Characteristics Studies on Engineering Properties of River Sand Substitutes for Conventional Concrete and Mortar Works

Withanage AK, Sugathadasa AGMRP, Mithushan T, *Dissanayake DMDOK and Rohitha LPS

Department of Earth Resources Engineering, University of Moratuwa, Sri Lanka
*Corresponding author – kithsiridissanayake@yahoo.com

Abstract

The main sand source of construction industry in Sri Lanka is river sand. However, being a developing country, the demand for river sand increases gradually. Based on engineering computations, sand demand for 2013 was estimated to be 12,266,186m^3. The GSMB currently keeps records of all the licenses issued for sand mining and transportation, and according to these records the approximate annual sand supply is 7,132,631m^3(GSMB records), which is far below the estimated demand. The difference may compensate by to illegal mining. Thus, this kind of unrestricted harvesting of sand is resulting in heavy rates of soil erosion; land degradation; increased river-water turbidity; lowered water tables; salinity intrusion in the lower reaches of rivers. Further, over use of river sand for construction industry has various undesirable social and ecological consequences. As a solution for this, various alternatives such as offshore sand, quarry dust, manufactured sand, dune sand, washed soil, waste building material, broken glass and blast furnace slag have been identified by various countries. Thus, this study attempts to identify suitable alternatives for river sand to mitigate the environmental issues related to river sand mining in Sri Lanka. In this project, we use manufacture sand, quarry dust, beach sand and off shore sand to test the suitability for conventional concrete and mortar works. Basically testing for concrete strength using uniaxial compressive strength and check grading of all river sand substitutes are performed. In addition to that two types of sand were mixed in various ratios and check those concrete and mortars for the compressive strength test to find the best mix ratio of sand for construction purposes. Finally those results were compared with strength of concrete for which river sand was used.

Keywords: Compressive strength, Concrete, Mortar, River sand Substitutes

1. Introduction

Concrete is generally composed of aggregates, cement and water. Asphalt concrete is another type of concrete where cement material is bitumen. But here only considering the Portland cement concrete. Mortar is used for joining stones, bricks and blocks. There are two types of aggregates: finer aggregates and coarser aggregates. Coarser aggregates are larger than 4.75mm and finer particles are lesser than 4.75mm. When hydrated, cement acts as a paste which accumulates around aggregates to make concrete mass. Commonly used cement type is Ordinary Portland Cement (OPC) of 42.5 N class. The aggregates should have engineering properties such as shape, density, grading, hardness, purity to achieve concrete durability and perfect strength. Good quality concrete depends on the quality of materials used, correct proportion and the way of mixing concrete [1]. As concrete grade is C 15, 1: 2: 4 is the mixing ratio for corresponding to cement, finer aggregate and coarser aggregates. For mortar 1: 3 ratio of cement and finer aggregates by volume is used as M12 is final grade of mortar. Aggregates should be clean and free from organic impurities. Sand should be clean and free from clay, organic content, silt and other inferior materials [2]. As river sand extraction affects many adverse effects on environment, manufactured sand, quarry dust, off shore sand and beach sand are experimented through several tests to find the suitability.

2. Methodology

2.1 Sieve analysis

Sieve analysis was done for all river sand and also four river sand substitutes to check the suitability. As mentioned in the ASTM standards, specific limits (lower limit, upper limit) are defined for fine aggregate especially for concrete works and also for mortars. 9.5mm, 4.75mm, 2.36mm, 1.18mm, 600µm, 300µm, 150µm and 75µm sieve sizes were used to find the grading curves. So with the purpose of check the grading is within specific limits, excel graphs were drawn using specified limits.

2.2 Bulk Density & Porosity

According to ASTM C 29 code bulk density and porosity can be found by calculations. First, a cylindrical metal measure of 3*l* is selected from the laboratory. Then, sand is filled completely to that measure and weighs the weight. As volume and the weight of the sample are known, bulk density can be directly calculated using simple equations [3].

Then, specific gravity of each sample is calculated. A density bottle and weighing balance is specially required to perform this test. Weight of the sample and weight of the water of similar volume of the sand sample is taken from the calculation and divided those values and finally taken the specific gravity for each sand samples. Void percentage can be calculated from equation (1).

$$\%Voids = 100[S \times W - M]/[S \times W] \ldots\ldots(1)$$

where:

M = bulk density of aggregate, lb/ft^3 [kg/m^3],

S = bulk specific gravity (dry basis)

W = density of water, 62.3 lb/ft^3 [1000 kg/m^3].

2.3 Fineness Module

The fineness modulus of finer aggregates are given in Table2.1.

Table 2.1 - Fineness modulus of finer aggregate

Sieve size (mm)	Cumulative Retained percentage
4.750	1.7
2.360	18.4
1.180	35
0.600	49.7
0.300	65.6
0.150	81.3

Fineness modulus of fine aggregate is obtained by adding retained percentage on sieve sizes of 4.75mm, 2.36mm, 1.18mm, 0.6mm, 0.3mm and 0.15mm.

Fineness Modulus is a term used as an index to the fineness or coarseness of aggregate. This is the summation of cumulative percentage of materials retained on the above standard sieves divided by 100 [4].

2.4 Compressive strength of concrete

For compressive strength, 150mm × 150mm × 150mm moulds were used to cast concrete. Concrete was poured in to mould in 3 layers. After 1 layer is poured 35 blows were applied.

Same procedure continued to other 2 layers. As compressive strength for 7 days, 14 days, and 28 days cubes should be tested, 3 cubes were casted from a one mix design.

After 24 hours, cube moulds were removed and concrete cubes were taken out. Then cube was submerged in the water until it is ready to check for compressive strength test.

2.5 Compressive strength of mortar

As in the concrete compressive strength 70.6mm × 70.6mm × 70.6mm moulds were used to cast mortars.

Mortar is mixed with cement and aggregate using mix design of 1:3 by volume. Three cubes were casted as it is required to check 7days, 14 days, 28 days for the compressive strength test.

After 24 hours cube moulds were removed and concrete cube was taken out. Then, cube was submerged in the water until it is ready to check for compressive strength test.

Finally, all test cubes were tested using compressive strength machine and check the maximum pressure (N/mm^2) to find out whether cubes achieved the target strength

3. Results and Discussion

3.1 Engineering properties of sand

According to the laboratory tests which were carried out, the following results were gathered on the physical properties are directly affect to convectional concrete and mortar works.

3.1.1 Fineness Module

Beach sand	- 1.825
Manufacture sand	- 2.529
Off shore sand	- 2.187
Quarry Dust	- 2.517

3.1.2 Bulk density (kg/m^3)

Beach sand	- 1443.55
Manufacture sand	- 1585.18
Off shore sand	- 1547.62
Quarry Dust	- 1514.71
River sand	- 1424.77

3.1.3 Specific gravity

Beach sand	- 2.75
Manufacture sand	- 2.95
Off shore sand	- 2.65
Quarry Dust	- 2.70
River sand	- 2.70

3.1.4 Voids percentage

Voids percentage of each sand substitute is calculated through an equation mentioned in ASTM C-29.

Beach sand	- 47.59 %
Manufacture sand	- 46.21 %
Off shore sand	- 41.69 %
Quarry Dust	- 43.86 %
River sand	- 47.22 %

3.2 Grading curves

Sieve analysis was done for all river sand and also for four river sand substitutes to check the suitability. As mentioned in the ASTM standards define specific limits (lower limit and upper limit) of fine aggregate for concrete works and also for mortars [5].

So, with the purpose of checking grading is within specific limits, excel graphs were drawn using specified limits.

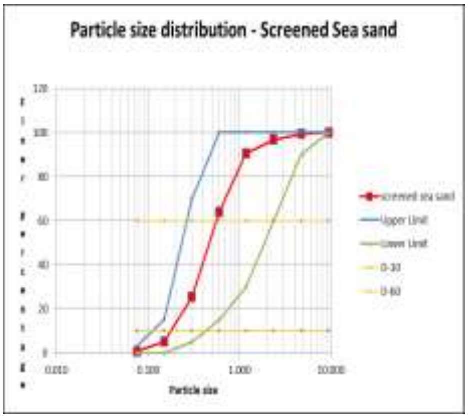

Figure 3.1 - PSD of screened sea sand

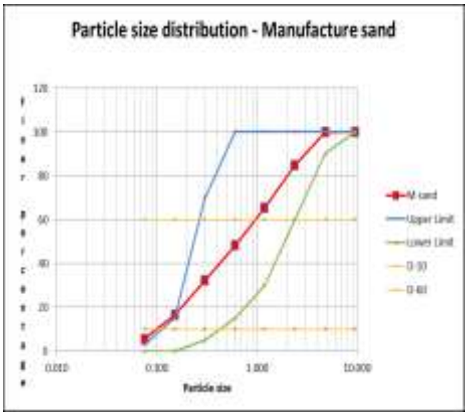

Figure 3.2 - PSD of M sand

The lower limit and upper limit were taken from ASTM C-33 standard code, and sand gradation curves should in between those limits.

3.3 Concrete Compressive Strength

Concrete compressive strength vs 22 various combinations of sand substitutes were graphically represented (figure 3.3) to obtain what mixtures are to give minimum strength within 28 days. Those graphs were made to compare strength of specimens with substitute with the river sand test specimen [6].

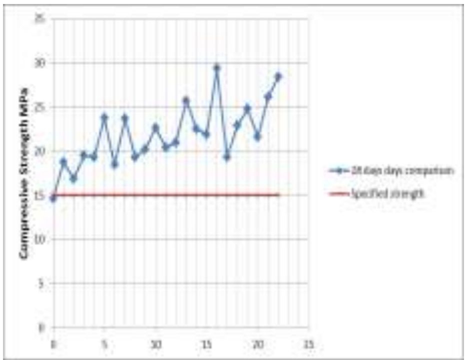

Figure 3.3 - Concrete strength for 28 days

Some of the strength values were not exactly taken at 28 days and those values were recreated by mathematical calculations [5].

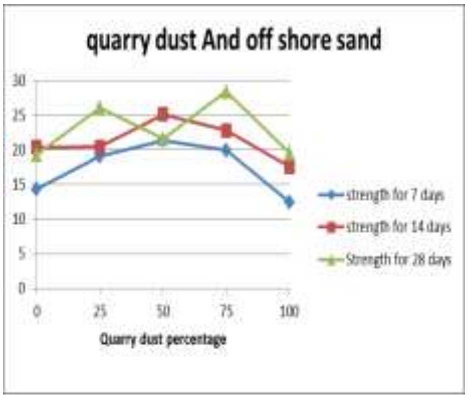

Figure 3.4 - Concrete strength for mixtures of quarry dust and sea sand

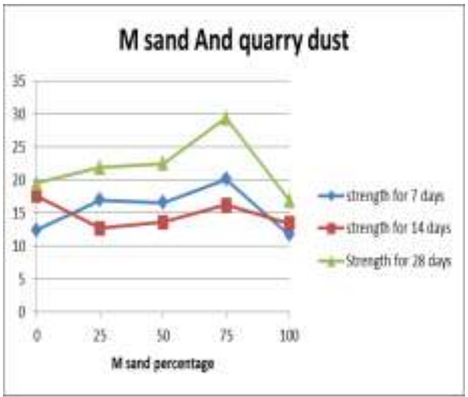

Figure 3.5 - Concrete strength for mixtures of M sand and quarry dust

These different strength comparisons were made for all combinations to check specified strength is gained at relevant date and to check the most efficient combination of sand to Sri Lankan construction industry.

3.4 Mortar Compressive Strength

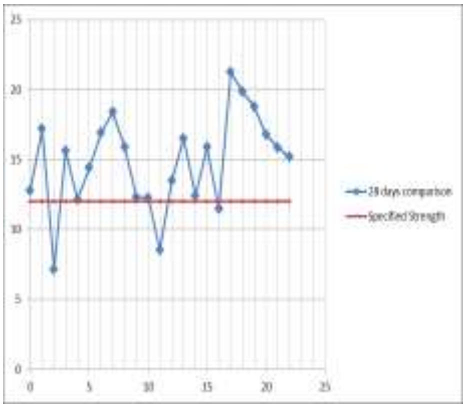

Figure 3.6 - Mortar strength for 28 days

So as the concrete, a graph for the variation of mortar strength at 28 days with different combination of substitutes were made and check the suitability of an each test specimen.

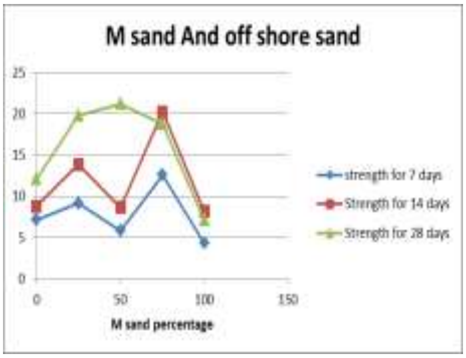

Figure 3.7 - Mortar strength for M sand and off shore sand mixture

Like above compressive strength varies with the composition of finer sand. All graphs were plotted to find the best composition of substitute related to compressive strength factor.

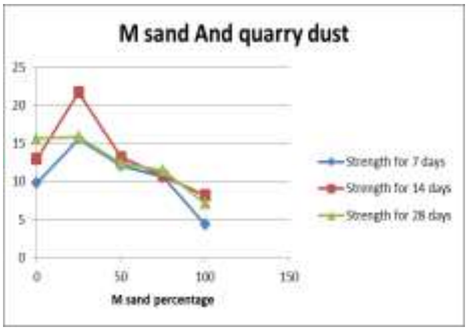

Figure 3.8 - Mortar strength for M sand and quarry dust mixture

4. Conclusion

4.1 Grading Curves

In general, if water cement ratio is kept constant and ratio between finer aggregates to coarser aggregate is chosen correctly, there will be not much noticeable effect to the strength of concrete and mortars. But in achieving the best economical concrete mixtures these finer aggregate gradation curves affect significantly.

The fine aggregate must not have more than 45% retained between any two consecutive standard sieves. However, two beach samples shows more than 50% retained between 300 µm and 600 µm sieves. Other substitutes are less than 45% retained between any sieves.

Concrete with fine aggregate grading near the minimums for percent passing 300µm and 150µm sometimes have difficulties with workability, pumping or excessive bleeding. However none of the substitutes shows close values to minimum finer percentage of 300µm and 150µm sieves.

Exceeding the upper limit of gradation implies large amount of finer particles present in sand. In manufactured sand and quarry dust, there is little abundance of finer percentage, but not others substitutes shows that kind of deviation.

4.2 Fineness Modulus

The value should be in the range of 2.3 to 3.1. Sand with 2.0 fineness module is considered as the finer sand while 3.0 defined as coarser sand. So most suitable fineness module is 2.5 for concrete works. Finer aggregates below 2.3 produce uneconomical concrete and mortar mixtures while above 3.1 fineness modulus sand produce harsh workable mixtures. Both off shore sand and beach sand are below 2.3 fineness modulus. However other substitutes produce preferred fineness modulus values.

4.3 Void Percentage

The required amount of cement paste is dependent upon the amount of void space that must be filled and the total surface area that must be covered. When the particles are of uniform size the spacing is the greatest, but when a range of sizes is used, the void spaces are filled and the paste requirement is lowered. When more of these voids are filled, the less workable the concrete becomes, therefore, a compromise between workability and economy is necessary. So void percentage for all substitutes are in between 40%-50% which implies all substitutes are within the standards.

4.4 Concrete Compressive strength

- In general, beach sand contained concretes gives better compressive strength. Compressive strength is around 20 MPa with all substitutes.

- M sand gives better strength with all substitutes more than expected strength. But significantly with the increment of M sand percentage strength is decreased.

- Comparing Quarry dust contained concrete; it gives better strength with all substitutes more than expected strength. However especially with off shore sand it gives highest values.

- Comparing off-shore sand contained concrete; it gives better strength with all substitutes more than expected value. With quarry dust, M sand and beach sand it gives higher strength.

- Generally, mixture of substitutes gives higher strength than using single substitute.

4.5 Mortar Compressive Strength

- M sand perform better than quarry dust in mortar works.

- M sand plus quarry dust gives the worst combination.

- Best combination is obtained with M- sand with off shore sand.

- Beach sand performs better when it is alone and also with higher percentages with other substitutes.

5. Recommendations

Following steps are recommended to obtain an economical and durable concrete and mortars in construction industry. Those recommendations are based on changing the properties of river sand substitutes and also introducing the best mixtures of river sand substitutes.

- Sea shell content of off-shore sand should be reduced
- Excessive finer percentage of quarry dust and M sand must be removed by further washing
- Beach sand should be mixed with other substitute to reduce gap grading between 600µm and 300µm.
- Both off-shore sand and beach sand should be mixed with other sand substitute with proper

gradation to maintain fineness modulus around 2.5

- It is highly recommended to use combinations of quarry dust and off shore sand in concrete works
- When using M sand as a substitute, it is better to combine with suitable substitute such as off-shore sand or beach sand.
- For mortar works, it is highly recommended to use the combination of M sand and Beach sand.
- Offshore sand should be sieved and remove shell particles before mixing with cement for mortar constructions

Acknowledgement

This project consumed huge amount of work, research and dedication. Still, implementation would not have been possible if we did not have a support of many individuals and organizations. We would like to express our sincere gratitude to all of them. We would like to express our deepest appreciation to all those who provided us the possibility to complete this report. A special gratitude we give to our main supervisor, DR. DMDOK DISSANAYAKA, whose contribution in stimulating suggestions and encouragement, helped us to coordinate our research especially in writing this report. Many thanks go to the head of the department DR. HMR PREMASIRI, whose have invested his full effort in guiding the team in achieving the goal. We have to appreciate the guidance given by the co-supervisors in our project who has improved our subject related skills and thanks to their comments and advices.

We are using this opportunity to express our gratitude to MR. LPS ROHITHA who gives the permission to utilize the mineral processing laboratory and giving us so many instructions for experiments. Furthermore, we would also like to acknowledge with much appreciation the crucial role of the staff, who gave the permission to use all required equipment and the necessary materials to complete the task “casting cubes and perform uniaxial compressive strength test”.

References

[1] Neville, A.M. (n.d) Properties Of Concrete.

[2] Lohani T. K., P.M.D.K.P.&.J.S. (2012) ' Optimum utilization of Quarry Dust as partial replacement of sand in concrete'.

[3] K. Shyam Prakash and Ch. Hanumantha Rao, D.o.C.E.P.S.I.o.T.K.V.A.P.5.I. (n.d) 'Study on Compressive Strength of Quarry Dust as Fine Aggregate in Concrete'.

[4] Rao, K.S.P.a.C.H. (n.d) Study on Compressive Strength of Quarry Dust as Fine Aggregate in Concrete.

[5] ASTM International (2006), December, [Online], Available: https://www.astm.org/SNEWS/DECEMBER_2006/melanderside2_dec06.html.

[6] 'Guide to durable concrete, American Concrete Institute, Detroit, Michigan. Boskalis International '.