The use of Papuan iron sand and river sand for fine aggregate in mortar for nuclear radiation shield application

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Abstract. This study explores the effect of fine aggregate on mortar properties and its application as a nuclear shield. This study was based on a hypothesis that the types of aggregate applied as radiation shield determined the level of its effectiveness on preventing nuclear radiation. There are two types and sources of fine aggregate that was used as main ingredients for mortar production in this research, namely iron sand and river sand. Both types of sand were derived from the respective regions of Sarmi and Jayapura, Papua. The results showed that the mortar materials that were produced with the iron sand provided better results in dispelling radiation than that of river sand. The compressive strength of fine aggregate from the iron sand was 21.62 MPa, while the compressive strength of the river sand was 16.8 MPa. Measuring the attenuation coefficient of material, we found that the largest aggregated value of mortar with fine iron sand reached 0.0863 / cm. On the other hand, the smallest HVT (Half Value Thickness) was obtained from the iron sand mortar, at 8.03 cm.

1. Introduction

Nuclear technology has been widely applied in many areas of daily life. However, despite having many advantages, this technology also possesses harmful effects on health and the environment. In order to reduce the risk of radiation hazards, there is a need for a protective shield that can absorb nuclear radiation and minimize its intensity. We expect the shield to reduce the radiation into a quantity that can be accepted by the human body.

This study proposes an application of iron sand as basic material for radiation shields. The experiment in this study consisted of placing a radiation shield between the ionized radiation source and its surrounding environment. The effectiveness of the shield depends on the type of radiation, radiation energy, and materials the shield is composed of [1]. The radiation shield is based on the principle of attenuation: the ability to block or to reduce the intensity of radioactive through photoemission and scattering performed by barrier materials. This study suggested the application of the iron sand into concrete or mortar, as a basic material for the radiation barrier [2]. When the radiation enters the shield, a portion of the radioactive will be absorbed by the shield. As a result, the intensity of radiation after entering the absorbent material is reduced significantly. In this case, the intensity of radiation after being absorbed by the protective material will decrease without diminishing the energy from radiation passing through the material. The resulting absorption value of the interaction is expressed quantitatively as a linear coefficient, or attenuation coefficient (μ). This
coefficient represents the probability of one interaction per unit of distance. The process of attenuation of both gamma-ray radiation in a shield material is exponential according to the following equation:

\[ I = I_0 e^{-\mu x} \]  

(1)

where \( I \) in this calculation means the intensity of radioactive after going through the radiation shield, \( I_0 \) as the intensity of radiation before it passes through the shield, and \( x \) as the thickness of the shield material [3]. Therefore, the attenuation coefficient can be calculated using the following equation:

\[ \mu = \frac{\ln(I_0/I)}{x} \]  

(2)

Previous studies have investigated the manufacturing process of mortar or concrete for use in nuclear radiation shields, especially in the medical sector, by replacing aggregates with materials that can block radioactive. Natural resources and materials such as arc furnace slag aggregate [4], steel balls [5], lead oxide [6], hematite [7], and other concrete mixtures [8] have been widely developed for medical purposes, including applications for nuclear radiation shields.

Principally, to shield radiation effectively, the materials should have high atomic number and density. According to Raju [9], high density can be found by using high density aggregates. In this research, mortars were created with a mixture of iron sand and river sand as fine aggregates with high density. The compositions of the iron sand and river sand were 4.311 [10] and 2.55, respectively. Whereas the density for normal aggregates were about 2.5-2.7.

Thus, we can conclude that both the iron sand and river sand fall under the category of high-density aggregates, suitable to produce high density mortar. It is also safe to conclude that the mortar can provide high levels of radiation shield capability by incorporating different types of aggregate. As in this study, two different types of aggregate were assessed from these two samples. The materials for the samples were obtained locally in Jayapura, Papua. The primary locations to retrieve the sands were Sarmi and Doyo. Sarmi is a regency in Papua Province, located in the outskirts of Jayapura. It is one of the prime locations where massive stocks of iron sand are found along rivers and beaches. Doyo, on the other hand, is a district in Jayapura regency with a substantial amount of sand on its rivers. The local people use sand for many purposes, such as building constructions.

The purpose of this research is to determine the value of mortar compressive strength and the coefficient value of material, to engage nuclear radiation. We developed the mortar by mixing pure iron sand and river sand. We then determined the Half Value Thickness (HVT) of the two types of mortar constructed from iron sand and river sand.

2. Experimental Method

2.1 Fine Aggregate

Two different types of fine aggregate with particle sizes smaller than 0.15 mm were treated as follows: 1) the iron sand obtained from Sarmi regency was treated using a permanent magnet to obtain pure iron sand, while 2) the river sand from Jayapura regency was not treated.

2.2 Development of Mortar

Preparing waterproof molds with varying thickness precedes the preparation of mortar. The result was in the form of paste that consisted of cement, fine aggregate, water, and viscocrete-10, with a general ratio of cement : fine aggregate : viscocrete-10 = 1 : 1.5 : 0.015. After this process, the paste was inserted into the mold to mark volume height for each mold. Variations created in the manufacturing process of mortar are variations in the ratio of river sand and iron sand as fine aggregate, as seen in the following table:
Table 1. Sample Code.

| Sample Code | Information |
|-------------|-------------|
| Mortar I    | Comparison of fine aggregates between iron sand & river sand (1 : 0) |
| Mortar II   | Comparison of fine aggregates between iron sand & river sand (0 : 1) |
| Mortar III  | Comparison of fine aggregates between iron sand & river sand (0.5 : 0.5) |

After the mortars were finished, they were then printed and dried, and afterwards tested to determine their compressive strengths by using a press machine. After that, the samples were tested for their capability for use in radiation shields.

2.3 Testing Mortar through press and strength
The strength of the mortar load was the magnitude of the load per unit area, which causes the mortar assay to be destroyed when burdened with a certain compressive force produced by the compressor [11].

2.4 Testing of Mortar Capability as a Radiation Shield
This test was performed with a set of Geiger counting/Geiger Muller series using $^{137}\text{Cs}$ as the source of radiation.

3. Result and Discussion

3.1. Compressive Strength of Mortar
The mortar compressive strength values for each type of mortars after 14 days can be seen in the following table:

Table 2. Mortar pressing values.

| No. | Sample Code | Pressing Strength Value (MPa) |
|-----|-------------|-------------------------------|
| 1.  | Mortar I    | 21.62                         |
| 2.  | Mortar II   | 16.68                         |
| 3.  | Mortar III  | 17.97                         |

According to Table 2, it can be seen that mortar with iron sand fine aggregate had the highest compressive strength value, at 21.62 MPa; while the mortar with river sand fine aggregate had the smallest compressive strength value of 16.68 MPa.

3.2. The Mortars’ Attenuation Coefficient to Radiation
The material attenuation coefficient values are displayed in the graphs below. The values represent a relationship between the ratio of initial radiation and the radioactive that passed through the mortar to the thickness of the mortars; as shown in Figure 1.
Figure 1. Graph of the relationship between ratio of the initial radiation and the radiation that passed through the mortar to the thickness of the mortar for (a) Mortar I, (b) Mortar II & (c) Mortar III.

Data processing using graph (a) gives us an equation of \( y = 0.0863x + 1.7423 \), where the straight line equation equals the material’s attenuation factor, hence \( \mu = 0.0863/\text{cm} \). Graph (b) gives us an equation of \( y = 0.0486x + 2.0875 \), and graph (c) gives us \( y = 0.0667x + 1.9627 \). Therefore, the attenuation coefficients are as seen in Table 3 below.

| Table 3. The mortars’ attenuation coefficient values. |
|---------------------------------|
| No. | Sample Code | Attenuation Coefficient (\( \mu \)) (per cm) |
|-----|-------------|---------------------------------|
| 1.  | Mortar I    | 0.0863                          |
| 2.  | Mortar II   | 0.0486                          |
| 3.  | Mortar III  | 0.0667                          |
Table 2 shows that the highest material attenuation coefficient value against nuclear radiation occurs on mortar with purified iron sand fine aggregate, at 0.0863/cm. It is then followed by the mortar with fine aggregate composed of 50% iron sand and 50% river sand, at 0.0667/cm. The lowest attenuation coefficient against nuclear radiation, at 0.0486/cm, occurred on the mortar with river sand fine aggregate.

3.3. Half Value Thickness (HVT)

Half Value Thickness (HVT) is the density of the mortar that allows it to effectively absorb 50% of the nuclear radiation. Half Value Thickness for each type of mortar depends on the material’s attenuation coefficient value against the nuclear radioactive. The HVT values for each mortar can be seen in Table 4.

| No. | Sample Code | Half Value Thickness (HVT) (cm) |
|-----|-------------|--------------------------------|
| 1.  | Mortar I    | 8.03                           |
| 2.  | Mortar II   | 14.26                          |
| 3.  | Mortar III  | 10.39                          |

Table 4 shows that Mortar I had the lowest HVT value of 8.03 cm and Mortar II had the highest HVT value of 14.26 cm. This proves that the lower a mortar’s Half Value Thickness, the better its quality as a nuclear radiation shield.

In addition to being influenced by fine aggregate materials, the mortar’s attenuation coefficient value against nuclear radioactive was also influenced by its compressive strength value. The higher compressive strength, the better its capacity in absorbing value to the radiation. The results of this study therefore indicate that by using iron sand as a fine aggregate in mortar, the mortar’s ability in absorbing radiation was increased significantly.

4. Conclusion

We have successfully developed mortars using Papuan iron sand and river sand as base materials. We have also clearly deduced from our observation that the type of fine aggregate plays a key role in applying concrete as a material in a nuclear radiation shield. From the measurement of compressive strength, the mortar composed of iron sand fine aggregate had a higher compressive strength value. In testing the mortars’ capabilities as radiation shields, we have also measured their material attenuation coefficient and HVT values. Consequently, the values in mortars composed of iron sand fine aggregate are higher compared to those composed of river sand, as well as to those composed of a mixture of iron sand and river sand. The findings of this study also suggests that more research on potential applications of natural resources for radioactive shields should be well considered in the future.

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