The influence of clay addition in fly ash concrete mixture for nuclear shielding

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Abstract. The disposal of ashes from power plants has caused health issues and reduce the air quality of the surrounding areas. The ashes have a potential to be used in construction of concrete mixture as partial replacement for cement. This research studies the potential fly ash and clay mixture (FAC) as a nuclear shielding material in concrete mixture. The raw materials and the testing were all done in Agensi Nuklear Malaysia. All concrete mixtures had a constant water/cement ratio of 0.266. The hardened concrete mixtures were tested for compressive strength. Scanning electron microscopy (SEM), energy dispersive X-ray (EDX) and small angle neutron microscopy (SANS) are used to characterize the properties of the mixtures. The results suggested that mixture of FAC concrete with 10% of clay addition showing good potential for nuclear shielding compared to other ratios.

1. Introduction

In concrete studies, most of the paper focused on the composite mixture to improve the mechanical properties of the concrete [1]. However, in the nuclear industry, other parameters such as shielding properties and radiation absorption need to be taken into consideration. Any material can be used for radiation shielding if it has enough thickness to absorb the incident radiation to a safe level [2]. But for concrete, the variation in moisture contents add uncertainty to the calculations of attenuation coefficient. The fundamental shielding prerequisites for radiation protection rely upon a few components. Radiation ray shielding is used to reduce the exposure to radiation. Diverse kinds of radiation are discharged with various levels of vitality behind them. Nowadays, the standards used for the selection of concrete radiation shields aggregates don't take into consideration the effect of the potential neutron activation on the size of the resulted radioactive wastes in these shields [3]. Most of the requirements of these standards concentrate on mechanical and shielding effectiveness of the resulting concrete.

The contribution of ordinary Portland cement (OPC) production worldwide to greenhouse gas emissions is estimated to be approximately 1.35 billion tons annually or approximately 7% of the total greenhouse gas emissions to the earth’s atmosphere [4]. One of the efforts to produce more environmentally friendly concrete is to partially replace the amount of OPC in concrete with by-product materials such as fly ash. Fly ash is one of the numerous substances that can cause air, water, and soil pollution. The disposal of this waste material is a matter of great concern as it has become a major...
environmental problem [5]. Disposal of high amount of fly-ash from thermal power plants absorbs huge amount of water, energy and land area by ash ponds [6]. It is an airborne material and the utilization of fly ash in construction materials shows some example of success. Also, research on the use of the waste product which is fly ash can reduce the environmental problems. Our previous studies also reported that fly ash has potential as shielding properties in concrete mixture [7].

Clay materials are used for constructions due to its durability compared to cement especially under tropical condition [8]. Bentonite is an absorbent aluminum phyllosilicate, essentially impure clay consisting mostly of montmorillonite. The utilization of organofunctionalized bentonite as pozzolan is a good option of the point of view environmental, financial and technical, the bentonite is a clay mineral highly abundant in various parts of the world [9]. Most natural bentonites are found in nature to exist in the sodium and/or the calcium form. The performance of a calcium bentonite as a viscosity builder can often be enhanced by its conversion to the sodium form [10]. Kaolin are also has potential properties, are white raw materials, their essential constituent being fine grained white clay, which are amenable for beneficiation that make them ideal for an assortment of industrial applications [11]. Kaolin is basically consisting of the hydrated aluminosilicate mineral kaolinite with minor amounts of quartz, feldspar, mica, chlorite and other clay minerals [12]. It is recognized from different clay by its delicate quality, whiteness, and simplicity of scattering in water [13].

On this basis, the goal of this study is to investigate the influence of the addition of clays in fly-ash concrete mixture in further enhancing the nuclear shielding properties, gamma radiation and neutron radiation.

2. Methodology

2.1. Materials

Both fly ashes and bottom ashes were obtained from TNB Janamanjung Sdn. Bhd., Stesen Janakuasa Sultan Azlan Shah Power Plant in Perak. The raw ashes were grinded to about 2 mm size. Two different type of clay addition is used in this studies; bentonite and kaolin clay, with ratio of 1:1 for each combination (e.g., 10 % of clay consisted of 5% of bentonite and 5% of kaolin). Different percentage of clay combination were added in fly ashes concrete mixtures, but the percentage of fly ash remains constant for 20%. For the other materials which are barite, colemanite, sand, plasticizer, and water were kept constant. Bentonite clay and Kaolin clay was obtained from R&M Chemicals Sdn. Bhd., and cement used is collected from Lafarge Sdn. Bhd. Colemanite is used for fine aggregate that have a good neutron absorber capability, and is obtained from Malaysia Nuclear Agency, while Barite is used as coarse aggregate with the range size of 10-20 mm has a good gamma absorption for nuclear shielding [14]. Both aggregates were obtained from Malaysia Nuclear Agency. The summary of composition of concrete mixtures are as illustrated in Figure 1. Three concrete samples (15 cm x 15 cm x 15 cm) were prepared for each A to D batches to maintain the consistency and reliability of the results. The concrete samples were put in room temperature for 28 days during the curing process.
Figure 1. Sample preparation of fly ash and clay (FAC) concrete mixtures,

2.1.1. Characterisation. The concrete samples were characterized using small-angle neutron scattering (SANS) to investigate the microstructural radiation damage for nuclear applications [15]. Barium-1333 is used as the gamma source for gamma absorption test and Geiger-Mueller is used to measure and recorded the count rate of gamma rays. The surface morphology of the concrete samples were examined using scanning electron microscopy and energy dispersive x-ray analysis (SEM-EDX). In addition, compression test is also conducted to investigate the strength and hardening properties of the concrete samples.

3. Results and Discussion

3.1. Effect of clay addition on radiation

Table 1 and Figure 2 shows the percentage of neutron absorbed and average equivalent neutron radiation on the concrete samples. The results showed that the highest amount of absorption of neutron radiation is from sample that consist of 20% fly ash and 20% of clay (Sample C), while the sample that absorbed the least amount of neutron is from sample which consist of 20% of fly ash and 30% of clay (Sample D). Sample C also shows lowest average equivalent neutron radiation detected with only 143.74 μSv/hr, showing good absorbent for neutron compared to other samples. This explains that the higher the percentage of neutron radiation being absorbed, the lower the average equivalent neutron detected. The results also concluded that the 20% of clay is the optimum amount of clay addition to be added in the fly-ash concrete mixture to achieve highest neutron absorption.

Table 1. Amount of neutron absorbed over different percentage of clay addition

| Concrete sample         | Neutron absorbed (%) |
|-------------------------|----------------------|
| 0% Clay (Control) - (A) | 96.88                |
| 10% Clay - (B)          | 95.80                |
| 20% Clay - (C)          | 98.02                |
| 30% Clay - (D)          | 96.92                |
Figure 2. Average equivalent neutron radiation detected vs concrete sample.

Table 2 and Figure 3 shows the amount of gamma absorbed and gamma count rate of detector. Concrete sample B which consisted of 20% of fly-ash and 10% of clay addition shows highest amount of gamma adsorbed with 72.1%. The gamma count rate detected strengthen the finding, in which concrete sample B shows the minimum amount of count rate detected with only 1085 counts/min. Therefore, this explains that the more the amount of gamma radiation absorbed in the concrete mixture, the lower amount of gamma radiation pass through the concrete. However more addition of clay does not really improve the gamma radiation absorption.

Table 2. Amount of gamma absorbed over different percentage of clay addition

| Concrete sample | Gamma absorbed (%) |
|-----------------|--------------------|
| 0% Clay (Control) - (A) | 70.69               |
| 10% Clay - (B)      | 72.1                |
| 20% Clay - (C)      | 71.80               |
| 30% Clay - (D)      | 70.61               |
3.2. Effect of clay addition on surface morphology

Figure 4 shows the surface morphology of fly ash concrete mixture with different amount of clay addition. It can be seen that there are changes in surface morphology with the addition of clay (B, C and D), showing the blending formation between clay and fly ash concrete mixtures.

In addition, Table 3 presented the elemental composition of concrete samples with and without the addition of clay. From the table, there are addition of elemental component, Cl, K for 10%, 20% and 30% of clay addition. For 30% of clay addition, more elemental were found; MgK, SK and BaL. It is suggested that the addition of elemental component were from the clay (bentonite and kaolin).

Figure 4. SEM results (x750 magnification) of fly ash and clay mixtures concrete
Table 3. Elemental composition of concrete samples in wt%.

| Elemental | 0% Clay | 10% Clay | 20% Clay | 30% Clay |
|-----------|---------|----------|----------|----------|
| C K       | 19.96   | nd       | nd       | 12.68    |
| O K       | 29.30   | 40.67    | 38.59    | 34.52    |
| AlK       | 18.48   | 4.83     | 3.96     | 5.34     |
| SiK       | 25.84   | 11.99    | 24.26    | 10.44    |
| K K       | 2.32    | nd       | 1.14     | nd       |
| CaK       | 0.66    | 34.67    | 24.54    | 13.63    |
| FeK       | 3.45    | 4.79     | 2.32     | 1.19     |
| CIK       | nd      | 3.04     | 5.15     | 2.10     |
| MgK       | nd      | nd       | nd       | 1.71     |
| S K       | nd      | nd       | nd       | 5.67     |
| BaL       | nd      | nd       | nd       | 12.73    |

3.3. Effect of clay addition on the hardening properties

Table 4 presents the compressive strength results all four concrete samples. Based on the results, it is shown that concrete sample B with 10% clay addition mixture can stand more forces and strength compared to the control sample (without clay addition). However, no compressive strength was recorded for concrete sample C and D, i.e. these samples failed the test. It is suggested that with more addition of clay might cause the concrete structure to expand and caused the increment of pores between the concrete while increasing the void ratio and decreasing the strength of the sample.

Table 4. Compressive strength results for different sample.

| Sample | Maximum compressive force (kN) | Compressive strength (N/mm²) |
|--------|--------------------------------|------------------------------|
| A      | 340                            | 15                           |
| B      | 540                            | 24                           |
| C      | -                              | -                            |
| D      | -                              | -                            |

4. Conclusion

This study has demonstrated that varying the ratios of clay in the fly ash concrete mixture has different reaction towards neutron and gamma radiation absorption. 20% of clay addition is most suitable for neutron shielding materials while 10% of clay addition is most suitable for gamma shielding materials. However, 10 % clay addition have high concrete strength, therefore it is recommended that 10% of clay addition in the flyash concrete mixture suit the most in nuclear shielding application. It is also suggested
that the properties of each bentonite and kaolin clay might affect the neutron and gamma absorption, hence the variation of the results presented.

5. References

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