Synthesis and characterization of silicone rubber composite silica as the x-ray shielding

S Y Astuti\(^1\), H Sutanto\(^1,2\), G W Jaya\(^1,2\), E Hidayanto\(^1,2\) and Z Arifin\(^1\)

\(^1\)Department of Physics, Faculty of Science and Mathematics, Diponegoro University
\(^2\)Smart Material Research Center (SMARC), Diponegoro University
Jl. Prof. Soedharto, SH, Tembalang, Semarang 50275, Indonesia
E-mail: santiastuti@st.fisika.undip.ac.id

Abstract. Radiodiagnosics are diagnostics utilizing X-rays or radiochemical tracers. At the time of exposure using radiation, there may be radiation exposure that will affect the radiation workers. The purpose of this research is to develop materials that can be used as radiation shielding while maintaining radiodiagnostic examination results. This material is made by combining silicone rubber (SR) and silica composites materials through a simple process with a sample size (12 x 12 x 0.5 cm\(^3\)). Samples were made in 2 variations using silicone rubber and silicone rubber-6% silica composite. Both samples were then tested using a mobile X-ray plane with tube voltage variations of 46 kV, 50 kV, 60 kV, 70kV, 81kV, 90kV, and 102kV, respectively. After being tested, the results of the X-ray transmission percentage for SR sheet at the minimum and maximum voltage are 60% and 75%, respectively. For SR-6% Silica sheet X-ray transmission percentage at the minimum and maximum stresses of 58% and 74%, respectively. This research results showed that the use of silica on SR has potential as a composite material that can provide increased absorption of X-ray radiation.

1. Introduction
Utilization of x-ray radiation in medical applications continues to increase its use throughout the world, so it becomes a special challenge for radiation practitioners to improve work procedures regarding radiation protection [1]. There are three principles of radiation protection, namely (1) justification, which uses radiation by considering the benefits compared to the losses; (2) radiation protection must be optimized in relation to the amount the dose, namely the number of exposed people, and also to optimize it for all socioeconomic degree of patients; (3) Limitation of doses, that is establishing annual dose limits for exposure to medical workers, public exposure, and exposure to the embryo and fetus [2]. Radiation protection can also be done by using radiation shielding. Radiation shielding is the practice of people and environment protecting from the harmful effects of ionizing radiation [3]. The material commonly used as radiation shielding in clinical applications is lead [3,4].

Lead is the standard material used as shielding and usually weights 3.25 kg to 0.25 mmPb, and 4.95 kg to 0.50 mmPb. It will be very heavy if it is used for a long time by medical workers, so making it difficult to move efficiently [4,5,6]. Other materials offered as a lead replacement as a radiation protection material are tungsten, bismuth, barium, boron, and tin [5]. However, these materials still have lacks regarding elasticity when it is used to cover the body's surface during exposure. An alternative material that can be used is a silicone rubber (SR) which has an advantage which regarding elasticity [7].
SR is an elastomeric material which is mainly consisting of polysiloxane with R₂SiO structure, and SR has Si-O bonds which show unique inorganic properties for conventional elastomeric materials [8]. Excellent properties, such as heat resistance, chemical stability, low toxicity, abrasion resistance, optical transparency, weather resistance, and ozone resistance, offer the potential of SR for wide applications in various fields such as acoustic applications, voltage insulators and capacitors applications [8-10]. In the medical field, SR material is widely studied in the application of radiotherapy as a bolus [11].

In this study, shielding material was made in two samples, those are SR, and SR added with the composite material of silica (SiO₂). The utilization of silica as a composite material in SR has been carried out in various fields such as electrical insulator applications, a coating of high-voltage insulators, and industrial sealing products with the purpose to increase physical density and mechanical properties of SR materials [8, 12, 13, 14]. Then, both samples were examined by using a conventional x-ray modality with a fixed tube current and varying the tube voltage.

2. Material and Method
2.1. Sample synthesis
In this study, one sample was made using silicone rubber-RTV 52 material, and another sample was prepared using SR material which was added with silica composite material of 6% which was the product of the synthesis of geothermal power plants with purity of 70%, and the particle size is 75 μm. The material is then mixed with catalysts originating from Blues catalyst 60 R (Indrasari Chemical Store, Semarang, Indonesia) to harden SR. The method of samples manufacture is a simple molded method with the dimensions of the sample size (12 x 12 x 0.5) cm³ in sheet form. The SR and catalyst material volumes used in this study are 72 ml and 3 ml, respectively. The sample manufacture process can be seen in figure 1.

![Figure 1](image)

Figure 1. The scheme of material shielding synthesis

2.2. Percentage of x-ray transmission
To find out the percentage of x-ray transmissions, the examination was conducted using mobile radiography systems (Polymobil Plus Siemens, Sweden) at the Diponegoro University Training Center. The samples were tested using a variation of the tube voltage of 46kV, 50 kV, 60 kV, 70 kV, 81 kV, 90 kV, and 102 kV. The tube current used in this study remains at 25 mAs. The distance between the x-ray tube and the sample is set at a distance of 100 cm. Then, the x-ray radiation
measurement starts by exposing the samples using a detector (Black Piranha, Sweden), and then the sample was placed above the detector. The measurement results can automatically be seen in the operator’s room using computer assistance. The research scheme can be seen in figure 2. to calculate the percentage of x-ray transmission using the following equation:

\[ P_X = \frac{D_B}{D_A} \times 100\% \]  

By means of \( P_X \) is the percentage of x-ray transmission, \( D_B \) is the dose of x-ray radiation using the sample (mGy), and \( D_A \) is the dose of x-ray radiation without using a sample (mGy) [15]. Then, the linear attenuation coefficient value can be calculated based on the percentage value of x-ray transmission that has been obtained before, so that the following equation becomes:

\[ \mu = -\frac{1}{x} \ln \left( \frac{D_B}{D_A} \right) \]  

with \( \mu \) is linear attenuation coefficient (cm\(^{-1}\)) and \( x \) is a thickness of SR sheet (cm) [16].

![Figure 2. Experiment set up to measurement x-ray transmission.](image)

**3. Result and Discussion**

3.1. Sample synthesis result

Figure 3 shows the results of samples that have been made with dimensions (12 x 12 x 0.5) cm\(^3\) in the shape of sheets. It can be seen that the produced sample has a flat surface without air bubbles. Both samples look identical to each other because the used composite material is a micro-sized powder that has been homogeneously distributed in SR material.

![Figure 3. Sample synthesis result (a) Silicone rubber (SR) sheet, (b) Silicone rubber composites Silica 6% (SR-Silica 6%) sheet](image)

3.2. Percentage of x-ray transmission
Figure 4 shows the results of the percentage of x-ray transmissions obtained based on equation (1). Based on figure 4, the use of SR material is obtained by the percentage of x-ray transmission for minimum and maximum voltages of 60% and 75%, respectively. Whereas for the SR-silica composite material, the percentage of x-ray transmission was 58% and 74% at the minimum and maximum voltages.

The results of this study indicate that the SR material synthesized can resist x-ray radiation up to 40% at a minimum voltage and 25% at maximum voltage. Whereas for SR-silica materials composites can resist x-ray radiation of 42% at a minimum voltage and 26% at maximum voltage. Thus the radiation protection material made of SR-Silica 6% can absorb radiation better than using SR even though it is only able to provide radiation absorption increment of 1% to 2%. This phenomenon can happen due to the addition of a material's density that has better absorbent radiation capability [17]. Also, it can be concluded that materials with a higher mass density can increase the effectiveness of radiation shielding [6].

![Figure 4. X-ray transmission of SR and SR-Silica 6% with tube voltage variation](image)

The shield for x-ray radiation depends on what happens, that is, on the effect of the collision between x-ray radiation and the atoms making up the shielding material [17]. The addition of silica composite material to SR has been shown to increase the density of SR material [18]. Materials with a higher density have increasingly constricting atoms. This can cut the probability of the x-ray being missed when it penetrates the shielding material.

Figure 5 shows the results of the calculation of the linear attenuation coefficient using equation (2). Based on figure 5, for SR material, the coefficients of linear attenuation for the minimum and maximum voltages are 1.02 cm\(^{-1}\) and 0.58 cm\(^{-1}\), respectively. For the SR-silica composite material obtained a value of 1.10 cm\(^{-1}\) for the minimum voltage and 0.59 cm\(^{-1}\) for the maximum voltage. The linear attenuation coefficient (\(\mu\)) is a reduction of radiation intensity through the target material [19]. So that, the higher the attenuation coefficient value, the better the ability to absorb x-ray radiation.
4. Conclusion
From the results of the study, it can be concluded that SR and SR-silica composite materials have the potential as shielding on mobile x-ray modality because SR material can absorb x-ray radiation up to 35% at maximum voltage and 40% at minimum voltage. For SR materials silica composites, it has a percentage of x-ray transmission of 58% and 74% at a minimum and maximum voltages. The results showed that the application of silica has the potential as a composite material that can provide an increment of x-ray radiation absorption.

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