Geopolymer's radiation absorption detected by Geiger-Muller counter

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Abstract. Fly ash (FA), which is an industrial solid waste released by the burning of coal in thermal power plants, is responsible for causing environmental problems. Radiation is also an environmental problem besides causing health problems for human being. Geopolymer is a specialized building material resulting from the reaction of a source material, which is rich in silica and alumina, with alkaline solution. It is ordinary Portland cement (OPC) free building material. It has been reported that geopolymer building material has good engineering properties with a reduced carbon footprint resulting from the total replacement of OPC as greener alternative. In this study, it is aimed to measure radiation absorption of geopolymers produced from the reaction of FA, which was supplied from İsken Sugözü Thermal Power Plant (Adana, Turkey) and rich in silica and alumina in total content of 83.74, with alkaline activators (sodium hydroxide and sodium silicate) at curing temperatures (70 °C and 100 °C). In the study, lattice measurement system consisting of nested lead plates to avoid unwanted radiation was designed to determine radiation absorption of geopolymers. By using this new system, geopolymer was found to be 5% better radiation absorption capacity than OPC building material when it is compared.

1. Introduction

In the case of waste disposal, the biggest problem facing industries is the safe and efficient disposal of by-products such as fly ash (FA) and blast furnace slag produced in large quantities during the combustion of waste, sediment and coal used. Most of this ash from thermal power plants is stored in appropriate areas and then dumped in landfills. Regular storage is not a highly preferred option because it not only causes a large financial burden for thermal power plants, but is also responsible for future environmental costs and regular storage arrangements. In addition to these problems, the increased burden of toxic metals in the storage area potentially increases the threat to groundwater contamination [1].

FA is driven out of the boiler with flue gases in coal-fired power plants and then generally captured from flue gases by some special equipment (e.g. electrostatic precipitator or other particle filtration equipment) before the flue gases reach the chimneys. It poses a major threat to the environment due to its adverse effects on biological diversity as well as its impact on groundwater [2].
One of the most important objectives in obtaining sustainable construction materials is to minimize the excessive use of virgin materials used to produce cement, coarse and fine aggregates and to minimize environmental damage. The use of industrial by-products such as FA, silica fume, ground granulated blast furnace slag and rice husk ash as a substitute for cement or as additional materials to cement has a constructive effect in minimizing greenhouse gas emissions. Millions of tons of industrial waste are produced each year, most of which is disposed of in the trash and very few are recycled. In recent years, there has been increased awareness of the amount and diversity of hazardous solid waste generation and its impact on human health. Increased concerns about the environmental consequences of waste disposal have led researchers to investigate the use of waste as potential construction materials.

In order to obtain an environmentally friendly and sensitive concrete, many studies are still going on for using waste concrete to produce green concrete. The most successful of the researches was the development of geopolymer concrete to eliminate the use of cement. FA-based geopolymer concrete was first introduced in 1979 by Davidovits to reduce the use of OPC in concrete [3].

Ordinary Portland cement (OPC) has been the most common cementitious material used to produce concrete, mortars, and cementitious composites in general. However, each ton of Portland cement releases about a ton of carbon dioxide into the atmosphere. The average world carbon intensity in cement production was assessed 0.81 kg CO$_2$/kg cement two decades ago. The greenhouse gas emission from the production of Portland cement is about 4 billion tons annually, which is about 7% of the global greenhouse gas emissions. The commitment towards limiting CO$_2$ emissions and stopping global warming has generated a burgeoning interest in finding alternative binders for OPC. Geopolymer concrete, obtained from different types of binder and having a completely different chemistry and microstructure than the one of OPC concrete, represents a promising alternative [4].

The radiation sources are generally occurred from cosmic and terrestrial radiation. Radiation sources are potentially harmful and they can be found in water, air, food and building materials [5]. The levels of radiation generally depend on the origin of the materials. Cement is an important construction material we use for buildings and it is known that some construction materials are naturally more radioactive. Therefore, radiation protection from natural radioactivity in building materials becomes important topic to be investigated [6-8]. Since the radioactivity is harmful to human health, the determination of natural radioactivity emitted from building materials is important for the protection of workers and public in a long term. In the present work, radiation absorption values of geopolymer building materials produced by using FA supplied from İskenk Suğözü Thermal Power Plant (ISTPP) in Adana (Turkey), Rilem Cembureau standard sand alkali activators (Na$_2$SiO$_3$ and NaOH) were measured by using Geiger-Müller Counter Gamma-Scout system which is a device for the detection of all types of radiation such as alpha, beta and gamma rays.

2. Materials and Methods

In this study, geopolymer building materials were used as material. Some details about contents of these materials are given in Table 1. The measurement of the radiation absorption for the each geopolymer samples was performed using Geiger-Muller counter with Cs-137 radioactive source covered 4 mm thick lead shielding box and carried out in physics laboratory of Niğde Ömer Halisdemir University.

In order to measure the radiation absorption percentage of the geopolymer building materials, a lattice system was designed. The schematic design of experimental setup is shown in Figure 1.
Table 1. Properties of materials used in this study.

| Contents                                                      |
|---------------------------------------------------------------|
| **ASTM C618 (2000) Class-F FA**                               |
| SiO$_2$: 62.28, Al$_2$O$_3$: 21.46, Fe$_2$O$_3$: 7.01, CaO: 1.53, Na$_2$O: 0.26, MgO: 2.37, K$_2$O: 3.81, SO$_3$: 0.07, Others: 1.21 in % |
| BET: 2.26 m$^2$/g, Loss on ignition (LOI): 1.78%             |
| **Rilem Cembureau standard sand**                            |
| Complied with TSE EN 196-1 (2009) specification               |
| **Alkali activator**                                         |
| NaOH/ Na$_2$SiO$_3$ within the ratios of 1:1, 1:1.5, 1:2, 1:2.5 and 1:3 by weight, respectively. |

The measurements were performed by reading the value on the counter that detects gamma rays emitted from the radioactive source. In the first step, the Geiger-Müller counter was placed outside the lead-shielded box, and then gamma-rays emitted from the radioactive source (Cs-137) placed inside the shielded box were detected (Figure 1.a) for 1 hour in the absence of geopolymer building materials. In the second step, a geopolymer building material was placed between the Geiger-Muller counter and radioactive source (Figure 1.b) inside the shielded box. Each measurement took for period of 1 hour, after the measurement the amount of radiation absorbed by each geopolymer specimen was determined (Table 2) proportionally.

![Figure 1](image)

**Figure 1.** The schematic representation of experimental setup.

3. Results and Discussion

Mixing ratios of geopolymer building materials cured at 70 and 100 °C for 24 hours in an oven are given Table 2. Radiation counts detected by Geiger Muller apparatus and radiation absorption percentage calculated by using these counts of the geopolymer building materials are also given in this table. For reference measurement, average radiation count was determined as ~1083 for 1 hour in this setup when geopolymer was not exist.
Table 2. Mixing ratios, radiation count and radiation absorption percentages for different geopolymer building materials used in this study.

| Sample Number | Curing Temperature (ºC) | Mixing ratios of geopolymer building materials | Counting time (h) | Average count | Radiation Absorption Percentage (%) |
|---------------|-------------------------|-----------------------------------------------|-------------------|---------------|--------------------------------------|
| 1             | -                       | Na₂SiO₃ (%20)                                 | 1                 | 1083          | -                                    |
| 2             | 70                      | NaOH/Na₂SiO₃=1:1 (%20)                        |                   | 1043          | 3.69                                 |
| 3             | 70                      | NaOH/Na₂SiO₃=1:1 (%20)                        |                   | 1050          | 3.04                                 |
| 4             | 70                      | NaOH/Na₂SiO₃=1:1.5 (%20)                      |                   | 1029          | 4.98                                 |
| 5             | 70                      | NaOH/Na₂SiO₃=1:2 (%10)                        | 1                 | 1055          | 2.58                                 |
| 6             | 70                      | NaOH/Na₂SiO₃=1:2 (%20)                        | 1                 | 1050          | 3.04                                 |
| 7             | 70                      | NaOH/Na₂SiO₃=1:1.5 (%10)                      |                   | 1036          | 4.33                                 |
| 8             | 70                      | NaOH/Na₂SiO₃=1:1.5 (%20)                      |                   | 1053          | 2.77                                 |
| 9             | 70                      | NaOH/Na₂SiO₃=1:2.5 (%10)                      |                   | 1074          | 0.83                                 |
| 10            | 70                      | NaOH/Na₂SiO₃=1:3 (%20)                        |                   | 1070          | 1.20                                 |
| 11            | 100                     | NaOH/Na₂SiO₃=1:3 (%20)                        |                   | 1066          | 1.56                                 |
| 12            | 100                     | NaOH/Na₂SiO₃=1:1 (%10)                        |                   | 1033          | 4.61                                 |
| 13            | 100                     | NaOH/Na₂SiO₃=1:2 (%10)                        | 1                 | 1024          | 5.44                                 |
| 14            | 100                     | NaOH/Na₂SiO₃=1:1.5 (%10)                      |                   | 1036          | 4.33                                 |
| 15            | 100                     | NaOH/Na₂SiO₃=1:1.5 (%20)                      |                   | 1025          | 5.35                                 |

As seen in Table 2, radiation absorption values were found between 0.83 and 5.20% in geopolymer building materials produced at 70°C. The material produced with NaOH/Na₂SiO₃ in ratio of 1:1.5 (20%) had the highest radiation absorption capacity for this group.

For the geopolymer building materials produced at 100 °C, radiation absorption values were determined between 1.56 and 5.44%. The material produced with NaOH/Na₂SiO₃ in ratio of 1:2 (10%) had the highest radiation absorption performance as 5.44% for this group.

4. Conclusions
It is important to know whether the geopolymer building material is useful for radiation protection. Although the determination of radiation absorption in geopolymer building material is important, there are limited studies in the literature regarding this parameter. Binici et al. (2012) determined the physical, mechanical and radiation permeability and absorption properties of slag, FA, silica sand and pumice-based geopolymers [11]. It was measured that these geopolymers absorbed radiations in 5.9 and 17.3 keV energy. Only FA-based geopolymers absorbed 26 keV radiation effectively. Therefore, they could be used for radiation absorption material in the places using 26 keV radiation. On the other hand, Binici (2013) produced geopolymer mortars incorporating granulated blast furnace slag, FA, silica sand and pumice with NaOH in curing temperature of 100 and 150 °C for 20 hours [12]. In his study, geopolymer mortars were exposed to gamma and X-ray radiation. Water absorption, unit weight, flexural and compressive strength, adhesion properties of ultrasonic sound transmission and radiation absorption of the samples were investigated. Highest linear absorption coefficient was obtained from the sample incorporating blast furnace slag. It was reported that these geopolymer mortars may be used in the structures that are exposed to radiation.
In the present study, FA-based geopolymer building materials activated with NaOH and Na$_2$SiO$_3$ and cured at 70 and 100 ºC were used as material. Radiation absorption of these materials were investigated. It was found that geopolymer building materials incorporating FA have radiation absorption capacity, especially due to their porous structure. The highest radiation absorption value (5.44%) was determined in the 13th sample produced in NaOH/Na$_2$SiO$_3=2$ mixture ratio and cured at 100 ºC. As a result of this study, it was concluded that geopolymer building materials could be used in structures exposed to radiation. In this context, it is considered that the use of FA in geopolymer building materials will contribute to the protection of human health against radiation. Reusing FAs in order to produce geopolymer building materials have another advantage. Since FAs are converted into geopolymers and used in building material mixtures, they offer a great environmental advantage by solving waste storage problems. Furthermore, using geopolymer building materials is also expected to reduce CO$_2$ emission, contributing solution of the industrial solid waste problem and saving money for economy.

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