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Investigation on different compositions of flyash concrete on gamma and neutron radiation

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Abstract. : Fly ash is a solid waste from a coal combustion product and about 43% is recycled. Fly ash is often used as a replacement of partial replacement for Portland cement in concrete production. Concrete has been widely used as radiation materials due to its lower cost. Five samples of fly ash concrete mixture were prepared and investigated by using small angle scattering (SAN) for neutron irradiation and gamma radiation test for gamma irradiation. It was found that 20% of fly ash concrete mixture absorbed more neutron radiation whereas 40% of flyash concrete mixture absorbed more gamma radiation.

1. Introduction

Concrete has been widely used as radiation shielding for neutron and gamma radiation because of its low price and good shielding performance [1]. Cement is the main component used in production of concrete. The manufacturing of cement creates huge amount of CO_2 as a by-product that possess a serious threat to the environment and human health [1][2]. Fly ash, is a non-combusted by product of coal-fired power plants, can be substituted for large amount of Portland cement [1]. This can improved concrete environmental characteristic and also reduced the cost production of concrete.

The substitution ratio for fly ash to cement is typically 1:1 to 1.5:1 which shows that a greater or equivalent weight of cement is substituted by fly ash [3]. Fly ash also requires lesser water than cement which reduces permeability, bleeding and crack problems [4]. The microstructure variation is important to value the mechanical properties and deformation factor [5]. In order to increase the absorption of neutron and gamma radiation, barite $BaSO_4$ is good as gamma absorber and colemanite $CaB_3O_4(OH)_3.H_2O$ is good as neutron absorber. Both materials were used to replaced fine and course aggregate in manufacturer of concrete [6].

Even though research had been made on fly ash concrete since 1981, it is still considered to be at the early stage and the application of fly ash concrete is still expected to be studied and implemented. In term of nuclear industry, fly ash concrete is said to perform as a nuclear shielding between the nuclear source and the surroundings [1].This paper investigated the effect of different composition of fly ash concrete on gamma and neutron radiation, also to determine the mechanical properties of fly ash concrete mixture.

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2. Methodology

2.1. Materials

Ordinary Portland cement (OPC) Type I from a local manufacturer was used. Fly ash was obtained from TNB Research came from Sultan Azlan Syah Power Plant, TNB Janamanjung Sdn. Bhd. The chemical properties of fly ash are shown in Table 1. Others materials used are fine aggregate (sand and colemanite), course aggregate (barite), water and plastisizer. Sand, barite and colemanite were provided by Malaysian Nuclear Agency (MNA).

Table 1. Properties of fly ash by weight percentage.

Chemical	Contents
SiO_2 (%)	46.46
Al_2O_3 (%)	18.07
Fe_2O_3 (%)	11.65
CaO (%)	6.35
MgO (%)	4.28
N_2O (%)	0.80
K_2O (%)	1.10
TiO_2 (%)	1.36
MnO_4 (%)	0.10
SO_3 (%)	8.88
P_2O_3 (%)	0.42
Specific gravity (kg/m^3)	2.32

The concrete mixture batches were prepared based on the six different ratios of cement and fly ash as shown in Table 2. The additional compositions of each mixture are consisted of 2.42 kg of sand, 0.121 kg of colemanite, 4.598 kg of barite, 0.242 kg of plasticizer and 0.484 kg of water. The water to cementitious ratio was kept at 0.266. The calculation of each mixture was based on concrete mix design provided by Malaysia Nuclear Agency (MNA). The cube mould is made of cast iron and the size is 15 cm^3. The concrete mixture is dried for 48 hours and afterward is submerged in water at room temperature for curing purpose for at least 28 days.

The standard barite-colemanite concrete sample, F produced at Malaysia Nuclear Agency (MNA) using the formula given by Farhi *et al.* as follows: Baryte-colemanite heavy concrete: 4% wt. water, 79% wt. baryte $BaSO_4$, 10% wt. colemanite $CaB_3O_4(OH)_3 \cdot H_2O$ and 7% wt. Portland cement [6]. The above composition is used to mix concrete cement that is used as the controlled sample. In concrete samples A to E, a portion of 7% wt. Portland cement portion is reduced to include fly ash as given in Table 2.

Table 2. Concrete mixture composition.

Sample	Cement	Flyash		Water	w/(c+fa)	Sand	Colemanite	Barrite	Plasticizer
		%	Weight						
A	1.45	20	0.36	0.484	0.266	2.42	0.121	4.598	0.242
B	1.09	40	0.73	0.484	0.266	2.42	0.121	4.598	0.242
C	0.73	60	1.09	0.484	0.266	2.42	0.121	4.598	0.242
D	0.36	80	1.45	0.484	0.266	2.42	0.121	4.598	0.242
E	0	100	1.82	0.484	0.266	2.42	0.121	4.598	0.242
F	1.82	0	0	0.484	0.266	2.42	0.121	4.598	0.242

2.2. Characterization

2.2.1. Neutron scattering test

Neutron scattering test was done at Small Angle Neutron Scattering machine at Malaysia Nuclear Agency. The samples were put at the front of the neutron beam from the machine and covered with other shielding material such as concrete to reduce the exposure of radiation during collecting the data. The sample was aligned at 180 degrees with the collimator. A neutron survey meter is placed at the front of the sample in order to record the radiation reading after it passes through the each of the samples.

2.2.2. Gamma absorption test

The gamma absorption test was performed using Cobalt-60 radioactive substance. The count rate of detected gamma rays as a function for the mass thickness of various concrete samples that were located between the detector and the source, was recorded by using Geiger-Mueller ratemeter. The attenuation coefficient of gamma ray was calculated by using Lambert-beer law. Based on Lambert-Beer law:

Intensity of beam,

$$I = I_0 e^{\mu_\rho X} \tag{1}$$

Mass attenuation coefficient,

$$\mu_\rho = \frac{\ln(I_0/I)}{X} \tag{2}$$

Density

$$\rho = \frac{\text{mass}}{\text{volume}} \tag{3}$$

Linear attenuation coefficient,

$$\mu = \mu_\rho \times \rho \tag{4}$$

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2.2.3. Scanning electron microscope (SEM)
The samples were coated first with gold coating by using BIO-Rad SEM Coating System before proceeding with the microstructure image. The samples undergone the SEM testing under 15.0 kV accelerating voltage. Energy Dispersive X-ray (EDX) was also used to test the samples to identify the composition of fly ash in the concrete mixture.

2.2.4. Compression test
Compression test was performed to investigate the strength and hardening of the concrete samples. The samples were done with the self-compacting concrete method under standard laboratory conditions.

3. Results and discussion

3.1. *Effect of flyash addition on radiation.*
Based on Figure 1, the average equivalent neutron radiation scattered for sample A (20% fly ash) is lower when compared to the control sample. For sample B, C, D and E, the radiation shows higher values than the control sample with sample C peaking up to 127.78 µSv. Figure 2 shows the percentage of neutron radiation absorbed is the highest from sample A which surpasses the control barite colemanite concrete. Sample B, C, D and E show a much lower percentage of neutron radiation absorbed compared to the control sample. The lowest percentage is discovered to be from sample C (60% fly ash) which is 96.9%.

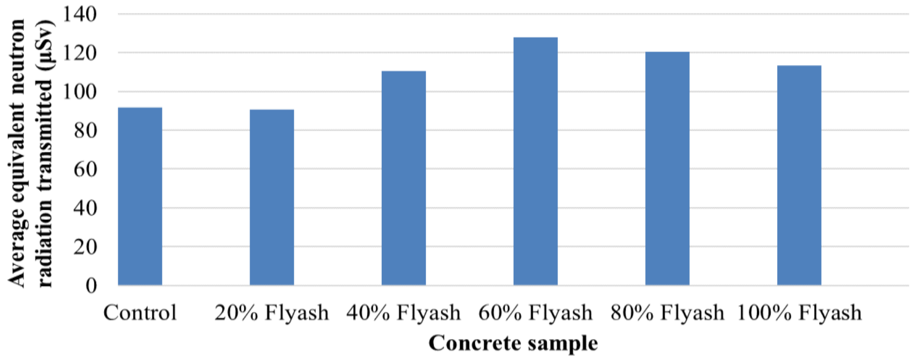

Figure 1. Average equivalent neutron radiation detected vs. concrete samples.

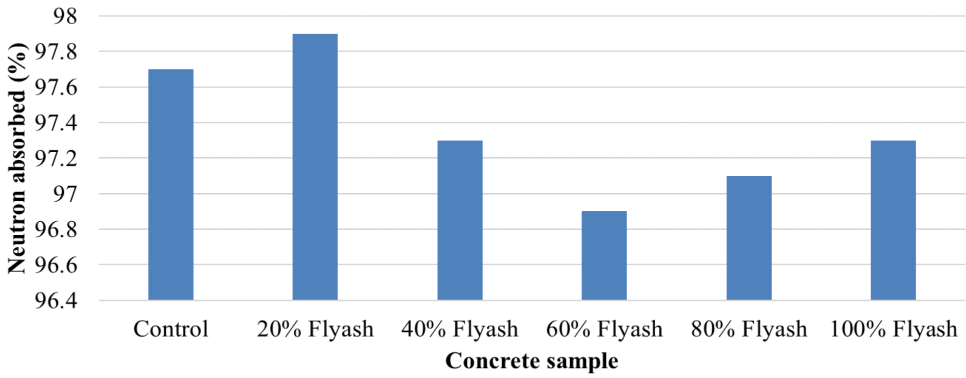

Figure 2. Percentage of neutron radiation absorbed over different samples ratio.

For neutron scattering test, the result shows that the control barite colemanite concrete sample, which contained a significant amount of neutron absorption particles, could attenuate neutrons by 97.7% which is more than ideal for radiation shielding purposes. However, based on the experiment, it is shown that sample A (20% fly ash) composite concrete held up to be better than the standard sample for obtaining 97.9% of neutron particles scattered. The finer particles of fly ash filled up the pores between the concrete to reduce the void ratio and increase the strength of the sample.

Based on Figure 3, the average gamma radiation emitted for sample B, C and D (20%, 40% and 60% fly ash) are lower when compared to the control sample with sample B having the lowest reading at 33844 counts per minute. For sample A and E, the radiation shows higher values than the control sample with sample A having the peak reading of 38936 counts per minute. Figure 3 and Figure 4 shows the relationship between average gamma waves radiation count rate and the amount of gamma radiation absorbed over the different ratios of concrete samples ranging from 0-100% fly ash composites. Five different readings were tabulated per each sample and the average values for the sample is calculated.

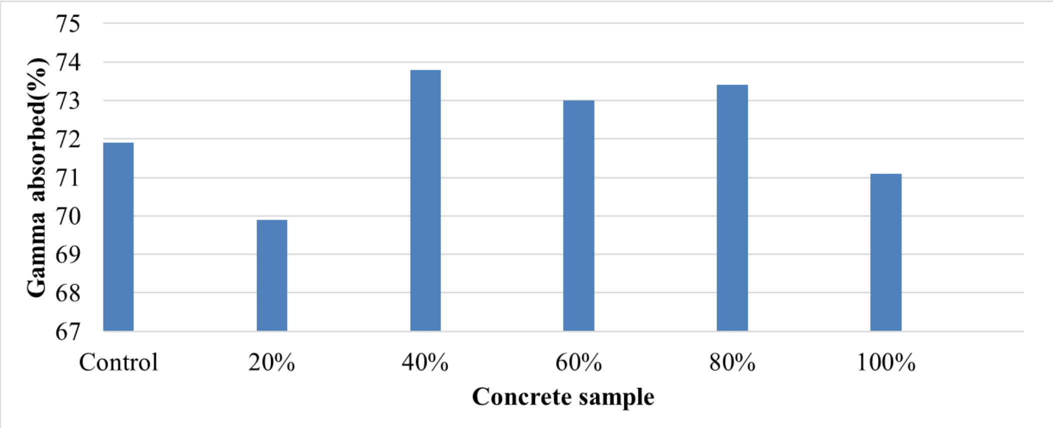

Figure 3. Amount of gamma absorbed over different samples ratio.

Figure 3 shows the percentage amount of gamma radiation absorbed is the highest from sample B (73.8%) followed by sample D and sample C which surpasses the control barite colemanite concrete. Sample A and E show a much lower percentage of gamma radiation absorbed in comparison to the control sample. The lowest percentage is discovered to be from sample A (20% fly ash) which is 69.9%.

Approximately, Figure 3 and Figure 4 show the exact opposite results as to the reason that the percentage amount of gamma ray is absorbed by the concrete sample, obtaining a different result to the amount of gamma radiation emitted onto the Geiger Mueller rate meter. The higher the amount of gamma ray absorbed, the lower the average count rates of gamma waves detected by the rate meter.

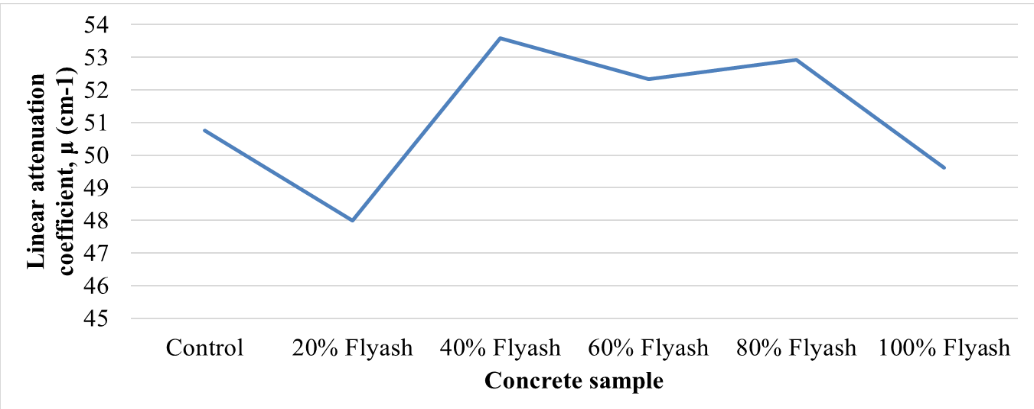

Figure 4. Linear attenuation coefficient for each concrete samples.

3.2. *Effect of flyash addition on surface morphology*

Figure 5 and Figure 6 show SEM images with two different magnifications, 750 and 5000. The SEM images obtained from sample A, B and C show that the fly ash components were bonded to the concrete mixture. It is also suggested that sample B and C may have a smaller fly ash particles which have a higher reaction when comparing with the larger ones. This can be associated with difference in their relative surface area. This is because the ratio for Ca/Si mol adjacent to the center smaller and larger particles are packed closely together [7]. Therefore, the reduction to the chock points can cause the gamma absorption to be improved.

The image obtained from all the concrete that contains fly ash shows that most of fly ash particles have a quite smooth surfaces on them and only partially contains foreign components sticking. The flyash in those composition ratios act as fillers (Figure 7) which will occupy the voids in between the concrete mixture [7]. This will cause the density of the concrete mixture to increase, hence leads to the increment of the attenuation coefficient of neutrons.

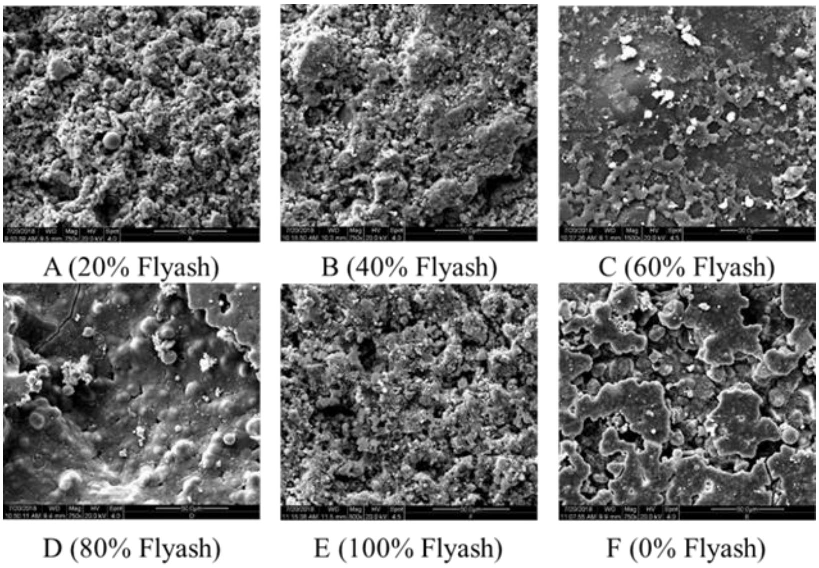

Figure 5. SEM results (x750 magnification).

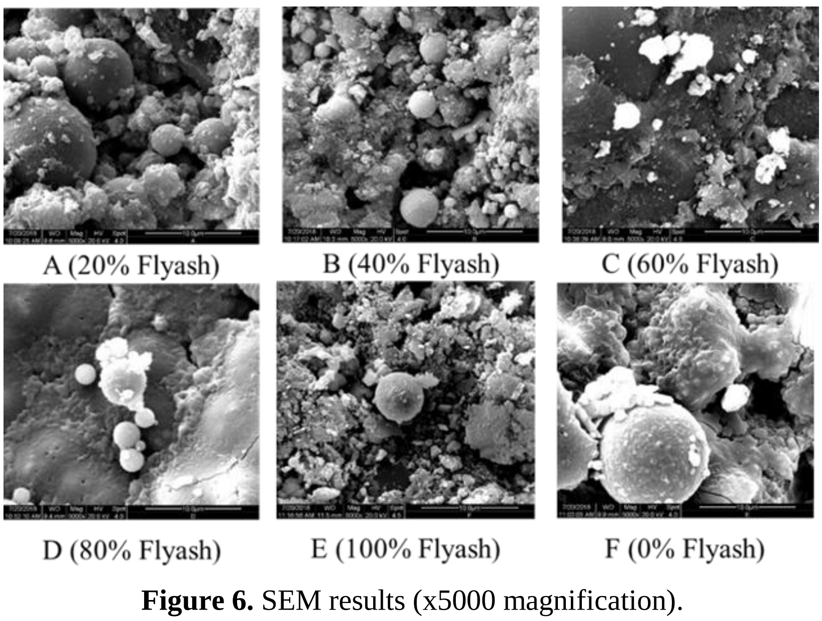

Figure 6. SEM results (x5000 magnification).

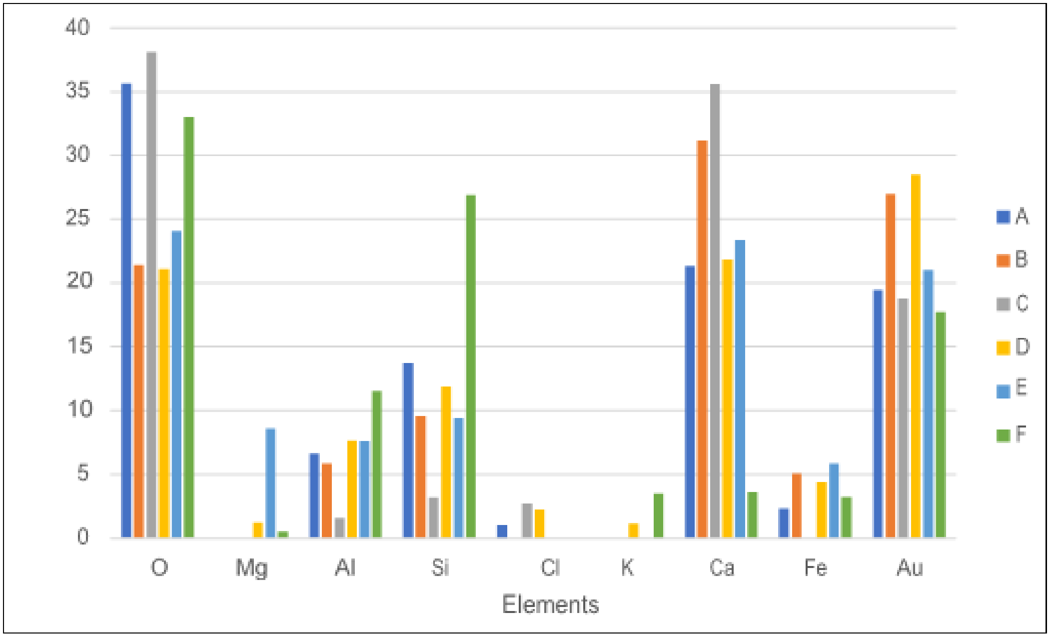

Figure 7. Weight percentage of every elements in each concrete sample from EDX.

3.3. *Effect of flyash addition on the hardening properties*

The compressive strength results are as shown in Table 3. The compressive strength obtained from sample A is much lower when compared to the controlled sample where the maximum compressive force that can be withstood is 340 kN. For sample B, the compressive strength is about proportionate with the controlled sample. In case of sample C, D and E, no compressive strength was recorded, i.e. these samples were failed during test. In conclusion, there is a decrease in compressive strength as more cement is replaced by fly ash exceeding 40%.

Table 3. Compressive strength results for different samples.

Sample	Maximum compressive force (kN)	Compressive strength (N/mm^2)
A	340	15
B	540	24
C	-	-
D	-	-
E	-	-
F (control)	560	25

4. Conclusion

This study has demonstrated that varying the ratios of cement to fly ash mixture in concrete sample has a significant influence on the gamma and neutron radiation. The fly ash in those composition ratios act as a binder and as a filler which occupied the voids in between the concrete mixture. This will cause the density of the concrete mixture to increase and lead to the increase in the attenuation of coefficient. It is found that 20% of flyash is suitable for neutron scattering and 40 – 80% of flyash is suitable for gamma absorption. It is also suggested that the decrement of the cement amount in the aggregate resulted on lower binding factor. In addition, the linear attenuation coefficient changes with fly ash replacement as it is dependent on the density of mixtures.

5. References

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