

Densification of Concrete using Barite as Fine Aggregate and its Effect on Concrete Mechanical and Radiation Shielding Properties

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ABSTRACT

This paper presents findings of research conducted on the improvement of radiation shielding in concrete, using barite as fine aggregate. Barite is a heavy mineral, having specific gravity in range of 3.5 to 4.5, and is abundantly available in different parts of Pakistan. Radiation shielding of barite concrete was studied experimentally for use in optimization of the thickness of radiation therapy bunkers. The Influence of barite on mechanical properties of concrete was also studied for a range of water-to-cement ratios from 0.30 to 0.45. ASTM standards were used to compute compressive and tensile strengths of concrete, whereas thermogravimetric analysis was carried out to determine percentage weight loss at elevated temperature. Radiation shielding potential of concrete was studied by subjecting concrete sections to gamma-ray source (Cobalt-60). Experimental results showed that the use of barite mineral as fine aggregate increases shielding ability of concrete. Linear attenuation coefficient was found to increase by 28.4% and varied proportionally with the variation in density of concrete. However, a slight decrease in compressive and tensile strengths was noted with the addition of barite as fine aggregate concrete. Due to high absorption capacity of barite, the problem of workability was overcome through the use of admixtures within allowable limit of ASTM (i.e., less than 3%). Finally, an optimum water-to-cement ratio of 0.45 for barite mineral infused concrete is recommended for the least reduction in mechanical properties and with significantly improved level of radiation shielding.

Keywords: Normal concrete; barite concrete; compressive strength; tensile strength; elastic modulus; radiation shielding.

INTRODUCTION

The advent of nuclear technology has been the cornerstone of technology. It has gained immense importance in various fields of science and technology for betterment of human kind. The role of nuclear technology for the benefit of mankind has been multifaceted including but not limited to electricity production, agriculture, industry, and medicine (Alan E *et al.*, 2004). The use of nuclear technology, however, has adverse effects on the living environment since it results in ionization of living cells resulting in death of living cells and endangering human life through cancer. One of the basic requirements related to the use of nuclear reactions is safeguarding against them by limiting exposure of living organisms to the radiations resulting from nuclear reactions (Y. Elmahroug *et al.*, 2013; Maxwell *et al.*, 2008; Gehlot Dilip *et al.*, 2014). Effective shielding against nuclear radiations has been the focus of many

studies; the objective of each work is the provision of an effective shield between ionization radiation source and the living environment (Y. Elmahroug *et al.*, 2013; Christopher A. Maxwell *et al.*, 2008). These studies have been carried out for different shielding materials with varying thicknesses and recommendations for optimum thickness against different sources such as X and Gamma rays, Alpha, Beta, and Neutron particles. The bombardment of each of these sources results in a different shielding requirement in the studied materials. In other words, the effectiveness of a shielding material is a function of its material properties and optimum thickness against all possible sources of nuclear radiations. Alpha and beta particles are easy to stop using ordinary building materials because of their charged nature, although specialized shielding materials are required to stop X-rays, Gamma rays, and Neutron because they have high penetration (McAlister *et al.* 2012).

The specialized shielding material should be selected so as to ensure penetration of x-rays, gamma rays, and neutron. Denser materials are required to stop gamma and x-rays while lighter materials are required to stop neutron (Y. Elmahroug *et al.*, 2013). Heavy metals are in common use to stop x-rays and gamma rays efficiently (O. B. Nwosu, 2015) but they cannot stop neutrons and cause photo neutron emission when struck by gamma rays (Y. Elmahroug *et al.*, 2013). Normal concrete is also a commonly used material for radiation shielding but it is uneconomical (in terms of material use and space occupation) because it requires increased thickness to shield x-rays and gamma rays. The given problem with normal weight concrete can be solved by increasing its density. Density of concrete is increased by using some heavier materials as aggregates. There are a number of heavier minerals as barite, magnetite, hematite, galena, etc., which can be used as aggregates in concrete to make it denser (Ahmed S. Ouda, 2015; S. M. J. Mortazavi *et al.*, 2007; Athira Suresh *et al.*, 2015). All these minerals are of equal importance but in this research work barite is preferred and is used as aggregates because of its local availability, high specific gravity, and inertness (S. Nayyer Ahsan *et al.*, 2007). Barite increases density of concrete and thus improves its shielding ability (Saidani *et al.*, 2015). Barite density reaches 4.46 at 26°C which is close to some iron ores such as lead, hematite, magnetite, and galena (Saidani *et al.*, 2015). Optimum amount of barite needs to be incorporated in concrete in order to enhance concrete shielding because higher amount may degrade mechanical properties of concrete. Shielding ability of barrier materials is measured in terms of linear attenuation coefficient which is defined as the probabilities of radiation interacting with material per unit traversed length. Tenth value layer and half value layer are other parameters used to measure shielding ability of a material. Tenth-value layer is defined as the thickness of shielding required to reduce the intensity of radiations to one-tenth of its value while Half-value layer is defined as the thickness of shielding material required reducing intensity to the half of its value. These parameters are measured by many researchers and concluded that barite addition in concrete increases its density and makes it a good radiation shielding material (Khaled Saidani *et al.*, 2015; I. Akkurt *et al.*, 2010; Davood Mostofinejad *et al.*, 2012; F. Demir *et al.*, 2011; Ilker Bekir Topçu, 2003; Berna Oto *et al.*, 2013; I. Akkurt *et al.*, 2008; K.Sakir *et al.*, 2003). Barite addition to concrete increases its shielding ability to gamma rays by making it denser while lighter elements in concrete such as hydrogen and oxygen from mixing water makes it an efficient shield to neutrons. Neutron collision with lighter elements (hydrogen, etc.) drops it to thermal range, then they are absorbed by heavier elements (Y. Elmahroug *et al.*, 2013).

In Pakistan normal concrete in combination with lead is used in radiation therapy bunkers. Normal concrete is not effective in radiation shielding with normal thickness. To overcome this problem either the wall thickness is increased (Primary wall thickness of bunker is 8 feet in Institute of Radiotherapy and Nuclear medicine, Peshawar Pakistan) or lead lining is provided to the concrete wall with normal thickness. The purpose of this research work is to modify concrete to make it an economical and efficient construction material for radiation shielding by increasing its density. Barite is incorporated into concrete as a sand replacement. Maximum amount of barite is needed to be incorporated into concrete but due to barite friability only sand is completely replaced with barite to reduce its adverse effects on mechanical properties of concrete (Khaled Saidani *et al.*, 2015; Martha Alejandra González-Ortega *et al.*, 2015). Barite concrete alone can be used as a shielding material with reduced thickness in radiation therapy bunkers and atomic reactors.

MATERIAL AND TEST METHODS

Materials

Limestone based crushed stones were used as coarse aggregates, obtained from local material stocks in Peshawar, Pakistan. 25mm was the maximum size used in the mix. Gradation according to standard ASTM C-33 was obtained by forming blend of different sizes. Physical properties and gradation of coarse aggregates are given in Table 1 and Figure 1(a), respectively.

Natural sand in saturated and surface dry condition was used as fine aggregates. Sand was made clean and free of any organic impurities by washing before use. Physical properties of the study material, gradation and standard (ASTMC33/C33M-13.) gradation are given in Table 1 and Figure 1(b).

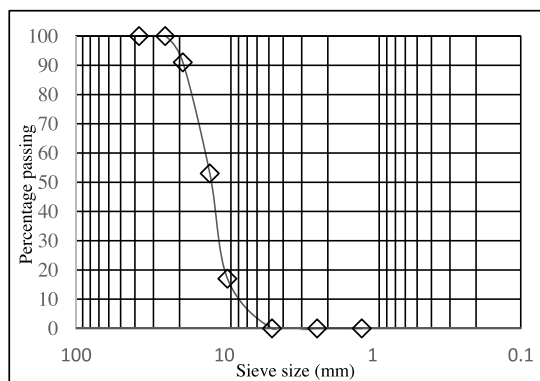


Fig. 1 (a)

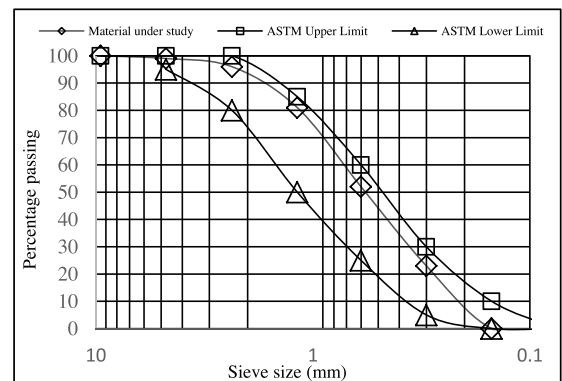


Fig. 1 (b)

Figure 1. Gradation curve of Coarse aggregates (a) and Fine aggregates (b).

Barite minerals were obtained from barite quarries in Jamrud, Federally Administered Tribal Areas (FATA), Pakistan. Physical properties and microscopic study results of barite are given in Table 1 and Figure 2, respectively. SEM results of barite showed crystalline structure, composed of layers. Layered crystalline structure is prone to be separated into constituent layers which reduced barite resistance to crushing.

Table 1. Physical property of aggregates.

	Specific Gravity	Bulk Density	Absorption Capacity	Max. Aggregate Size	Fineness modulus	Abrasion value
Coarse aggregate	2.65	591.1 kg/m ³	1.3%	25.44 mm Down	-----	-----
Fine aggregate	2.38	-----	1.88%	-----	2.34	-----
Barite mineral	3.75	-----	3.05 %	-----	2.31	73%

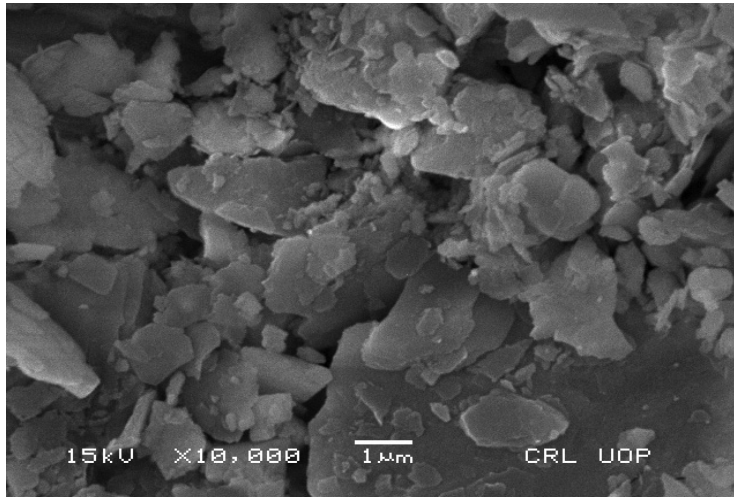


Figure 2. SEM result of fine barite.

Chemical composition of the Ordinary Portland cement which was used as binder is given in Table 2 obtained from X-ray fluorescence spectroscopy.

Table 2. Chemical composition of OPC.

Constituents	CaO	Al ₂ O ₃	SiO ₂	Fe ₂ O ₃	ZnO+MnO+TiO ₂	K ₂ O
Mass (%)	79.0	13.82	5.8	1.16	0.22	--

Ultra superplast470 was used as chemical admixture. Ultra superplast470 is useful when high workability is required at lower water-cement ratio. Table 3 discusses properties of ultra superplast470. As per ASTM standard, it is normally used in concrete in the range of 1.0 to 3% by weight of cement. This admixture fully complies with ASTM C-1017 for concrete chemical admixtures

Table 3. Properties of Ultra superplast470.

Property	Appearance	Alkali content	Air Content	Specific Gravity
Value	Brown Liquid	<72.0g. Na ₂ O	<3%	1.155 at 20°C

Mix proportioning

Two sets of the concrete specimens were prepared. One set of concrete specimens consisted of natural aggregates named as normal concrete and in the other set of concrete specimens, sand was completely replaced with barite named as barite concrete.

Experimental work consisted of preparing concrete cylinders of dimensions 300mm in height [x] 150mm in diameter. ACI method (ACI 211.1) was used for mix proportioning of concrete mixes. Mix proportioning was carried out by weight. For the proportioning of the mixes the properties of the materials were obtained by laboratory testing. Mix design details are given in Table 4.

Fine aggregate was completely replaced by barite in barite concrete samples. Replacement was carried out by volume of fine aggregate. Admixture (Ultra superplast470) was added at the rate given in Table 4.

Table 4. Mix design details.

W/CM	Weight of ingredient for normal concrete (Kg/m ³)				Chemical admixture (%)	Weight of ingredient for barite concrete (Kg/m ³)				Chemical admixture (%)
	W	CM	F.A	C.A		W	C	F.A	C.A	
0.30	174	580	462	1145	1	174	580	719	1066	2.0
0.35	203	580	547	1145	0.8	203	580	819	1066	1.5
0.40	232	580	610	1145	0.5	232	580	893	1066	1.5
0.45	261	580	660	1145	0.3	261	580	946	1066	1.0

W= Water, CM= Cement, F.A= Sand in normal concrete, barite in barite infused concrete, C.A= Coarse aggregate

Due to lower water-cement ratios and high absorption capacity of barite, super plasticizer was used to achieve workable concrete. As shown in Table 5, a slightly higher dosage of super plasticizers can significantly increase the workability of barite concrete. For a water-cement ratio of 0.3, the workability of barite concrete (for an admixture dosage of 2% by weight of cement) is higher than normal concrete (for an admixture dosage of 1%).

Table 5. Fresh concrete properties.

Water/Cement	Slump Type	Slump values (mm)	
		Control samples	Treated samples
0.3	True	36	46
0.35	True	63	69
0.4	True	74	78
0.45	True	89	84

Laboratory testing

Compressive strength test

Compressive strength test was performed on five concrete cylinders for each water-cement ratio of both sets of specimens. Therefore, a total number of 40 cylinders were tested according to ASTM C31/39 using Hydraulic Universal testing machine. Tests were performed on cylindrical samples shown in Figure 3(a). Specimens were prepared in 3 equal layers with each layer rodded 25 times for proper compaction. Samples were kept in molds for 24 hours, which were then demolded and kept in curing tank for 28 days. Tests were conducted after 28 days of moist curing. Axial load at failure was noted for all the samples to calculate compressive strength.

Tensile strength test

Tensile strength is one of the basic and important properties of concrete. It is necessary to determine tensile strength of concrete because concrete is weak in tension due to its brittle nature. Split cylinder tensile strength test was conducted on three concrete specimens for each water-cement ratio from both sets of specimens to determine tensile strength of concrete. A total number of 24 cylinders were tested according to ASTM 496C/496M for the determination of tensile strength of concrete. The test setup is shown in Figure 3(b).

Elastic modulus

Ultrasound pulse velocity method is generally used for the measurement of dynamic elastic modulus of concrete. ASTM C597-09 Standard Test Method was used for the determination of elastic modulus of concrete. This method consists of measuring time taken by wave generated at one face of concrete cylinder and received at the other face as shown in Figure 3(c). The longitudinal velocity is calculated from the distance between the two transducers and time that is measured. Relationship exists between ultra sound pulse velocity and dynamic elastic modulus which is given by equation (1).

$$E = \frac{\rho V^2(1 + \nu)(1 - 2\nu)}{(1 - \nu)} \quad (1)$$

Ultra sound pulse velocity test was conducted on three concrete cylinders from both sets of specimens for each water-cement ratio.

Thermogravimetric analysis test (TGA)

Thermogravimetric analysis was carried out in accordance with ASTM-E1131 as shown in Figure 3(d), to check stability of specimens at elevated temperature. Stability was determined by forcing materials to undergo chemical and physical changes at elevated temperature. The percent weight loss of a test specimen was then measured by heating the specimen at uniform rate in an appropriate environment.

Scanning electron microscopy (SEM)

The application of the SEM is petrographic analysis of *cementitious* materials and concrete microstructure. SEM imaging provides detailed images of the microstructure. This test was carried out to compare microstructure of control and barite concrete samples (ASTM C1723). Test setup is shown in Figure 3(e).

Gamma rays dosimetry test

Cobalt-60 (Co^{60}) was used as a source to produce gamma rays from the Phoenix Machine in IRNUM Hospital Peshawar for the dosimetry of concrete samples, shown in Figure 3(f). The given machine is used for radiotherapy in cancer treatment. Co^{60} radiates gamma rays at two different energies, i.e., at 1.33 MeV and 1.17 MeV energy levels. The two gamma rays can be taken as a single ray with energy equal to average of the two rays, i.e., 1.25 MeV. To measure the gamma-ray attenuation coefficient, the amount of gamma-rays was measured by detector after 1 minute without concrete samples (N_0). Then concrete samples of different thickness were placed and amount of gamma rays was measured (N) after 1 minute by the detector.

Linear attenuation coefficient (cm^{-1}) of gamma rays for control and barite concrete was then computed using equation (2).

$$\mu = \frac{1}{x} \ln \frac{N_0}{N} \quad (2)$$

μ = Linear attenuation coefficient

x = material thickness in cm

N_0 = Dose detected by detector without concrete samples between detector and source

N = Dose detected by detector with concrete samples between detector and source.

Half value layer for control concrete and barite concrete sample was determined using equation (3).

$$HVL = \frac{\ln(2)}{\mu} = \frac{0.693}{\mu} \quad (3)$$

μ = .Linear attenuation coefficient



Fig. 3 (a)



Fig. 3 (b)



Fig. 3 (c)



Fig. 3 (d)

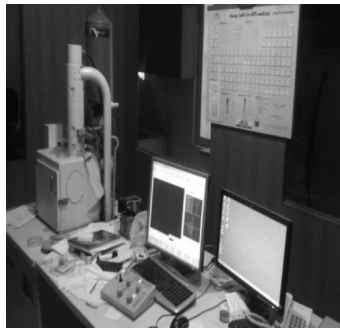


Fig. 3 (e)

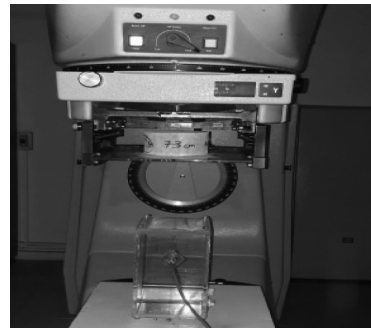


Fig. 3 (f)

Figure 3. Laboratory Testing, (a) Compressive strength test, (b) Tensile strength test, (c) Ultra sound pulse velocity test, (d) TGA, (e) SEM, and (f) Gamma dosimetry.

RESULTS AND DISCUSSION

Compressive strength test results

Compressive strength was determined by crushing concrete samples in hydraulic universal testing machine after 28 days of casting. Compressive strength results are given in Figure 4.

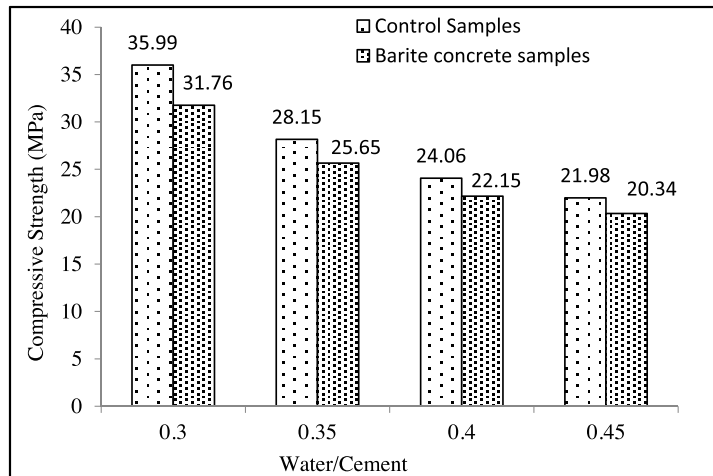


Figure 4. Compressive strength test results.

There is reduction in compressive strength of concrete with addition of barite as fine aggregate replacement. Maximum reduction has occurred at lowest water-cement ratio of the study, i.e., 11.75% at water-cement of 0.30. Reduction in compressive strength has reduced at higher water-cement ratio and reached 7.46% at maximum water-cement ratio of the study.

Low crushing strength of barite minerals is probably responsible for reduction in the compressive strength of barite concrete samples as compared to control concrete samples. In addition to this, abrasion value of barite was noted to be high and grinded to powder form when subjected to load greater than its crushing value.

Tensile strength test results

Split cylinder test was conducted on concrete samples after 28 days of moist curing to determine tensile strength of concrete using hydraulic testing machine. Tensile strength test results are presented in Figure 5.

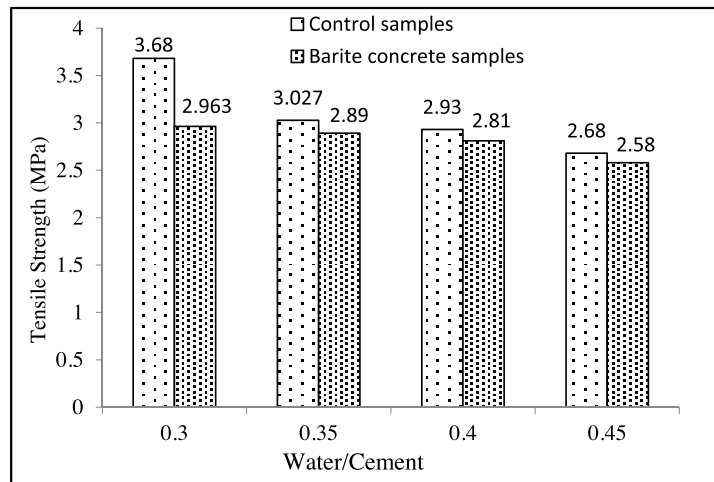


Figure 5. Tensile strength test results.

It can be readily seen in Figure 5 that the tensile strength of concrete decreases with the addition of barite; however, the reduction in strength is within acceptable range. Maximum reduction was found to occur at the lowest water-cement ratio of the study, i.e., 19.75% at water-cement of 0.30. Reduction in tensile strength was observed to decrease at higher water-cement ratio, which was found to reach 3.7% at maximum water-cement ratio of 0.45.

Decrease in tensile strength may be due to weak adhesion of concrete ingredients. As barite is friable and is liable to grind to grain size during mixing, causing barite dust, this dust accumulates around coarse aggregate causing decrease in adhesion between cement paste and lime stone aggregate which may cause a considerable reduction in tensile strength.

Elastic modulus test results

Ultra sound pulse velocity tests were conducted on concrete samples using Pundit apparatus to determine dynamic elastic modulus after 28 days of casting for both the sets of concrete specimens. The test results presented in Figure 6 show that elastic modulus of concrete has been decreased with the addition of barite minerals as replacement of sand. Percentage reduction is higher at lower water-cement, which is then reduced at higher water-cement ratio. Barite has less effect on elastic modulus of concrete as compared to compressive and tensile strength.

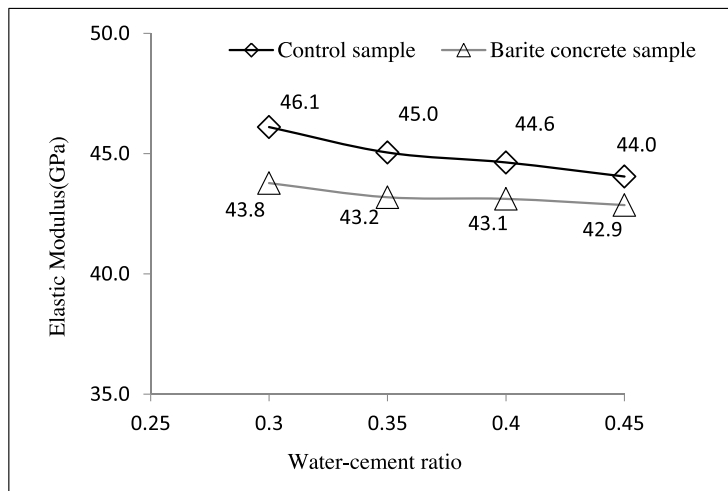


Figure 6. Elastic moduli of control and barite concrete.

Thermo-gravimetric analysis test results

TGA was conducted on concrete samples to determine concrete stability at elevated temperature. Figure 7 shows that concrete stability has been reduced at elevated temperature with the addition of barite as sand replacement.

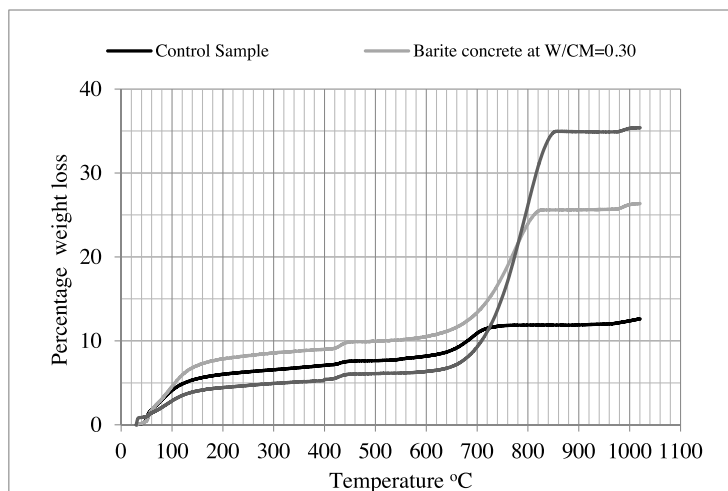


Figure 7. TGA results of control concrete and barite concrete.

It was found that the increasing amount of barite decreases the stability of concrete at elevated temperatures. The possible reason for the reduction in concrete stability may be due to high water absorption of barite. 13% reduction in mass of control concrete samples was observed for temperature range of 0-1000°C. In case of control samples, abrupt change was found to occur at temperature range from 600°C to 750°C. A total percentage reduction of 28.1 and 35.4 occurred in mass of barite concrete sample prepared at water-cement ratio of 0.30 and 0.45, respectively. It was concluded from the test results that concrete stability at elevated temperature decreases with increase of barite content in concrete. In case of barite concrete samples, abrupt change occurred at temperature range from 600°C to 850°C.

Scanning electron microscopy (SEM) test results

SEM was carried out to compare drying shrinkage cracks and voids for both set of specimens. SEM results are given in Figure 8 and Figure 9.

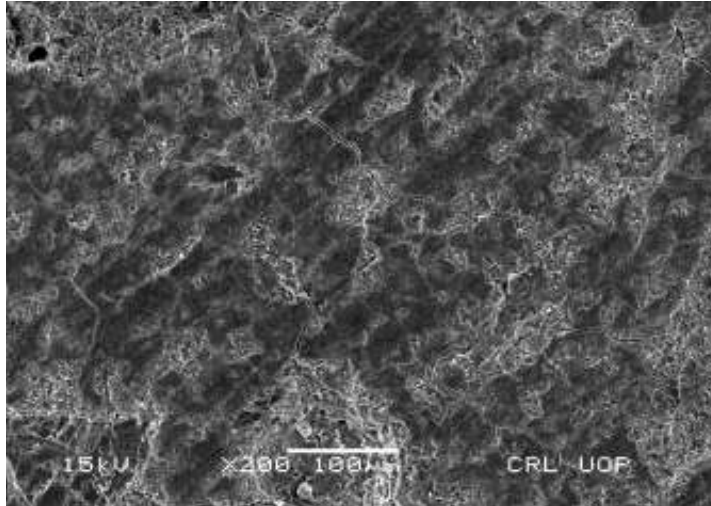


Figure 8. SEM results of control concrete sample.

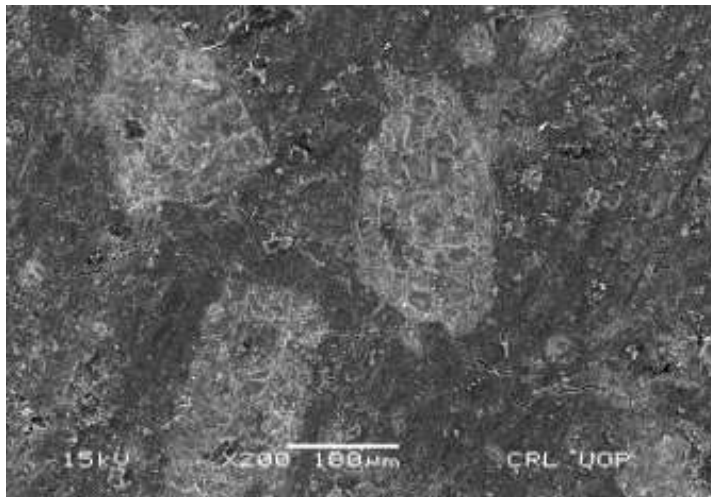


Figure 9. SEM results of barite concrete sample.

SEM results show that there are fewer shrinkage cracks and voids in barite concrete sample in comparison to control sample, which shows that addition of barite to concrete as a sand replacement controls shrinkage cracks.

Gamma rays dosimetry test results

Linear attenuation coefficient values

Linear attenuation coefficient is determined for both control and barite concrete to compare their shielding ability. Results of linear attenuation coefficient are given in Figure 10. Shielding ability of concrete has been increased with the addition of barite to the concrete.

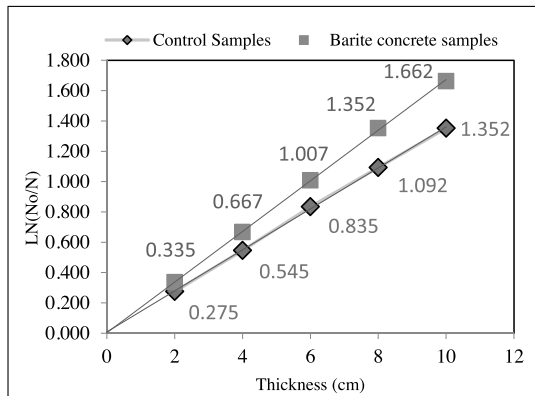


Fig. 10 (a)

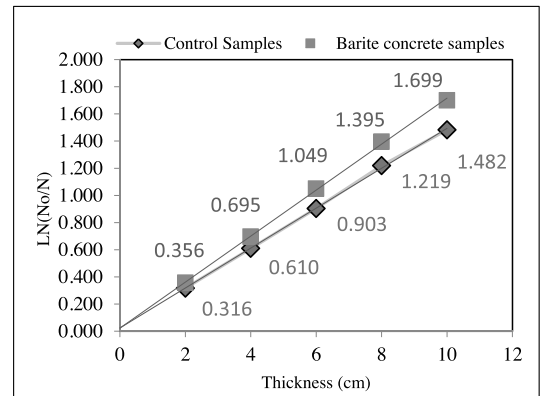


Fig. 10 (b)

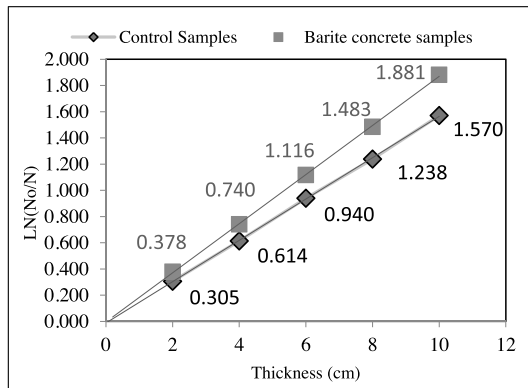


Fig. 10 (c)

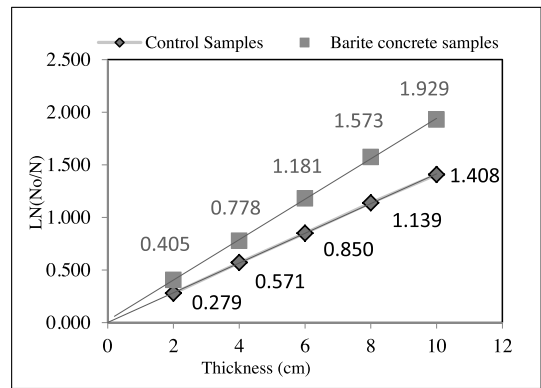


Fig. 10 (d)

Figure 10. Linear attenuation coefficient results at water-cement ratio of 0.30 (a), 0.35 (b), 0.40 (c), and 0.45 (d).

Linear attenuation coefficient of barite concrete samples was found to be higher than that of control samples at given water-cement ratio, as shown in Figure 11.

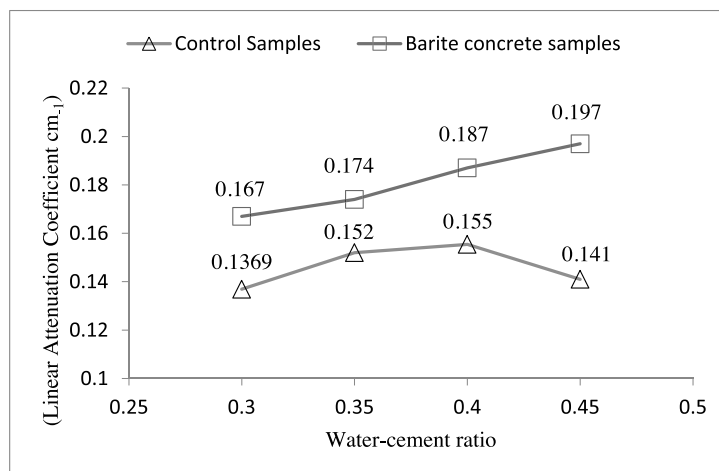


Figure 11. Variation of linear attenuation coefficient with water-cement ratio.

For normal concrete linear attenuation coefficient increase with increase in water-cement ratio until 0.40, beyond water-cement ratio of 0.40, there is decrease in linear attenuation of normal concrete because of decrease in density of normal concrete. Maximum attenuation is at water-cement ratio of 0.40 for normal concrete. For barite concrete samples linear attenuation coefficient increase with increase in water-cement ratio, there is no decrease beyond water-cement ratio of 0.40 as there is no decrease in density beyond water-cement ratio of 0.40. Maximum attenuation is at water-cement ratio of 0.45 which contains high barite content as compared to lower water-cement ratios.

Linear relationship exists between linear attenuation coefficient and density of concrete, given in Figure 12.

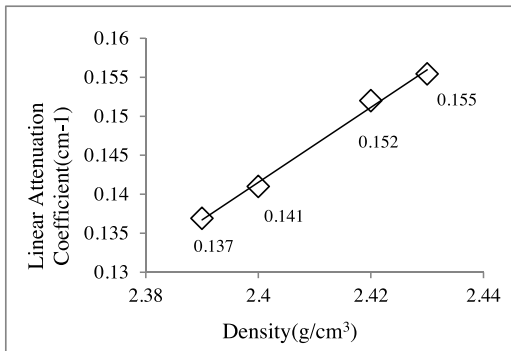


Fig. 12 (a)

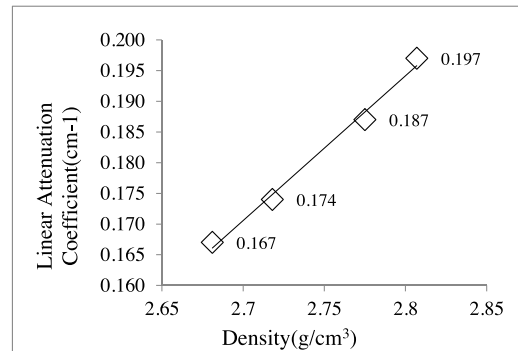


Fig. 12 (b)

Figure 12. linear attenuation coefficient vs. samples density for control concrete (a) and barite concrete (b).

For normal concrete density is maximum at water-cement ratio of 0.40; that is why linear attenuation coefficient is also maximum at the given water-cement ratio. For barite concrete samples maximum attenuation is at water-cement ratio of 0.45 because density is maximum at the given water-cement ratio.

Half value layer

Half value layer is determined to predict reduction in thickness of radiation bunker walls. Half value layer result is given in Figure 13.

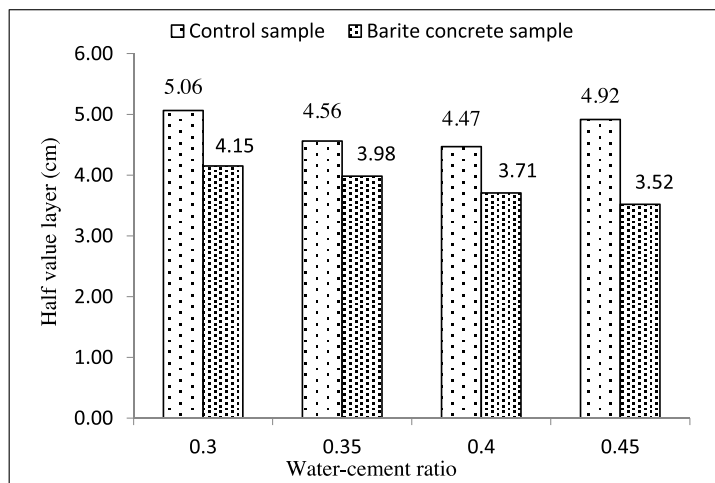


Figure 13. Half value layer result.

There is decrease in half value layer for barite concrete compared to its counterpart control concrete. At water-cement ratio of 0.30 there is a decrease of 18% in half value layer which increased to 28.4% at water-cement equal to 0.45. Half value layer shows reduction in thickness of concrete walls if normal concrete is replaced with barite concrete.

CONCLUSIONS

Based on the testing and analysis presented herein, the conclusions of the study are summarized as follows:

1. Shielding ability of concrete has been improved by the addition of barite as fine aggregate. There is almost 29% increase in linear attenuation coefficient and 28% reduction in half value layer for barite concrete in comparison with control samples.
2. A linear relation was observed between linear attenuation coefficient and density; therefore, the shielding of concrete to gamma radiations can be further improved by increasing barite contents in the form of coarse aggregate.
3. Use of barite as a sand replacement has no profound effects on mechanical properties of concrete as compared to its counterpart (i.e., normal concrete) and thus barite concrete can be used as a special concrete in construction. Maximum reduction in compressive and tensile strengths occurred at lowest water-cement ratio of 0.3. This reduction in strength was found to decrease with increasing water-cement ratio. Percentage decrease in compressive and tensile strengths were 7.46% and 3.7%, respectively, for a water-cement ratio of 0.45.
4. Elastic modulus was also found to slightly decrease with decreasing water-cement ratio; however, maximum reduction was not more than 5% at lowest water-cement ratio of the study, which further reduced to 2.5% at water-cement ratio equal to 0.45.
5. It was also noticed that the addition of barite into concrete reduces drying shrinkage cracks; therefore, barite can be used in massive concrete to control drying shrinkage.
6. Comparison of different water-cement ratios in the present study suggests that 0.45 is the optimum water-cement ratio for barite concrete, which provides maximum shielding with a minimum effect on mechanical properties.

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تكثيف الخرسانة باستخدام الباريت كركام ناعم وتأثيره على خواص الحماية الميكانيكية والإشعاعية للخرسانة

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الخلاصة

يقدم هذا البحث نتائج الأبحاث التي أجريت على تحسين خواص الحماية الإشعاعية في الخرسانة، من خلال استخدام الباريت كركام ناعم. الباريت عبارة عن معدن ثقيل، ذو جاذبية نوعية تتراوح من 3.5 إلى 4.5، ويتوفر بكثرة في أجزاء مختلفة من باكستان. تم دراسة التدريع الإشعاعي لخرسانة الباريت تجريبياً لاستخدامها في تحسين سماكة مستودعات العلاج الإشعاعي. كما تم دراسة تأثير الباريوم على الخواص الميكانيكية للخرسانة في نطاق من الماء - إلى - الاسمنت بنسب تتراوح من 0.30 إلى 0.45. واستُخدمت معايير ASTM لحساب قوة الضغط والشد في الخرسانة، في حين تم إجراء تحليل الوزن النوعي الحراري لتحديد نسبة فقدان الوزن عند درجة الحرارة المرتفعة. تم تحديد إمكانات التدريع الإشعاعي للخرسانة عن طريق إخضاع أجزاء من الخرسانة لمصدر أشعة غاما (الكوبالت-60). وأظهرت النتائج التجريبية أن استخدام معدن الباريت كركام ناعم يزيد من قدرة التدريع للخرسانة. وقد وُجد أن معامل التوهين الخطي يزداد بنسبة 28.4% ويتنوع بالتناسب مع الاختلاف في كثافة الخرسانة. ومع ذلك، لوحظ انخفاض طفيف في قوة الضغط والشد مع إضافة الباريوم للخرسانة كمادة ركام ناعم. ونظراً لقدرة الباريوم العالية على الامتصاص، تم التغلب على مشكلة قابلية التشكيل من خلال استخدام المواد المضافة ضمن الحدود المسموح بها من ASTM (أي أقل من 3%). وأخيراً، يُوصى باستخدام نسبة الماء إلى الأسمنت البالغة 0.45 للخرسانة المحتوية على الباريت من أجل تقليل الخواص الميكانيكية بأقل مستوى مع تحسين مستوى الحماية من الإشعاع بشكل ملحوظ.