The attenuation coefficient of barite concrete subjected to gamma-ray radiation

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Abstract. Barite is a non-metallic mineral, which composed of Barium Sulfate (BaSO4), has specific gravity about 4.5. It can be used for high density concrete as a shielding against gamma-ray. This paper presents the use of barite as concrete aggregates to block gamma-ray radiation. Two concrete grades fc'25 and fc'35 were prepared. The effect of barite to the attenuation coefficient of samples was studied by replacing coarse aggregate with barite and replacing both coarse and fine aggregates with barite. The results show that the protection ability of the concrete using barite aggregates subjected to gamma-ray is better than those of concrete using barite as coarse aggregate and the normal one. The attenuation coefficient of concrete fc'25 with barite as aggregates and concrete with barite as coarse aggregate is 0.294 cm^{-1} and 0.230 cm^{-1}, respectively; The attenuation coefficient of concrete fc'35 with barite as aggregates and concrete with barite as coarse aggregate is 0.304 cm^{-1} and 0.271 cm^{-1}, respectively; While the attenuation coefficient of normal concrete fc' 25 and fc'35 is 0.205 cm^{-1} and 0.225 cm^{-1}, respectively. The average density of normal concrete fc' 25 and fc'35 was 2252 kg/m^3 and 2323 kg/m^3, 3004 kg/m^3 and 3064 kg/m^3 for concrete with barite as coarse aggregate, and 3461 kN/m^3 and 3464 kg/m^3 for concrete using barite for its aggregates.

1 Introduction

Lead is metallic material that commonly used as a shielding against gamma-ray radiation emission [1]. However lead is very expensive so that it is not economical to be installed on large scale. According to The National Council on Radiation Protection and Measurements [2], only materials which have high Specific gravity and atomic number exhibit capability to absorb radiation emission. Several materials that have high specific gravity (or density) are barite, magnetite, hematite, and other type of iron ores. Therefore these high density materials can be used as aggregates for concrete that specifically produced for radiation protection [3]. The minimum unit weight (γ) of concrete that can be used to block gamma-rays and x-rays radiation emission is 3.2 ton/m^3 [4]. With specific gravity of 4.5, barite is very common and effectively to be used as high density concrete to absorb radiation emission [5,6]. Esen and Yimazer [4] stated that there was a significant relationship among the increase of barite content, density of the concrete, and radiation permeability. As the specimen thickness and barite ratio increase, radiation permeability decreases and becomes zero after a certain thickness. The capability of materials to absorb radiation emission commonly presented as linear attenuation coefficient (μ).

Barite is a non-metallic mineral that composed of barium sulfate ($BaSO_4$) exhibits specific gravity (Gs) as high as 4.5. Barite was produced in the United States in 1845 and was used originally as a filling material in production of white paint. In 1926, the consumption and importance of barite increased significantly when it was began to be used in drilling muds [4]. It was reported that in 2017, 70% of barite was consumed as weighing agent for drilling muds activities [7].

It is known that the attenuation coefficient influenced by material density. As for concrete, it's density depends mostly on the density of the aggregates [5]. Therefore, the higher the contents of barite in concrete, the higher the attenuation coefficients [6]. However, barite is brittle material that not suitable to be used as aggregates for structural concrete production [8].

The linear attenuation coefficient (μ) of a 10 mm thick of material (concrete) subjected to radiation emission can be determined by formula proposed by Beer-Lambert law [9] as:

$$I = I_0{}^{e^{-\mu x}} \quad (1)$$

Where x is the sample thickness, I and I_0 are the number of counts recorded in the detector with and without the shielding targets, respectively. Plotting each ln (I_0/I) versus x would give a straight line and μ was obtained using the value of the slope

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Numerous studies on the use of barite as radiation shielding have been conducted. Akkurt et al [10] stated that barite is one of the most effective materials used as an aggregate in heavy-weight concrete production, and it can be used as radiation shielding effectively.

The effect of barite content in geopolymer fly ash concrete has been studied by Muhammed et al. [11]. It was found that the linear attenuation coefficient of the regular concrete increases with the higher the percentage of barite in the concrete. However, the linear attenuation coefficient of geopolymer fly ash concrete was lower than that of normal concrete

Zorla et al [12] investigated the effectiveness of high strength concrete mixed with basalt fibers, which was infused with boron, to protect emission against gamma-ray radiation. It was stated that the mix could absorb radiation emission better than that of regular normal concrete, so that it can be used to reduce the thickness of the concrete wall as radiation protection.

Chen [1] developed precast board consists of fiber concrete layers and high density concrete barite purposedly used as radiation shielding. It was reported that the board was effective to protect radiation emission and easy to be installed in medical hospitals.

Akarslana et al. [13] studied the absorption capability of barite coated fabrics subjected to radiation. It was mentioned that linear attenuation coefficient of barite coated fabrics increases up to 28%.

2 Objectives

The purpose of this study is to investigate the effect of barite content to the attenuation coefficient of concretes subjected to gamma-rays radiation. Two grades of concrete samples, namely fc'25 MPa and fc'35 MPa, were tested using CS-137 source of energy, which produced gamma-rays of 662 kV or exposure of 46.427 mGy.

3 Testing program

Two grades of concrete specimen having compressive strength of fc'25 MPa and fc'35 MPa were formulated. For each concrete grade, three set of different types of samples were prepared. The first set of samples was normal concrete using natural sand and crushed stone as aggregates. The second set of samples was concrete with natural sand as fine aggregate and barite used as coarse aggregate. While the last set of samples was concrete incorporated barite as both fine and coarse aggregates. The thickness of the samples was 3 cm, 6 cm, and 10 cm. The summary of the tested samples is presented in Table 1.

Table 1. The tested samples

No	Specimen	Thickness (cm)	Compressive strength	
			fc'25 MPa	**fc'35 MPa**
1	Normal concrete	3	3	3
		6	3	3
		10	3	3
2	Concrete with barite as coarse aggregate	3	3	3
		6	3	3
		10	3	3
3	Concrete with barite as coarse and fine aggregates	3	3	3
		6	3	3
		10	3	3

3.1 Aggregates

The samples were prepared using Ordinary Portland Cement (Type 1). Cement content of the concrete having compressive strength of fc' 25 MPa and fc' 35MPa was 320 kg/m^3 and 415 kg/m^3, respectively. Water cement ratio of the specimen was 0.61 for fc'25 MPa and 0.47 for fc'35 MPa. While the gradation of the fine and coarse aggregates both natural and barite are presented in Fig. 1 and Fig. 2, respectively.

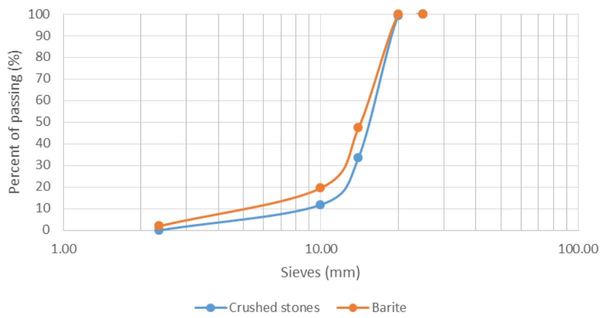

Fig. 1. The gradation of fine aggregates

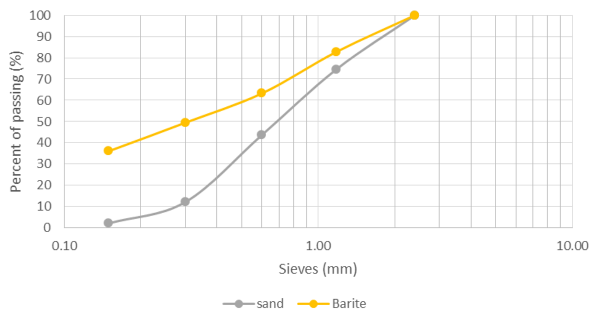

Fig. 2. The gradation of coarse aggregates

Crushing values of crushed stones and barite used in the study was 36% and 43%, respectively. The barite consists of 94.3% of barium sulfate (BaSo4)

3.2 Testing procedure

The concrete sample was subjected to gamma-rays emitted from the source CS-137 (Fig. 3) that emanates energy of 662 kV or exposure of 46.427 mGy. The detector apparatus (Fig. 4) to measure the exposure of radiation was located at the distance of 200 cm from the source. The duration of testing was 60 seconds. The exposure of the gamma-rays that passing of each samples was recorded.

Fig. 3. Setup of the tested sample

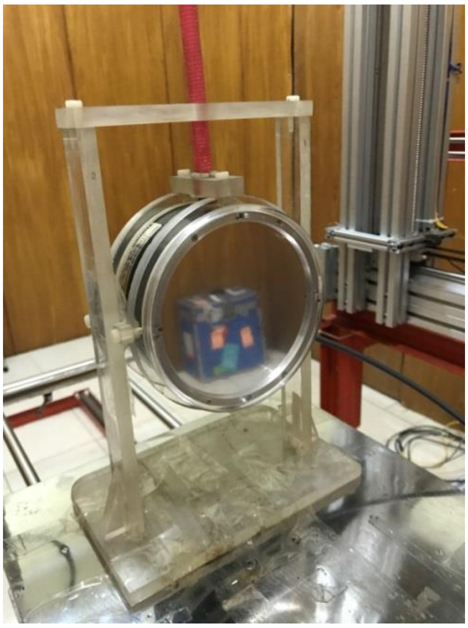

Fig. 4. Gamma-ray exposure detector apparatus

4 Results

The recorded exposure and calculated linear attenuation coefficient (μ) of each samples for both concrete grades fc' 25 MPa and fc' 35 MPa were in Table 2 and Table 3, respectively. The comparison of exposure between specimen fc' 25 MPa and fc' 35 MPa is presented in Figure 5 and Figure 6, respectively. It can be seen that the linear attenuation coefficient of the samples increases with the percentage of barite content. The average linear attenuation coefficient of the specimen having compressive strength fc' of 25 MPa is 0.173 cm^{-1} for the samples using natural aggregates, 0.225 cm^{-1} for the sample using barite as coarse aggregate, and 0.246 cm^{-1} for the samples using barite as aggregates. While the average of linear attenuation of the specimen fc' 35 MPa is 0.190 cm^{-1} for the samples using natural aggregates, 0.254 cm^{-1} for the sample using barite as coarse aggregate, and 0.277 cm^{-1} for the samples using barite as aggregates, as shown in Table 4.

Table 2. Linear attenuation coefficients of the specimen of fc' 25 MPa

Specimen	Thickness (cm)	Exposure (mGy)	Linear attenuation coef. μ (cm^{-1})
Normal concrete	3	25.126	0.205
	6	19.923	0.150
	10	8.842	0.166
Concrete with barite as coarse aggregate	3	23.253	0.230
	6	12.356	0.221
	10	5.018	0.222
Concrete with barite as coarse and fine aggregates	3	19.240	0.294
	6	13.573	0.205
	10	4.214	0.240

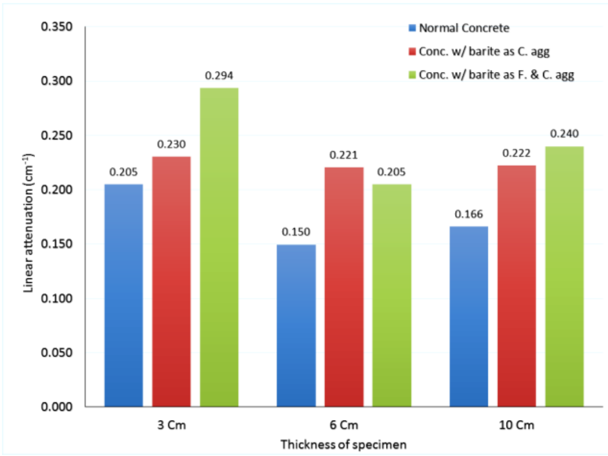

Fig. 5. Linear attenuation of concrete specimen fc'25

Table 3. Linear attenuation coefficients of the specimen of fc' 35 MPa

Specimen	Thickness (cm)	Exposure (mGy)	Linear attenuation coef. μ (cm^{-1})
Normal concrete	3	23.646	0.225
	6	16.506	0.172
	10	8.159	0.174
Concrete with barite as coarse aggregate	3	20.597	0.271
	6	9.419	0.266
	10	4.867	0.226
Concrete with barite as coarse and fine aggregates	3	18.668	0.304
	6	9.331	0.267
	10	3.486	0.259

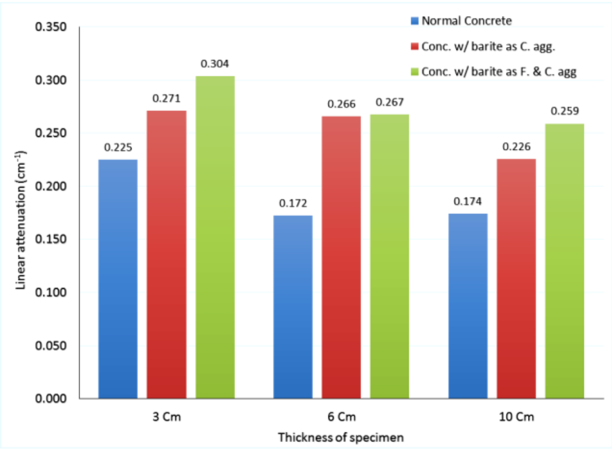

Fig. 6. Linear attenuation of concrete specimen fc'35

Table 4. The average linear attenuation coefficients of the specimen fc' 25 MPa and fc' 35 MPa

Specimen	Concrete fc' 25 MPa		Concrete fc' 35 MPa	
	Density (kg/m^3)	Linear attenuation coef. (cm^{-1})	Density (kg/m^3)	Linear attenuation coef. (cm^{-1})
Normal concrete	2252	0.173	2323	0.190
Concrete with barite as coarse aggregate	3004	0.225	3064	0.254
Concrete with barite as coarse and fine aggregates	3461	0.246	3464	0.277

The relationship between density and linear attenuation coefficient of several materials is presented in Table 5 and Fig. 7. It shows that the linear attenuation coefficient increases with the density of material.
Akyuz [14] stated that the linear attenuation coefficient can be correlated to the material density as:

$$\mu = 0.006\, e^{1.04\,\gamma}\ cm^{-1} \quad (2)$$

Where γ is density in kg/dm^3

Using the available data, the linear attenuation coefficient μ of material subjected to gamma-ray radiation emission might be approximated linearly as:

$$\mu = 0.0001\gamma - 0.0855\ cm^{-1} \quad (3)$$

Where:
μ = linear attenuation coefficient (cm^{-1})
γ = density in kg/m^3

Adopting the form of formula proposed by Akyuz [14], correlation between the linear attenuation coefficient μ and material density can be predicted using the expression:

$$\mu = 0.047\, e^{0.00054\,\gamma}\ cm^{-1} \quad (4)$$

Where γ is density in kg/dm^3

The correlation between linear attenuation coefficients and material densities of available data and approximation expressions (Eqn.2 and Eqn.4) are presented in Fig. 8

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Table 5. The relationship between density and linear attenuation coefficient

Material	**Authors**	**Radiation source**	**Density (kg/m³)**	**Energy (KV)**	**Linear attenuation coef. (cm^{-1})**
Concrete	Binowo et al. [15]	Cs-137	-	661.37	0.166
Barite concrete			-		0.231
Mangaan concrete			-		0.084
Concrete	Akhadi [16]	-	2350	200	0.291
		-	2350	500	0.204
		-	2350	800	0.166
Lead (Pb)		-	11300	500	1.64
		-	11300	800	0.945
		-	11300	1500	0.579
Barite concrete (barite as f. and c. agg.)	Sumarni et al. [17]	Cs-137	3121	661.37	0.3887
Concrete (iron sand - steel for c. agg.)	Alhadi [18]	Cs-137	5786	661.37	0.4633
Geopolymer (fly ash)	Mohammed et al [11]	Cs-137	2894	661.37	0.317
			3186		0.351
			3398		0.382
			4189		0.396
Concrete		Cs-137	2945	661.37	0.311
			3283		0.382
			3530		0.412
			4438		0.459
Concrete (fc' 25)	Budi et al (current study)	Cs-137	2252	661.37	0.205
Concrete (fc' 25)w/ barite as c. agg)			3004		0.23
Concrete (fc'25) w/ barite as f. and c. agg.			3461		0.294
Concrete (fc' 35)			2323		0.225
Concrete (fc' 35) w/ barite as c. agg.			3064		0.271
Concrete (fc' 35) w/ barite as f. and c. agg)			3464		0.304

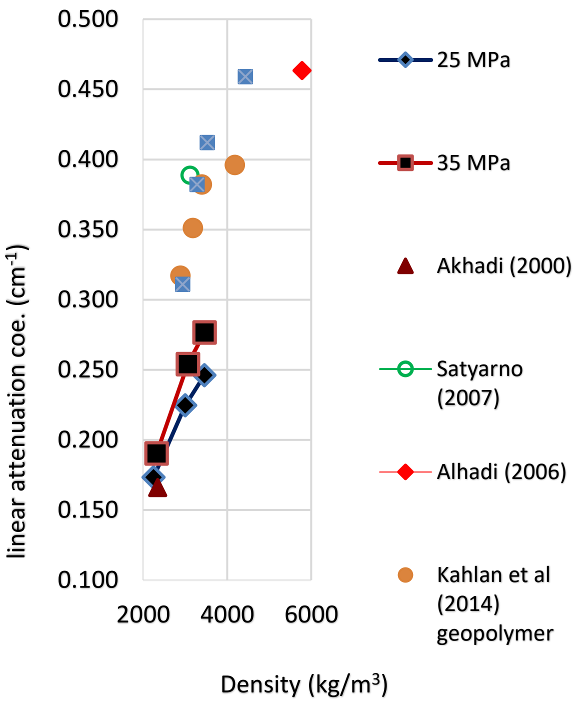

Fig. 7. Relationship between linear attenuation coefficient and density

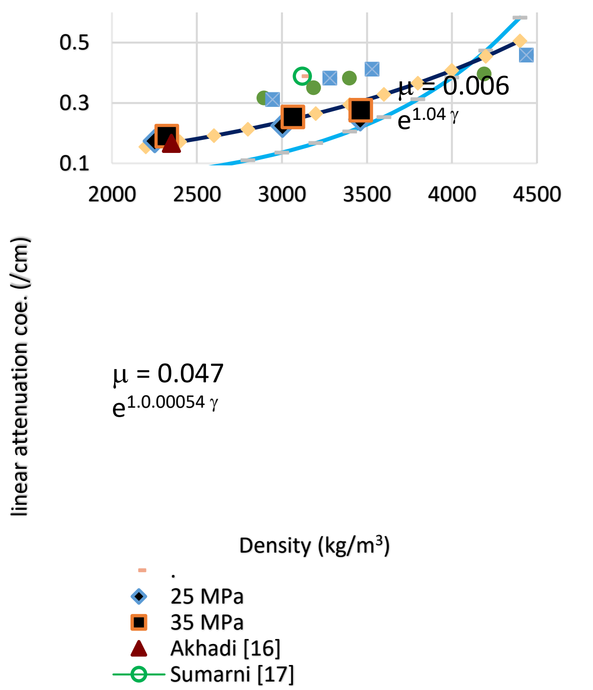

Fig. 8. Correlation between linear attenuation coefficient and material density, and proposed expression

5 Conclusion

Density of barite concrete was 32% to 54% heavier than that of normal concrete.

There was only concrete specimen with barite as both fine and coarse aggregates that exhibit density larger than 3200 kg/m^3, which can be used as radiation shielding against gamma-rays

Linear attenuation coefficient of the specimen increases with the increase of barite content in concrete.

Linear attenuation coefficient of the specimen increases with the increase of the concrete strength.

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References

1. Tzong-Jer Chen. *The 3rd Int. Conf. on Green Mat. and Env Eng* (2017)
2. NCRP. *Report No. 105 – Rad. protect for med and allied health personnel* (Supersedes *NCRP Report No. 48*). (1989)
3. Gencel, O., Bozkurt, A., Kam, E., Korkut, T. Ann. Nucl. Energy **38** (12), 2719–2723 (2011)
4. Yüksel Esen and Berivan Yilmazer. Bull. Mater. Sci., **34**, 175 (2011).
5. I. Akkurt, C. Basyigit, S. Kilincarslan, B. Mavi and A. Akkurt, Cement & Concrete Composites, **28**, 153-157 (2006)
6. I. Akkurt, C. Basyigit, S. Kilincarslan and B. Mavi, Progress in Nuclear Energy, **46**, 1-11 (2010)
7. Schlumberger Limited. *Weighting agent*. http://www.glossary.oilfield.slb.com/Terms /w/weighting_agent.aspx, (Retrieved on Agustus, 2nd 2017).
8. Ariyuni, E., Tjahjono, E., & Kadarisman, B.. *Prosiding pertemuan dan presentasi ilmiah*, 116-121. (1999) [in Indonesian].
9. Akkurt, I., Basyigit, C., Kilicarslan, S., Mavi, BProg. Nucl. Energy **46**, 1–11 (2005)
10. I. Akkurt, S. Kilincarslan and C. Basyigit, Ann. Nucl. Energy, **31**, 577-82 (2004)
11. Kahtan S. Mohammed , Ali Basheer Azeez, A. M. Mustafa Al Bakri, Kamarudin Hussin, Azmi B. Rahmat. International Journal of Science and Research (IJSR). **3** Issue 10 (2014)
12. Eyüp Zorla a,1, Cagatay Ipbüker, Alex Biland, Madis Kiisk, Sergei Kovaljov, Alan H. Tkaczyk, Volodymyr Gulik, J. Nucl. Eng. and Design, **313,** 306–318 (2017)
13. F. Akarslana, T. Mollab, Akkurt c, Kilinçarsland and I.S. Üncüe . *Proceedings of the 3rd International Congress APMAS*, (April 24_28, 2013)
14. Akyuz S Istanbul Teknik Universitesi (ITU) J, **No. 35**, 39 (1997)
15. Binowo T., Kismolo E., & Darsono , *Prosiding Pertemuan dan Presentasi Ilmiah PPNY-BATAN,* **2**, 289-294 (1996) [in Indonesian].
16. Akhadi, M., *Dasar-dasar Proteksi Radiasi*, *PT Rineka Cipta, Jakarta*, (2000) [in Indonesian].
17. Sumarni, S., Satyarno, I. & Wijatna A, B., Media Teknik Sipil, **7 (2)**, 93-99 (2007) [in Indonesian].
18. Alhadi Aria *Penggunaan Potongan baja untuk beton berat sebagai perisai radiasi sinar gamma*, *tesis*, *UGM, Yogyakarta* (2006) [in Indonesian].