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Investigation of the Compressive Strength of Heavy Concrete Made with Locally Sourced Barite Aggregates

Dauda Dahiru
Department of Building, Faculty of Environmental Design, Ahmadu Bello University, Zaria, Nigeria

Abstract: Concrete is the material mostly used for radiation shielding and to a large extent, the quality of it depends on aggregate used to produce it. This is a report on investigation carried out on one of the aggregates used to produce heavy concrete used for radiation shielding. Barite aggregates were locally sourced from 2 states. Using British Standard, these samples were subjected to apparent specific gravity, Bulk density, Void ratio, Sieve analysis, absorption capacity and moisture content tests. Thereafter a concrete of nominal mix 1:2:4 using W/C ratio of 0.65 was used to prepare 3 types of concrete cubes of 150×150×150 mm, A, B and C. A total of 135 cubes were produced for the 3rd, 7th, 14th, 21st and 28th day's test so that each type of sample has 45 cubes. Fresh concrete was subjected to workability test while the hardened concrete samples were subjected to density and compressive strength test. Test results show that the specific gravity of the 2 heavy aggregates are the same -4.2, while granite has 2.63; the bulk density of aggregates from Azara, Lesse and Zania are 2523.8, 2509.7 and 1563.2 kg m^{-3} and absorption capacity are 1.84, 2.35 and 5.83, respectively. The slump value for the samples A, B and C are 101, 109 and 42, respectively. The compressive strength of samples after 28 days of curing are 21.16, 21.04 and 17.60 N mn^{-2}. Based on the results of investigation, it was concluded that the quality of concrete produced using locally sourced barites is better than the one made of granites. In addition, our local barites can be used as aggregates for producing heavy concrete, used for shielding nuclear radiation. It was, however recommended that the nuclear attenuation characteristics of concrete made of such aggregate should be investigated. In recent times, human activities have introduced new sources of radiation such as X-rays used in medicine, nuclear weapons and nuclear reactors for power generation. These pose risks as such research effort to find solution to such problem like radiation shield will assist most especially with the recent commissioning of nuclear reactor in Nigeria. Besides, too much pressure is put on granite and gravels for the production of concrete, this can be a right step in solving this problem.

Key words: Barite, aggregates, nuclear, radiation, heavy concrete shielding, compressive strength

INTRODUCTION

Nuclear power is now part of our everyday life, many types of nuclear reactors are currently operating throughout the world. Here in Nigeria, the Energy Research recently commission a nuclear reactor at Zaria. However, no human activity can be completely without risk, as such, the use of atomic energy for peaceful purposes has to provide means for protecting the personnel against the radiation hazard caused by nuclear reactors and use of plants for manufacturing and processing isotopes, particle accelerators, industrial radiography and X-ray, gamma ray therapy etc particularly, hazardous to living organisms are X-rays, gamma radiation and neutrons.

According to Neville (1996), the X-rays and gamma rays are fundamentally the same in nature (electromagnetic, high energy and frequency waves) though they differ in origin and properties. X-rays results from an atomic process outside the atomic nucleus, while gamma rays usually steam from a nuclear process. Neville (1996) observed that gamma rays given off when neutrons are absorbed by nuclear often complicate the design of shields, which must attenuate neutrons as well as gamma rays.

Ironically, the attenuation of neutrons and absorption of gamma rays require the presence of different elements in the shielding materials. For, the degree of protection against gamma is determined by the thickness of the shield and its bulk density, it is also an established fact that substances with a considerable amount of hydrogen, offer effective protection against neutron. This means water provides protection against neutron radiation but water has low density (Polivka and Davis, 1987). The material that possesses both properties required for a biological shield is concrete.

According to Neville (1996) and Neville and Brooks (2002), aggregate occupy 70-80% of the volume of concrete that is why it is very important constituents of concrete. Aggregates give body to the concrete, reduce shrinkage and affect economy as such; their impact on various characteristics and properties of concrete is undoubtedly considerable. Without the study of the aggregate in depth and range, the study of concrete is incomplete. Aggregates used for producing concrete for radiation shielding are materials that have a high specific gravity.

The concrete used for shielding operate at high temperature and stress level greater than conventional structures, for instance pre-stressed concrete reactor pressure vessels (PCRV) for nuclear power generation can be expected to operate at bulk vessel temperatures of about 70° (160°F) under relatively multi-axial stress and the vessel will be subjected to some thermal cycling during its lifetime. Inelastic deformations such as creep and shrinkage should be minimized as they can cause microcracking of the concrete and loss of prestress Likewise, thermal incompatibility between aggregate and cement paste can also cause microcracking within the concrete especially if temperature cycling occurs (Polivka and Davis, 1987). In addition, microcracking not only reduces the predictability of vessels response to prestress and pressure forces, but also reduces concrete strength and increase in permeability. This, probably explain the reason why, according to Polivka and Davis (1987), research in the past 20 years has been directed towards learning more about the behavior of concrete under multi-axial stresses at elevated temperature and condition of temperature cycling. It was however, observed that in many cases, knowledge of concrete properties under rather complex condition is insufficient for proper analysis.

What is more important, is the knowledge about the properties of concrete material which will enables designers, specifiers and users of it make an informed choice of the construction material used for shielding (Polivka and Davis, 1987). A lot of effort was made in that direction. For example, Adams and Lokan (1979) investigated the attenuation of fast neutrons in Ilmenite concrete. Kolaly and Makarious (1987) carry out a research on different types of locally prepared concretes and their usability for reactor neutron shielding. Abdul-Majid and Othman (1994) investigated the neutron attenuation characteristics of polyethylene, polyvinylchloride and heavy aggregate concrete and mortars. Makarious *et al*. (1996) study total and secondary doses in Ilmonite and Limonite concrete biological shields. Bashter *et al*. (1997) undertook a research on investigation of Hematite-Serpentine and Ilmenite-Limonite concretes for reactor shielding, while Bashter (1997) has carry out a research on the calculation of radiation attenuation coefficients for shielding concretes. Ibrahim and Rashed (1998) study the neutron shielding parameters for different types of concrete made with local materials. Besides that, Kansouh *et al*. (2001) studies the radiation shielding properties of dolomite and Ilmenite concrete. Other researches that were carried out are the proton attenuation coefficient of barite, marble and limra by Akkurt *et al*. (2004), study the shielding of gamma rays by concrete produced with barite (Akkurt *et al*., 2004). Another research by Akkurt *et al*. (2005) was on an investigation of the radiation shielding ability of concrete containing different aggregates. Besides that, Zakari (2007) has undertaken a research on the use of locally sourced serpentine as a shielding material. In all these researches, effort was made to study the properties of materials (especially the locally sourced materials) in order to determine their suitability for use in nuclear radiation shielding.

For the fact that the use of construction material depends on, among others, the location and availability of construction materials (Arora and Bindra, 2005), this calls for the need to carryout a careful investigation on the viability of using locally sourced aggregates for concrete shields. Especially, considering the fact that no particular rock or mineralogical type in itself is required for aggregate (Neville, 1996). The only thing is that, once any rock attains certain desired properties, it can be used for heavy concrete. BS 4619 (1970) and ASTM C192-281 (ASTM, 1981a) cover aggregate used for radiation shielding.

Barite is one of the aggregates that are used to produce heavy concrete used for radiation shielding and to a large extent, the properties of such concrete depends on the properties of aggregates. In view of the fact that Nigeria is blessed with this type of aggregate in Benue, Nasarawa and some part of Zamfara State, there is the need to examine these barite so as to carry out an investigation on properties of aggregates as provided in BS 4619 (1970) in order to know, whether they conform to the minimum requirement needed to serve as one of the ingredient for the production of concrete used for shielding. This is especially important in view of the fact that concrete making properties of aggregates are influenced, to some extent, on the basis of geological formation of the parent rock and the subsequent processes of weathering and alteration. According to Shetty (2004), within the main rock group, the quality of aggregate may vary to a great extent due to change in the structure and texture of the main parent rock from place to place. Although, the usual acceptable standard for ordinary super structural reinforced concrete under high quality control are adequate for shielding concrete, except for certain additional testing which involves the density and hydrogen content. Other desirable properties include reasonably high and consistent density, low drying shrinkages, resistance to irradiation and reasonable cost.

For the fact that many experts (Neville and Brooks, 2002; Taylor, 2002) have observed that compressive strength is the most important property of concrete and that other properties largely depend on it, this research investigated the properties of local barite in Nasarawa and Benue States and its influence on compressive strength of concrete produced with it. So that, knowledge of the properties of our local barite aggregate can help in the use of such aggregates not only for radiation shielding but for high quality constructions this will, in turn, reduce the high demand on the popularly used aggregates .such as gravels and granites.

MATERIALS AND METHODS

The materials used in this research work include the following:

Cement: The cement used was Ordinary Portland Cement (OPC) manufactured and recently supplied by the Ashaka Cement Company Plc.

Fine aggregates: The fine aggregates used in this research work was fine river sand obtained from Samaru-Zaria and sieved with a 5 mm BS112 (1971) sieve so as to remove larger aggregates and organic impurities.

Coarse aggregate and sample identification: The coarse aggregate used in this research work was barite aggregate sampled from 2 geographical locations in Nigeria. i.e., sample A was obtained from Azara local government area of Nasarawa state, sample B was obtained from Lesse local government area of Benue state. The samples were obtained in large lumps and broken down into aggregate size.

The third sample was granite obtain form Sabon-Gari local government area of Kaduna state. The sample (sample C) was used as reference aggregate and was combined such that it conform to standard grading curve similar to that of sample A and B.

Harmful impurities: Visual inspection was used in order to determine whether the aggregate contain harmful material in such a form or quantity as to affect adversely the property of the concrete.

The experiment was carried out in 3 stages. The 1st stage entails investigating the various properties of the 2 barites samples in accordance to procedures outlined in British Standard BS 4619 (1970), BS 812 (1985), BS 812 (1990) BS 882(1992) and BS 933 (1997). The properties investigated are: apparent specific gravity, Bulk density, Void ratio, Sieve analysis and Moisture properties of aggregates.

In the 2nd stage, a concrete was produced using a nominal mix ratio of 1:2:4 and a water/cement ratio 0.65; then the fresh concrete was subjected to slump test in order to determine its workability. The slump test was performed in accordance to the relevant British Standards, most especially BS 1881 (1983).

The 3rd stage consists of preparation of concrete cubes of 150×150×150 mm size. These concrete cubes are of three types. There is sample A-which is concrete produced using barite aggregates from Azara-Nasarawa State, sample B is concrete sample made from barite aggregates obtained from Lesse-Benue State and sample C which was produced using ordinary aggregates obtained from granite stone in Sabon-Gari, Kaduna State and it is the third sample C that was used as control specimen. These samples were cured under controlled temperature and moisture condition for 24 h, then stripped and cured inside curing tank at 18-20°C for 7, 14, 21 and 28 days. They were then subjected to compressive strength test at air dry condition. After each of these curing days, a total of 9 samples were used, with 3 each for samples A, B and C; and for each day's test, the casting and subsequent crushing were carried out in 3 days, so that each day's test has total (9×3) = 27 samples and the average of the test results was used. This amount to 45 cubes for each set of concrete, thus making a total of 135 cubes. The sample made on the first day has an identification number SA1-for sample A, while the sample produced in the second day is SB2-for sample B and the sample prepared in the third day, SC3-for sample C, etc. The preparation of the samples and subsequent testing were carried out in accordance to the appropriate British Standard; such as BS 1881: 126 (1986), BS 812 (1990) and BS 1881: 124 (1988).

RESULTS AND DISCUSSION

Properties of aggregates samples

Sieve analysis: As it can be observed from the result of sieve analysis in Table 1 and 2, over 90% are passing the B.S 112 sieve 20 mm. thus conforming to the (same)

Table 1: Details of sieve analysis for sample A coarse aggregate

Sieve No	Weight passing (kg)	Weight retained (kg)	Passing (%)	Retained (%)
19 mm	23.01	0.39	98.30	1.67
9.5 mm	9.96	13.05	42.56	55.80
4.75 mm	6.17	3.80	26.34	16.20
2.36 mm	3.49	2.68	14.91	11.40

Table 2: Details of sieve analysis for sample B course aggregate

Sieve No	Weight passing (kg)	Weight retained (kg)	Passing (%)	Retained (%)
19 mm	44.13	4.47	90.00	9.30
9.5 mm	15.23	28.90	31.30	59.50
4.75 mm	7.93	7.30	16.00	15.00
2.36 mm	3.15	4.78	6.40	9.80

Table 3: Average values of evaluated properties of aggregate samples

Property	Aggregate ID	Unit	Value/result
Specific gravity	SA		4.2
	SB		4.2
	SC		2.63
Bulk density	SA	Kg m^{-3}	2523.8
	SB	Kg m^{-3}	2509.7
	SC	Kg m^{-3}	1563.2
Void ratio	SA		0.4
	SB		0.4
	SC		0.41
Moisture content	SA		0.167
	SB		0.502
	SC		0
Particle shape	SA		Angular
	SB		Angular
	SC		Angular
Particle texture	SA		Rough
	SB		Rough
	SC		Rough
Absorption capacity	SA		1.84
	SB		2.35
	SC		5.83

Table 4: Slump test results

Sample ID	W/C ratio	Slump value (mm)	Degree of workability	Average strength at 28 days
Sample A	0.65	101	High	21.16
Sample B	0.65	109	High	21.04
Sample C	0.65	42	Medium	17.60

standard grading curve number four. This is to be expected, because the aggregates were obtained in lumps broken down to aggregate sizes and effort was made to ensure that sample A and B confirm to almost the same grading curve Fig. 1 and 2.

Specific gravity, bulk density, moisture content and absorption capacity: Looking at the results of various test performed on the samples, it would be observed that the aggregate samples A, B and C have specific gravity of approximately 4.2, 4.2 and 2.63, respectively. This clearly show that there is wide difference between samples A and B on one hand and sample C, which is a normal aggregate obtained from granite. It also show that the specific gravity of the 2 barite aggregates are within the heavy

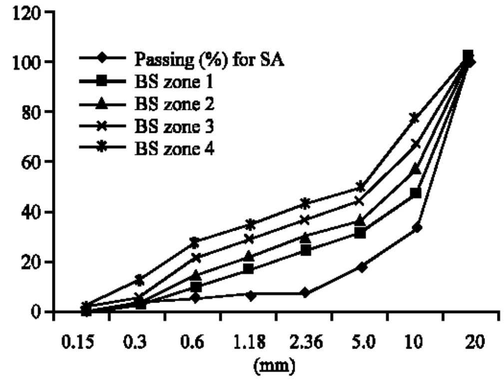

Fig. 1: Aggregate garding zone for sample A

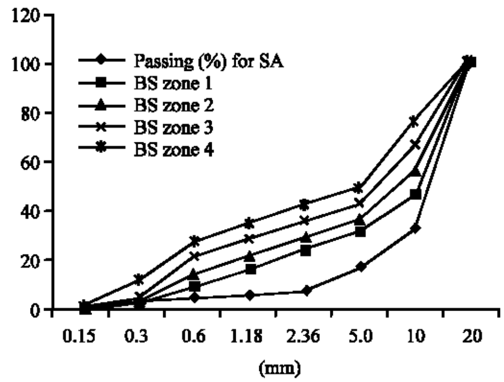

Fig. 2: Aggregate garding zone for sample B

aggregate class as the value provided by BS 4619 (1970) is 4.0. According to Gambhir (2002), the specific gravity of an aggregate gives valuable information on its quality and properties. The higher the specific gravity of an aggregate, the harder and stronger it will be.

The value of bulk density of the 2 barite aggregates samples fall within the range of 2518.5-254.5 kg m^{-3} and 2488.8-2518.5 kg m^{-3} for samples A and B, respectively. This also shows that they satisfy the minimum values of the bulk density because according to Neville (1996) and Charles (2006), the minimum value of bulk density for any aggregate to fall under the heavy weight aggregate class is 2100 kg m^{-3}. Although, some expert used higher value of the bulk density e.g. High bulk density is an indication that there are fewer voids to be filled by sand and cement. Thus, it is a good way of judging the quality of aggregate. It also, determines the types of concrete that can be produced with good aggregate.

When the other test results as contained in Table 1-11), are closely examined, it would be noted that some of these (test results) are the same or very close to each other. These include void ratio of the 3 aggregates in which the 2 barites have the same void ratio of 0.4 and

Table 5: Weight-density relationship with respect to curing days

		Average weight of sample (kg)				Average density of sample (kg m^{-1})			
Sample ID	Volume	7 days	14 days	21 days	28 days	7 days	14 days	21 days	28 days
SA	0.003375	9.7	9.8	9.8	9.6	2883.9	2893.3	2913.6	2844.4
SB	0.003375	9.8	10.0	9.8	9.8	2893.8	2933.3	2893.8	2903.7
SC	0.003375	8.0	7.8	7.8	7.9	2360.5	2321.0	2301.2	2340.7

Table 6: Results for sample after 7 days curing

Sample identity	SA1	SA2	SA3	SB1	SB2	SB3	SC1	SC2	SC3
Weight (kg)	9.7	9.7	9.8	9.8	9.7	9.8	8	7.8	8.1
Density (Kg m^{-3})	2874.07	2874.07	2903.7	2903.7	2874.07	2903.7	2370.37	2311.11	2400
Max loading (KN)	355	370	390	410	370	400	330	290	310
Maximum bearing pressure(N mm^{-2})	15.78	16.44	17.33	18.22	16.44	17.78	14.67	12.89	13.78

Table 7: Result for sample after 14 days curing

Sample identity	SA1	SA2	SA3	SB1	SB2	SB3	SC1	SC2	SC3
Weight (kg)	9.7	9.7	9.9	10	9.9	10	7.9	7.8	7.8
Density (Kg m^{-3})	2874.07	2874.07	2933.3	2962.96	2874.07	2962.96	2340.74	2311.11	2311.11
Max loading (KN)	400	420	405	448	404	420	318	324	320
Max bearing pressure(N mm^{-2})	17.77	18.67	18.00	19.91	17.96	18.67	14.13	14.40	14.22

Table 8: Result for sample after 21 days curing

Sample identity	SA1	SA2	SA3	SB1	SB2	SB3	SC1	SC2	SC3
Weight (kg)	9.8	10.0	9.7	9.8	9.8	9.9	7.8	7.7	7.8
Density (Kg m^{-3})	2903.7	2962.96	2874.07	2903.7	2903.7	2874.07	2311.11	2281.48	2311.11
Max loading (KN)	440	452	447	470	460	478	338	350	342
Max bearing pressure(N mm^{-2})	19.56	20.08	19.87	20.89	20.44	21.24	15.03	15.56	15.20

Table 9: Result for sample after 28 days curing

Sample identity	SA1	SA2	SA3	SB1	SB2	SB3	SC1	SC2	SC3
Weight (kg)	9.6	9.6	9.6	9.8	9.8	9.7	7.9	8.0	7.8
Density (Kg m^{-3})	2844.4	2844.4	2844.4	2903.7	2903.7	2874.1	2340.7	2370.4	2311.11
Max loading (KN)	458	492	478	500	430	490	388	404	396
Max bearing pressure(N mm^{-2})	20.36	21.87	21.24	22.22	19.11	21.78	17.24	17.96	17.60

the control aggregate (granite) has 0.41. Increases in void content of the coarse aggregate will in turn, increase the quantity of mortar required for the mix. The reverse is also true (Raju, 1990). Also, the particle shape and texture of all the three aggregate samples are the same. They are angular and rough, respectively. According to Taylor (2002), angular aggregates may produce higher workability than rounded ones while rough surface provides an extremely good key to cement; although it tends to reduce workability and this result in increased strength provided the aggregate satisfy other requirements. Besides that, rough textured aggregate develops higher bond strength.

In the case of moisture content and absorption capacity tests, results show that there is wide variation between the values obtained for the 3 samples. For example results of moisture content test shows that samples A, B and C have 0.167, 0.502 and 0, respectively while for the absorption capacity, the following values or results were obtained: 1.84, 2.35 and 5.83., respectively

Table 10: Average value of compressive strength for various samples with respect to curing days

	Compressive strength		
No. of days	Sample A	Sample B	Sample C
7 days	16.52	17.48	13.78
14 days	18.15	18.85	14.25
21 days	19.84	20.86	15.26
28 days	21.16	21.04	17.60

These could be due to the fact that the sources of these aggregates are not the same in terms of geographical location and hence, there may be variation in the weather condition of these places. This will, ultimately, affect the moisture content and possibly the absorption capacity for the fact that water is the main Lubricant in concrete mixes, small changes in water content, may produce marked changes in workability (Taylor, 2002). This means sample B with relatively high moisture content and sample C with no moisture content would need different water requirement. In the case, of sample B and even, perhaps

Table 11: Values of average specific gravity and bulk density for sample A and B

Sample ID	Bulk density	Apparent specific gravity
SA	2523.8	4.2
SB	2509.7	4.2

A, they will require a deduction of water at the mixer equal to the total free moisture present in the batch of aggregate. But sample C, on the other hand may not require additional water. If it were light weight aggregate concrete it may, even, require extra water.

If the absorption capacity is taken into consideration, it clearly shows that sample C, with high absorption capacity may need the addition of water. It should be noted that less absorption capacity of aggregate allows the design water of hydration to properly react with the design cement thus resulting in complete hydration process which yields high strength concrete as in the case of sample A and B in this research work. While, aggregate with high absorption capacity tends to absorb water of hydration which would not allow for complete hydration.

Fresh concrete

Workability: Results of slump test on fresh concrete shows that samples A, B and C have the following slump values: 101, 109 and 42 mm. This shows that the first 2 samples (A and B) have high workability, while the concrete made of granite aggregate has medium workability. Looking at the results of moisture contents and absorption capacity test, it is obvious, that the relatively Low value of Workability of sample C (granite aggregate) is due to high absorption capacity value and absence of moisture in the aggregate added to the fact that the nature of the surface texture, being rough, reduces the workability. In the case of the first 2 samples (A and B), result of the moisture content test shows that they contain moisture (especially sample B). The gap between the values of slump for samples A and B may be higher if not for the absorption capacity of sample B is comparatively higher than sample A.

On the whole, the workability test results for all the samples show that more work is needed in consolidating the concrete made of granite aggregate than the ones made up barite aggregate. Also, if the water-ratio is reduced to such a level that would be enough to produce a dense and homogenous concrete, it is likely to produce concrete of higher strength; because many expert have observed that there is an inverse relationship between the water-cement ratio and strength (Neville and Brooks, 2002; Taylor, 2002; Varghese, 2006). It was also, noted that to produce high

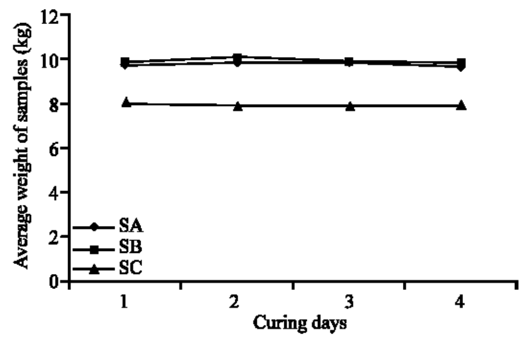

Fig. 3: Graph of density of various samples with curing days

density and high strength concrete, it is necessary to control the water-cement ratio very strictly. For instance too much water for hydration would result in voids caused by entrained air which affects the strength of concrete in the same way as voids of any other origin (Neville, 1996). This probably is the reason, why Topcu (2002) after undertaking a research barite concrete, concludes that the most effective w/c ratio to be used for Barite concrete should be 0.4.

Harden concrete

Density: Results of the test on density of hardened concrete showed that the values for concrete samples made of barite aggregate are high. This can be seen clearly from the graph in Fig. 3. The Lowest value of density is 2844 kg m^{-3} at 28 days which, still, falls above the minimum value for heavy weight concrete that can be used for the constructions of structures where heavy load is involved or where there is a need for shielding against radiation (Charles, 2006). According to Neville (1996), the use of high-density concrete in shielding radiation is necessary where thickness of shield is governed by space availability. The capacity of various heavy aggregates to absorb gamma is almost entirely proportional to their density, also heavier element are more effective in absorbing fast neutrons by elastic collisions than the light ones therefore, as heavy as possible concrete should be used for the shielding purpose. That is why it was suggested that the radiation shielding quality of concrete can be increased by increasing the density.

Compressive strength: From the results of the compressive strength test, the relationship between compressive strength and number of curing days can be seen. For the strength of the three samples increases

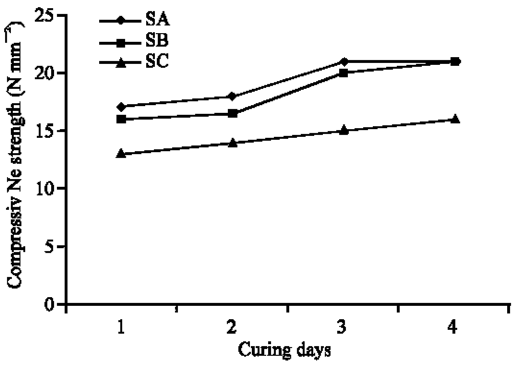

Fig. 4: Graph of compressive strength of various samples with curing days

considerably from 16.52, 17.48 and 13.78 N mm^{-2} at 7 curing days to 21.16, 21.04 and 17.60 N mm^{-2} at 28 curing days for sample A, B and C, respectively. This also, clearly indicate the marked difference between the compressive strength of concrete made with barite aggregate and the one made with granite-a difference of 19.5-20%.

The strength variation between Barite samples (A and B) and that of reference aggregate (granite) could be attributed to the difference in some of the properties of these aggregates such as specific gravity, density and void ratio. According to Neville (1996), the strength of concrete is a direct function of its density this means also that the density of aggregate can affect the strength of concrete. It can also be observed that the compressive strength for the barite aggregate are all greater than 21 N mm^{-2}. This is within the range of compressive strength given by Gambhir (2002), who observed that the range of compressive strength is of the order of 20-21 N mm^{-2} when water/cement ratio of between 0.5-0.65 is used and a cement aggregate ratio of 1.5-1.9. However, the author is confident of achieving higher compressive strength if the water/-cement ratio is reduced because the aggregates have satisfied the minimum requirement in terms of the desired properties of aggregates to be used as heavy aggregates. For instance, according to Neville (1996), using a mix of 1:4.6: 6.4 with water/cement ratio of 0.58 the strength of concrete measured on standard cylinders, has been found to be 42 MPa (6100 psi) at 28 days while for a water/-cement ratio of 0.90 a strength of 24 MPa (3500 psi) was obtained.

The compressive strength value of heavy concrete strength is yet another very important property needed for effective shielding of nuclear radiation. It is the property that can give good indication of most of the other properties of concrete. If it is good it implies most of the properties of concrete are good (Raju, 1990; Neville and Brooks, 2002; Varghese, 2006). This implies that concrete produced using barite as coarse aggregate is more qualitative than ordinary concrete produced with granite or gravels. Since, the compressive strength for the barites are approximately 20% higher than the concrete made of granite aggregates. This can be seen at the graph in Fig. 4.

CONCLUSION

From the result of various test and research carried out in the crushed barite aggregate and concrete, the following conclusions can be drawn:

- The apparent specific gravity of barite aggregate from both Azara-Nasarawa state and Lesse-Benue state is 4.2. This is far greater than that of reference granite aggregate from Sabo gari, Zaria which is 2.63.
- The average bulk density of barite aggregate from Azara-Nasarawa state is 2523.8 kg m^{-3} and of Lesse-Benue state is 2509.7 kg m^{-3} which can be categorize as heavy weight aggregate. The density for heavy weight concrete is 1750 kg m^{-3}, while that of reference aggregate is 1540.74 kg m^{-3} which falls under the category of normal aggregate.
- The crushing of both barite aggregate produces predominantly angular shape (with greater proportion of the aggregate shaped in a glass like structure) and a rough texture with average absorption capacity of 1.84 and 2.35 for Azara-Nasarawa state and Lesse-Benue state samples, respectively while reference aggregate has a value of 5.83 as the absorption capacity.
- Concrete made with barite has an average density of 2822.4 and 2903.7 kg m^{-3} for Azara-Nasarawa state and Lesse-Benue state sample, respectively. This falls under category of heavy weight concrete which has an average density greater then 2600 kg m^{-3} compared to the concrete made with reference aggregate (granite) which has a density of 2340 gk m^{-3}. This falls under category of normal weight concrete.
- The average compressive strength of the barite concrete is 21.16 and 21.04 N mm^{-2} for Azara-Nasarawa state and Lesse-Benue state samplesm, respectively at 28 days curing. While the reference aggregate maintains a compressive strength of 17.60 N mm^{-2}. The barite concrete has reasonably greater strength than the reference aggregate using the same w/c ratio.

RECOMMENDATIONS

- Barite can suitably replace the traditional gravel in as coarse aggregate for the production of concrete for structural purposes such as beams, columns, slabs, retaining walls etc. It should be noted that due to the weight of concrete produced by these aggregate, extra form work would be required as stipulated by BS 4619 (1970). Also, such aggregates should be used for where emphasis is not made on dead load, like in the construction of foundation, block work in the substructure, cement concrete pavement, embankment, etc.
- The locally sourced aggregate sample should be used for construction of should be used for structures that would serve as a nuclear radiation shield such as prestress concrete reactor pressure vessel or concrete shield in the core of nuclear reactor.
- Further investigation should be carried out on the barite concrete to establish the best water/cement ratio and Aggregate/cement ratio to be used, the tensile characteristics of the concrete, the radiation attenuation property of the concrete, creep and shrinkage properties, anchorage bond strength, shear and flexural strength and its deformation characteristics.
- In using the locally sourced barite aggregates, for the production of heavy concrete, adequate care should be paid to the preparation of such concrete. Most especially the proportioning, the water/cement ratio to be used should be less than the one used in this research work. Water-cement ratio of 0.4 can be used.

REFERENCES

Abdul-Majid, S. and F. Othman, 1994. Neutron attenuation characteristics of Polyethylene, Polyvinyl, Chloride and Heavy Aggregate concrete and Mortars. Health Phys. Soc., 66 (3).

Adams, R.J. and K.H. Lokan, 1979. Attenuation of fast neutrons in Ilmenite Concretes. Health Phys., 63: 671-678.

Akkurt, I. *et al*., 2004. The photon attenuation coefficients of Barite, Marble and Limra. Ann. Nuclear Energ., 31: 577.

Akkut, I. *et al*., 2005. Radiation Shielding of Concrete Containing Different Aggregate. www.Sceincedirect. Com.

American Society for Testing and Materials ASTM; C: 192-281, 1981a. Constituents of Aggregates for Radiation Shielding Concrete. In: Annual book of ASTM Standards, Part 14, Philadelphia P.A., USA.

Arora, S.P. and S.P. Bindra, 2005. The text book on Building Construction. Dhampat Rai Publication New-Delhi, India.

Bashter, I.I., 1997. Calculation of Radiation Attenuation Coefficients for Shielding Concretes. Annals of Nuclear Energy, 24: 1389.

Bashter, I.I., A.E. Abdo and A.S. Makarious, 1997. A comparative study of the attenuation of reactor thermal neutrons in different types of concrete. Ann. Nuclear Energ., 23: 1189-1195.

British Standard B.S. 112, 1971. Determination of Properties of Fine Aggregate' BSI, 389. Chiswick High Road London W4 4AL, UK.

British Standard B.S. 1881:116, 1983. Method for the Determination of Compressive strength of Concrete Cubes. BSI, 389. Chiswick High Road London W4 4AL, UK.

British Standard B.S. 812: 109, 1990. Method for Determination of Moisture Content of Aggregate' BSI, 389. Chiswick High Road London W4 4AL, UK.

British Standard B.S. 812: 2, 1985. Determination of Density of Aggregate' BSI, 389. Chiswick High Road London W4 4AL, UK.

British Standard B.S. 882: 109, 1992. Aggregates from Natural Sources for Concrete. BSI, 389. Chiswick High Road London W4 4AL, UK.

British Standard B.S. 933: 1, 1997. Determination of Particle Size Distribution-Sieving Method, BSI 389. Chiswick London W4 4AL, UK.

British Standard Institution BS 1881:124, 1988. Methods of Analysis of Hardened Concrete. BSI, 389. Chiswick High Road London W4 4AL, UK.

British Standard Institution BS 1881:126, 1986. Methods for Mixing and Sampling Fresh Concrete in the Laboratory. BSI, 389. Chiswick High Road London W4 4AL, UK.

British Standard, BS 4619, 1970. Heavy Aggregate for Concrete and Gypsum Plaster. BSI, 389. Chiswick High Road London W4 4AL, UK.

Charles K. Nmai, 2006. Properties of Heavy Weight Concrete. www.Sciencedirect.com

Gambhir, M.L., 2002. Concrete Technology. Tata McGraw-Hill Publishing Company Limited West Patel Nagar, New-Delhi, India.

Ibrahim, M.A. and R.A. Rashed, 1998. Deduction of some neutron shielding parameters for different types of concrete made from local materials. Nuclear Sci. J., 35 (4): 245-250.

Kansouh, M.F., A. El-Sayed Abdo and R.M. Megahid, 2001. Radiation Shielding Properties of Dolomite and Ilmenite Concrete. Fourth Conference and Workshop on Cyclotrons and Applications, Cairo, Egpt.

Kolaly, M.A. and A.S. Makarious, 1987. Inter-comparison of Different Types of Local Prepared Concretes and Its Usability for Reactor Neutron Shields. 1st Egyptian-British Conference on Biophysics, Cairo University, Egypt.

Makarious, A.S., M.A. Elkolaly, I.I. Bashter and W.A. Kansouh, 1996. Total and Secondary Gamma Doses in Ilmonite-Limonite Concrete Biological Shields. Kernenegie 34.

Neville, A.M. and J.J. Brooks, 2002. Concrete Technology. Pearson Educational Ltd, Edinburgh Gate, Harlow Essex, United Kingdom.

Neville, A.M., 1996. Properties of Concrete. 4th Edn. Addison Wesley Longman Limited Edinburgh Gate, Harlow Essex, England.

Polivka, M. and M.S. Davis, 1987. Radiation Effects and Shielding. In: Significance of Tests and Properties of Concrete and Concrete- making Materials ASTM STP 169B, Philadelphia, USA.

Raju, N.K., 1990. Design of Concrete Mixes. Bangalore CBS Publishers and Distributors, India.

Shetty, M.S., 2004. Concrete Technology, Theory and Practice S. Chand and Company Ltd; Ram Nagar, New-Delhi 110 055, India.

Taylor, G.D., 2002. Materials in Construction, Principles, Practice and Performance. 2nd Edn. Pearson Education Ltd; United Kingdom.

Topcu, I.B., 2002. Properties of Heavy Weight Concrete Produced With Barite. Osmengazi University, Turkey.

Varghese, P.C., 2006. Building Materials. Prentice Hall of India Private Limited, New-Delhi-1100001, India.

Zakari, Y., 2007. An Investigation on the Use of Locally Sourced Serpentine as a Nuclear Radiation Shield. An Unpublished Ph.D Dissertation, Ahmadu Bello University, Zaria, Nigeria.