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Eggshells as Alternative Shielding Material Against Diagnostic X-rays

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ABSTRACT

With the advancement in diagnostic imaging, providing shielding against X-rays has become a significant concern. While Lead has been extensively used as the shielding material, it is costly and toxic to humans and the surrounding environment. This study aims to evaluate the feasibility of eggshells as alternative shielding material against diagnostic X-rays. To this end, the eggshells were collected, ground, sieved and mixed with cement and water with an increasing amount. Radiographic analysis was utilized to measure the performance of the shields. The results showed that increasing the number of eggshells increased its shielding performance; however, more shielding is required at higher X-ray energies. Nevertheless, the performance of the standard Lead shield and the shield with the highest number of eggshells yielded a comparable result. The eggshells can be used as alternative shielding material against diagnostic X-rays.

Keywords: Diagnostic X-rays; Eggshells; Lead alternative; Shielding

INTRODUCTION

While X-rays have immensely aided the medical exploration of various diseases, risks of its exposure have posed daunting issues not just in the healthcare industry, but also in the society as a whole. These highly energetic waves are electromagnetic ionizing radiation capable of disrupting the molecular and atomic structures of the body, causing skin burns, cataracts, leukemia, and life span shortening (Bushong, 2013). In a list of known human carcinogens or cancer-causing substances, the International Agency for Cancer Research (2018), an agency of the World Health Organization, classifies X-rays as carcinogenic to humans. In the same vein, extensive cohort studies provided evidence of the association between cancer risk and X-ray exposure from the medical imaging modalities (Pearce et al., 2012; Mathews et al., 2013; de Gonzalez et al., 2016). Aside from these hazards, high doses of X-rays at a short period are known to induce acute clinical symptoms in the hematologic, gastrointestinal, and central nervous systems, which ultimately result in acute radiation lethality or death (Bushong, 2013).

Given the health risks and escalating utilization of X-rays in the medical practice, the International Commission on Radiological Protection (2007) set standards on radiation safety on all entities which directly or indirectly operationalize radiation. Optimization, justification, and dose limits are the three concepts of the radiation protection model of the International Commission on Radiological Protection (ICRP). The governing body also suggests that doses to individuals from a particular source should be restricted. This recommendation leads to the concept of dose constraints or radiation shielding.

Radiation shielding is based on the principle of attenuation, which is the ability to reduce a radiation effect by blocking or bouncing particles through a barrier material. It is used to protect sensitive organs of the body such as the gonads, eyes, and thyroid glands. The standard shield recommended by ICRP in diagnostic radiology is Lead (Pb). Lead, a shiny blue-white soft metal, has been used as the standard radiation shield in radiology because of its high density, stopping power, and ease of installation. According to Bushong (2013), the standard thickness of protective shielding should be 0.5 cm Pb. This thickness is deemed to be appropriate as the value is approximately equivalent to two Half-Value-Layers, thereby reducing radiation exposure to 25%. However, the shielding material entails additional financial burden in rural hospitals and medical schools that are implementing Radiologic Technology education, which ultimately results in the non-utilization of the protective apparel. Among surveyed hospitals in the United States, Safiullah et al. (2017) found that 40% do not utilize shielding despite the majority acknowledging the principle of As Low As Reasonably Achievable and agreeing that shielding is a beneficial practice. The study further reported that cost is the primary reason for the non-utilization of shielding materials. In the Philippines, the total cost of Lead gown, one of the radiation-shielding materials, is Php 6,300 (Philippine Medical Supplies, 2019).

With these issues, numerous studies have been dedicated to finding alternative materials. Clay-white cement mixture (Akbulut, Sehhatigdiri, Eroglu, & Celik, 2015), silica-based commercial glasses (Yasmin et al., 2018),

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Ball clay and Kaolin (Olukotun et al., 2018), coated textiles (Aral, Nergis, & Candan, 2015), mortars made with cement, sand, and eggshells (Binici, Aksogan, Sevinc, & Cinpolat, 2015), polymer nanocomposites (Nambiar, Osei, & Yeow, 2012), and fabrics coated with Tungsten and Barium sulfate additives (Aral, Nergis, & Candan, 2016) were found to shield radiation. However, none of these studies compared the linear attenuation coefficients of the experimental and standard Lead shields. Also, none formulated a device that shields X-rays in the diagnostic range. The samples used in the previous studies have economic value, thus may compromise the profit of the manufacturing firms.

According to the Bureau of Agricultural Statistics (2011), the Philippines produced 4.24 million tons of chicken and duck eggs in 2010. These eggs represent a significant ingredient in a large variety of products, such as cakes, salad dressings, and fast foods. However, the production results in several daily tons of eggshell waste and incur considerable disposal costs in the world. It was estimated that there are 250,000 tons of eggshell waste produced annually worldwide (Verma et al., 2012).

Previous studies reported significantly higher shell thickness, specific gravity, and breaking strength in eggshells compared to other domesticated shells (Joseph, Robinson, Renema, & Robinson, 1999; Soria, Bueno, & Bernigaud, 2013). These three parameters are directly proportional to mass density, one of the factors that should be considered in the construction of ideal shielding material (DeHoff, Rummel, LaBuff, & Rhines, 1966; Goel, 2007).

On the other hand, few studies have been carried out concerning the shielding effectiveness of eggshells against radiation. In the study conducted by Fecheyr-Lippens, Nallapaneni, and Shawkey (2017), eggshells had under 10% transmittance of Ultraviolet (UV) radiation. In the same study, the shielding efficacy was 43.5% higher for white eggshells compared to nylon with Titanium dioxide particles. On the other hand, eggshells were used as an additive to increase the radiation absorption property of mortars (Binici et al., 2015). The addition of eggshells improved the linear attenuation coefficient of mortars from 1.49 cm-1 to 1.76 cm-1 at 26.1 keV gamma-ray energy. The result of this study also revealed that an increase in the eggshell powder additive ratio increased the linear attenuation coefficient of the mortars. With these studies, an investigation of the X-ray shielding ability of eggshells is worthwhile to undertake.

There is a significant imperative to find an alternative to address the issues of costs and the non-utilization of radiation shields and solid waste management. However, there is a lack of research that explores the effectiveness of other materials in blocking radiation, such as X-rays. For this reason, the researcher is motivated to evaluate the shielding performance of eggshells against X-rays using a standard radiographic analysis approach. The main thrust of this study is to find an environmentally and economically appealing material that can be effectively used as shielding by both radiation workers and patients against X-rays.

METHODOLOGY

Collection and Preparation of Eggshells

Eggshell wastes were collected from the poultry farms, restaurants and hotels in Davao City. After retrieval, the eggshells were washed immediately with distilled water. The washed eggshells were air-dried for five days at a temperature range of 25-30^{0}C. The eggshells were then ground into powder using a grinding machine. Finally, these shells were filtered through a 75-micron sieve.

Preparation of Eggshells Shield and Controls

Five samples of radiation shield were prepared by mixing powdered eggshells with cement and water. Ordinary Portland cement of 43 grade (Ramco) was used following IS 8112-1989 standards. The mix proportion used in this study was a 5:3 cement-water ratio conforming to the IS 10262-2009 standard mix design. The mix proportion of the materials is shown in Table 1.

The fifth sample was considered as a negative control. The sixth sample was a positive control, which is the standard radiographic Lead shield with 0.5-cm thickness. This sample was labeled as 'PC.' After mixing based on the mix proportions, the first five samples were placed in a concrete mold measuring 0.5 cm x 0.5 cm x 0.5 cm. These were then labeled and set aside for 48 hours at room temperature to ensure complete hardening.

Radiographic Analysis of Shielding Performance of Various Samples

The radiographic analysis of the shielding performance of various samples was undertaken at a Radiologic Technology Laboratory. The test followed the standard radiographic procedures of Bushong (2016). The following radiographic materials were prepared:

Table 1

Mix Propotion of Eggshells Shield and Negative Control (NC)

Shield Name	Eggshell (g)	Cement (g)	Water (g)
E1	25	50	30
E2	50	50	30
E3	75	50	30
E4	100	50	30
NC	0	50	30

radiographic imaging system, X-ray film processor, 400-speed 14 in x 17 in screen-film cassette, 14 in x 17 in X-ray film, Lead marker, view box, and densitometer. A radiographic technique of 30-150 kilovoltage-peak, 5.2 milliampere-seconds, and 40 inches source-to-image distance was used. The 30-150 kilovoltage-peak is the range of energy value of diagnostic X-rays (Bushong, 2013).

The X-ray film processor was warmed up, and a couple of scrap films was run through it to stabilize temperature and circulation. The cassette was then loaded with an X-ray film in the darkroom and placed on the tabletop of the exposure room. Six samples of the shield were placed side-by-side on the cassette. Six different Lead markers were placed 2 inches above the sample of shield to indicate the type of shield used. The light field was then collimated to a 14 in x 17 in the area and centered on the radiographic cassette. The first exposure was taken using the radiographic technique mentioned. Five trials of exposure were taken using the same steps.

After exposure, the cassette was transmitted to the darkroom. After transmission, the X-ray film was taken from the cassette in total darkness at a relative humidity of 40-60% inside the darkroom. The film was then fed in the X-ray film processor and processed for about 90 seconds. After processing, the film was then placed in view box for quantitative calculation of transmitted X-ray intensity. Using the densitometer, the optical density as well as the corresponding transmitted intensity in milliRoentgen (mR), was measured for each area in the X-ray film. From the intensity readings of the densitometer, the linear attenuation coefficient of each shield will be calculated using the formula:

$$\mu = -\frac{\ln\left(\frac{I}{I_0}\right)}{t} \qquad (1)$$

Where μ is the linear attenuation coefficient with a unit of cm^{-1}, I is the intensity of X-ray radiation after interaction with shielding material (transmitted X-ray intensity), I0 is the initial intensity (constant at 1 mR), and t is the thickness of shielding material in centimeters (constant at 0.5 cm).

The linear attenuation coefficient is the fraction of a radiation beam that is absorbed or scattered per unit thickness of the shielding material. According to Bushong (2013), materials with a higher linear attenuation coefficient allow a greater number of absorbed or scattered x-rays when controlling for thickness and, thus, could shield radiation better. Conversely, materials with lower linear attenuation coefficient allow a higher number of transmitted x-rays when controlling for thickness and, thus, have lower shielding performance.

Data Analysis

A One-Way Analysis of Variance (ANOVA) was run to compare the mean of the six samples of the radiation shield. A Post Hoc Test using Tukey's Honest Significant Difference (HSD) was employed to confirm the differences that occurred between groups. A p-value of less than 0.05 was considered significant.

RESULTS AND DISCUSSION

In this study, the shielding performance of eggshells was measured in terms of linear attenuation

Table 2

Summary of ANOVA in the Shielding Performance

X-ray Energy		Sum of Squares	df	Mean Square	F
30kVp	Between Groups	59.94	5	11.99	973.62***
	Within Groups	0.30	24	0.01	
	Total	60.24	29		
60kVp	Between Groups	59.94	5	11.99	973.62***
	Within Groups	0.30	24	0.01	
	Total	60.24	29		
90kVp	Between Groups	59.94	5	11.99	973.62***
	Within Groups	0.30	24	0.01	
	Total	60.23	29		
120kVp	Between Groups	59.94	5	11.99	973.62***
	Within Groups	0.30	24	0.01	
	Total	60.24	29		
150kVp	Between Groups	59.94	5	11.99	973.62***
	Within Groups	0.30	24	0.01	
	Total	60.24	29		

Note. ***p < 0.001
Post hoc analysis using Tukey's HSD (Table 3) indicated that among the comparisons, PC and E4 have statistically similar shielding performance (p>0.05)

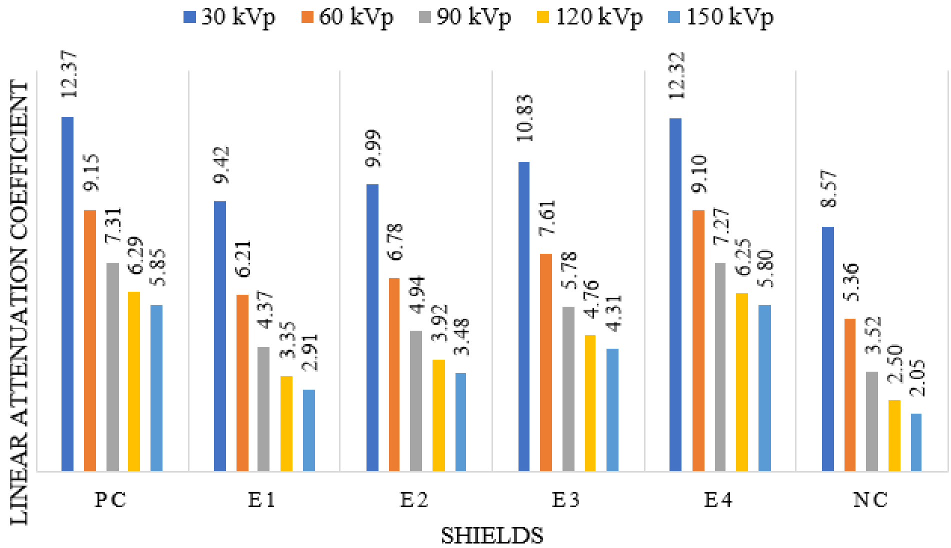

Figure 1. Linear attenuation coefficient (measured in cm-1) of shields

Table 3

Tukey's HSD Comparison for Shielding Performance (Homogeneous Subsets)

		Subset for alpha = 0.05				
X-ray Energy	Group	1	2	3	4	5
30 kVp	NC	8.57				
	E1		9.42			
	E2			9.99		
	E3				10.83	
	E4					12.32
	PC					12.37
60 kVp	NC	5.36				
	E1		6.21			
	E2			6.78		
	E3				7.61	
	E4					9.10
	PC					9.15
90 kVp	NC	5.36				
	E1		6.21			
	E2			6.78		
	E3				7.61	
	E4					9.10
	PC					9.15
120 kVp	NC	2.50				
	E1		3.35			
	E2			3.92		
	E3				4.76	
	E4					6.25
	PC					6.29
150 kVp	NC	2.05				
	E1		2.91			
	E2			3.48		
	E3				4.31	
	E4					5.80
	PC					5.85

Note. No significant difference within the subset; Significant difference between the subsets coefficient and compared to the standard Lead shield. The shielding performance was analyzed in the 30-150 kVp range to capture the diagnostic X-ray energy range. Figure 1 represents the shielding performance of the six shields used based on X-ray energy. Apparently, at the lowest energy range (30 kVp), the shielding performance was high. However, the shielding performance of all shields reduced rapidly with increments of X-ray energy. Across all energies, PC yielded the highest performance among other shields used. NC, on the other hand, yielded the lowest performance. As shown, an increase in the amount of eggshell increased the shielding performance of the shield.

Due to the extensive use of radiation in the field of medicine, the International Commission on Radiological Protection (ICRP) regulates the doses to the occupational workers and patients to as Low As Reasonably Achievable (ALARA) through requiring all X-ray facilities with shielding. X-ray shielding reduces the total number of X-rays after penetrating through a given thickness of shielding material due to absorption and scattering interactions (Bushong, 2013). Both of these interactions depend on the X-ray energy, and effective atomic number, and mass density of shielding material (Huda, 2010). When controlling for X-ray energy, an ideal shielding material should fulfill several criteria: it must have a high effective atomic number and a high mass density (Allisy-Roberts & Williams, 2008; Fosbinder & Orth, 2011).

In the study, it was observed that an increase in the amount of eggshell powder added to the cement and water increased the linear attenuation coefficient. The increase can be explained by the high ratio of Calcium carbonate, Magnesium carbonate, Calcium phosphate, and organic matter content in eggshells. These molecules were reported to increase the specific gravity, surface area, and weight of the eggshells (Joseph et al., 1999; Soria et al., 2013). The mentioned parameters are directly related to mass density, one of the criteria considered in the development of ideal shielding material (DeHoff et al., 1966; Goel, 2007).

The increase in X-ray energy reduces the shielding performance of all shields used. This reduction of performance can be attributed to the penetrability of X-rays, which increases with energy (Bushong, 2013). Highly penetrating X-rays require greater shielding to attenuate its intensity. The present study observed that there is a rapid decrease in the performance of shields as energy increases; however, the standard Lead shield and the shield with the highest number of eggshells yielded a statistically similar shielding performance across the diagnostic X-ray energy range.

Most diagnostic facilities are lined with Lead shields to protect the patient and radiation workers from radiation. The toxicity of Lead poses hazards to humans, and its disposal is associated with several environmental risks (Moawad et al., 2016). The thick walls and personal protective equipment that are composed of Lead are expensive compared to the eggshells proposed in the study. With the results of the study, the eggshell waste could be assessed as a shielding material.

CONCLUSIONS

X-ray shielding materials are essential in diagnostic imaging facilities. Increasing the number of eggshells increased its shielding performance; however, more shielding is required at higher X-ray energies. Nevertheless, the performance of the standard Lead shield and the shield with the highest number of eggshells yielded a comparable result. This research provides new information on the use of eggshells as alternative shielding material against X-rays in the diagnostic imaging. Future studies may be conducted to include mechanical tests to ascertain the strength and durability of the eggshell shields.

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