

Mineralogical composition (through grain counting) and relative roundness were determined using reflected light microscopy on grains mounted on glass slides of each sand sample.

CHLORIDE CONTENT TEST

Chloride content in the collected sand samples was measured according to the guidelines given by BS 1377: Part 3 (1990) that were developed based on the Volhard's method (Vogal, 1961)

for determining the water soluble chloride in soil. In this method, water soluble chloride ions in the sand samples were precipitated by adding $AgNO_3$ and the resultant $AgCl$ precipitate was titrated to calculate the excess $AgNO_3$ using $KSCN$ solution and Ferric Alum indicator. Duplicate analysis was carried out for all the samples to determine the accuracy.

CONCRETE CRUSHING STRENGTH MEASUREMENTS

Grade 30 concrete (see Table 1) cubes of laboratory scale specimens (BS 1881: Part 108: 1983) were made using offshore sand collected from Muthurajawela stock piles and 7 and 28 day strength was tested according to the BS 1881: Part 108 (1983) guidelines. Usually, concrete gains 65% strength in 7 day and 99% strength in 28 day (Kabir et al., 2012). Same brand of cement was used to build all the concrete specimens. All the weight measurements were carried out using an electronic balance. These mixtures were thoroughly mixed using a small scale concrete mixture prior to pouring into the pre-casted molding. An empty molding (150 mm × 150 mm × 150 mm) was placed on a vibrating table and filled completely with above concrete mixture in three layers vibrating about 1 minute after pouring each layer. At least four concrete cubes were casted for all sea sand, river sand,

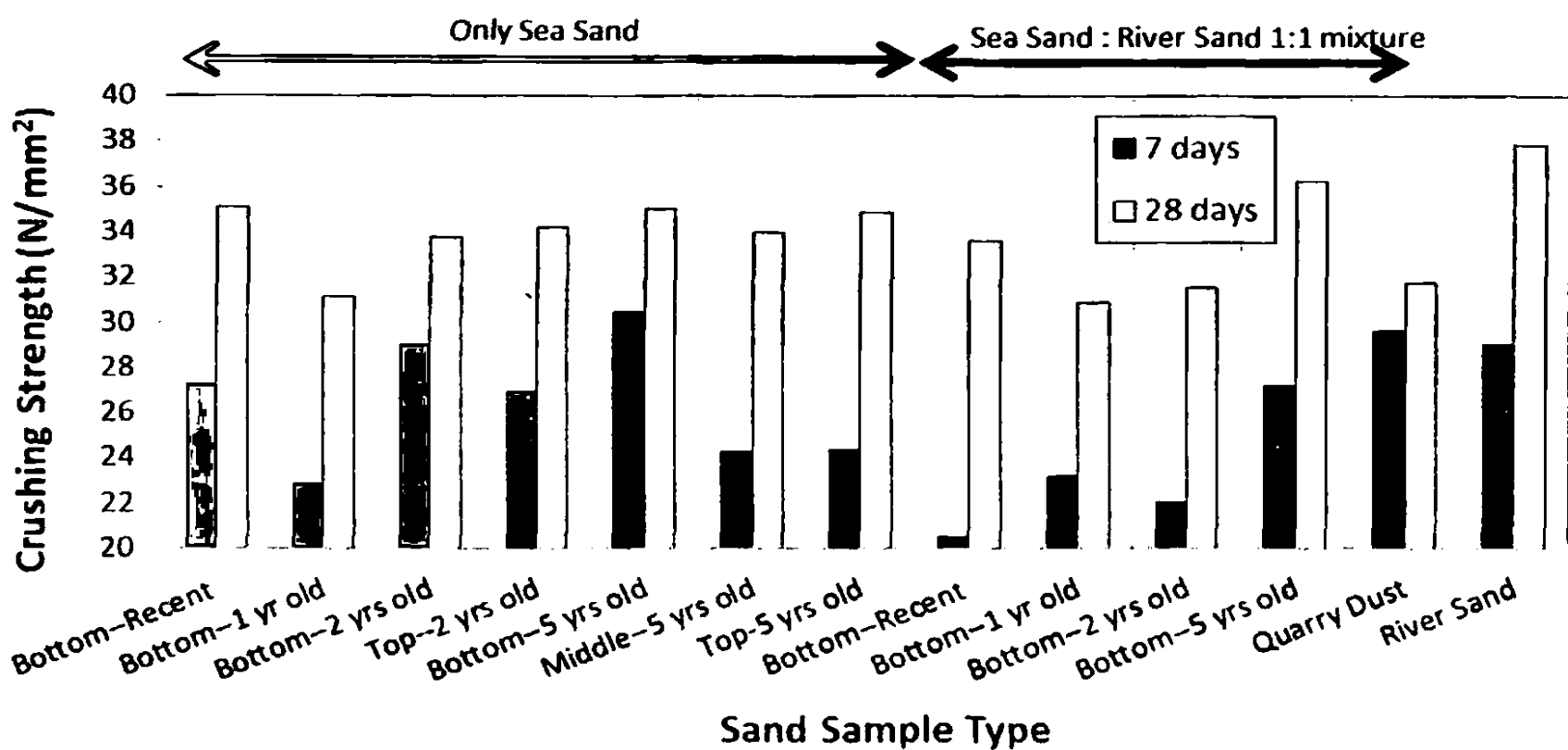


Fig. 1 The 7 and 28 day crushing strength of the concrete of different fine aggregates of sea sand types, mixed sea sand and river sand (1:1) compared to river sand and quarry dust.

Table 2 7 day and 28 day load and crushing strength and the textural parameters of the fine aggregates used of the concrete cubes produced using various sea sand samples compared to quarry dust and river sand

Type of Fine Aggregates	Sampling location on the sea sand stock pile and its shelf period	Number of Cubes Casted	Weight (kg)	7 Days Load (MT)	28 Days Load (MT)	7 Days Strength (N/mm ²)	28 Days Strength (N/mm ²)	Density (kg/mm ³)	Median D ₅₀	Quartile Ratio D ₇₅ /D ₂₅	Sorting Index
Sea Sand	Bottom--Recent	6	8.6	62.6	-	27.2	35.1	2475.6	770.0	2.44	0.88
	Bottom--1 yr old	6	8.6	52.0	72.0	22.8	31.1	2456.7	680.6	1.66	0.58
	Bottom--2 yrs old	6	8.7	66.7	77.7	29.0	33.8	2482.1	896.5	1.92	0.53
	Top--2 yrs old	5	8.6	62.2	79.8	26.9	34.2	2451.9	861.2	1.77	0.68
	Bottom--5 yrs old	6	8.5	69.0	80.7	30.4	35.1	2468.4	502.6	1.82	1.18
	Middle--5 yrs old	12	8.5	55.5	78.4	24.3	34.0	2432.0	419.0	3.15	1.19
1:1 mixture of River Sand and Sea Sand	Top-5 yrs old	6	8.6	55.3	81.5	24.4	34.9	2461.8	538.1	2.60	1.05
	Bottom--Recent	4	8.6	47.0	78.0	20.5	33.6	2468.3	784.1	2.40	0.89
	Bottom--1 yr old	4	8.7	52.5	70.3	23.2	30.9	2527.3	720.0	2.09	0.71
	Bottom--2 yrs old	4	8.7	50.9	74.0	22.0	31.6	2448.6	879.6	2.42	0.74
Quarry Dust River Sand	Bottom--5 yrs old	4	8.6	62.2	82.8	27.3	36.3	2501.3	623.1	3.47	1.07
		6	8.6	67.6	72.2	29.7	31.8	2500.3			
		4	8.6	67.0	87.0	29.1	37.9	2468.0	845.0	3.99	0.87

quarry dust and mixture of sea and river sand (1:1) samples at the Civil Engineering Laboratory of the University of Moratuwa. Precise details on the number of casted cubes were recorded in the Table 2. The cubes were de-molded after 24 hours and soaked in a curing tank. Then, all the cubes were crushed by using a cube crushing machine to measure the crushing strength after 7 and 28 days later.

RESULTS

The sea sand samples collected from different stock piles of Muthurajawela, Sri Lanka consist entirely of quartz, except for presence of less than 1 % sea shells as an impurity. The average grain sizes (D_{50}) of the sea sand ranged from 419 μm to 896 μm (medium sand to coarse sand) confined with very well sorted to moderately well sorted aggregates (Table 2). However, river sand collected from the Kaluganga River, Kaluthara area show an average grain size (D_{50}) of 845 μm with moderately well sorted aggregates. Figure 1 shows the representative gradation curves of sea sand compared with river sand used for this study. Table 2 shows the average grain sizes, quartile fraction and the sorting of all the sand samples studied.

Figure 1 shows the average 7 day and 28 day crushing strength values. The 7 day average crushing strength of the concrete (23 concrete cube casts) developed using the sea sand as fine

aggregate was 26.4 N/mm^2 whereas the 28 day average crushing strength (24 concrete cube casts) was 34.0 N/mm^2 . On the other hand, 1:1 mixture of sea-sand and the river sand as the fine aggregate had the 7 day average crushing strength (8 concrete cube casts) of 23.2 N/mm^2 while that of 28 day (8 concrete cube casts) was 33.1 N/mm^2 . For the quarry dust, 7 day average crushing strength was 29.7 N/mm^2 whereas that of 28 day was 31.8 N/mm^2 that was the lowest recorded 28 day values (Table 2). On the other hand, river sand had the 7 day average crushing value (2 concrete cube casts) of 29.1 N/mm^2 whereas the 28 day average value of (2 concrete cube casts) 37.9 N/mm^2 that was the recorded highest strength for all the 28 day strength measurements. Table 2 shows average values of the 7 and 28 day crushing strength and the load tests data of each type of sample.

Chloride contents of these sea sands were ranging from 0.026 % to 0.123 % (Figure 2) in which chloride contents were lower in the samples collected from oldest mined stock piles.

DISCUSSION

RELATIVE STRENGTH OF THE CONCRETE WITH DIFFERENT FINE AGGREGATES

This sea sand, mixed sand and quarry dust based concrete resulted with 10%, 13% and 16% lower compressive strengths respectively compared to

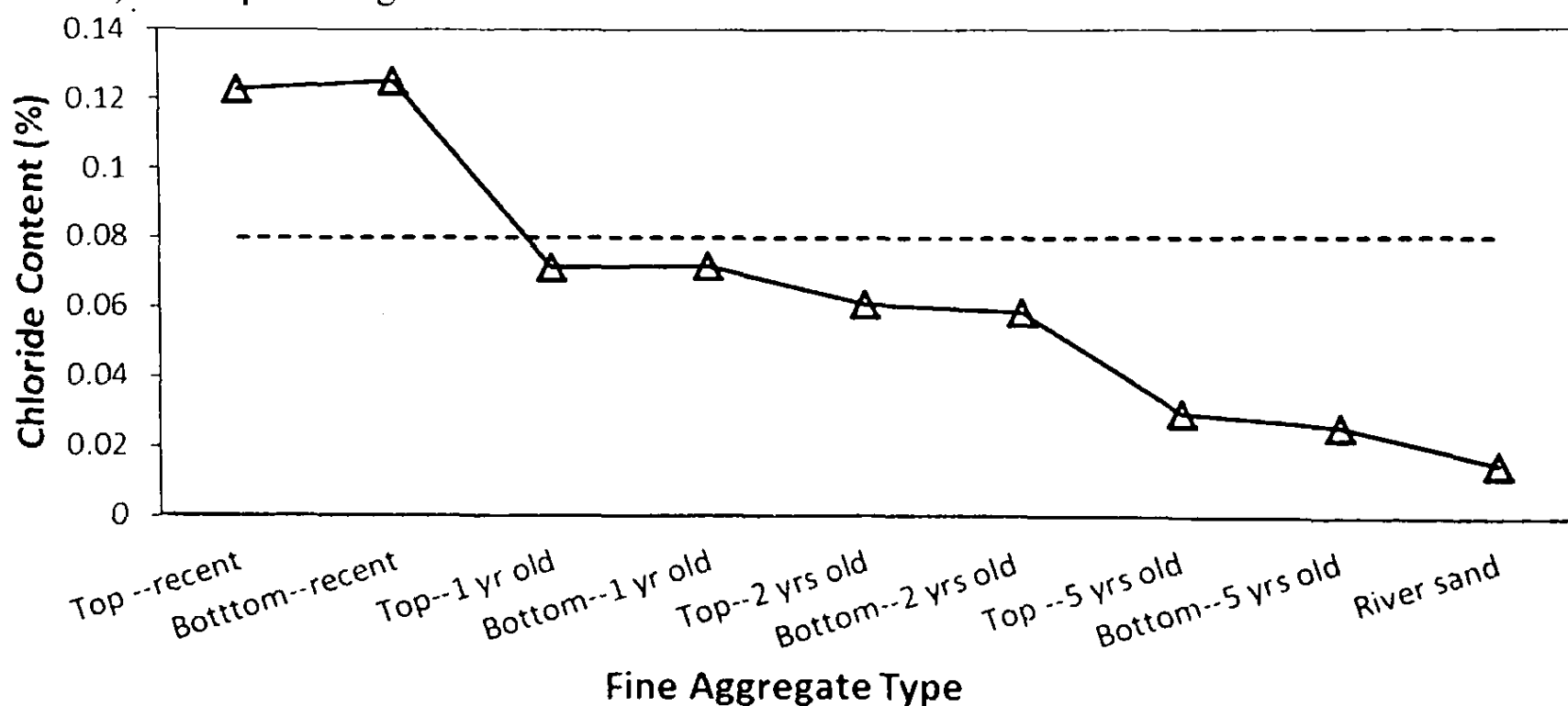


Fig. 2 Chloride content of various sea sand types used from the Muthurajawela stock piles for the concrete production.

indicate following order of compressive strength for the concrete casts produced using different sand types: river sand > sea sand > mixed sand (sea sand to river sand 1:1 ratio) > quarry dust (Figure 1). This is in agreement with the general acceptance in the construction industry of Sri Lanka that river sand is preferable in producing conventional concrete. Usually, conventional concrete has a compressive strength between 30 to 40 N/mm² (Donza et al., 2002) and all the concrete casts produced in this study are within this range (Table 2). Therefore, sea sand can also be used successfully as an alternative source for concrete production within the required strength limits. Market prices of river sand in Sri Lanka are quite high when compared with sea sand and quarry dust, therefore it is cheaper to use sea sand or quarry dust as an alternative. Moreover, it is noteworthy that mixing sea sand and river sand reduces the strength of concrete (Figure 1 and Table 1).

with 28 day requirement for full strength. On the contrary, river sand based concrete achieves hardening at much lower rate. For instance 75% of strength could reach within 7 days, while sea sand and mixed sand based had the lowest hardening rates of 71% and 69% respectively.

MINERALOGY AND TEXTURE OF FINE AGGREGATES VS CONCRETE COMPRESSIVE STRENGTH

Types of minerals in the fine aggregate control the strength of the concrete (Neville and Brooks, 1993; Aitcin and Mehta, 1990). Sea sand used for this study consists 99 to 99.5 % of quartz with 0.5-1.0 % shell fragments. River sand consists of 99 % quartz with minor amounts of heavy minerals. However, quarry dust used in this study, has more mafic minerals such as hornblende and biotite when compared with river and sea sands. Since river and sea sand consist mainly of quartz with a higher hardness,

CONCRETE HARDENING VS AGGREGATE

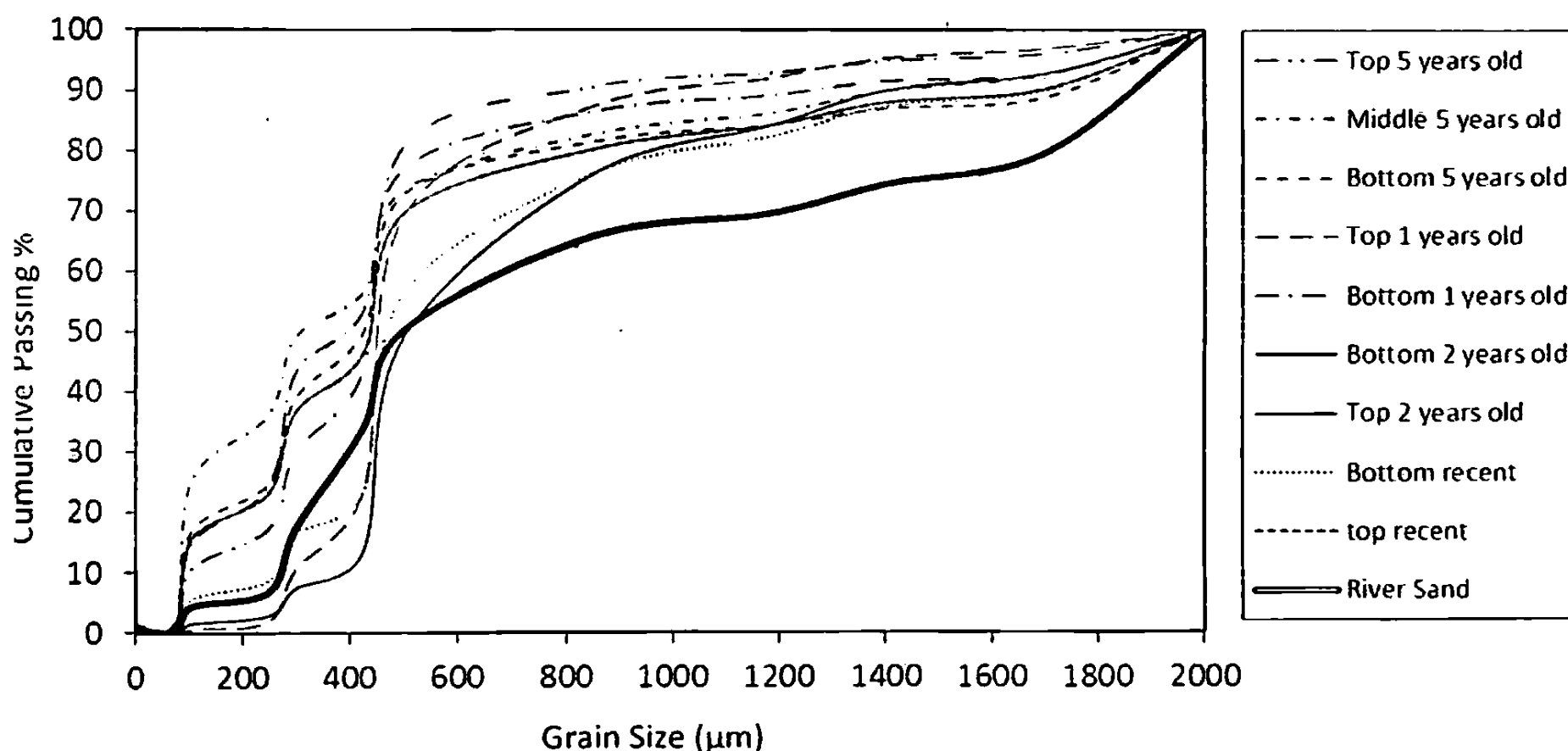


Fig. 3 Cumulative passing curves for the sand samples used for the concrete compressive strength.

TYPES

This study also pointed out that concrete produced based on quarry dust could rapidly hardened agreeing with the general acceptance among the Sri Lankan construction personnel (Figure 1). Quarry dust based concrete could reach 93% strength within 7 days in comparison

concrete produced using such sand can withstand higher compressive strength compared to quarry dust based concrete. Quarry dust used for this study came from a quarry site operated in hornblende biotite gneiss. The rock has 25-55 % of mica and hornblende (Jayawardana and Dissanayake, 2008). Therefore, compared to biotite and hornblende,

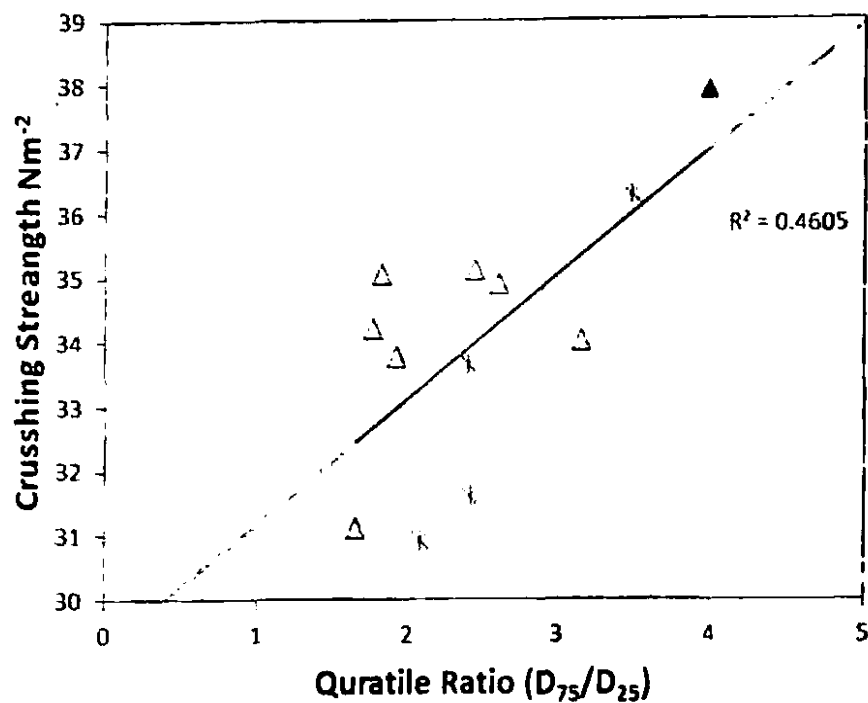


Fig. 4 Crushing strength vs quartile ratio of different fine aggregates.

(Jayawardana and Dissanayake, 2008). Therefore, compared to biotite and hornblende, quartz can withstand higher compression. Perhaps overall lower strength of the quarry dust bearing concrete might be indicating higher percentages of fragile and flaky Fe/Mg minerals.

Physical characteristics of aggregates, especially texture, size, shape and grading are known to affect concrete strength in varying degrees (Neville and Brooks, 1993). In addition, controlling factors such as degree of roundness and surface roughness of fine aggregates are also important for concrete strength (Neville and Brooks, 1993). The samples from river and sea sand show grains with rounded to sub rounded shapes with smooth surfaces. However, samples from quarry dust contained angular and rough surfaced grains. In general, angularity and surface roughness promote stronger binding capacity with cement (Neville and Brooks, 1993). Contrastingly, concrete produced using quarry dust consist with angular and rough surfaced grains had the lowest compressive strength while much rounder and smoothed surfaced river sand, sea sand and mixed sand based concrete displayed higher compressive strengths. Therefore, degree of angularity or surface roundness could not be an important controlling factor for the observed changes of compressive strength.

Grading of the fine aggregates is also an important controlling factor for the concrete strength (Neville and Brooks 1993). By examining cumulative curves (Figure 3) of the river and sea sand samples, one could see that river sand represent coarser grain sizes, thus contributing to the strongest compressive strengths. Median grain size of the samples does not show particular relationship with crushing strength (Table 2). Since all the samples used are consist of medium to coarse sand we suggest all those grain sizes are good for concrete production. A D_{50} value of around 0.6 mm is considered very good for concrete production (Dias et al., 2008). It must also be mentioned here that previous work has indicated offshore sand grading can vary from one location to another around the Sri Lankan coast (Wijayananda, 1994). Low abundance of fine grain fraction perhaps promotes the compressive strength of the concrete. Figure 4 supports the idea that the quartile ratio even in sea sand is weakly correlated with the compressive strength while the highest recorded values are with the river sand. Since the compressive strength is a function of many factors this weak correlation is more realistic and shows the importance of quartile fraction. Therefore, when sea sand is explored one of the important parameter to check is the quartile strength. Grain size might have also contributed to the lower strength for the concrete produced using quarry dust, since most grains were dust particles (clay and silt) imposing lower compressive strengths. Celik and Marar (1996) have shown that increasing dust particles in quarry dust over 10% could drastically decrease the compressive strength. Sorting index also showed very weak correlation, indicating poor the sorting stronger the concrete (Table 2) agreeing to the common conception among the Sri Lankan consumers. Consumers prefer specifically coarse grain poorly sorted sand for the concrete.

BS 882 (1990) limits on shell content in sea sand usage for concrete. There was a limit of 20% for 5–10 mm aggregate and 8% for larger aggregates, however, no limits on the fraction below 5 mm. In general, hollow shells in

concrete strength (Chapman and Roeder, 1970). Even though, the shell fragments themselves are usually fragile, they may not indicate lower compressive strengths as observed both in sea sand and the mixed sand based concrete.

Different sea-sand stock piles of the Muthurajawela dump site, mined at different times showed a varying amount of chloride contents (Figure 2). The highest chloride content was recorded at the most recently mined (which

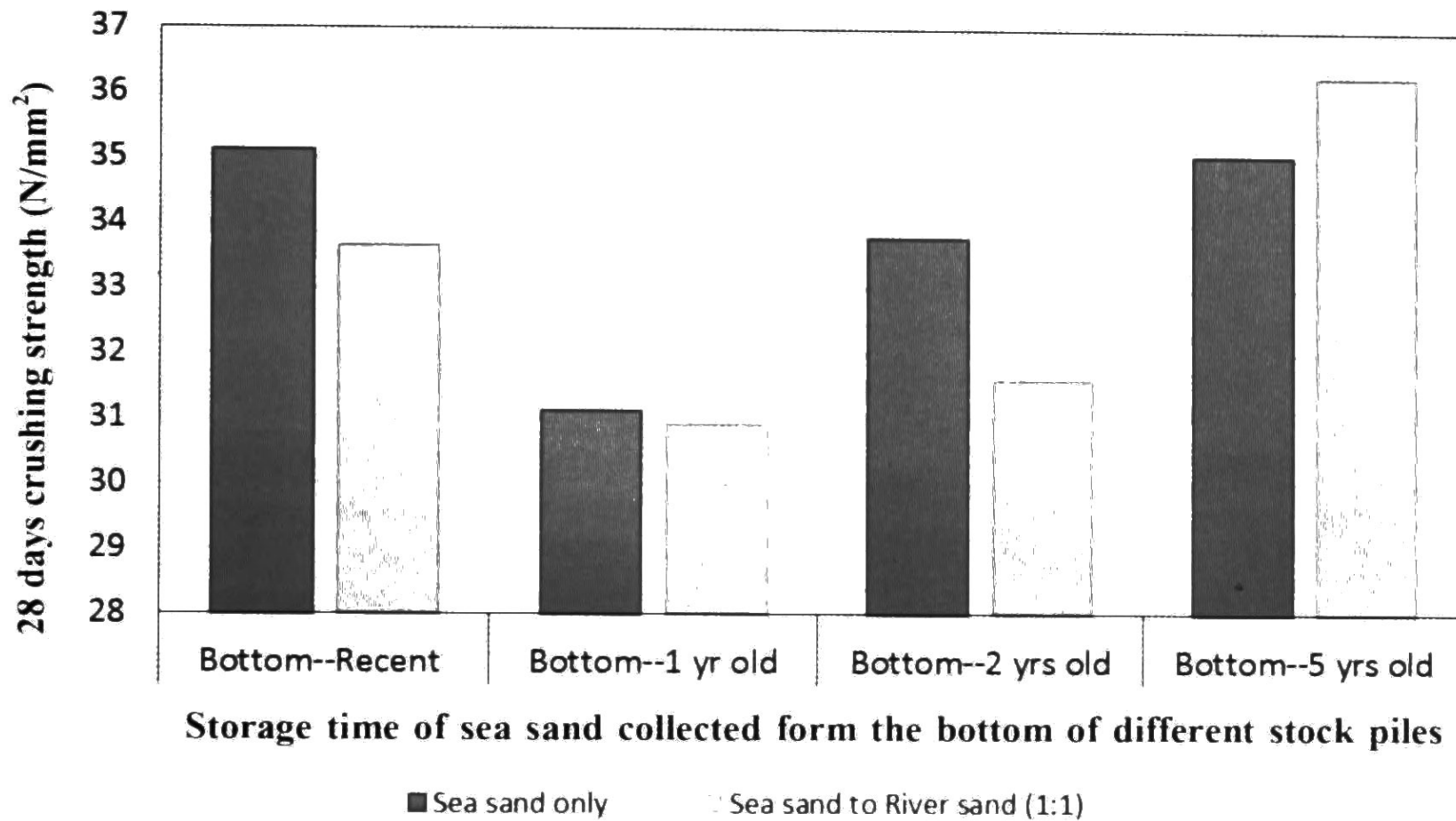


Fig. 5 Comparison of 28 days crushing strength of sea sand only and river sand to sea sand 1:1 mixture. Sea sand was obtained from the bottom of different piles stocked from recent up to 5 years.

Moreover the sea sand used in this study has a very little amount of sea shells.

Even though the trends are not clear, the compressive strength of concrete has the tendency of decreasing with higher chloride content (Figure 5). Perhaps cementation reaction is retarded to certain extent by the presence of salt ions or perhaps it is due to textural effects rather than the chloride content.

CHLORIDE CONTENT

Chloride content is a significant parameter for strength of concrete. It is a disadvantage for sea sand if the absolute chloride content of construction sand goes beyond 0.075% (Dias et al., 2008). It could cause corrosion of the reinforcements and enhance soluble salt efflorescence within concrete (Kayaliand Zhu, 2005, Matsunaga et al 1999). Use of dry beach deposits in the Middle East has led to the very early inception of corrosion.

has a lower shelf life) stockpile whereasthe lowest chloride contents were recorded at the oldest mined stock piles (which have a higher shelf life). Stocks with several months of shelf life had very high chloride content which is more than the permissible limit of 0.075%. Sea-sand with one year of the shelf life period had chloride content slightly below the permissible level. Such sand usage, especially for the concrete construction, could be unsafe and can adversely affect the longtime strength since chloride ion promotes corrosion of the reinforcements and enhance soluble salt efflorescence (Kayaliand Zhu, 2005; Matsunaga et al., 1999). Japan is one of the first countries to use sea sand for the construction industry and subsequently faced with adversivity due to chloride induced corrosion of reinforcements and subsequent failure of concrete structures. A well-known accident occurred in 1999 at the Shinkansen railway tunnel, Japan, in which a train collided with a concrete block, is one of the many suspected concrete structural failures due to higher chloride (Watanabe and Koga, 2006).

many suspected concrete structural failures due to higher chloride (Watanabe and Koga, 2006). However, this study clearly shows that the sea-sand stock piles even as high as 30 m can be kept inland at least two years, so that the chloride content will lower well below the permissible level of construction standards. This is due to natural washing away caused by the monsoon rains. Therefore, it is much cheaper to rinse this unwanted chloride by natural rainfall rather than using an expensive mechanical washing process which costs high capital for the machines and also for the fresh water supply. Since the land value in the Muthurajawela, which is a filled salt marsh, much cheaper and located very close to the commercial capital Colombo, natural washing has become a cost effective process.

CONCLUSIONS

Study of sea sand for the concrete production in the context of Sri Lanka concludes:

- (1) Sea sand, mixed sand and quarry dust based concrete has 10%, 13% and 16% lower 28 day compressive strength respectively compared to the river sand based concrete.
- (2) Concrete hardening speed is relatively rapid in quarry dust compared to both river sand, sea sand and mixed sand concrete.
- (3) Concrete produced using sea sand has slightly lower though acceptable compressive strength compared to river sand while much higher compression strength compared to quarry dust.
- (4) Quartile ratio is an important factor for producing higher strength concrete while lower quartile ratio produces stronger concrete.
- (5) Chloride content in the sea sand prior to natural or artificial washing exceeds the permissible level and therefore dangerous for concrete production that uses reinforcements.
- (6) One to two years of natural washing by monsoon is sufficient to remove chloride in the sea sand stock piles as high as 30 m to an acceptable level of concrete production.

Therefore, sea sand is a competitive alternative or fine aggregates to replace river sand for concrete production.

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