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Full Length Research Paper

Effect of aggregates minerology on the strength of concrete: Case study of three selected quarry products in Ghana

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Concrete is the most popular construction material worldwide. More than 50% of construction worldwide use concrete materials, mainly because of its versatility and economy compared to steel in relation to total height of building. The final output of the concrete material is, however, affected by factors including the rock type and its attendant physio-mechanical properties. This paper seeks to investigate the effect of the physio-mechanical properties of three rock types (quartz, sandstone, and quartzite) on the compressive strength of the constituent concrete product, with a maximum rock size of 25 mm. A concrete mix design of C25 was used with a nominal mix of 1:2:4 calculated by absolute weight method and water cement ratio of 0.4. Cube test results show that concrete produced from quartz aggregates produced the highest at all-time strength of 25.6 kN, 0.2% above the expected strength at the end of the 28 day period. Thus concrete produced from quartz rocks revealed a superior strength of 13 and 31% above that of crushed sand stone and quartzite, respectively. Again crush quartz (igneous) rock revealed the highest workability in concrete. The poor compressive test results in strength of the crushed quartzite may be attributed to the week properties such as high porosity, moisture content, permeability and lack of toughness. It is obvious that engineers, practitioners and the local authority should take keen interest in these results in the wake of the recent buildings collapse in Accra.

Key words: Strength properties, compressive strength, concrete, slump, workability, aggregates.

INTRODUCTION

Concrete, a mix component typically comprising four construction materials: coarse aggregates, fine aggregates, cement, water, and sometimes other additives, is noted as the most widely used man-made construction material in the world. Concrete is made up of fines and coarse aggregates and a principal constituent binding medium used to bind the aggregates particles together to form a very hard composite material.

The commonly used binding medium is cement which increases chemical reaction between the aggregates to

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form the composite concrete. The future of concrete looks even brighter because for most construction works, it offers suitable engineering properties at lower cost. For a properly engineered mix design, an in-depth knowledge of the properties of cement, aggregates and water is critical to understanding the behavior of concrete (Oduroh et al, 2000).

A number of factors affect the compressive strength of concrete. These includes the water cement ratio, degree of compaction, ratio of cement to aggregates, bond between mortar and aggregates, grading of aggregates, physio-mechanical and mineralogical properties of aggregates (Abdullahi, 2012). In ordinary structural concrete, the aggregates occupy 70 to 80% of the volume of hardened concrete, and occupy more than 90% of asphalt cement concrete. Aggregates are a very significant constituent in concrete since they give body to the concrete, reduce shrinkage and affect economy. It is imperative that a constituent with such a high proportions would affect the strength of concrete (Tsado, 2015). Studies have shown that the basic reason for coarse aggregates is to provide bulk to the concrete, as economic filler which is much cheaper than cement. Other studies have shown that aggregates provide volume stability and durability of the resulting concrete (Wight, 2012).

The coarse aggregates can be classified as a mixture component of various sizes of stone or rock particles, which is in contact with each other. They can either be gravel, crushed stone or a combination of both, such as quartz, sandstone and quartzite in addition to blast furnace slag, or recycled concrete fragments (Nevile, 2011). A wide spectrum of coarse aggregates materials are available in the construction industry ranging from sand, gravel, crushed stone, recycled concrete to geo-synthetic materials. Studies have shown that there is a direct correlation between the changes in coarse aggregates size to changes in the strength and fracture properties of concrete. Aggregates can be classified as fine or coarse depending on the particle size distribution. (Dawood and Ramil, 2011). Fine aggregates is generally natural sand or soil collected from the riverbank and is graded from particles of 5 mm in size down to the finest particles but excluding dust. Mishuk et al. (2015) holds that perhaps a maximum size of 80 mm coarse aggregates can be used for concrete. Neville (2011) holds that coarse aggregates is natural gravel or crushed stone usually larger than 5 mm (Buertey et al., 2016).

In this research, the emphasis is laid on the coarse aggregates from various rock, used primarily for the purpose of providing strength to the concrete product. The universality in the use of concrete is hinged on the invaluable strength properties of the 'cementitious' product, although in many practical cases other characteristics such as, durability, permeability and workability are also equally important (Gambir, 2006). Nevertheless, strength usually gives an overall picture of the quality of rock aggregates because strength is directly related to the structure of the hydrated concrete (Cheng and Liu, 2004). In civil engineering design, the focus is placed on compressive and flexural concrete strength. The compressive strength of concrete is commonly considered to be its most valued property, although in many practical cases, other characteristics, such as durability, impermeability and volume stability, may also be important (Nevile, 2011). Nevertheless, compressive strength usually gives an overall picture of the quality of concrete in relation to particle size, shape, types and source of an aggregates in question, a research gap that must be filled in relation to concrete technology (Miguel and Vicente, 2016). The focus of this research is to establish the correlation between the aggregates features and the strength of the corresponding concrete product. Because of the important contribution of aggregates to the strength of concrete, this paper seeks to examine the effect of coarse aggregates (rock) material types on strength of concrete (igneous rock - crushed quartz stone; sedimentary rock – sandstone; and metamorphic rock - quartzite rocks) on the compressive strength of Ghacem cement concrete, and also to compare their concrete strength with the British Standard (BS) Code of practice (Buertey et al., 2016).

LITERATURE REVIEW

There are three kinds of rocks, namely, igneous, sedimentary and metamorphic. These classifications are based on the mode of formation of rocks. It may be recalled that igneous rocks are formed by the cooling of molten magma or lava at the surface of the crest or deep beneath the crest. The sedimentary rocks are formed below the sea bed and subsequently lifted up. Metamorphic rocks are originally either igneous or sedimentary rocks which are subsequently meta-morphosed due to extreme heat and pressure. The concrete making properties of aggregates are influenced to some extent on the basis of geological formation of the parent rocks together with the subsequent processes of weathering and alternation. Thus many properties of the aggregates such as chemical and mineral composition, specific gravity, hardness, strength, physical and chemical stability and porosity depend on the properties of parent rocks (Mishuk et al., 2015).

Pasad and Harris (2013) held from a series of studies that deviations in fine aggregates gradation had relatively larger influence on properties of concrete compared to coarse aggregates. Also, the differences in gradations of aggregates within control gradations had more significant influence on properties of concrete, thus properties such as slump of fresh concrete, split tensile strength and rapid chloride ion permeability were more significantly influenced by the deviations in the gradations (Abdullahi, 2012).

Concrete design using local crushed rock material was conducted to analyse performance and to establish a mix design that would be sustainable throughout the lifetime of the project in South Africa. Tillite of the Dwyka formation was found to satisfy all test prerequisites best with minimal slaking due to the arid conditions at Matjiesfontein. Quartzite (Table Mountain Group) was found to be very durable, revealing a cube strength tests result of 40 MPa. These problems were however with the workability of the concrete when river sand from nearby non-perennial rivers was used as fine aggregates in the concrete. This relates to too many particles of the same size within the sand (van Wyk and Croucamp, 2014). According to Nevile (2002), concrete has a highly heterogeneous and complex structure with large range of particles sizes which makes it very difficult to constitute exact models of the concrete structure. The particle sizes range from nanometers to centimetres. The gel pores of calcium silicate hydrate level correspond to nanometers and the coarse aggregates particles to centimetres. The large range of sizes are usually grouped into three main phases, viz. aggregates phase, bulk cement phase (hydrated cement past, hcp) and an interfacial transition zone (ITZ) which is the region between the aggregates and the bulk cement phase. These three phases can also be categorized into two classes; the macrostructure and microstructure levels. The macrostructure level can be regarded as consisting of two phases, that is, aggregates phase and binding medium phases (hcp). The third phase, the interfacial transition zone (ITZ), is however regarded as part of the microstructure level. Since the strength and durability properties of concrete are dependent upon the structure of concrete, the following subdivisions briefly review the structure of each phase and their importance in relation to the properties of concrete (Chen and Liu, 2004).

Neville (2002) conjectured that some aggregates, mostly quarry dust are inert materials that are dispersed throughout the matrix cement paste whose strength depends mostly on its shape, surface area textures, and purity. He postulated that, an entirely smooth-coarse-aggregates lowered the strength of concrete by an average 10%, than when the aggregates were rough. Young and Samuel (2008) opined that smooth rounded coarse aggregates was more workable but yielded a lesser compressive strength in the matrix than irregular aggregates with rough surface texture. It was also established that a fine coating of impurities such as silt on the aggregates surface could hinder the development of a good bond and thus affects the strength of concrete produced with the aggregates. Zhang et al. (2014), in a research to determine the effect of curing age on concrete, revealed that the highest strength was obtained from concrete made with the highest days of curing and the amount of paste required is believed to depend on the amount of void spaces to be filled and the total surface of the aggregates to be coated with paste (Aginam et al., 2013).

There are various schools of thought on the effects of coarse aggregates content on the compressive strength of concrete. In a related research (Bayasi and Zhou, 1993). Buertey at al. (2016) showed that the percentage of crushed coarse particles had a significant effect on laboratory permanent deformation properties of concrete. They explain that the percentage of crushed coarse particles decreased as the rutting potential of the mixtures increased. It has been held in other studies that, there is a little correlation between compressive strength and coarse aggregates content (Popovics, 2008). In another research to investigate the effects of aggregates content on the behavior of concrete, variations between the compressive strengths of concrete products from crushed stone and gravel stone in respect of aggregates size, revealed that crushed stone resulted in better compressive strength than gravel stone. This strength performance was as a result of several factors like water/cement ratio, grading, surface area texture, shape and size of the sample, strength and stiffness of aggregates used (Chen and Liu, 2004).

According to Aginam et al. (2013), concrete is sensitive to the geological origin of the natural aggregates used. It further explains that, aggregates's porosity is an important characteristic that affects the elastic modulus of concrete because dense aggregates have better mechanical property. In an experimental result from the modulus of elasticity used in concrete design computation were usually estimated from empirical expression that assumed direct dependence on the strength of concrete, the concrete unit weight and aggregates origin. Thus for high-strength concrete, deviations from empirical expression are highly dependent on the properties and proportions of the coarse aggregates. A strong evidence of aggregates type is a strong factor in the strength of concrete. Aitcin et al. (2011) analysed results of concrete products with the similar design mix proportions but containing four different coarse aggregates types. It was concluded that in high-strength concretes, higher strength coarse aggregates typically yield higher compressive strengths, while in normal-strength concretes, coarse aggregates strength has little effect on compressive strength. According to Rammurthy and Gumaster (1998), the compressive strength of coarse aggregates concrete was relatively lower and variation was depended on the strength of parent rock the aggregates is been obtained. These afore-mentioned study gives credence on the need to study the correlation between rock type, aggregates type and aggregates sizes holdings, its physio-mechanical properties in mind, and concrete strength produced (Wilbersforce, 2015).

METHODOLOGY

As a quantitative based study, the target population is drawn from both Primary and Secondary users of quarry products (contractors and civil engineers). The process involved in this research used a series of samples from three quarry mines for the purpose of evaluating the physical and geo-mechanical properties of the products from the sites. Based on a previous publication by Buertey et al. (2016), a laboratory experiment was undertaken to determine the physio-mechanical properties of aggregates around Accra. As a work in progress, this publication is an extension of that research to determine the correlation between the physio-mechanical properties of said aggregates. Following a concrete mix design, forty-eight (48) samples cubes were developed from rock aggregates of samples picked from each of the three engineering quarry sites. Namely, quartz mineral aggregates formed from igneous rock from Geochina quarry site at Nsawam, metamorphic rock from Dam side quarry site at Weijaand quartzite mineral aggregates from sedimentary rock from Art of God quarry site at Aburi.

Before tests were carried out, the aggregates sample was fetched and a lump of the three sample of rocks also taken from the pertinent assigned location under design consideration into sack and transported to the laboratories (AIT Civil Engineering laboratory) for test evaluation. Two set of laboratory experiments were done:

(1) To determine the workability of concrete from the various rock aggregates and
(2) To review the strength of concrete from the various rock aggregates and compare similar strengths result usiing the BS code of concrete strength chart.

Laboratory experiments

Slump and aggregates compaction factor test (ASTM C143)

Using a newly designed concrete mix, a slump and aggregates compaction tests were done with the objective of determining the workability of concrete mix by slump test. The test was conducted according to ASTM C143. A concrete mix with a known proportions of 1:2:4 was prepared, the slump cone (mould) was placed on a smooth flat and non-absorbent surface, the base plate, then filled with concrete to about a forth of the height. Compacting of the concrete was made with the help of steel rod 0.6 m long and 16 mm in diameter. The mould was then half filled to its height and compacted again. The procedure was repeated till the mould was completely filled. Excess concrete was trimmed off from the top and made good. The slump cone was carefully as in the vertical direction removed to obtain the mould shape of the concrete, but in a subsided state. The height of the concrete after subsidence (the final slump) was measured.

Observations made and the process of calculation of slump for metamorphic rock is as follows:

(1) Proportion of concrete mix was 1:2:4,
(2) Water cement ratio = 0.4,
(3) Weight of cement = 200 g,
(4) Weight of sand= 400 g,
(5) Weight of aggregates = 800 g,
(6) Height of concrete before slump subsidence = 35 cm,
(7) Final height of concrete after subsiding = 19 cm,
(8) Slump value of given concrete mix is found to be = 35 -19 cm = 16 cm height = 19 cm.

Compressive cube test-ASTM C1716

This test was undertaken to determine the compressive strength of a mix proportion of concrete samples in relation to various source aggregates. It was therefore useful to study the phenomenon behind the various quarry site near Accra with a view to promoting measures for quality enhancement of construction works within Accra. The test consisted of determining the compression strength of cubes prepared at 7, 14 and 28 days. The test procedure was carried out according to ASTM C1716. Taking 1 kg of Portland cement (Ghacem), 2 kg of river sand, and 4 kg of coarse aggregates (4.75 and 25 mm), this gave a design mix of 1:2:4. The compound was mixed thoroughly and consistently after which 4 L clean distilled drinking water was added to the dry mixed sample and then thoroughly stirred again to obtain a uniform grey colour. The cube mould surface was coated from inside and joint sealed with grease so that no water would escape during compaction. The concrete was poured into the mould and tampered to remove all voids. The mould containing the concrete was kept at a room temperature for 24 h. The concrete was thereafter removed and kept in water for 28 consecutivetive days. The cube specimens were then crushed using the compressing testing machine for different curing days. The characteristic compressive strength was obtained by dividing the average load on the cube by the cube area.

The compressive strength for metamorphic rock (kN/m^2) was calculated as follows:

Cross sectional area of cube = 150 mm × 150 mm = 225 mm^2

Compressive load for 7 days = 331 kN (1)

Cross sectional area of cube = 225 mm^2

Characteristic compressive strength = 14.71 kN/mm^2

Tables 1 to 7 show the test results and computed compressive strength obtained from the concrete for the various days.

For the purpose of validity of the instrument, all documentations, manuals and leaflets of the instrument used for the test was read over and over again. An in-depth research was undertaken on how to improve reliability by adhering to the dos and don’ts of the instruments and civil engineering materials standards such as ASTM and ASSHTO. The instruments were then sent forth to the Ghana Standards Board for calibration.

DATA ANALYSIS AND DISCUSSION

Data collected from the study was analysed using univariate statistical analysis. Descriptive analysis was performed to determine the background of the experiment whilst actual experiment was done in the Civil Engineering Laboratory to determine the strength of the various rock lumps and the coarse aggregates which provided answers to the calculated variables in the research. The compressive strength of the concrete produced from the various coarse aggregates in accordance with BS EN 12390-3:2009 with a water cement ratio of 0.4 and designed concrete strength of C25 are shown in Tables 1 to 4.

For all the ages of curing (BS EN 12390-2:2009) as the hydration takes place, the highest strength was obtained from concrete made with igneous rock, followed by sedimentary rock and the lowest being the metamorphic rock as shown in Figure 1. The values for the slump test of the fresh concrete shown in Table 1 column 5 depict

Table 1. Summary compressive cube test table.

Rock type	7 days strength		14 days strength		28 days strength		Slump test value (cm)
	(kN)	(N/mm^2)	(kN)	(N/mm^2)	(kN)	(N/mm^2)	
Igneous	492	21.87	520	23.11	576	25.6	23
Sedimentary	420	18.67	460	20.44	503	22.36	21
Metamorphic	331	14.71	366	16.27	392	17.42	16
Mix ratio	-	-			1:2:4		
Water to cement ratio	-	-			0.4		

Table 2. Laboratory crushing load for igneous rocks (kN).

Item	Sample No.	Crushing load in 7 days		Crushing load in 14 days		Crushing load in 28 days	
		$Mean_7$	$S.D_7$	$Mean_{14}$	$S.D_{14}$	$Mean_{28}$	$S.D_{28}$
1	INGR1201	488	18.66	512	20.85	570.96	19.88
2	INGR1202	466	14.18	494	17.88	545.22	21.68
3	INGR1203	495	22.35	520	23.33	579.15	19.15
4	INGR1204	484	14.14	518	18.86	566.28	23.44
5	INGR1205	505	15.99	530	14.66	590.85	20.99
6	INGR1206	497	17.17	525	22.38	581.49	23.44
7	INGR1207	493	23.15	522	19.16	576.81	21.68
8	INGR1208	491	22.34	516	22.33	574.47	19.19
9	INGR1209	494	18.77	521	19.38	577.98	24.77
10	INGR1210	492	20.65	536	21.44	575.64	23.19
11	INGR1211	490	17.33	517	19.45	573.3	22.67
12	INGR1212	502	18.38	527	19.28	587.34	21.45
13	INGR1213	500	24.22	525	21.36	585	20.39
14	INGR1214	499	21.89	523	22.33	583.83	21.55
15	INGR1215	487	20.67	511	19.15	569.79	23.18
16	INGR1216	499	22.16	524	21.45	583.83	22.38
	Average	493	20	520	20	576	22

the nature of the response of the various coarse aggregates to slump. This ranges between 15 and 35 cm. The lowest slump was obtained with fresh concrete made with metamorphic rock. This could be deduced from the premise that metamorphic rock has a relatively week bonding particles and rounded in shape and again being water-worn due to the action of running water and thereby enhancing its workability of fresh concrete. It needs cement paste for surface coating to serve as interacting between aggregates particles during mixing. The fragmented rock of igneous and sedimentary gives the highest and relatively equal slump value of the fresh concrete. This was as a result of rough and angular characteristic surface shape. More quantity of water is needed for concrete work to serve as lubricant to enhance construction work using this type of rock.

From Tables 2 and 3, it was realized that the characteristic compressive strength of concrete made from igneous rock achieved cube strength of 21.87 kN/m^2 at 7 days. This represents 87.5% of the required strength at 28 days. The strength achieved was a good indication that the rock was likely to achieve the required 28-day strength. The rock increases in cube strength by 6.57% from the 7 days to the 14 days and then progressing in strength cumulatively by 17.2% reaching 25.6% at 28 days. The rock undoubtedly achieved the required strength due to its low porosity and relatively low permeability. Strength results revealed that the mean deviations in compressive strength ranged from 0.63 to 1.08 at 7 days, 0.65 to 1.04 at 14 days and 0.88 to 1.1.

From Tables 4 and 5, it can be observed that the test results on the cube strength for the sedimentary rocks were not too encouraging. The computed compressive strength values (Table 5) were below the expectation according to the BS codes. At 7 days, the rock recorded 18.67 kN/mm^2 representing 74.68% of the expected strength at 28 days. Though this result was fairly ok, the rock failed to pick up the required strength at 14 and 28 days. The strength appreciated by 7.08% to 20.44 kN/mm^2 in 14 days and 22.34 kN/mm^2 in 28 days. At the

Table 3. Computed compressive test results for Igneous rocks.

Item	Sample No.	Strength in 7 days		Strength in 14 days		Strength in 28 days	
		Mean7	S.D7.	Mean14	S.D14	Mean28	S.D28
1	INGR1201	21.69	0.83	22.77	0.93	25.38	0.88
2	INGR1202	20.71	0.63	21.95	0.79	24.23	0.96
3	INGR1203	22.00	0.99	23.10	1.04	25.74	0.85
4	INGR1204	21.51	0.63	23.02	0.84	25.17	1.04
5	INGR1205	22.44	0.71	23.57	0.65	26.26	0.93
6	INGR1206	22.09	0.76	23.33	0.99	25.84	1.04
7	INGR1207	21.91	1.03	23.20	0.85	25.64	0.96
8	INGR1208	21.82	0.99	22.91	0.99	25.53	0.85
9	INGR1209	21.96	0.83	23.16	0.86	25.69	1.10
10	INGR1210	21.87	0.92	23.83	0.95	25.58	1.03
11	INGR1211	21.78	0.77	22.98	0.86	25.48	1.01
12	INGR1212	22.31	0.82	23.43	0.86	26.10	0.95
13	INGR1213	22.22	1.08	23.33	0.95	26.00	0.91
14	INGR1214	22.18	0.97	23.24	0.99	25.95	0.96
15	INGR1215	21.64	0.92	22.73	0.85	25.32	1.03
16	INGR1216	22.18	0.98	23.29	0.95	25.95	0.99
	Averages	22	1	23	1	26	1

Table 4. Laboratory crushing loads for sedimentary rocks.

Item	Sample No.	Crushing load in 7 days		Crushing load in 14 days		Crushing load in 28 days	
		$Mean_7$	S.D7	$Mean_{14}$	$S.D_{14}$	$Mean_{28}$	$S.D_{28}$
1	SEDR101	408	14.11	445	15.55	488	17.22
2	SEDR102	415	16.18	447	16.66	496	15.66
3	SEDR103	435	15.55	461	17.88	520	18.11
4	SEDR104	411	14.13	436	15.15	492	15.58
5	SEDR105	440	15.11	482	12.33	526	18.66
6	SEDR106	422	14.38	490	18.18	505	15.58
7	SEDR107	404	12.16	469	16.78	483	21.33
8	SEDR108	438	11.38	464	14.44	524	16.67
9	SEDR109	433	13.38	459	15.58	518	17.89
10	SEDR110	438	15.16	456	14.07	524	19.18
11	SEDR111	445	14.88	472	18.18	532	18.55
12	SEDR112	405	16.15	427	15.15	495	19.83
13	SEDR113	400	19.33	464	15.55	478	21.33
14	SEDR114	398	15.38	462	18.44	476	19.33
15	SEDR115	414	18.19	446	15.15	495	19.38
16	SEDR116	411	15.54	477	14.88	492	20.65
	Averages	420	15	460	16	503	18

end of the 28 days, the samples achieved only 89.36% of the expected strength. Only 2 samples hit the 23 kN/mm^2 strength values, with other samples recording values as low as 21.47 kN/mm^2. The mean deviation of the results at 7 days was 0.622 with a range of 0.59 to 0.72, the mean deviation for 28 days was 0.821 with a range of 0.69 to 0.92.

The poorest test results were achieved from products of metamorphic rock. From Figure 1, the rock started with an all-round low figure of 14.71 kN/mm^2 at 7 days and failing to record any appreciable strength increase. It marginally increased to 16.27 KN/mm^2 at 7 days and then 17.42 kN/mm^2. From Tables 6 and 7, it barely achieved a 70% average designed cube strength at 28 days. Mean

Table 5. Computed compressive strength results for sedimentary rocks.

Item	Sample No.	Strength in 7 days		Strength in 14 days		Strength in 28 days	
		$Mean_7$	**S.D7**	**$Mean_{14}$**	**$S.D_{14}$**	**$Mean_{28}$**	**$S.D_{28}$**
1	SEDR101	18.13	0.63	19.78	0.69	21.69	0.77
2	SEDR102	18.44	0.72	19.85	0.74	22.06	0.70
3	SEDR103	19.33	0.69	20.49	0.79	23.12	0.80
4	SEDR104	18.27	0.63	19.36	0.67	21.85	0.69
5	SEDR105	19.56	0.67	21.43	0.55	23.39	0.83
6	SEDR106	18.76	0.64	21.76	0.81	22.43	0.69
7	SEDR107	17.96	0.54	20.83	0.75	21.47	0.95
8	SEDR108	19.47	0.51	20.63	0.64	23.28	0.74
9	SEDR109	19.24	0.59	20.40	0.69	23.02	0.80
10	SEDR110	19.47	0.67	20.25	0.63	23.28	0.85
11	SEDR111	19.78	0.66	20.96	0.81	23.65	0.82
12	SEDR112	18.00	0.72	18.99	0.67	22.00	0.88
13	SEDR113	17.78	0.86	20.62	0.69	21.26	0.95
14	SEDR114	17.69	0.68	20.52	0.82	21.16	0.86
15	SEDR115	18.40	0.81	19.82	0.67	22.01	0.86
16	SEDR116	18.27	0.69	21.19	0.66	21.85	0.92
	Averages	18.66	0.67	20.43	0.71	22.34	0.82

Table 6. Laboratory crushing load for metarmorphic rocks.

Item	Sample No.	Crushing load in 7 days		Crushing load in 14 days		Crushing load in 28 days	
		$Mean_7$	**S.D7**	**$Mean_{14}$**	**$S.D_{14}$**	**$Mean_{28}$**	**$S.D_{28}$**
1	METRCK 301	329	11.18	334	11.9626	390	12.7452
2	METRCK 302	345	12.66	349	13.5462	408	14.4324
3	METRCK 303	342	13.15	349	14.0705	405	14.991
4	METRCK 304	335	12.99	339	13.8993	397	14.8086
5	METRCK 305	344	13.55	352	14.4985	407	15.447
6	METRCK 306	349	12.19	354	13.0433	413	13.8966
7	METRCK 307	335	18.45	341	19.7415	397	21.033
8	METRCK 308	355	15.15	360	16.2105	420	17.271
9	METRCK 309	344	14.06	351	15.0442	407	16.0284
10	METRCK 310	331	13.33	336	14.2631	392	15.1962
11	METRCK 311	299	12.49	306	13.3643	354	14.2386
12	METRCK 312	314	15.18	319	16.2426	372	17.3052
13	METRCK 313	318	14.44	321	15.4508	377	16.4616
14	METRCK 314	329	10.08	337	10.7856	390	11.4912
15	METRCK 315	309	12.38	314	13.2466	366	14.1132
16	METRCK 316	314	14.11	319	15.0977	372	16.0854
	Averages	331	13	336	14	392	15

deviations of the samples range from 0.45 to 0.82 for 7 days, 0.48 to 0.88 for 14 days and 0.51 to 0.93 for 28 days.

Buertey et al. (2016) revealed that air spaces in rock samples picked from the same quarries with valued percentages varied from 29 to 34% to 41% for igneous rock, sedimentary and metamorphic rock, and this has a direct proportional effect on the water content of the rock. Again, the moisture contents of the rock aggregates of 8.1, 7.6 and 10.7% translating into its water absorption and porosity of 10.25, 14.11 and 7.7% for igneous, sedimentary and metamorphic rocks, respectively. Again Buertey et al. (2016) held that there was a direct correlation between the impact resistance and load

Table 7. Computed compressive strength results for metarmorphic rocks.

Item	Sample No.	Strength in 7 days		Strength in 14 days		Strength in 28 days	
		$Mean_7$	S.D7	$Mean_{14}$	$S.D_{14}$	$Mean_{28}$	$S.D_{28}$
1	METRCK 301	14.62	0.50	14.84	0.53	17.31	0.57
2	METRCK 302	15.33	0.56	15.51	0.60	18.15	0.64
3	METRCK 303	15.20	0.58	15.51	0.63	18.00	0.67
4	METRCK 304	14.89	0.58	15.07	0.62	17.63	0.66
5	METRCK 305	15.29	0.60	15.66	0.64	18.10	0.69
6	METRCK 306	15.51	0.54	15.73	0.58	18.37	0.62
7	METRCK 307	14.89	0.82	15.16	0.88	17.63	0.93
8	METRCK 308	15.78	0.67	16.00	0.72	18.68	0.77
9	METRCK 309	15.29	0.62	15.60	0.67	18.10	0.71
10	METRCK 310	14.71	0.59	14.93	0.63	17.42	0.68
11	METRCK 311	13.29	0.56	13.61	0.59	15.73	0.63
12	METRCK 312	13.96	0.67	14.18	0.72	16.52	0.77
13	METRCK 313	14.13	0.64	14.27	0.69	16.73	0.73
14	METRCK 314	14.62	0.45	14.97	0.48	17.31	0.51
15	METRCK 315	13.73	0.55	13.96	0.59	16.26	0.63
16	METRCK 316	13.96	0.63	14.18	0.67	16.52	0.71
	Averages	14.70	0.60	14.95	0.64	17.40	0.68

resistance results of the samples. Igneous rock recorded the highest impact resistance of 802 mm followed by sedimentary and then metamorphic rocks with 602 and 201 mm, respectively with a corresponding load resistance of 57, 29 and 13 kN.

In a study to evaluate the effects of coarse aggregates type and size on the compressive strength of normal and high-strength concrete, Aïtcin et al (1998) concluded that normal-strength concretes are not greatly affected by the type or size of coarse aggregates. However, for high-strength concretes, coarse aggregates type and size affect the strength and failure mode of concrete in compression. For high-strength concretes with weaker coarse aggregates, cracks pass through the aggregates, since the matrix-aggregates bond is stronger than the aggregates itself, resulting in a trans-granular type of failure. For high-strength concretes with stronger aggregates, both matrix aggregates deboning and trans-granular failure occur. It was established that cracks pass through the weaker portions of aggregates particles and then propagate into the cement paste. They also observed that the coarse aggregates types and sizes used in the study did not significantly affect the flexural strength of high-strength concrete.

Conclusion

Based on results ensuing from this study, it can be concluded that crushed quartz coarse aggregates (Igneous rock) gave the highest compressive strength at all curing ages of 25.2 kN/mm² at 28 day and a slump of 23 mm; this is owed to the fact that crushed quartz stone is very strong, tough and has good irregular surface texture, less porous which enhances proper bonding between the aggregates particles and GHACEM cement paste. Crushed sandstone (Sedimentary rock) aggregates produced higher compressive strength than metamorphic rock (quartzite coarse aggregates). The crushed sand stone produced a strength of 22.36 kN/mm² and a slump of 21 mm. The strength at 28 days for the crushed sand stone was relatively lower than the expected design strength at 28 days. The metamorphic rock - quartzite coarse aggregates was the weakest in strength amongst the three, with strength of 17.42 kN/mm^2 at 28 days and slump of 16 mm. Again from figure 2, it was observed that igneous rock gives the highest slump value of 23cm compared the value for metamorphic rock of 16cm. the higher slump value of igneous rock is as result of its rough characteristic angular shape which would require more cement paste to make it workable as compared to the metamorphic rock which is relatively week in bonding properties.

Concurrent with previous works by Buertey et al. (2016), Gambir (2006), Young and Samuel (2008), and Aignam et al. (2013), revealed that features like the internal structure of the aggregates and the physio-mechanical properties affect the strength of concrete. Thus metamorphic rock-quartzite coarse aggregates were the very porous amongst the three rocks aggregates since the weak particle flab on each side makes it easy to crush when used for the cube test. And again, it was observed from Buertey et al. (2016) that quartz aggregates from igneous rock has stronger

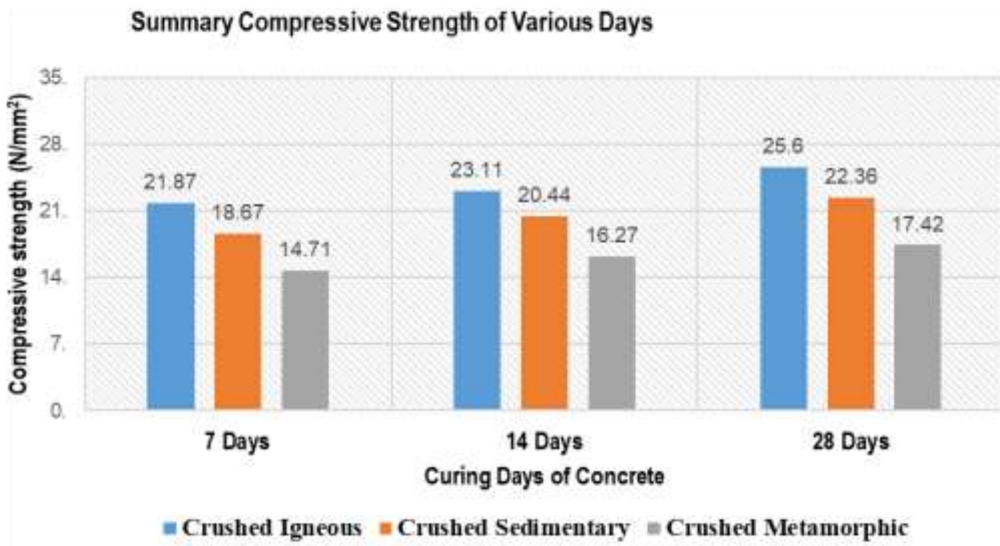

Figure 1. Compressive strength of various days.

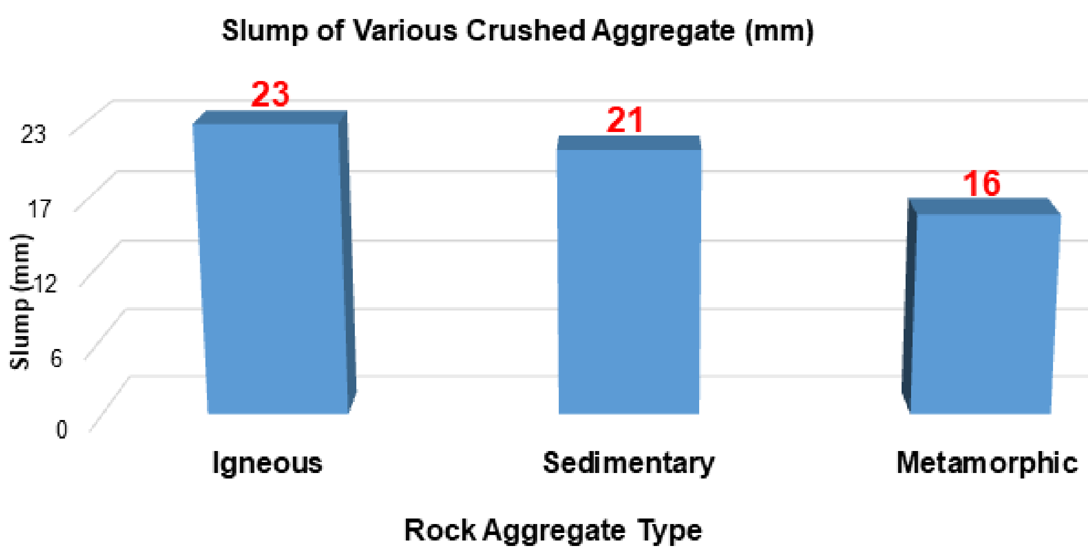

Figure 2. Slump of various crushed aggregates.

particles bonding properties than that of sandstone from sedimentary rock aggregates used in the study. Although sedimentary rock has smoother surface shape which may lend to poorer interlocking properties, it was observed to be stronger than that of metamorphic rock but less than that igneous rock and as a result of its bonding with the cement paste.

These findings corroborate the findings of Abdullahi (2012) who revealed from his research to determine the effect of aggregates type on compressive strength that river grave has the highest workability followed by crushed quartzite and crash granite aggregates. The highest compressive strength was at all ages was noted with concrete made from quartzite aggregates followed by river gravel and granite aggregates.

IMPLICATION OF FINDINGS ON THE CONSTRUCTION INDUSTRY

Giaccio et al. (1993) compared fracture energies for concretes with a wide range of compressive strengths. Strength levels from 22 to 100 MPa with corresponding aggregates type basalt, limestone and gravel, and aggregates size of 8, 16 and 25 mm, concurrent with aggregates surface roughness as additional variables.

They concluded that concretes with weaker aggregates, such as limestone, yield lower compressive strengths than concrete with stronger coarse aggregates. Fracture energy increases as concrete compressive strength increases, although the increase in energy of only 4% corresponds to an increase in strength of 10%. They also concluded that fracture energy increases with increasing aggregates size. Load-deflection curves for fracture energy were also analyzed. They show that, as the compressive strength increases, concretes have a greater peak load followed by a steeper gradient of the softening branch. They also show that the final deflection (at total fracture) is much lower for high-strength mortar than for high-strength concrete. The mortar specimens had the steepest gradient of the descending branch, followed by concretes containing basalt and limestone coarse aggregates.

Thus it can be concluded from literature and confirmed from the laboratory experiment conducted that aggregates type and mineralogical properties has significant effect on the constituent concrete product. It is evident that most construction professionals, developers and project financiers may not be aware of these results since no thorough laboratory test has been conducted on these mined construction products. On the contrary, developers are at the best of engineers who may have to step-up their effort to ensure that the aggregates with the appropriate qualities and properties are acquired for construction projects. By implication, the industry is at risk since it is likely that design mix using sedimentary and metamorphic rock may likely fail to achieve their strength, if the mix proportions are not varied. Thus, this would require that safety factors are increased and higher concrete grades are recommended to achieve the relative strength due to the weaker physio-mechanical properties of the aggregates. This impliedly may not be cost effective since more Portland cement would be required, with cement being a higher cost centre in the concrete construction. Impliedly, if lower strength are achieved with respect to the structural members of building, possibly cracks, fault lines deflections and creeping concrete failure may develop in these structures thereby resulting in possible collapse when the yield load is reached. It may be appropriate that the use of aggregates from these sites are be restricted to single storey non-critical load bearing structures if redesign of concrete mix are not undertaken using the aggregates physio-mechanical properties.

It is unfortunate that in an industry practice, testing of aggregates to confirm their physio-mechanical properties is not a key requirement in respect of material specification. With this stunning revelation, it would be appropriate to extend the research to all other quarries within the major municipalities to ensure that safety is compromised. It is time the built environment player and regulatory players take a closer look at these issues since they could be an upsurge factor in the recent building collapse in Ghana.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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