Study of radiation attenuation ability of clay and cement mixture with added eggshell

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Abstract. Concrete is a common material used to build physical barrier as protection against ionized radiation. However, excessive used of concrete may lead to increase volume on mining of cement and sand, thus contribute to catastrophic on nature. This project is done to find suitable material that can replace the usage of concrete in order to build physical barrier for radiation shielding. Hence, combination of Kaolin clay and eggshell powder are chosen as these materials are cheap, biodegradable and eco-friendly. Two main types of sample blocks are prepared: concrete and clay blocks. The portion of eggshell powder are varied, with increment of 1/10 cups for each sample. All samples are exposed on 60, 80 and 100 kVp of x-ray energy and absorbed dose were recorded. Results shows that blocks with adding eggshell powder contribute to greater value of radiation absorption ratio compared to blocks with non-added of eggshell powder. In addition, Sample 4 (consist of 4/10 cup of eggshell powder) were found to be the suitable portion due to optimum value were seen between these concrete and clay blocks. Hence, the clay blocks with additional of eggshell powder can be used to replace the usage of concrete for radiation shielding building.

1. Introduction
Waste production in Malaysia is increasing from year to year and majority of these waste are composed of organic waste. Food waste such as eggshells is included in this category. An efficient food waste management system is required to sustain a good environment for living. However, the cost for waste collection, suitable waste management depending on local condition and increasing in number of landfills area around Malaysia are factors that need to be considered for efficiency of this system [1].

Concrete are commonly used as basic material for radiation shielding. Concrete are composed of filler which fills empty spaces in concrete and binder which act as binding agent to hold fillers. In concrete, aggregates are the filler and cement is the binder [2]. Production of cement is costly, emits CO₂ to atmosphere and uses lot of energy during manufacturing. To partially replace cement, various limestone-based materials can used at the same time act as filler in concrete. Eggshell can be one of the limestone-based filler in concrete. Reusing these waste can reduce amount of average cement used in concrete production and prevent the waste been dumped into landfills [3].

Clay has good refractory properties (high melting point which makes it resistant to fire, poor conductor, stable thermochemical properties, durable: good mechanical strength at high temperature, resistant to thermal shock, low thermal shrinkage and resistant to corrosion). Kaolin clay is suitable to be used as shielding material as they has radiation attenuation ability close to conventional concrete [4].
Plasticity of clay after water is added to it and become solid when dried and burnt (to remove water content) make clay as suitable material for making bricks since ancient [5].

Soil can be used as shielding material since soil is cheap and available at all time. Photon absorption ability of 5 different soils were investigated where percentage of clay, silt and sand in each soil is analyzed and their chemical composition is characterized. Then the soils samples are exposed to radioactive sources with different energies. It is found that soil with high percentage of clay has the best photon absorption ability compared to other soils [6].

2. Materials and Methods

Sample blocks are prepared using eggshell powder, clay, cement and sand. Then, the samples attenuation ability was tested by measuring their absorbed dose at different kVp values.

2.1. Sample preparation

Eggshells are collected and cleaned by using ionised water to remove any foreign material on the eggshell surface. Then, they are dried in oven with temperature of 100 °C for 4 hours to ensure all water are removed from the eggshells. Cleaned eggshell were grinded into fine powder. Eggshell powder was characterized by Energy Dispersive X-ray (EDX) Analysis to determine its elemental composition.

For clay block samples, eggshell powder was mixed with clay with different weight portion for each sample. Water is added accordingly, depend on mixture viscosity. Mixture was placed in mould with 2 cm height and 4 cm x 4 cm base area for every sample. Then, the sample are left to dry at room temperature for 36 – 48 hours, or until the samples became hard enough.

Cement, sand and eggshell powder is used to make cement block samples. For cement block samples, same portion and height is considered. Weight of cement is kept constant, thus only sand and eggshell are varied according to respective portion weights. The samples were left to dry for 24 hours at room temperature.

2.2. Measurement of x-ray attenuation

The absorb dose of the samples were measured at 60, 80 and 100 kVp of x-ray energies. The exposure was set at 20 mAs and the distance between the x-ray tube and the detector was set at 100 cm. Block samples were placed on detector. Absorbed dose rate was measured. Equation 1 is used to calculate Radiation absorption ratio (RAR) for each measurement [7].

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R = 1 - \frac{I_T}{I_0}
\]  

where, \(I_T\) is radiation intensity at sample block thickness, \(T\), and \(I_0\) is radiation intensity without sample block. The experimental results of RAR for every kVp were used for modelling the attenuation abilities of samples. The cubic regression line is used as reference for modelling.

3. Results and Discussion

3.1. Eggshell characterisation

The EDX analysis shows that the eggshell powder is consist of oxygen (46.59 %), carbon (28.76 %), calcium (19.50 %), phosphorus (3.98 %) and magnesium (1.17 %). These values are almost similar with other studies [3, 8-11].

3.2. Attenuation analysis

A portion is said to be optimum when the sample can block most of the radiations, thus it is efficient to be used as a shielding barrier to build the radiation facilities. Referring to Table 1, RAR value of clay blocks are highest at sample 6 and 8 while for cement blocks are at sample 4 and 7. This shows that different kVp and different composition resulting on different optimum portion.

However, by referring to Figure 1, the RAR value for pure concrete and clay blocks (sample 1) has a large difference between them at all kVp. However, the RAR value for clay blocks increased rapidly from Sample 0 until Sample 4, contrary to cement blocks. This show that eggshell powder gives a
positive effect to clay blocks. Addition of eggshell into cement mixture does not shows obvious different in attenuation ratio between sample portions.

Starts form Sample 4 and beyond, addition of eggshell into clay mixture does not has much difference. Sample 4 until Sample 9 of cement blocks shows only slightly higher RAR value compared to clay blocks. When both materials are compared, a portion can be said as optimum if the difference of RAR between both materials become smaller compared to initial portion which is in their pure state (without addition of eggshell powder). Sample 4 can be concluded as an optimum portion of sand-eggshell and clay-eggshell among 2 cm blocks.

Cubic model was selected and listed in Table 2 as this model show higher value compared to linear and quadratic model. However, only clay blocks show R² values ≥ 0.75.

Table 1. Fraction of eggshells and clay/sand with RAR values of sample blocks at various kVp

| Sample number | Weight fraction (cup) | 60 kVp Clays | 60 kVp Cements | 80 kVp Clays | 80 kVp Cements | 100 kVp Clays | 100 kVp Cements |
|---------------|-----------------------|--------------|---------------|--------------|---------------|--------------|---------------|
|               | Eggshell powder | Clay or Sand | 0.730 | 0.934 | 0.648 | 0.870 | 0.586 | 0.819 |
| 0             | 0                     | 1 | 0.816 | 0.950 | 0.732 | 0.892 | 0.666 | 0.839 |
| 1             | 1/10                  | 9/10 | 0.889 | 0.948 | 0.813 | 0.887 | 0.755 | 0.836 |
| 2             | 2/10                  | 8/10 | 0.914 | 0.942 | 0.840 | 0.889 | 0.783 | 0.840 |
| 3             | 3/10                  | 7/10 | 0.937 | 0.952 | 0.877 | **0.895** | 0.824 | 0.842 |
| 4             | 4/10                  | 6/10 | 0.933 | 0.948 | 0.864 | 0.884 | 0.815 | 0.833 |
| 5             | 5/10                  | 5/10 | 0.945 | 0.948 | 0.868 | 0.888 | **0.831** | 0.827 |
| 6             | 6/10                  | 4/10 | 0.931 | **0.958** | 0.867 | **0.895** | 0.812 | 0.841 |
| 7             | 7/10                  | 3/10 | 0.944 | 0.948 | **0.880** | 0.881 | 0.824 | 0.825 |
| 8             | 8/10                  | 2/10 | 0.938 | 0.950 | 0.872 | 0.886 | 0.820 | 0.839 |
| 9             | 9/10                  | 1/10 | 0.980 | 0.930 | 0.880 | 0.780 | 0.680 | 0.580 |

Figure 1. Attenuation of 2 cm block samples at different kVp
Table 2. Regression line equation and R² values of each measurement

| Blocks of exposed on x-ray energy of | Equations                                      | R² values |
|-------------------------------------|------------------------------------------------|-----------|
| Cement                             | $y = 0.00004x^3 - 0.0008x^2 + 0.0055x + 0.9382$ | 0.4585    |
|                                    | $y = 0.0001x^3 - 0.0025x^2 + 0.0123x + 0.8739$ | 0.5195    |
|                                    | $y = 0.0003x^3 - 0.0039x^2 + 0.0159x + 0.8211$ | 0.5490    |
| Clay                               | $y = 0.0009x^3 - 0.0171x^2 + 0.1054x + 0.7306$ | 0.9927    |
|                                    | $y = 0.0009x^3 - 0.0178x^2 + 0.1116x + 0.6455$ | 0.9898    |
|                                    | $y = 0.0008x^3 - 0.0169x^2 + 0.1123x + 0.5818$ | 0.9895    |

4. Conclusions

This study focused on studying attenuation ability of a material to replace commonly used materials as physical barrier to shield x-ray radiation. Clay is successfully proven as a material that can substitute cement for radiation shielding. Even though individual samples show different optimum portion sample with different kVp value, sample 4 can be seen as another optimum sample when both materials are compared. Addition of eggshell powder into mixture also shows a positive effect to clay contrary to cement. Clay attenuation ability improves with adding eggshells compared to with cement.

5. References

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Acknowledgment

The authors thank to RUI grant of Universiti Sains Malaysia (1001/PFIZIK/8011059) for funding of this project.