Effect of Sand Fines and Water/Cement Ratio on Concrete Properties

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Abstract

Sand fines (clay/silt) and water/cement ratio have been reported to be one of the causes of weakness in concrete strength. A study was conducted to determine the effect of fines content in sand and water/cement ratio on some properties of concrete. Fines content in sand of 2%, 4%, 6%, 8%, 10% and 12% as well as water/cement ratio of 0.55, 0.6 and 0.7 were used. The concrete were prepared using the basic mix 1:2:4. Workability test on flesh concrete as well as compression and split tensile strengths were conducted in accordance with BS 1881. The results show that, workability of concrete decreased as fines content increases. At the same level of fines content, workability increases when the W/C increased. The study again revealed that up to 4% fines content, compressive strength increased as the fines content increases. There was a decreased in the compressive strength with increased in all W/C. The same trend was found for the tensile splitting strength results. Predicting the effect of fines and W/C on work ability and strengths of concrete using regression analysis suggest that, over 80% of the variation in the workability and strengths were influenced by fines and W/C. It was concluded from the study that, fines content of 4% in sand and water/cement ratio of 0.55 is appropriate for concrete for structural use.

Keywords: Sand Fines; Water/cement Ratio; Workability; Strength; Concrete

Abbreviations: BS: British Standards; ASTM: American Standard for Testing and Materials

Introduction

Concrete is a very important material in the construction industry which is spearheading infrastructural development in Ghana leading to the expected prosperity and growth of the nation. The quality of concrete constituent materials controls its strength [1] which has also been found to be one of the causes of building collapse all over the world [2-4]. For this reason attention must be given to the factors which affect the strength of concrete [5-7].

Among these factors are sand fines which are materials that passes through the 75μm sieve. These fines are considered as an impurity in building sand in the BS882:1992 [8]. The presence of sand fines in concrete is likely to affect the workability, strength and long-term performance of concrete [9]. To this effect, the percentage limit of sand fines (clay/silt) is recommended by various building standards in other to check their effects on the strength of concrete. Some of which are the British Standards (BS), and the American Standard for Testing and Materials (ASTM) which recommends 4% and 10% of fines in building sand respectively. Nonetheless, Ghana is yet to specify the limit of fines (clay/silt) percentage in building sand for producing

concrete. Moreover, it has been recommended by Danso and Boateng [10] to investigate the quality of building sand used in the Ghanaian construction industry which is yet to be realized.

Another contributing factor affecting concrete strength is the water content used which in some cases are increased to improve workability [11,12]. When the fines content in sand are excessive, there is the need to add more water to the concrete mix in other to improve the workability. That is fine particles such as clay and cement interact with water in a physiochemical state which leads to more absorption of water than that of fine and coarse aggregates. Research have shown that higher amount of sand fines in concrete results in poor workability. This eventually leads to the addition of water to the concrete mix before or even during the unloading process to improve workability [12].

Meanwhile, research have also shown that an increase in water/cement ratio result to a decrease in the compressive strength of concrete [13,14]. Additionally, the increase in sand fines content has also been found to decrease the compressive and tensile strengths of concrete [15,16]. Inadequate sand fine

content also has adverse effect of the strength of concrete due to poor adhesion. Researchers have therefore develop various models for predicting the effect of sand fines and W/C on the strength of concrete. However, there is a gap in literature for the combined effect of sand fines and water/cement ratio's effect on the properties of concrete. This paper seeks to address this gap in literature.

Materials and Methods

Materials

The materials used were crushed granite as coarse aggregate, natural pit sand, ordinary Portland cement and water. Physical properties of the aggregates were analysed. These properties included the specific gravity, water absorption, fineness modulus, surface texture, particle shape and colour. The specific gravity and water absorption were conducted in accordance with the ASTM C128:1997 for fine aggregate and ASTM C127:2007 for coarse aggregate.

Testing methods and procedures

Sample size: A total of 216 specimens were cast for strength testing. Out of this, 162 were made of 150mm cubes for compressive strength testing at 7, 28 and 91 days curing whereas 54 were made of 150x300mm cylinders for splitting tensile strength testing. The number of concrete batches prepared was 18 containing the various sand fines (clay/silt) replacement in the fine aggregate with three different water/cement ratios.

Figure 1: Extraction of Fines (Clay/Silt) from Sand.

Mixing of concrete: Fines (clay/silt) were initially extracted from sand using dry sieving (Figure 1). During this stage, the sand was first spread and dried in air for some days and sieved with the 600μm sieve. Sand passing through the 600μm was further sieved with the 75μm sieve where the sand particles passing through this sieve were collected for replacement of the sand content in concrete. The sand particles retained on the 75μm sieve were gathered, washed with water to remove left over fines and dried by spreading in air for 7 days.
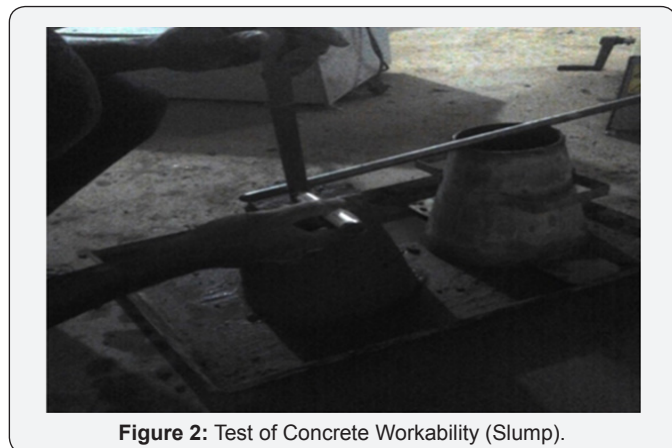
Table 1: Concrete Mix Proportion for Casting Specimens.

Fines (%)	Cement (kg)	Sand (kg)		Coarse Aggregate (kg) (12 mm max. size)
		(Fines)	Normal Sand	
2	15.789	0.632	30.946	63.156
4	15.789	1.263	30.315	63.156
6	15.789	1.895	29.683	63.156
8	15.789	2.526	29.052	63.156
10	15.789	3.158	28.42	63.156
12	15.789	3.789	27.789	63.156
Water Proportion in the Mix				
Water/Cement Ratio		0.55	0.6	0.7
Amount (kg)		8.684	9.473	11.052

Figure 2: Test of Concrete Workability (Slump).

The amount of various materials needed for each mix proportion which could cast 9 cubes and 3 cylinders were batched for concrete mixing (Table 1). Different batches of concrete consisting sand with fines content of 2%, 4%, 6%, 8%, 10% and 12% with three constant water/cement ratios of 0.55, 0.60 and 0.70 were prepared for the study. The amounts of coarse aggregate used were kept constant for all batches. The concrete were mixed using 1m^3 drum concrete mixer.

Workability test: Slump measurement was taken immediately after mixing each batch of concrete before casting them into specimen moulds (Figure 2). The moulds were coated with oil just before concrete casting. The concrete were cast in three layers into the moulds and each layer was tamped 25 times

with 16mm diameter rod to removed entrapped airs present in the concrete. Excess concrete were cut away and the surface levelled with the trowel.

Curing of specimens: The specimens were initially cured in air for 24 hours. The moulds were then removed and were then immersed into water in a curing tank for 7, 28 and 91 days.
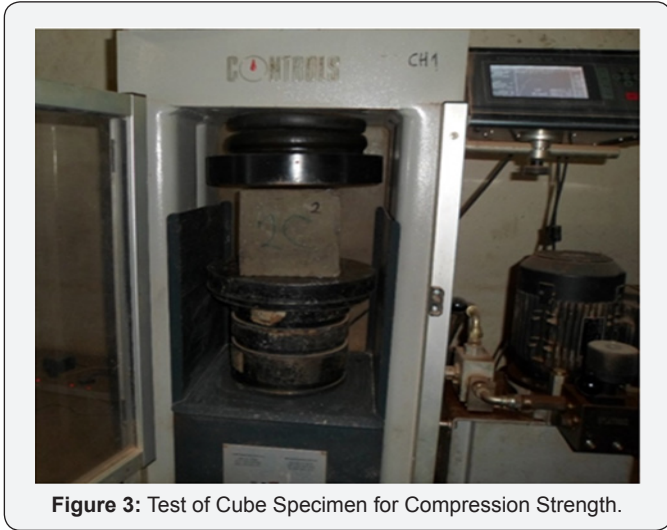

Figure 3: Test of Cube Specimen for Compression Strength.

Strength testing: Cube specimens for compressive strength test were conducted in accordance with the BS EN 12390-3 [17]. The cube specimens were inserted into a universal testing machine of which the surface of the cubes were aligned perpendicularly to the platens. An automatic loading rate within the range of 0.04MPa/s to 0.06MPa/s was applied to the specimen until failure occurred (Figure 3). The capacity of the testing machine was 2000kN maximum loading.

Figure 4: Test of Cylindrical Specimen for Splitting Tensile Strength.

The cylindrical specimens for splitting tensile strength test were conducted in accordance with the BS EN 12390-6 [18]. A diametrical compressive force was applied on the cylindrical specimens placed centrally with its axis horizontal between the platens of the universal testing machine. The specimen was supported in a jig with plywood used as parking strips conforming to EN 316. An automatic constant rate of loading within the range of 0.04MPa/s to 0.06MPa/s was applied without shock which increased continuously until splitting of specimen occurred (Figure 4).

Results and Discussion

Physical properties of aggregates

Table 2: Physical Properties of Study Aggregates.

Property	Fine Aggregate	Coarse Aggregate
Fines (%)	13.91	-
Specific gravity	2.6	2.61
Water absorption (%)	1.4	0.5
Fineness modulus	2.61	2.5
Surface texture	Rough	Rough
Particle shape	Angular	Irregular
Colour	Gray	Imperial gray

Table 2 gives the physical properties of the aggregates that were used for the study. The specific gravity of saturated surface-dry samples measured were 2.60 and 2.61 for fine and coarse aggregates respectively. This indicates the aggregates used for the study were within the accepted specified values for concrete production in accordance with BS EN 1097-6 [19]. The water absorption for the sand used was 1.4% which is below the specification limit of 2%. This explains that, much of the water used for mixing the concrete will be absorbed by the aggregate to keep it at the saturated surface dry state and the rest for mixing the concrete and hydration of cement. The water absorption of coarse aggregate was 0.5% which was within the normal range from 0.1 to 0.6%. The fineness modulus obtained suggest that, the aggregates used had an approximately average sizes of 600μm and 12.5mm for fine and coarse aggregates respectively. Thus, the sand used was normal sand since it lies within Zone II of geological grading.
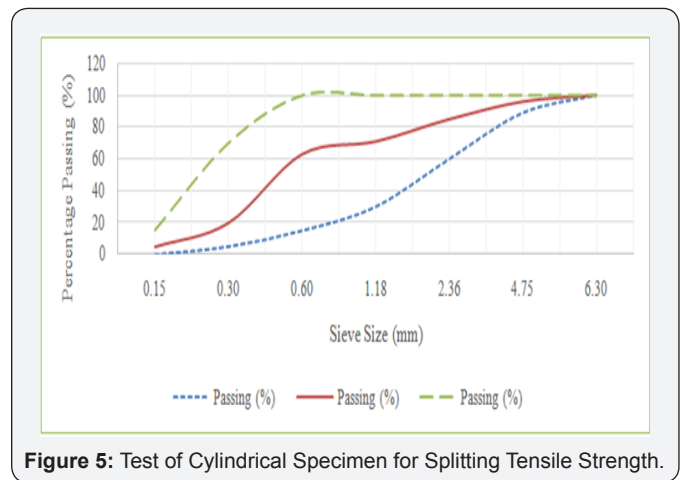

Figure 5: Test of Cylindrical Specimen for Splitting Tensile Strength.

The particle size distribution conducted in accordance with the BS882 were used to plot grading curve for the fine and coarse

aggregates shown in Figure 5 & 6 respectively. The grading curves and the physical properties given in Table 2 indicate the aggregates used for the study were within the accepted range for producing concrete.
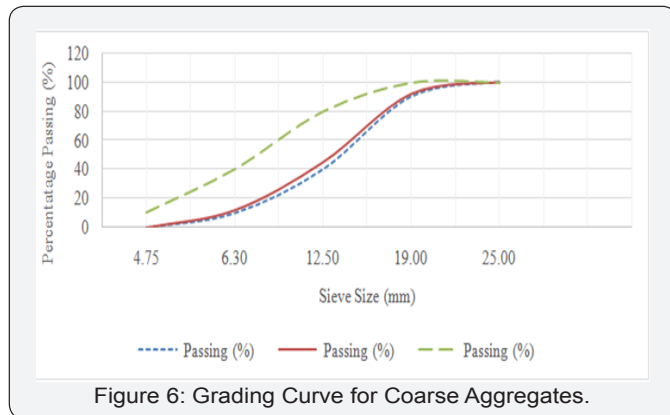

Figure 6: Grading Curve for Coarse Aggregates.

Workability

Table 3 presents the result of workability test given the slump values for the various mixing batches. It is noted that, slump values decreased as the fines percentage in sand increased whereas the slump increased as the water/cement ratio increased agreeing with earlier reports [16,20,21]. The decrease in slump value as a result of increase in fines percentage in sand can be attributed to the fact that finer particles have larger surface area which absorbs more water in concrete mix. Meanwhile, higher water/cement ratio is able to disperse the concrete constituents leading to a higher slump value. This result is again similar to the reports by Alawode and Idowu and Olusola et al. [13]. The degree of workability is explained in the Table 3 where concrete batches with 0.70 water/cement ratio had better slumps ranging from minimum of low to maximum of medium slump.

Table 3: Slump Values for Workability of Concrete.

Water/Cement Ratio (w/c)	Fines (%)	Slump (mm)	Degree of Workability
0.55	2	25	Low
	4	15	Very low
	6	13	Very low
	8	12	Very low
	10	11	Very low
	12	9	Very low
0.6	2	35	Low
	4	30	Low
	6	26	Low
	8	24	Very low
	10	19	Very low
	12	17	Very low
0.7	2	95	Medium
	4	60	Medium
	6	56	Medium
	8	52	Medium
	10	49	Low
	12	47	Low

Table 4: Regression Coefficients for Concrete Workability (Slump).

	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
Constant	-141.905	18.367		-7.726	0
Fines (F)	-235.714	52.989	-0.364	-4.448	0
Water/ Cement Ratio (w/c)	310.476	29.023	0.876	10.697	0

Regression analysis was conducted to predict the relationship among the fines percentage in sand, water/cement ratio and workability of concrete presented in Table

4. The coefficient of multiple determination, R^2 given as 0.899 (Adjusted R^2=0.886) indicates fines percentage in sand and water/cement ratio explains about 90% of the variations in concrete workability. Moreover, the ANOVA suggest the predicted equation is appropriate for determining the effects of fines percentage in sand and water/cement ratio on concrete workability (F = 67.111, p < 0.001). From Table 4, an increase in fines content in sand by one percent resulted to a decrease in concrete slump by approximately 236mm when all other variables are kept constant. On the other hand, an increase in water/cement ratio by one unit (0.01) resulted to an increase in slump by approximately 310mm with all other variables kept constant. The Beta values from the standardized coefficients suggest that, an increase of the fines percentage in sand by a

standard deviation will result to a decrease in concrete slump on the average by 0.364mm. Meanwhile, an increase in the water/cement ratio by one standard deviation will result to an increase in slump on the average by 0.876mm. Equation for predicting concrete workability is hence given as:

$$Wc = -141.905 - 235.714F + 310.476w/c \text{ with } R^2 = 89.9\% \quad \text{(Eqn. 1)}$$

Goodness of fit: $R^2 = 89.9\%$ (Adjusted $R^2 = 88.6\%$); F = 67.111, p<0.001

Compressive and tensile splitting strength

The compressive strength of concrete cubes tested at 7, 28 and 91 days curing as well as splitting tensile strength tested at 28 days curing are presented in Table 5. It can be noted that, the strength of concrete (both compressive and tensile splitting)

increased to 4% fines content in sand beyond which the strength decreased at constant water/cement ratio. The trend was found to be consistent with the report by Seeni et al. ; Cho [16]; Dammo et al. [22]; Iyappan and Manu [21]. Meanwhile, at constant fines content in sand, the compressive and tensile splitting strength of concrete decreased with an increase in water/cement ratio at all curing ages. This trend again supported previous investigation [13,14,23]. The reason may be that concrete with higher fines content in sand absorb more water thereby living inadequate amount of water for the hydration of cement leading to decreased strength. Moreover, higher percentage of fines in sand will require higher amount of water to make the concrete workable which intend result to lower strength of concrete. Thus, higher water/cement ratio disperse the concrete constituents resulting to less bridging of calcium-silicate-hydrate of cement hydration rendering weaker strength of concrete.

Table 5: Average Results of Concrete Compressive and Tensile Splitting Strength.

Water/Cement Ratio	Fines (%)	Compressive Strength (N/mm²)			Tensile SplittingStrength (N/mm²)
		7 Days	28 Days	91 Days	28 Days
0.55	2	15.73	20.83	22.86	1.89
	4	18	21.69	24.18	2.03
	6	16.11	21.25	23.28	1.85
	8	13.9	20.8	22.46	1.61
	10	12.91	20.38	21.66	1.51
	12	12.88	19.32	21	1.51
0.6	2	14.16	18.96	20.82	1.71
	4	15.62	19.93	21.45	1.83
	6	12.98	19.57	20	1.75
	8	12.12	15.78	18.99	1.69
	10	12.09	15.77	17.47	1.62
	12	11.61	13.23	15.77	1.5
0.7	2	12.08	14.68	18.49	1.37
	4	12.47	16.05	18.58	1.44
	6	12.3	15.06	18.32	1.35
	8	12.06	14.04	16.29	1.32
	10	11.37	13.49	15.34	1.31
	12	11.13	12.19	14.96	1.2

Computing regression analysis as shown in Table 6 for predicting compressive strength of concrete at 28 days curing, the ANOVA indicates appropriate prediction using the model (F = 41.998, p < 0.001) however is valid for concrete with 4% fines and beyond. The coefficient of multiple determination, $R^2 = 0.848$ (Adjusted $R^2 = 0.828$) explains that fines percentage in sand and water/cement ratio explains about 85% of the variations in the compressive strength of concrete. The unstandardized coefficients indicates that an increase in fines content in sand by one percent will result to a decrease in compressive strength by 37.1N/mm² when all other variables are kept constant. On the other hand, an increase in water/cement ratio by one unit (0.01) will cause a decrease in the 28-day compressive strength

of concrete by 41.1N/mm² keeping all other variables constant. Table 6 again indicates that an increase in fines percentage in sand by one standard deviation will cause a decrease in compressive strength of concrete cube on the average by 0.408N/mm². The water/cement ratio when increased by one standard deviation will also decrease the compressive strength of concrete on the average by 0.826N/mm². The predicting equation is therefore given as:

$$f_{cu,28} = 45.4357 - 37.143F - 41.136w/c \text{ with } R^2 = 84.8\% \quad \text{(Eqn. 2)}$$

Goodness of fit: $R^2 = 84.8\%$ (Adjusted $R^2 = 82.8\%$); F = 41.998, p < 0.001

Table 6: Regression Coefficients of Compressive Strength.

	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
Constant	45.357	3.169		14.313	0
Fines (F)	-37.143	9.142	-0.408	-4.063	0.001
Water/Cement Ratio (w/c)	-41.136	5.007	-0.826	-8.215	0

Table 7 also presents the regression analysis for the tensile splitting strength of concrete. The coefficient of multiple determination, R^2 indicates that, fines percentage in sand and water/cement ratio explains about 84% (Adjusted R^2 = 0.814) of the variations in the tensile splitting strength of concrete. More so, the test statistic from the ANOVA suggest adequate prediction using the regression model developed (F=38.191, p<0.001) also valid for concrete with 4% fines and beyond. The unstandardized coefficients therefore indicate that, an increase of the fines content in sand by one percent will cause a decrease of 3.195N/mm² in the tensile splitting strength of concrete when all other variables are kept constant. On the other hand, by keeping all other variables constant and increasing the water/cement ratio by one unit (0.01) will result to a decrease in tensile splitting strength by 2.798N/mm². Meanwhile, the standardized coefficients indicate that, an increase of fines percentage in sand by one standard deviation will cause an average decrease in tensile splitting strength of concrete by 0.485N/mm². An increase in water/cement ratio by one standard deviation also decreased the tensile splitting strength of concrete on the average by 0.775N/mm². This explains that water/cement ratio contributes the highest effect on concrete tensile splitting strength. The model predicting the tensile splitting strength is hence expressed as:

Table 7: Regression Coefficients of Tensile Splitting Strength.

	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
Constant	3.532	0.239		14.78	0
Fines (F)	-3.195	0.689	-0.485	-4.635	0
Water/Cement Ratio (w/c)	-2.798	0.378	-0.775	-7.409	0

$f_{ct,28}$ = 3.532 - 3.195F - 2.798w/c with R^2 = 83.6% (Eqn. 3)

Goodness of fit: R^2 = 83.6% (Adjusted R^2 = 81.4%); F = 38.191, p<0.001

Conclusion

This study showed that, compressive strength of a cube specimen made from the basic 1:2:4 mix proportion using cement class of 32.5R is expected not to be less than 20N/mm². On this note, it was concluded from the study results that, sand fines and water/cement ratio beyond 4% and 0.55 respectively significantly weakens the strength of concrete. It is recommended that sand used in Ghana for producing concrete should have fines limited to 4% maximum. Admixtures are also recommended to be used to improve workability instead of increasing water content with no recourse to cement addition during concrete production. Moreover, the chemical and biological composition of fines are recommended to be investigated to determine their influence on concrete properties.

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