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An Experiment to Determine the Effect of Partial Replacement of Natural Sand with Manufactured Sand on the Strength of Concrete

Anthony Woode David Kwame Amoah Bright Aforla Freeman Kofi Logah Maxwell Yaw Dzakah
Department of Civil Engineering, Accra Polytechnic, P.O.Box 561 Accra, Ghana

Abstract
Natural sand is getting depleted from the environment, because of over exploitation for construction purposes, resulting in loss of vegetation and fertile land for farming. An investigation was, therefore, conducted to determine the suitability of using manufactured sand from crushed gneisses as partial replacement for natural sand for concrete production. In the experiment natural sand was replaced with manufactured sand of the same grading as the natural sand, while keeping all other variables constant. Apart from the control concrete sample which had 100% natural sand all the other samples were treated to 10%, 20%, 30%, 40% and 50% replacement of the natural sand with manufactured sand. Concrete cubes of 150mmx150mmx150mm were made with the various proportions of cement, sand and stones in a mix ratio of 1:2:4, water -cement ratio of 0.45 and cured over 28 days.The results of compressive strength tests show that the strength of the concrete cubes with varying amounts of natural sand and manufactured sand changed marginally. This was interpreted to mean that the partial replacement of natural sand with manufactured sand up to 50% in concrete results in about 6% increase in the strength of the concrete. Manufactured sand, therefore, is regarded as suitable for concrete production on the basis of strength. However, it may affect the concrete in the long run because it contains higher amounts of deleterious substances as compared to the natural sand.
Keywords: Manufactured sand, Natural sand, Concrete, Compressive strength, Gneiss

1. Introduction

In the production of concrete different sand types are used. They include natural sand which, usually occurs as geological deposits of sand-sized materials in streams, rivers, estuaries, lakes, lagoons, dunes and along marine coastal areas. The use of sand dredged from the sea or mined from the coast, however, is being discouraged due to the fact that it contains high levels of chloride which enhances the corrosion of steel reinforcement in concrete. Additionally, mining of coastal sand may also affect the morphology of the coast leading to environmental problems such as flooding. Natural sand also occurs as a product of weathering of some rocks (Cement concrete and aggregates Australia 2008).

In situations where natural sand is not available, manufactured sand or crushed rock sand is used as alternative to natural sand. Manufactured sands or crushed rock sands are obtained intentionally from rocks which are quarried, crushed and graded into requisite sizes. According to Chang et al., (2013) some manufactured sands are obtained by crushing source rocks such as granite, gneiss, dolerite, basalt and gabbro. They indicated that granite dust, as one of the many substitutes to natural sand, is favoured for construction in some countries including Canada, Singapore and New Zealand. In Korea, limestone rock sand is the most preferred manufactured sand substitute to natural sand (Choi and Choi, 2013). Other substitutes to natural sand include crushed and screened waste glass and recycled copper slag.

Even though source rocks for producing manufactured sand may be identified and exploited, the key factors that have to be considered in selecting alternative fine aggregate to natural sand include its availability and cost, accessibility, environmental impact and suitability for local construction works (Chang et al 2013).

Manufactured sand for concrete production may have some inherent problems which could negatively affect the strength of concrete. Manufactured sand is known to contain about 10 to 20 percent micro-fines as compared to about 7 percent micro-fines in natural sands (Cement concrete and aggregates Australia 2008). Consequently, manufactured sand when used for concrete requires more water than natural sand for a given workability, which could affect the strength of the concrete.

In Ghana, gneiss rock sand, though expensive, is the only type of manufactured sand produced by commercial aggregate producers (Woode et al 2015) and used as substitute to natural sand. Gneiss rocks aggregate characteristics and their mineral constituents, therefore, are very important as far as the quality of concrete products made with gneiss rock sand is concerned.

The characteristic shape of the grains of crushed rock sand is the major distinction between crushed rocks sand and natural sand. The crushed rocks sand contain grains of irregular shape, and may also contain free mica flakes which are easily weathered. The natural sand, on the other hand, lacks free mica due to weathering, and the grains are more regular (Lagerblad, Gram and Westerholm, 2013).

According to Danielson and Rueslatten (1984) mica minerals such as biotite in crushed rock sand are more harmful to concrete than weathered and altered mica in natural sand due to changes in cation exchange capacity. They also suggested that a major factor influencing mortar strength is the extent of alteration of feldspar mineral into sericites, indicating that natural sand contains less feldspars and mica minerals due to weathering which converts the minerals into clay minerals.

Since the level of micro-fines in manufactured sand far exceeds the proportion required for a concrete mix, blending of the manufactured sand with natural sand is, therefore, the most useful and productive way of controlling some of the undesirable properties of crushed rock sand, which also lowers the internal friction between the particles, thereby improving workability. The effects of high levels of micro-fines include the fact that it lowers bleeding. Micro-fines may contain minerals that are likely to increase the water requirement of the concrete mix (Cement concrete and aggregates Australia 2008). Additionally, the micro-fines (dust) may form a coating on the aggregates and weaken the bond between the cement paste and aggregates.

The production of manufactured sand has significant effect on the environment. Biondini and Frangopol (2008) have suggested that to crush one ton of rocks into sand very high amount of energy is required, resulting in high carbon dioxide emission, which may affect the environment and contribute to global warming. Though mining of natural sand also affects the environment, less carbon dioxide is generated due to the fact that low energy is required for its mining.

The need for the use of manufactured sand has become imperative since the sources of natural sand are getting depleted as a result of massive sand winning activities which have led to extensive land degradation, loss of biodiversity and fertile land for farming (Elavenil and Vijaya, 2013). Therefore, in Ghana and other countries, it is becoming increasingly difficult to get deposits of natural sand of consistent grading requirement and appropriate silt and clay content. Hence, the use of manufactured sand is gradually gaining acceptance even though more expensive than natural sand. Additionally, manufactured sand contains some deleterious substances which could adversely affect concrete. Natural sand is free from some of these harmful substances due to weathering. Blending of natural and manufactured sands may be important due to the disadvantages associated with manufactured sand. The blending will reduce the amount of deleterious substances and the risks associated with them and the cost of the sand, which will eventually lower the cost of the final product.

The aim of this experiment, therefore, is to determine how the strength of concrete will be affected when natural sand and manufactured sand are blended and used as fine aggregates for concrete production.

2. Materials and methods

2.1 Materials

The natural sand which was used as fine aggregate for producing concrete, was obtained from pits in the Greater Accra region of Ghana. The manufactured sand, however, is derived from gneiss rocks of the Basin Granitoid formation (formally Cape Coast Granitoid Complex) in Ghana by commercial aggregate producing companies who crush the rocks into appropriate sizes. The coarse aggregates were also obtained from crushed gneiss rocks.

2.2 Methods

2.2.1 Particle size analysis

Representative samples of the natural sand and the manufactured sand were poured into different stacks of sieves and shaken mechanically. The soil retained on the sieves and the percentage passing are recorded and plotted in line with ASTM C136. The natural sand and the manufactured sand were sieved separately using sieve sizes of 0.5mm, 1.0mm, 2.0mm, 3.0mm and 5.0mm.

2.2.2 Concrete production

The concrete was produced using a mix ratio of 1:2:4 by weight and water- cement ratio of 0.45. All ratios and concreting procedures were maintained throughout the experiment. In the first test hundred percent natural sand was used as fine aggregate for the concrete with no manufactured sand. In the subsequent test, ten percent of the weight of the natural sand was replaced with ten percent of the weight of manufactured sand. In other tests, the weight of natural sand was further reduced by ten percent and that of the manufactured sand increase by ten percent. In the final test, fifty percent of the natural sand was replaced with fifty percent manufactured sand before being used for the concrete. The coarse aggregates used are of 10 and 14mm nominal sizes. A total of 12 concrete cubes were produced and cured using standard procedures, and were crushed on 28 days. Mixing of the concrete was done by means of a concrete mixer.

2.2.3 Compressive Strength Tests

The Compressive Strength tests were carried out using a 2000KN capacity compressive strength test machine at constant loading rate. The compressive strength of each sample was determined by dividing the failure load by the cross sectional area of the 150mm x150mm x 150mm cube.

3. Results

The results of particle size analysis of the natural and manufactured sands as well as the outcome of the compressive strength tests are recorded in the Tables below.

Table 1. Results of particle size analysis of the natural sand (NS)

Particle size (mm)	Mass of natural sand retained (g)	% natural sand retained	% of natural sand passing
5.0	0	0	100
3.0	234.22	9.9	90.1
2.0	372.43	15.7	74.4
1.0	723.66	30.5	43.9
0.5	1043.03	43.9	0

Table 2. Results of particle size analysis of the manufactured sand (MS)

Particle size (mm)	Mass of Manufactured sand retained(g)	% Manufactured sand retained	% of Manufactured sand passing
5.0	0	0	100
3.0	287.14	12.9	87.1
2.0	255.90	11.5	75.6
1.0	623.66	28.1	47.5
0.5	1050.47	47.3	0.2

Table 3. Compressive strength test results and percentage sand added

Weight of cube (Kg)	Density (Kg/dm3)	Maximum Load(KN)	Compressive strength (MPa)	Average Compressive strength (MPa)	Percentage Manufactured sand (%)	Percentage Natural sand (%)
7.31	2.17	384.35	17.08	17.42	0	100
7.38	2.19	399.36	17.75		0	100
7.43	2.20	395.70	17.59	17.79	10	90
7.44	2.20	404.84	17.99		10	90
7.45	2.21	409.59	18.20	17.78	20	80
7.53	2.23	390.99	17.36		20	80
7.30	2.16	397.99	17.69	17.91	30	70
7.32	2.17	408.04	18.14		30	70
7.79	2.31	410.41	18.24	18.19	40	60
7.71	2.28	408.04	18.14		40	60
7.76	2.30	417.90	18.57	18.33	50	50
7.70	2.28	406.76	18.08		50	50

4. Discussion

Using values from Figure 1, which is a plot of the results of the particle size analysis, the uniformity coefficient, the coefficient of gradation and the hydraulic conductivity of the two soil types were generated from equations 1, 2 and 3 respectively and values obtained are recorded in Table 4.

The uniformity coefficient (Cu) = $\frac{D_{60}}{D_{10}}$ ……………………………….....1

The coefficient of gradation (Cg) = $\frac{(D_{30})^2}{D_{60}\ x\ D_{10}}$ ……………….................2

Hydraulic conductivity (k) = 10^{-2} x $(D_{10})^2$ ……………………………3

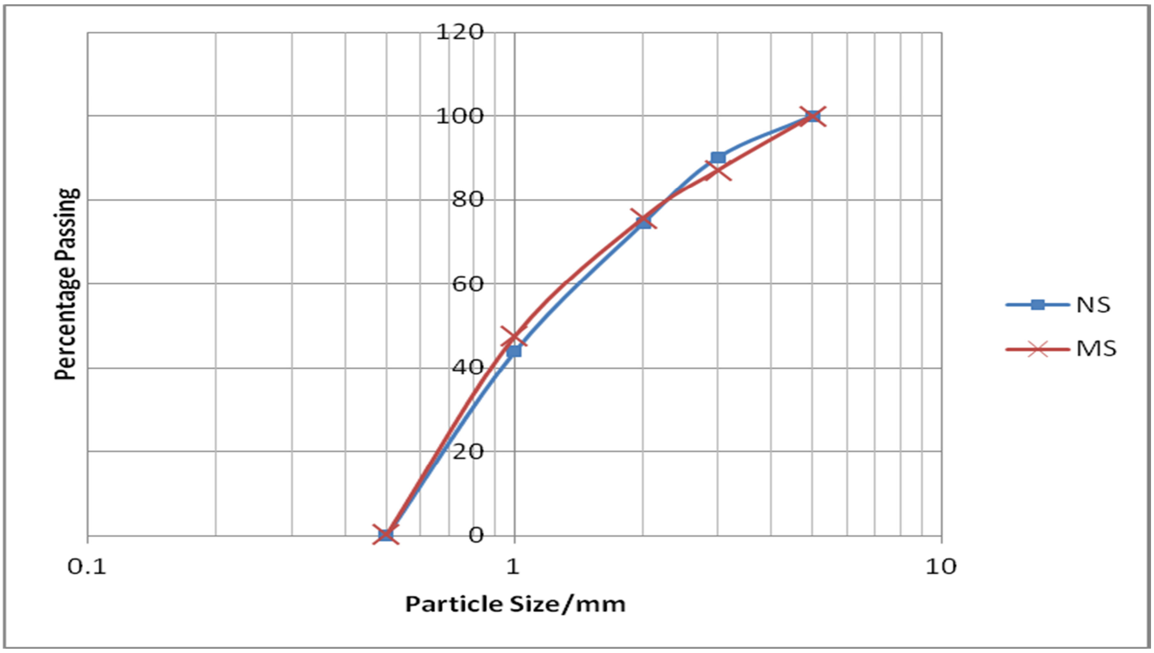

Figure 1. Graph showing particle size distribution for natural sand (NS) and manufactured sand (MS) using value from Tables 1 and 2.

From Table 4, the natural sand has D_{60} of 1.50mm, D_{30} of 0.80mm and D_{10} of 0.57mm, and its uniformity coefficient is 2.63 and the coefficient of gradation is 0.748. This has been interpreted to mean that the soil is well graded. The hydraulic conductivity of the natural sand is low represented by a value of 3.2 x 10^{-6} ms^{-1}.

Table 4. Data generated using results of particle size analysis

Sand Type	D_{10}/mm	D_{30}/mm	D_{60}/mm	Cu	Cg	k/ms^{-1}
Natural sand	0.57	0.80	1.50	2.63	0.748	3.2 x 10^{-6}
Manufactured sand	0.57	0.75	1.40	2.46	0.705	3.2 x 10^{-6}

The manufactured sand on the other hand has D_{60} of 1.4mm, D_{30} of 0.75mm and D_{10} of 0.57mm and uniformity coefficient of 2.46. Its coefficient of gradation is 0.705 indicating that the soil is well graded. The hydraulic conductivity for the manufactured sand is also 3.2 x 10^{-6} ms^{-1}since both soils have the same effective size (D_{10}) of 0.57. The overall permeability of the two soils is low.

From Fig. 1 the natural sand contains a narrow range of sizes consisting of 26 % fine gravels and 74% coarse sand and could be described as well graded gravel coarse sand. Similarly, the manufactured sand also covers a narrow range of sizes comprising 24% fine gravels and 76% of coarse sand and could also be described as well graded gravel coarse sand. Consequently, in terms of grading and particle size characteristics, manufactured sand and the natural sand are similar and can be described as well graded gravel coarse sand. Since the manufactured sand and the natural sand have nearly the same particle size distribution, the aggregate sizes would have insignificant effect on their engineering properties.

The natural sand and the manufactured sand have similar size ranges and so the overall aggregate surface area will virtually remain unchanged after blending. If the proportion of fines is increased in relation to the coarse aggregates, however, the overall aggregate surface area will increase. Generally, manufactured sand has more micro-fines than natural sand and so blending of the two fine aggregates is likely to result in increase overall surface area and water demand, and consequently a reduction in compressive strength, especially as the quantity of manufactured sand is increased. Since the fine aggregates size distribution for the experiment were nearly the same there was virtually no change in water demand, thus the water-cement ratio remained constant for all the test samples.

Values from Table 3 shows that for the control concrete cube, which contain natural sand as the only fine aggregate and no manufactured sand, gave the average compressive strength test result of 17.42 N/mm^2. The strength of the concrete increased gradually with each addition of manufactured sand until the strength came to 18.33N/mm^2 when 50% natural sand was mixed with 50% manufactured sand. This represents about 6% change in strength as the amount of manufactured in the concrete increases up to 50% (Fig. 2). This change in strength is expected to increase as the percentage manufactured sand increases due to an increase in irregularly shaped particles contribution from the manufactured sand. A further research may be necessary to confirm this assertion.

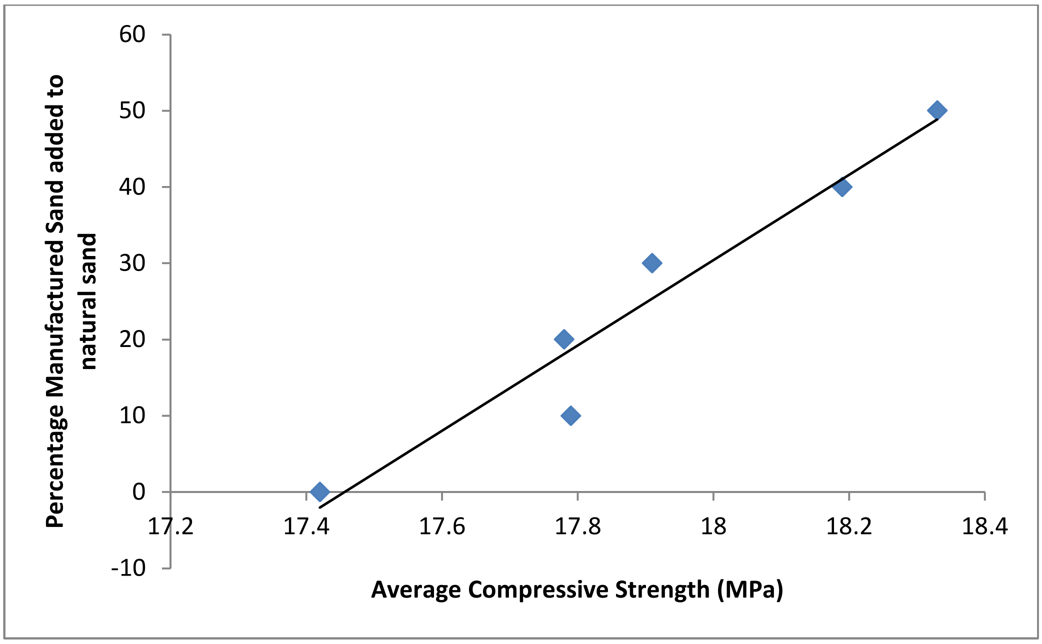

Figure 2. A graph of percentage manufactured sand added to natural sand against average compressive strength

It is generally known that manufactured sand contains more micro-fines than natural sand (Cement concrete and aggregates Australia 2008) and the micro-fines could lead to weak bonds between the coarse aggregates and the cement paste and resultant weak concrete strength. The compressive strength test results obtained, however, rather showed an increase though small. This implies that the effect of other factors might have overturned that of the micro-fines. The most likely factor is the differences in the shape of the two soil types.

The long term effect of blending manufactured sand and natural sand on concrete may be dependent on the quantity of deleterious substances, such as biotite, feldspar and strained quartz minerals and dust particles, present in them if all other factors are kept constant. Woode (1994) found that the major minerals in gneiss rock found in south-east Ghana include quartz, biotite, hornblende and plagioclase feldspar. Using petrographic point counting methods he obtained average mineral volumes of 39%, 17%, 10% and 33% for the quartz, biotite, hornblende and plagioclase feldspar respectively. Thin section analysis which he conducted indicate that the hornblende is partially chloritized, the feldspar has undergone incomplete sericitization and the quartz shows evidence of straining characterized by mechanical twins.

The strained quartz, the biotite and the altered forms of the hornblende and feldspar, which are present in the manufactured sand, can be harmful to concrete in the long term. The strained quartz in concrete could lead to alkali-silica reaction whilst the presence of biotite, which is anisotropic, is known to weaken concrete if present in large volumes. The average volumes of the biotite in some manufactured sand in Ghana is significant (17%) and, therefore, could lower the strength of concrete made with large quantity the manufactured sand by as much as 15% due to its smooth surface resulting in weak bonds between the cement paste (Wakizaka, Ichikawa, Nakamura and Anan, 2005; Jayawardena and Dissanayake ,2008). It is necessary, therefore, that in selecting manufactured sand for concrete production it should be ensured that the level of fresh biotite should be very minimal (< 5%) since they are more harmful than the weathered and altered biotite in natural sand (Danielson and Rueslatten, 1984).

The biotite in natural sand has weathered and, therefore, may be minimal or not available in the sand. When natural sand is blended with manufactured sand, the risk posed by biotite in manufactured sand to bonding of cement and fine aggregates is lowered due to the reduction in their overall quantities. The strained quartz is present in both manufactured sand and natural sand.

5. Conclusion

The experiment has shown that when the natural sand is replaced with 50% manufactured sand the strength of the concrete showed an increase of about 6%. This is attributed to the irregular shaped particles of the manufactured sand which tend to enhance the soil properties and improve bonding resulting in high strength. The blending of natural sand with manufactured sand reduces the quantity of deleterious minerals such as biotite and the level of harmful micro-fines in the blended sand, and also the risks associated with them. In the long term, however, the deleterious minerals in the manufactured sand could reduce the strength of the concrete. Partial replacement of natural sand with manufactured sand is therefore, suitable if it is ensured that the level of fresh biotite is minimal in the manufactured sand.

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