The Effect of Maximum Coarse Aggregate Size on the Compressive Strength of Concrete Produced in Ghana

Anthony Woode* David Kwame Amoah Issaka Ayuba Aguba Philip Ballow
Department of Civil Engineering, Accra Polytechnic, P.O.Box 561 Accra, Ghana
*Email of Corresponding Author: pstwoode@gmail.com

Abstract
An experiment was conducted to determine the effect of different sizes of machine crushed gneisses used in Ghana for concrete production on the compressive strength of concrete. Coarse aggregate samples of maximum sizes of 10mm, 14mm and 20mm were used to produce concrete at constant water/cement ratio of 0.63. In all the experiments, the concreting procedures and materials were kept constant whiles the maximum coarse aggregate sizes were varied. A total of 36 concrete cubes were crushed at 7, 14, 21 and 28 days to determine their compressive strengths.The results show that the smallest coarse aggregate size gave the highest compressive strength and lowest slump at constant water/cement ratio. A regression analysis also shows that the relationship between the maximum coarse aggregate size and the compressive strength follows a polynomial with R^2= 1; indicating that the model is reliable. The optimum maximum coarse aggregate size for the best compressive strength of 28 day concrete was therefore found to be 8mm for the water/cement ratio of 0.63. The analysis further shows that as heterogeneity increases the compressive strength of concrete reduces.
Keywords: Gneiss, compressive strength, aggregate sizes, slump, heterogeneity.

1. Introduction

Concrete is stone-like material used for the construction of bridges, pavements, highways, houses and dams. It is produced by mixing sand, gravel or crushed rocks, cement and water and allowed to cure over a period of time.
Several factors are known to influence the strength of concrete. They include their batch ratios, mixing mechanism, transporting and curing processes, aggregate texture and shape and nature of other constituent materials. Additionally, the sizes of the aggregates have been shown to have some influence on the strength of concrete.

Several coarse aggregate types including basalt, quart-dolerite, quartzite, gneisses, granites, limestone, marbles and gabbro have also been shown to affect the compressive strength of concrete.

In Ghana, the rocks which are commercially crushed for use as coarse aggregates in concrete production include quartzites, gneisses, migmatites, granites and granodiorites. The use of granites and granodiorites for concrete production is common in the middle belt of the country (Adom-Asamoah et al. 2014). The quartzites, which form part of the Togo Structural Unit (Togo series) found in the southern part of the country, are metamorphosed to different degrees as suggested by the presence of some sandstone textures and structures, resulting in varying strength characteristics. They are usually hand crushed due to their low quality and as such cost less. The gneisses and migmatites are found within the Dahomeyan Supergroup and the Cape Coast Granitoid Complex in the southern part of the country. They are typically mechanically crushed into desired sizes by commercial aggregate producers. Although expensive compared to the crushed quartzites they are preferred for use in major concrete works which would be subjected to high stresses because of their high quality.

Abdullahi (2012) investigated how quartzite, granite, and river gravel influence the strength of concrete and established that aggregate type has effect on the compressive strength of normal concrete, and that concrete made from crushed quartzite would give the highest compressive strength at all ages but concrete made with granite as coarse aggregate would give the least strength. On the contrary, Aginam et al. (2013) found that concrete made with granite as coarse aggregate gave higher compressive strength compared to concrete made with washed and unwashed gravels as coarse aggregate component.

Yaqub and Bukhari (2006) found that 10mm and 5mm aggregates concrete gave higher compressive strength than other types of aggregates when they conducted tests to determine the extent of influence of 37.5mm, 25mm, 20mm, 10mm and 5 mm aggregate sizes on the compressive strength of high strength concrete.

Oyewole et al. (2011) also investigated the effects of aggregate sizes on the properties of structural concrete so as to establish the aggregate size that will improve the properties of structural concrete. They concluded that the average compressive strength of concrete increases as the sizes of coarse aggregates are reduced. In another experiment to determine the influence of the size of coarse aggregate on the compressive strength of concrete, Xie et al. (2012) confirmed the earlier findings that the compressive strength decreased when the maximum coarse aggregate size was increased.

Kumar and Krishna (2012) found that cinder based lightweight concrete of 20MPa attained optimum compressive strength with the use of 12.5mm aggregate size, whilst in the production of 30MPa concrete the best

28-day compressive strength was obtained with 10mm size aggregates.

In a study to assess the effect of size of aggregate in higher grade concrete using high volume fly ash, Bhikshma and Florence (2013) found that aggregate sizes influence its strength and that maximum size of coarse aggregate of 12.5 mm gave the highest compressive strength, splitting tensile strength and flexural strength.

A string of compressive tests on normal strength concrete and high strength concrete with maximum aggregate sizes of 10 mm and 20 mm conducted by Su and Cheng (2013) concluded that normal strength concrete with compressive strength lower than 60 MPa, larger maximum aggregate sizes would yield a lower compressive strength, but for high strength concrete with compressive strength greater than 80 MPa the effect of aggregate size was insignificant. They further suggested that aggregate sizes of 10 mm and 20 mm have little effect on the elastic modulus.

Even though coarse aggregates produced from gneisses have been used for many years in Ghana for concrete production, there are no known documented evidence as to how their sizes influence the compressive strength.

The aim of this study therefore, is to determine the extent to which different sizes of gneissic coarse aggregates produced in Ghana and used for concrete production would influence the compressive strength of 28-day concrete.

2. Materials and methods

2.1. Materials

2.1.1. Fine and coarse aggregates

The coarse aggregates used for the concrete were 10, 14 and 20mm maximum sizes commercially crushed stones obtained from garnet gneiss rock deposit found within the Dahomeyan Supergroup in the Shai Hills area (5° 54′ 0″ N, 0° 4′ 0″ W) of the Greater Accra Region of Ghana. The garnet gneiss rock has average consolidated bulk and relative densities of 1650kg/m3 and 2.97 respectively (Ian Lunt-Bell (na)). Naturally occurring fine aggregates (sand) of maximum size of 2mm obtained from pits in the Greater Accra region were used for the concrete.

2.1.2. Cement

The cement used is the commercially available Ordinary Portland limestone cement of 32.5 Grade and conforming to Ghana Standard 914:2007. Portable water free from any visible impurities was used for the experiments.

2.2. Methods

2.2.1. Batching of materials and Workability

The batching of materials for concrete production was done by weight in the ratio 1:2:3 and water /cement ratio of 0.63. In all 36 concrete cubes (150mm x150mm x 150mm) were made after batching and mechanical mixing for the compressive strength test. Apart from the variation in the coarse aggregate sizes the concreting procedures and water/cement ratio were kept constant for all the samples. The workability of the fresh concrete was determined by slump test in line with ASTM C 143.

2.2.2. Compressive strength tests

Compressive strength tests were carried out on the 150mm x150mm x 150mm cubes in a 2000KN capacity compressive strength machine after curing and in line with BS EN12390 series. The smoothest parts of the cube were placed on the machine and load was then applied. A strain gauge was attached to the compression machine and after every 15seconds the failure load was recorded until the cube was finally crushed. The peak load was noted as the crushing load. The compressive strength of each sample was determined as follow:

$$\text{Compressive strength} = \frac{Crushing\ Load\ (N)}{Area\ Of\ Cube(mm^2)}$$

3. Results

Table 1. Results of compressive strength test and Slump test of concrete using 10mm size gneisses.

Maximum size and type of Coarse aggregate	Slump (mm)	Age (Days)	Average Weight (Kg)	Average Density (Kg/m^3)	Average Failure Load (KN)	Average Compressive Strength (N/mm^2)
10mm Gneiss	175	**7**	8.047	2384	417	18.5
	175	**14**	8.114	2404	468	20.8
	175	**21**	8.035	2381	497	22.1
	175	**28**	8.074	2392	532	23.7

Table 2. Results of compressive strength test and Slump test of concrete using 14mm size gneisses.

Maximum size and type of Coarse aggregate	**slump** (mm)	Age (Days)	Average Weight (Kg)	Average Density (Kg/m^3)	Average Failure Load (KN)	Average Compressive Strength (N/mm^2)
14mm Gneiss	**190**	**7**	8.035	2382	367	16.3
	190	**14**	8.052	2386	421	18.7
	190	**21**	8.094	2398	454	20.2
	190	**28**	8.113	2404	495	22.0

Table 3. Results of compressive strength test and Slump test of concrete using 20mm size gneisses.

Maximum size and type of Coarse aggregate	slump (mm)	Age (Days)	Average Weight (Kg)	Average Density (Kg/m^3)	Average Failure Load (KN)	Average Compressive Strength (N/mm^2)
20mm Gneiss	210	**7**	8.154	2416	278	12.4
	210	**14**	8.142	2413	320	14.2
	210	**21**	8.141	2412	341	15.2
	210	**28**	8.126	2.408	364	16.2

Table 4. Maximum size of aggregates, ratio of sizes and the compressive strength of 28 day concrete.

Compressive strength of 28 day concrete (N/mm^2)	Maximum size coarse aggregate (mm)	Maximum size of fine aggregate (mm)	Ratio of maximum size of fine to size of coarse aggregate
23.7	10	2	0.20
22.0	14	2	0.14
16.2	20	2	0.10

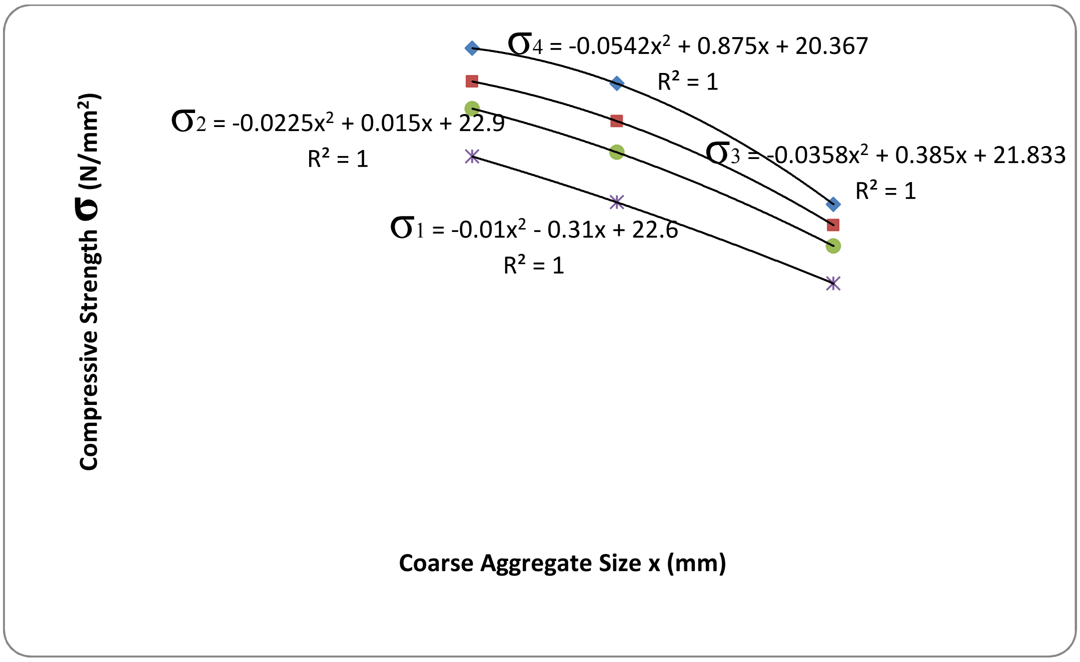

Figure 1. A graph of Compressive Strength (σ) of concrete of varying ages against oarse Aggregate Size (x) showing regression equations.

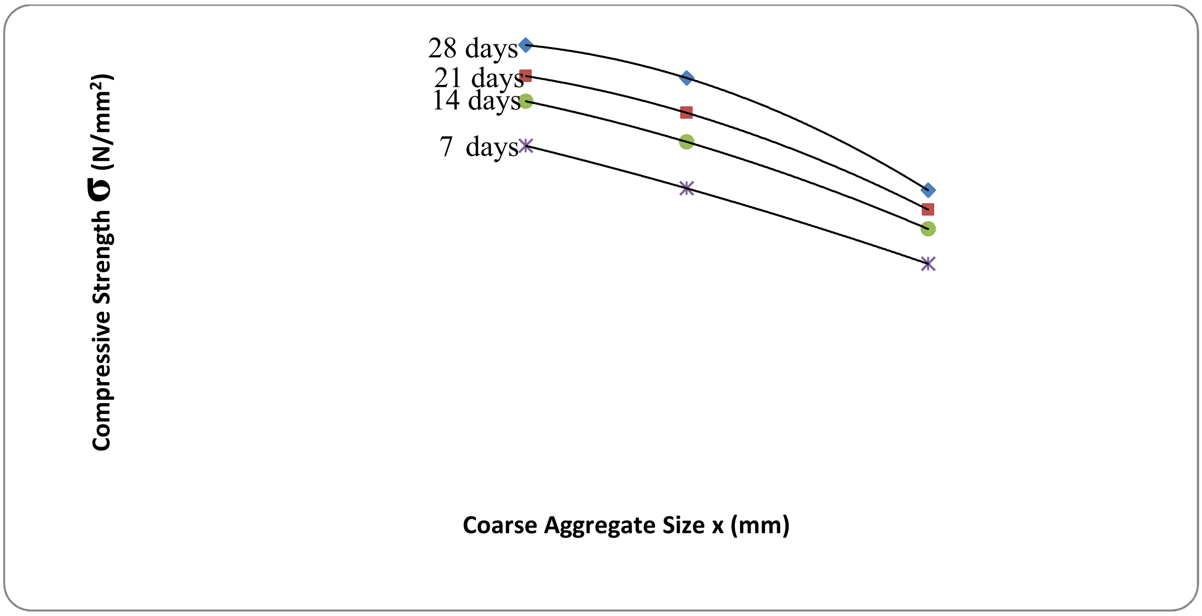

Figure 2. A graph of Compressive Strength (σ) of Concrete of varying ages against Maximum Coarse Aggregate Size (x).

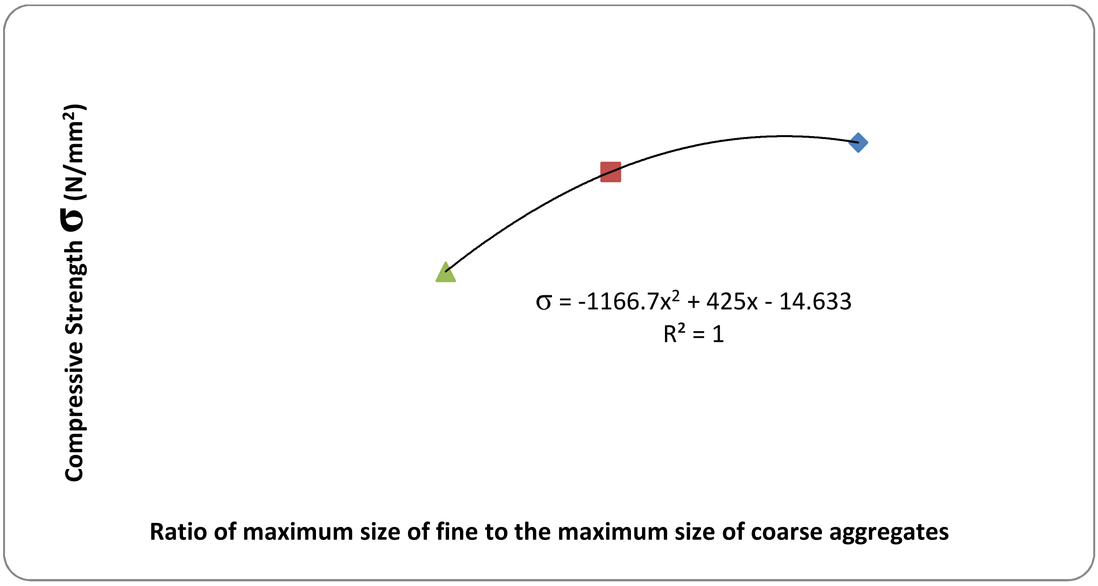

Figure 3. A graph of 28-day Compressive Strength of Concrete against the ratio of size of fine aggregates to the maximum size coarse aggregates.

4. Discussion

The slump values increase as the maximum coarse aggregate size increases, and decreases with smaller coarse aggregate size at constant water/cement ratio (Tables 1, 2 and 3). This relationship is consistent with known experimental fact that the larger the aggregate size the smaller the surface area to be wetted per unit mass and therefore if the water/cement ratio is kept constant there will be more water available to increase the slump for concrete with larger aggregate size. Larger aggregate sizes will consequently require less water in other to maintain high strength (Neville 1999).

The change in the slump values also reflect in the compressive strength of the hardened concrete. Concrete made with smaller coarse aggregate size have higher strength than concrete made with bigger size of coarse aggregate due to the weak bonds in the later resulting from greater heterogeneity, internal bleeding and the development of micro cracks (Shetty, 2000).

A simple regression analysis of compressive strength and the maximum coarse aggregate size values in Tables 1 to 3 are shown in Figures 1 and 2. The figures show that the maximum size of the coarse aggregates strongly influences the compressive strength of the concrete irrespective of the age of the concrete. It is clear from the figures that the relationship between the maximum coarse aggregate size and the compressive strength follows a polynomial with $R^2 = 1$, indicating that the model is reliable and can be used to predict the compressive strength of concrete for a given size of coarse aggregate. The trend persists as the concrete progresses in age.

From Figures 1 and 2 the dependency of the 28 day compressive strength of concrete (σ_4) on the maximum size of the coarse aggregate (x) is defined by the regression equation (1)

$$\sigma_4 = -0.0542x^2 + 0.875x + 20.367 \quad (1)$$

From equation (1) the optimum maximum size of coarse aggregate for 28 days compressive strength of concrete (σ_4) is 8mm for a water/cement ratio of 0.63. This finding confirms the relationship between optimum maximum size of coarse aggregate and water/cement ratio as in Neville (1999).

All things being equal, if this optimum maximum coarse aggregate size (x) is exceeded the compressive strength of 28 day concrete begins to decline. This is also consistent with the findings of Shetty (2000).

In order to determine how the heterogeneity of aggregates influences the concrete strength, a regression graph (Figure 3) of compressive strength of concrete is plotted against the ratio of the maximum size of fine aggregate to the maximum size of the coarse aggregate, using values from Table 4. The result is defined by equation (2) having $R^2 = 1$.

$$\sigma = -1166.7\,x^2 + 425x - 14.633 \quad (2)$$

Where σ = compressive strength and

x = ratio of maximum size of fine aggregate to the maximum size of coarse aggregate.

It can be deduced from equation (2) that the optimum ratio of maximum size of fine aggregate to the maximum size of coarse aggregate in order to attain the best compressive strength is 0.18.

From Figure 3 it can also be seen that as heterogeneity increases, due to increased maximum coarse aggregate size as against constant maximum fine aggregate size, the strength of concrete reduces. This is consistent with the findings of Neville (1999) and Shetty (2000).

5. Conclusion

The compressive strength of concrete made with10mm maximum aggregate size is higher than that of 14mm and 20mm sizes. However, the slump values of concrete made with 20mm sizes of gneisses is higher than that of 10mm and 14mm sizes gneisses at the same water/cement ratio.

The relationship between the compressive strength and the maximum coarse aggregate size follows a polynomial with $R^2 = 1$, indicating that the model is reliable for predicting the compressive strength of concrete for a given size of coarse aggregate. Consequently the optimum maximum coarse aggregate size for the best compressive strength of 28 day concrete was found to be 8mm for water/cement ratio of 0.63.

The optimum ratio of the maximum size of fine aggregate to the maximum size of coarse aggregate for the highest compressive strength is 0.18 for the water/cement ratio selected. This shows that the greater the heterogeneity the lower the compressive strength of concrete.

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