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Strength characteristics of hand-quarried partially-weathered quartzite aggregates in concrete

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Abstract: The use of hand-quarried weathered quartzitic aggregates as the coarse component of concrete was investigated. Samples of hand-quarried quartzite aggregates exhibiting different degrees of weathering were evaluated in quality and their suitability as coarse component of concrete. The 7, 14, 28 and 56 day compressive strengths were obtained from 100mm concrete cube samples prepared with the weathered aggregates in 1:1:2, 1:1.5:3, 1:2:4 and 1:3:6 concrete mixes and different water: cement ratios 0.45, 0.5 and 0.6. Modulus of rupture beams were tested aged 28-days. Control samples were also tested for compressive and tensile strengths using sound granite aggregates obtained from a commercial quarry. The quality tests showed very little difference between the un-weathered quartzite aggregates and the sound granite aggregates. The weathered quartzite aggregates except the highly weathered grade were found to have properties that met specification requirements for concrete. However, the partially weathered aggregates were marginal in quality and had high water absorption values. The 28-day compressive strength of the partially weathered quartzite concrete averaged 86% of the granite. It is concluded that except when the degree of weathering is very high, the partially weathered quartzite stone could be used as coarse aggregates in concrete that would be subjected to low stresses.

Keywords: Aggregate Index Properties, Compressive Strength, Creep, Water Absorption, Hand-Quarry, Weathered Quartzite

1. Introduction

Concrete is the most widely used construction material worldwide. Coarse aggregate which is a major component of concrete occupies about 70-75% either of the concrete mass or volume. As a result of the depletion of natural sources of coarse aggregates and lack of synthetic aggregates, several research initiatives have, in recent times, been dedicated to sustainable aggregate use [1-8].

Coarse aggregates supplied by commercial quarries to the construction industry in Ghana are derived mostly from igneous rocks particularly granites and granodiorites and sometimes from metamorphic rocks such as gneiss and quartzite. In the central part of the country called the Ashanti Region and some parts of the northern belts of the country where large granite batholiths can be found, commercial quarry aggregates are of granitic origin. In the south, particularly the Greater Accra Region, quarry aggregates are mostly metamorphic rocks derived mostly from gneissic rocks forming the Shai Hills and quartzite from the Achimota and McCarthy Hill areas. Aggregates of igneous origin are generally obtained from quarry sources located outside the region.

Generally, production and overhead costs in commercial quarry operations make coarse aggregates from such sources relatively more expensive than aggregates from other sources. Since availability, proximity, and cost of coarse aggregates are very important issues that determine the use of a particular type [6], they have tended to encourage the use of relatively less expensive coarse aggregates such as all-in natural gravel from river deposits and hand-quarried partially-weathered quartzite aggregates for concrete works in areas where such materials can be found. In the Greater Accra area, in particular, the use of hand-quarried partially-weathered quartzite aggregates for concrete is commonplace and extensive and it is estimated that more than 80% of private building projects in that area use that type of aggregates as the coarse component of concrete. Within the city of Accra, for example, the high demand for hand-quarried partially-weathered quartzite aggregates has encouraged the establishment of extensive hand quarries at the fringes of the city. In the Ashanti Region, where there is very little demand, small workings are sited at only one place where a small number of quartzite rock outcrops can be found. The quartzite aggregates from these sources may exhibit different degrees of rock quality that range from sound rock to highly weathered rock depending upon the extent of exposure to the atmosphere of the rock outcrop from which the materials are mined or quarried and the depth of mining.

In Ghana, quartzite is the rock mass forming the row of mountains referred to in local geology as the Akwapim Range which cuts across part of the Eastern Region and continues into the Volta Region. This rock mass forms part of the regional geology referred to as the Togo Series [9]. Quartzite is a non-foliated quartz-rich rock derived from the metamorphism of quartz sandstone. In the sound state, the rock has a vitreous lustre and its colour can vary from white to black, going through cream, pink, red and grey, though in most cases, quartzite rocks are light in colour with a sugary texture reflecting the granules of quartz [10]. In the weathered state, quartzite may take on a dull lustre and a reddish brown tint with the granules of quartz becoming texturally more pronounced. The use of quartzite to substitute granite coarse aggregates could be in the right direction to conserve the natural resource of common coarse aggregates including granite and sandstone [11].

In the sound or un-weathered state, quartzite is among the rocks known to have good engineering properties and is excellent as the coarse component of concrete, but the use of the rock in the weathered state as a component of concrete in the country raises a number of engineering concerns. It is an accepted fact that the type of aggregate used in concrete affects the structural behaviour of concrete. Firstly, there is the problem of aggregate quality in terms of strength as generally when rocks weather, they assume properties that are dissimilar and inferior to those of the sound parent rock. As a component of concrete, therefore, such aggregates may provide the plane of weakness for shear failure when the concrete is subjected to loading [12]. It is also established that the type of aggregate affect the shear strength through its effect on aggregate interlock capacity [12-15]. In other studies on phyllite aggregates beams [16] and recycled concrete aggregate beams [11,17], early shear cracks and premature failure in shear were observed.

Secondly, there is also the problem of quality of aggregate in terms of size. Quartzite aggregate samples obtained from hand-quarry sources have about 75% of the constituent particles having sizes that range between 20 and 50mm. Such relatively large-size materials may be detrimental to concrete works particularly where there is steel reinforcement. These issues of engineering concern will probably persist for a long time with the hand-quarried aggregates because unlike commercial quarries in the country which must operate under controlled conditions in order for the aggregates to meet industry's specifications to have market significance, hand-operated quarries in Ghana are invariably operated under subsistence conditions with a clientele (essentially private individuals) with no defined standards. As a result, the quality of the quartzite aggregates is unlikely to become an issue that will dictate public patronage/rejection of the materials even in situations where the bulk of the aggregates may have unacceptably low quality for engineering applications. The danger and concern then become the safety of structures built with such materials by the unsuspecting public. These concerns have been reinforced by the collapse of a couple of concrete structures in the capital city and elsewhere in the country within the past one year. This paper in no way attempts to present hand-quarries as offering any advantages in coarse aggregate production over modern quarry operations, but rather seeks to draw attention to the fact that, hand quarries, however unscientific their modes of production are, constitute another source of coarse aggregate supply to the construction industry in Ghana, particularly in the Greater Accra area, which cannot be ignored. The purpose of this study was, therefore, to evaluate the suitability of hand-quarried partially-weathered quartzite aggregates as a coarse component of concrete.

2. Weathered Grades of Aggregates

Table 1. *Subjective criteria for grading weathered aggregates.*

Weathering grade	Visual description and characteristics
Sound (un-weathered)	Colour of fresh surface may be dark, purple or light pink with a vitreous lustre. Fracture surfaces are generally smooth-textured.
Partially weathered	Aggregates tend to have a reddish-brown tint with fracture surfaces showing a dull or opaque lustre. Sugary texture is visible though not very pronounced.
Highly weathered	Aggregates have reddish-brown or rusty colouration with a complete loss of lustre. Sugary texture of granules of quartz very pronounced. Rock may be friable and pieces can be chipped away by hand with a little bit of effort.

At the quarry site located near Juaso in the Ashanti Region where samples were collected for study, the aggregates were differentiated and assigned into three subjective weathering groups on the basis of their visual appearance using colour, lustre of fracture surface, and surface texture before representative samples were taken to the laboratory for study. The three weathered grades assigned were; sound (un-weathered), moderately weathered, and highly weathered with the details of the rating criteria used given in Table 1.

3. Experimental Program

3.1. Materials

Ordinary Portland cement conforming to BS812[18] was used for concrete works. Natural river sand was used as fine aggregates whilst two types of coarse aggregates; normal granites and partially-weathered quartzite were obtained from a commercial quarry and hand quarry respectively. The aggregate sieve distribution of both fine and coarse aggregates was done as per the requirements of BS882 [19]. From the grading analysis for coarse aggregates, as shown in Fig. 1a and b, the sieve on which most of the granite and partially-weathered quartzite aggregates were retained was sieve size 12 mm (1/2 in.) and passed 19 mm (3/4 in.). Therefore the particle size distribution of both aggregates fall within the range of 5-20 mm. It is obvious that both aggregates had similar grading characteristics; hence all things being equal similar concrete properties were expected to develop. The fine aggregate used was graded according to BS882 (Fig. 1c).

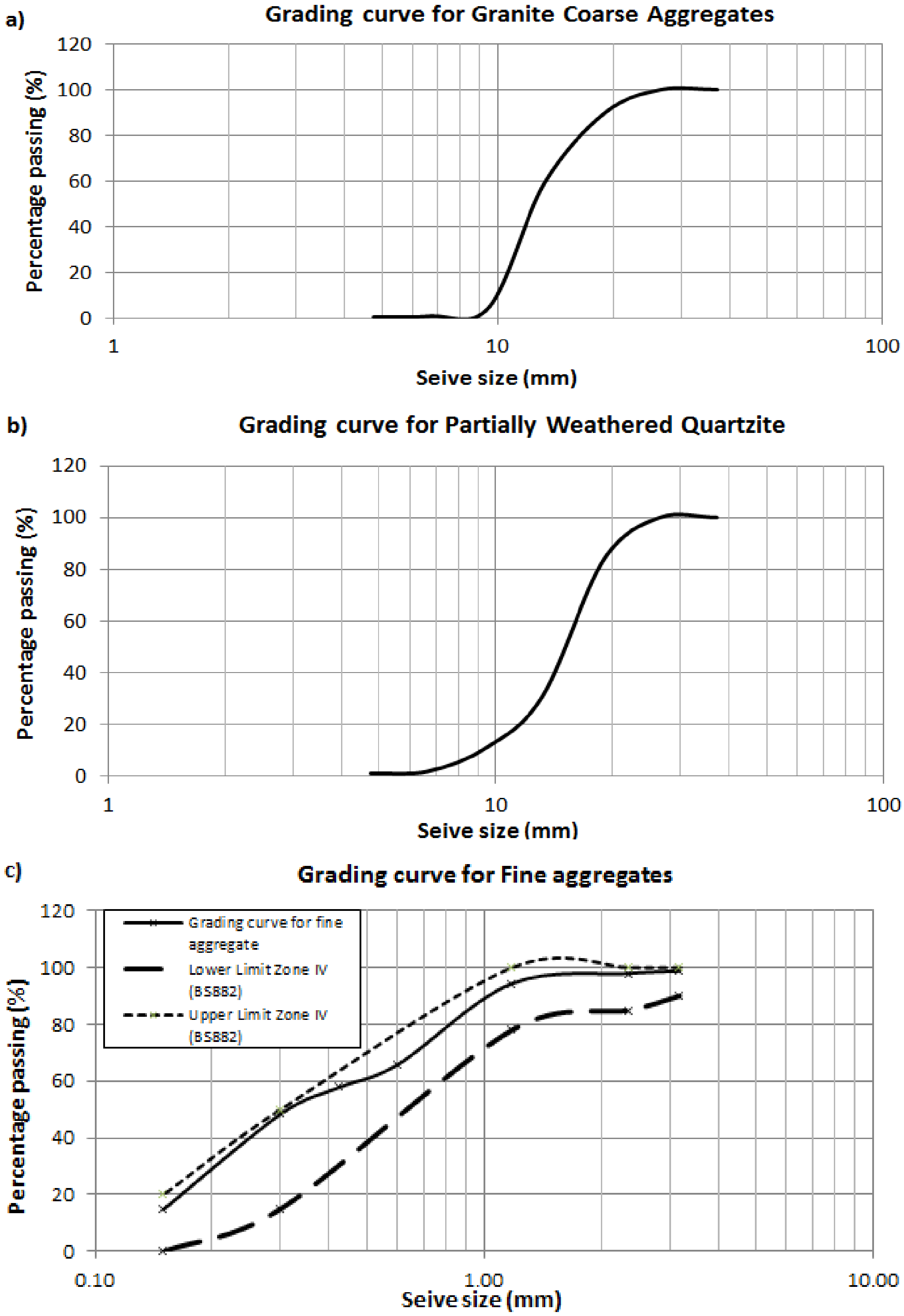

Figure 1. *Aggregates grading curves.*

3.2. Evaluation of Aggregate Index Properties

Representative aggregate samples from each of the above weathering categories were subjected to the following standard aggregate tests in the laboratory in accordance with BS 882 [19].

1. Aggregate Impact Test
2. Aggregate Crushing Test
3. 10% Fines Test
4. Los Angeles Abrasion Test
5. Flakiness Index Test
6. Water Absorption Test

Sound granite aggregates from a commercial quarry located within the Kumasi area served as the control material.

3.3. Compressive Tests

The quartzite aggregates from the production source were oversized (75% within size range 20-50mm) and had to be reduced in size in the laboratory by manual crushing. The portion of the crushed sample passing the 14mm sieve and retained on the 10mm sieve designated in this project as having 12mm nominal size was used for concrete formula tion. Concrete test specimens were kept under the same curing condition of total immersion. The variables considered for study in the tests included water/cement ratios, aggregate/cement ratio and age of concrete. Initially, thirty six (36) concrete cubes made from only partially weathered quartzite aggregates were produced from four different concrete mixes (1:1:2, 1:1.5:3, 1:2:4 and 1:3:6) using cement ratios of 0.45, 0.5 and 0.6. Twelve (12) extra cubes made from granite aggregates produced from the same mixes using water cement ratio of 0.5 were made. Additionally, seventy two (72) concrete cubes made from both partially weathered quartzite aggregates and granite aggregates (36 each) produced from concrete mix ratio of 1:1.5:3 using water cement ratio of 0.5 were cured for the ages of 7days, 14 days, 28 days and 56 days.

3.4. Modulus of Rupture Tests

Concrete prisms (100x100x500mm) were prepared from mix proportions 1:1:2, 1:1.5:3, 1:2:4 and 1:3:6 using water-cement ratios of 0.45, 0.5 and 0.6 for partially weathered quartzite aggregates. They were tested under third-point loading at age 28 days to determine their modulus of rupture and its variation with water-cement ratio.

4. Test Results and Discussions

4.1. Aggregate Index Properties

Generally, aggregates with good physical and mechanical properties are expected to produce concrete of high strength properties. Factors that contribute to good ductility behaviour of aggregates are toughness and good shock absorbance nature [6, 20] which are indicated by the aggregate crushing value (ACV) and aggregate impact value (AIV). The percent water absorption of aggregates affects the durability of concrete whilst the flakiness index controls the water absorption to an extent. Table 2 contains the results of the index property tests carried out on samples of the quartzite aggregates and the control – granite aggregates, investigated.

Table 2. *Index properties of weathered quartzite aggregates from Juaso.*

Quality Index	Quartzite Aggregate			Granite (Control)	Standard Specification BS 812 (1992)
	Sound	Partially weathered	Highly weathered		
Flakiness Index (%)	19	14	12	12	≤40 for 40mm stone and above; ≤35 for 20mm stone and below
Water Absorption (%)	1.0	2.0	3.0	1.0	≤2.5
Aggregate Impact Value (%)	8	19	32	9	≤45
Aggregate Crushing Value (%)	16	20	32	15	≤35
Los Angeles Abrasion (%)	29	46	71	25	≤50
10% Fines Value (kN)	311	116	75	278	≥160

4.1.1. Flakiness Index

BS882 [19] classifies aggregate particles as flaky by means of simple gauges. The method is based on the assumption that a particle is flaky if its thickness (least dimension) is less than 0.6 times the mean sieve size fraction to which the particle belongs. High flakiness index value indicates increased water absorptive capacity which affects compressive strength of concrete made from such aggregates. In relation to this work, the grades of weathered quartzite aggregates and the control material were sampled from the portion which passed 14 mm sieve size and retained on the 10 mm sieve size. The flakiness index of each type of material is the ratio of the mass of the quantity that is flaky to the total mass of the sample taken expressed in percentage. Flakiness index values (Table 2) show that all the different grades of weathered quartzite aggregate as well as the sound granite aggregates have adequate measure to produce good concrete.

4.1.2. Aggregate Impact Value (AIV)

To measure the relative resistance of aggregate to sudden impact loads, AIV of the different aggregate materials were determined. The resistance of the aggregates to impact loads greatly influences the load carrying capacity of the concrete made from the particular aggregates. The oven-dry AIV was determined per the requirements of BS 882:1992 [19].

Aggregate particles passing 14mm and retained on 10mm were sampled and subjected to impact strength test. During the impact loading, the aggregates tend to break into particles and this can change the original grading of the aggregate used. The sample is graded and the quantity of particles passing 2.36 mm sieve size is obtained to evaluate the AIV. According to the BS specification all four types of aggregates satisfied the maximum limit of 45%. However, it is suspected that the weathered quartzite aggregates will have a reduced shock resistance compared with the sound granite aggregates.

4.1.3. Aggregate Crushing Value (ACV)

Gradual application of load has different effect on aggregates from sudden load application. The relative resistance of aggregates to gradual loading to crushing is measured as aggregate crushing value (ACV). The ACV is obtained by conducting four aggregate crushing tests for different compressive loads and plotting a graph of the load against the percentage of fines. As shown in Table 2, quartzite aggregate resistance to crushing decreased with extent of weathering with the un-weathered (sound) quartzite aggregates having similar resistance to the control aggregates. The highly weathered quartzite which recorded an average ACV of 32% cannot be recommended since it is very close to the limit (35%) stipulated by the BS code. However the partially weathered quartzite aggregate which recorded average ACV of 20% is satisfactory.

4.1.4. Ten Per Cent (10%) Fines Value

The ten per cent fines value indicates the load at which aggregates may crush to produce fines whose mass is 10% of the sample mass. Results (Table 2) show that the weathered quartzite aggregates required very small loads indicating weak resistance to crushing loads and higher susceptibility to producing fines.

4.1.5. Abrasion

The Los Angeles abrasion test was done to determine the combined wearing and breaking property of the aggregates. In this test, aggregate samples are placed in a steel drum with steel balls and the drum made to rotate at a set speed for 500 revolutions. In the abrasion machine all possible causes of wear are present as follows: (a) attrition- friction between the aggregates, (b) abrasion- friction between the steel balls and aggregates and (c) crushing –breaking by hitting the walls of the testing machine. This property measures the hardness of the coarse aggregates [21]. Table 2 shows that apart from the sound quartzite aggregates which recorded similar Los Angeles abrasion values (LAAV) as the control (29% and 25%, respectively), the highly weathered quartzite aggregates will have bad resistance to surface wearing and the partially-weathered quartzite marginally satisfies the limit of 50% maximum.

4.1.6. Water Absorption

The water absorption of the aggregates was observed to increase with the degree of weathering but only the aggregate described as highly weathered was found to have a water absorption value that was above the specification limit. The increase in water absorption of the aggregates with the degree of weathering was not unexpected because generally when rocks deteriorate in properties by weathering, changes in the micro-structure result in an increase in material porosity. Generally high water absorption characteristics of concrete aggregates become of concern in so far as the possibility exist for the material to absorb water from the concrete matrix and cause some amount of self-desiccation which lead to retardation in strength development [22]. Removal of water by absorbent aggregates could also lead to a higher degree of un-saturation and the consequent presence of empty spaces within the concrete microstructure which may lead to higher concrete compressibility than in a fully saturated state [23]. For such concrete materials, the application of a sufficiently high compressive load could lead to internal structural collapse which in turn may lead to irreversible creep [23]. These negative effects of absorbent aggregates are expected to become even more significant when one moves from the sound quartzite aggregates towards the highly weathered material.

The physical properties of the aggregates as discussed above proved that the sound quartzite aggregates has similar properties as the granite aggregates apart from the fact that it is flakier. The properties of the partially weathered quartzite aggregates also revealed that the material can produce concrete of good quality.

4.2. Compressive Strength

Figure 2 indicates how proportions of aggregates and water/cement ratio affect the 28-day compressive strength of partially weathered quartzite aggregates. It is evident that for each mix proportion the compressive strength of concrete increased with reduced water cement ratio. Several researchers [3,24] have shown that when the water-cement ratio is altered and the quantities of every other material remain the same, compressive strength will increase with decrease in water-cement ratio (w/c). The hydration reaction which is responsible for strength development requires minimum amount of water for the process [25].

For the high grade concrete (w/c= 0.45) the concrete reduced in compressive strength with increased proportion of aggregates. This could be attributed to the increased surface area requiring large amount of water for good bonding. Comparing both concrete from the two aggregates (Figure 2) reveals that the partially-weathered quartzite aggregate concrete showed only a slight difference in compressive strength from the granite concrete for lower aggregate ratios. As the aggregate ratio increased, however, the difference in strength became well pronounced.

Hydration of cement in concrete which is responsible for strength development is a gradual process. For a satisfactory development of strength though, it is not necessary that all the cement in concrete be hydrated [24]. Typical compressive strength development with age is shown in Figure 3 to Figure 5. As expected the compressive strength of both concrete increased with age. In both concrete types the rate of early age strength development is higher than strength development beyond 28 days. This confirms the reason why many codes of practice clearly states that design of concrete should be based on the 28 day characteristic strength. Although the granite concrete (control) recorded higher compressive strength than that of partially weathered quartzite, the partially weathered quartzite concrete obtained an average 28-day compressive strength of 86% of the granite concrete. The rate of concrete strength gain with age of concrete increased with increased water-cement ratio (Figures 4-6).

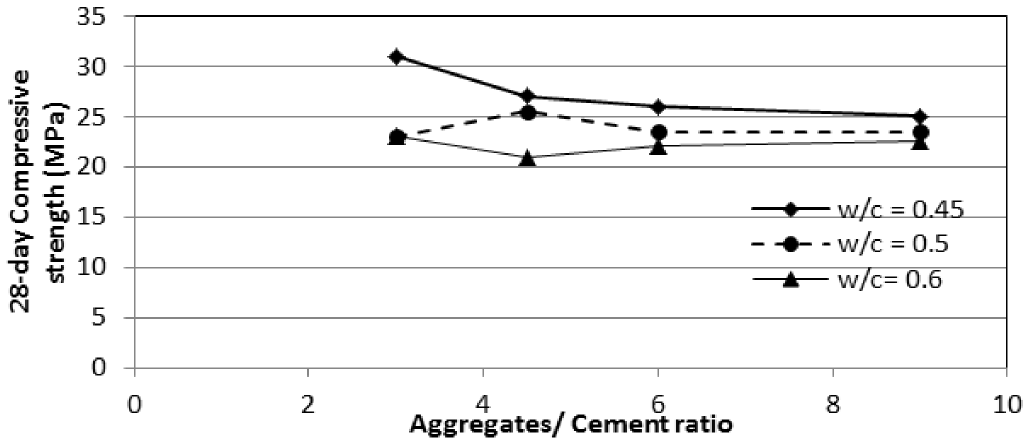

Figure 2. *Effect of variation of aggregate/cement ratio and water cement ratio on compressive strength of partially weathered quartzite aggregate concrete.*

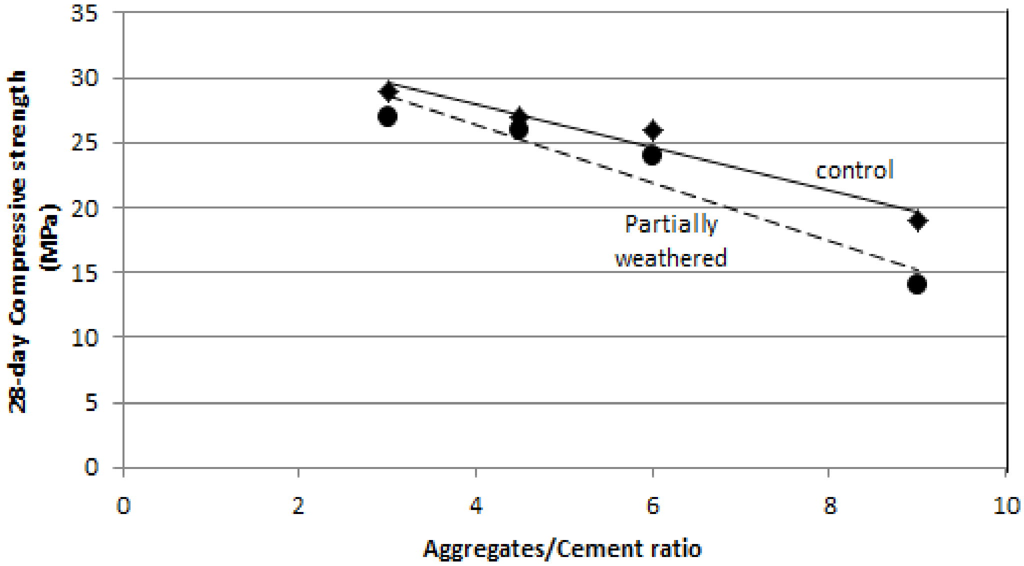

Figure 3. *Effect of variation of aggregate/cement ratio and water cement ratio on compressive strength concrete.*

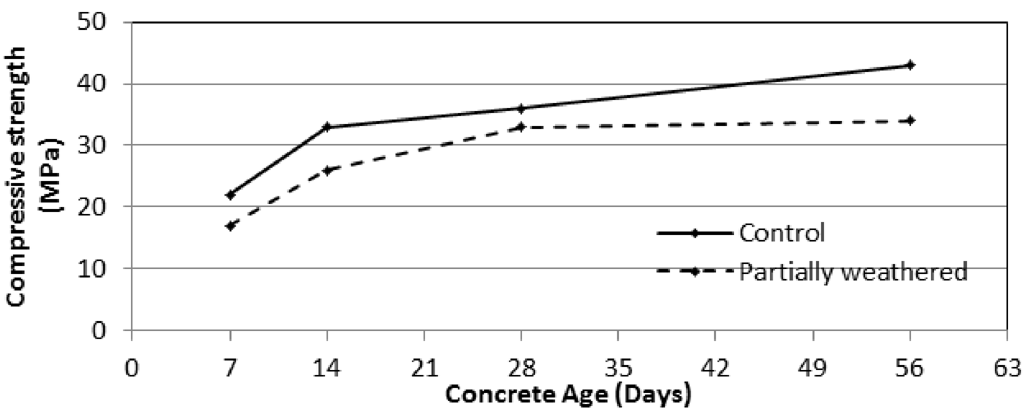

Figure 4. *Compressive Strength development of concrete mix 1:1.5:3, w/c=0.45*

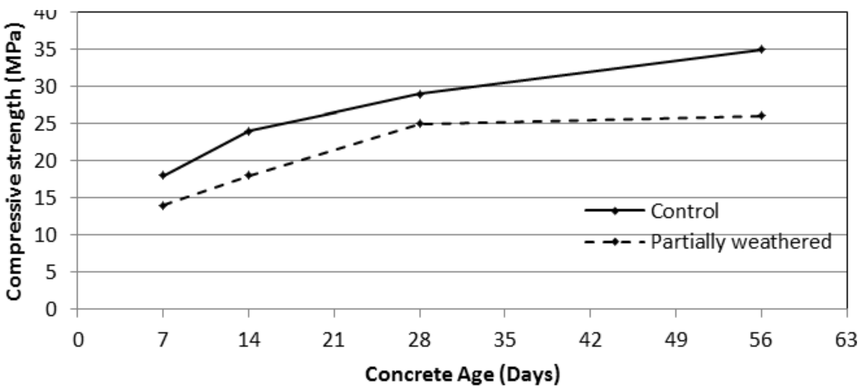

Figure 5. *Compressive Strength development of concrete mix 1:1.5:3, w/c=0.5.*

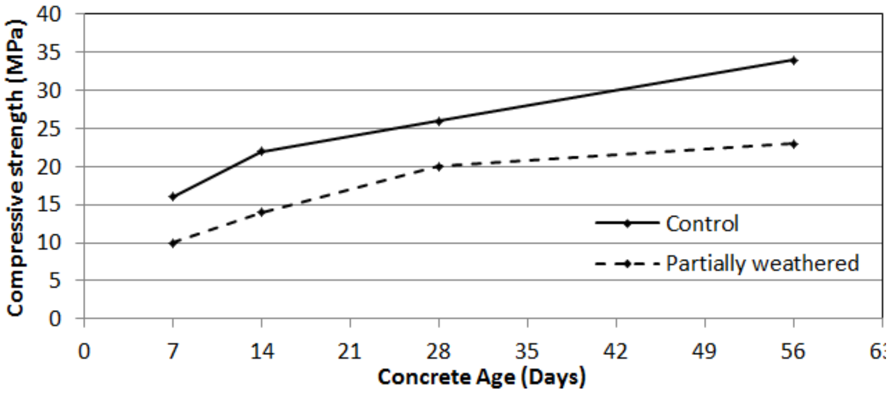

Figure 6. *Compressive Strength development of concrete mix 1:1.5:3, w/c=0.6.*

4.3. Tensile Strength

Although concrete is not normally designed to resist direct tension, the tensile strength of concrete is very important in estimating the load under which cracking will develop. It was reported that aggregate type influenced split tensile strength [26]. The tensile strength of concrete is very important especially in road and runway design. It is useful for distributing the concentrated loads over a wider area of road pavement [27]. It is also an important property in structural concrete design since it affects the bond strength, shear strength, brittleness ratio and flexural cracking [26]. The tensile strength of concrete (modulus of rupture) was measured by subjecting a plain concrete beam in flexure. In order to determine the tensile strength of concrete the ACI 318 [28] and the IS 456 [29] codes use the relation:

$$f_t' = 0.7\sqrt{f_{ck}} \quad (1)$$

where,

f_t' =tensile strength of concrete

f_{ck} =characteristic compressive strength of concrete (N/mm^2)

The above relation represents about 11 to 23 percent of the cube compressive strength [24]. As expected, the tensile strength of concrete made from partially-weathered quartzite increased with decreasing water-cement ratio and proportion of aggregates (Figure 7). As may be noted from Table 3, the quartzite aggregate concrete recorded tensile strengths which averaged 15.76% of the compressive strengths.

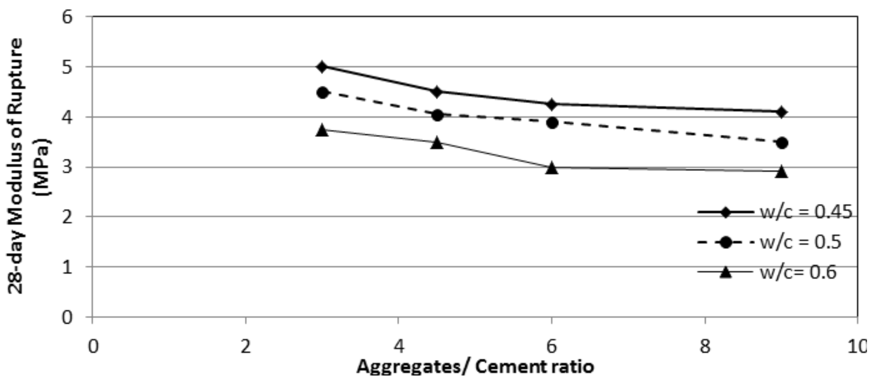

Figure 7. *Tensile Strength development of concrete mix 1:1.5:3 for different w/c.*

Table 3. *Compressive versus Tensile Strength of quartzite concrete: mix 1:1.5:3 w/c=0.5.*

w/c	Compressive Strength (N/mm^2)	Tensile Strength (N/mm^2)
0.45	33	4.5
0.5	25	4.05
0.6	20	3.5

5. Conclusion

Based on the results of this study, the following conclusions are drawn:

1. There was a marked difference between the aggregates in terms of strength and quality as demonstrated by their quality indices. These differences seem to give credibility to the subjective rating used in differentiating between the materials in terms of quality.
2. The sound (un-weathered) quartzite aggregates exhibited quality characteristics superior to those of the weathered grades but essentially the same as those of the sound granite aggregates used as the control.
3. Although the partially-weathered aggregate was low in strength in terms of the 10% Fines Value (below specification limits), it was generally satisfactory with respect to the other quality requirements and could be used as a marginal material in situations where there is complete non-availability of better quality materials.
4. The aggregates categorised as highly weathered failed completely to meet specification requirements for a concrete aggregate.
5. Concrete produced from partially-weathered quartzite exhibited similar properties as the granite concrete and obtained an average 28-day compressive strength of 86% of the granite concrete with similar properties. Partially-weathered quartzite aggregates, therefore, are recommended for concrete structures resisting low stresses.

References

[1] Chen, H. J., Yen, T., and Chen, K. H. (2003). Use of building rubbles as recycled aggregates. *Cement and Concrete Research*, *33*:125–32.

[2] Topcu, I. B, and Sengel, S. (2004). Properties of concretes produced with waste concrete aggregate. *Cement and Concrete Research, 34*:1307–12.

[3] Senthamari, R. M, and Devadas, P. M. (2005). “Concrete with ceramics waste aggregates”. *Cement and concrete. 27: 910-913.*

[4] Xiao, J., Li, J., and Zhang, Ch. (2005). Mechanical properties of recycled aggregate concrete under uniaxial loading. *Cement and Concrete Research, 35*:1187–94.

[5] De Brito, J, Pereira, A. S and Correia, J. R. (2005). Mechanical behaviour of non-structural concrete made with recycled ceramic aggregates. *Cement Concrete Compos*.,*27*: 429–33.

[6] Adom-Asamoah, M., and Afrifa, R.O, (2010). “A study of concrete properties using phyllite as coarse aggregates”. *Journal of Materials and Design 31*(9): 4561-4566

[7] Yue, P., Tan, Z., and Guo, Z. (2013). “Microstructure and mechanical properties of recycled concrete in seawater environment.” S*cientific World Journal*, Vol.2013 *Article ID 306714*

[8] Wang, J., Huang, T., Liu, X., Wu, P., and Guo, Z. (2013). “Mechanical properties of recycled concrete in marine environment.” *Scientific World Journal*, Vol. 2013. *Article ID 728357*

[9] Kesse, G. O. (1985). The mineral and rock resources of Ghana. A. A. Balkerma.

[10] Rodriguez, A. R, Del Castillo, H. and Sowers, G. F. (1988). Soil Mechanics in Highway Engineering. Trans Tech Publications.

[11] Gonzalez-Fonteboa, B. and Martinerz, A. F. (2007). Concrete waste aggregates from demolition waste and silica fumes materials and mechanical properties. *Building and Environment* doi:10.1016/j.buildenv.2007.01.008 (2006).

[12] Valera, T. S, Ribeiro, A. P, Valenzuela-Diaz, F. R, Yoshiga, A., Ormanji, W., and Toffoll, S. M. (2002). “The effect of phyllite as a filler for PVC plastisols”. *Annual Tech Conf Soc Plast Eng, 60*(3):3949–53.

[13] Taylor, H. P. J. (1974). The fundamental behaviour of reinforced concrete beams in bending and shear. In: *Proceedings ACI-ASCE Shear Symposium, Ottawa,* 1973 (ACI Special Publication SP42), ACI, Detroit, p. 43–77.

[14] Kong, E. (1994). Reinforced and prestressed concrete. Third edition, London, Chapman & Hall.

[15] Jumaat, M. Z., Alengaram, U. J., and Mahmud, H. (2009). Shear strength of oil palm shell foamed concrete beams. *J Mater Des, 30*:2227–36.

[16] Adom-Asamoah, M.**,** and Afrifa, R. O. (2011). “Investigation on the flexural behaviour of reinforced concrete beams using phyllite aggregates from mining waste.” *Materials and Desig*n, Vol. 32, 5132-5140.

[17] Gonzalez-Fonteboa, B., and Martinerz, A. F. (2007). Shear strength of recycled concrete beams. *Construction and Building Materials 21(4); 887-893*.

[18] British Standard Institute (1989). Specifications for ordinary Portland cement. BS812; 1989.

[19] British Standard Institute. Specification for aggregates from natural sources for concrete. BS882; 1992.

[20] Teo, D. L., Mannan, M. A., and Kurian, J. V. (2006). Flexural behavior of reinforced lightweight concrete beams made with oil palm shell (OPS). *J Advanced Concrete Technology 4*(3):1–10.

[21] Kahraman, S., and Toraman, O. Y. (2008). “Predicting Los Angeles abrasion loss of rock aggregates from crushability index.” *Bull. Mater. Sci, 31*(2*)*,173-177.

[22] Poon, C. S., Shui, Z. H., Lam, L., Fok, H., and Kou, S. C. (2004). Influence of moisture states of natural and recycled aggregates on the slump and compressive strength of concrete. *Cement and Concrete Research, 34*: 31-36.

[23] Chatterji, S. (2004). An explanation for the unsaturated state of water stored concrete. *Cement and Concrete Composites*, Vol. 26, pp 75-79.

[24] Neville, A. M. (1996). "Properties of Concrete", Fourth edition, Pearson Education Limited, Prentice Hall.

[25] Jackson, N., and Dhir, R. H. (1996). "Civil Engineering Materials, Fifth edition, Palgrave Macmillan Publishers.

[26] Beshr, H, Almusallam, A. A., and Maslehuddin, M. (2003). Effect of coarse aggregate quality on the mechanical properties of high strength concrete. *Construction and Building Materials*, 17:97–103.

[27] Sabnis, M.Y, and Sabnis, G,. M. (2001). "Mix Design of concrete – Principles and Practice, Fifth revised edition.

[28] ACI Committee 318 (2002): "Building code requirements for structural concrete ACI 318-02 and commentary USA.

[29] IS456 (2000). "Plain and reinforced concrete code of practice". Bureau of Indian Standards (fourth revision) ICS 91.100.30 July 2000.