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Characterization Of Silicone Rubber–Tungsten (SR-W) Composite Using Density And EDX Analysis For Potential Radiation Shielding Applications

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Abstract-The need for safe, lightweight, and flexible radiation shielding materials continues to increase as medical radiography technology develops. This study aims to characterize Silicon Rubber–Tungsten (SR-W) composites as candidates for lead-free radiation shielding materials through density assays and Energy Dispersive X-ray (EDX) analysis. Variations in tungsten weight fractions used include 0%, 3%, 6%, 9%, 12%, and 15%. Density testing was performed by mass and volume measurement methods, while EDX analysis was used to determine the element composition and tungsten distribution in a rubber silicon matrix. The test results showed that the density of the composite increased with the addition of the tungsten weight fraction, from 1.1076 g/cm³ in a composite without tungsten to 1.2179 g/cm³ in a composite with 15% tungsten. EDX analysis showed a decrease in silicon content from 97.236% to 68.371%, accompanied by an increase in tungsten content from 0% to 25.023%. The increase in density and tungsten content suggests that the addition of tungsten powder successfully increases the proportion of heavy metals in composites. Overall, the results of this study show that SR-W composite has good physical characteristics and has the potential to be used as a flexible and non-toxic radiation protection material.
Keywords: SR-W Composite, Silicone Rubber, Tungsten, Density, EDX.

I. INTRODUCTION

The use of ionizing radiation in medicine has made a major contribution to improving the quality of diagnosis and therapy of various diseases [1]. However, exposure to radiation that is not properly controlled can have biological effects on tissues, including deterministic and stochastic effects [2]. Therefore, the principle of radiation protection, which includes justification, optimization, and dose restriction, must be applied consistently in every radiological procedure [3]. In the practice of diagnostic radiography, patients and medical personnel have the potential to receive exposure to scattered radiation that can increase the cumulative dose especially in sensitive organs such as the thyroid gland and gonads [4]. The NCRP report shows that the increase in the number of radiology procedures has significantly increased the exposure to medical radiation in the population in the last two decades [5]. In line with this, AAPM recommends the application of the as low as reasonably achievable (ALARA) principle as well as the use of external protective materials that are appropriate to the X-ray energy used [6]. One of the important efforts in radiation protection is the use of shielding materials. So far, lead (Pb) is the main material used because it has a high

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atomic number and good absorption to radiation [4],[7]. However, lead is toxic, environmentally unfriendly, and less flexible for applications on areas of the body with uneven contours [8]. These limitations have encouraged the development of alternative protective materials that are lead-free but still have high absorption effectiveness against ionizing radiation [9].

Recent research shows that polymer-based composites with heavy metal fillers, such as tungsten (W), bismuth (Bi), or barium (Ba), are capable of being a safer and more flexible alternative to radiation shielding [9,10]. Tungsten has the advantage of its high density and atomic number (Z=74), so it can increase the attenuation of X-rays without causing toxicity [10,11]. When combined with silicone rubber, this material can produce an elastic, lightweight, and malleable composite as per clinical requirements [9]. Some previous studies have also supported this potential, reporting that an increase in the weight fraction of tungsten in silicone rubber increases the density and attenuation ability of X-rays at energies of 60–120 kVp [9]. Other research suggests that silicon–tungsten composites have stable mechanical characteristics and radiation absorption, making them potential candidates for flexible radiation shielding [10].

This research was conducted to fill this gap by developing a Silicone Rubber–Tungsten (SR–W) composite using a synthesis approach based on PEG dispersion and ultrasonic homogenization. This method is designed to increase the dispersion of tungsten particles and minimize the formation of agglomerations or micro-cavities that can degrade the quality of the material. The main novelty of this study lies in the application of the gradual dispersion technique (PEG–W → SR–W), which is theoretically able to produce a more even distribution of particles than the direct mixing technique, as well as in the thorough characterization using density analysis and EDX to ensure the accuracy of the elemental composition. With this approach, this study not only assesses the change in density due to variations in tungsten weight fractions but also verifies the regularity of the distribution of elements as an indicator of the quality of composite structures.

Overall, this study aims to produce a more homogeneous, stable, and potentially used SR–W composite material as a lead-free flexible shielding material in medical radiography applications. Through the integration of improved dispersion methods and density-based characterization and EDX, this research is expected to make a relevant scientific contribution to the development of new generation radioprotective materials [12].

II. Experimental Procedure

The process of making rubber-tungsten silicon composite (SR-W) is carried out in stages to produce a homogeneous, elastic, and tiggi-density material as an X-ray radiation protection material. The main materials used are silicone rubber (RTV-52) as the matrix and tungsten powder (W) as a filler, with a concentration variation of 0% to 15% wt. Additional ingredients include PEG 4000, aquades, bluesil catalyst, and silicone oil.

1. SR-W Shielding Manufacturing

The initial process of synthesis of SR-W composites is carried out by making a PEG–W solution as a tungsten powder dispersing medium. Polyethylene glycol (PEG 4000) serves to help the distribution of metal particles to be more homogeneous when mixed with silicone rubber. PEG is dissolved using aquades at a temperature of 60 °C with a stirring speed of 550 rpm for 10 minutes, then tungsten powder (W) is added gradually according to the composition variation, namely 0%, 3%, 6%, 9%, 12%, and 15%. The mixture is stirred until a homogeneous PEG–W solution is formed.

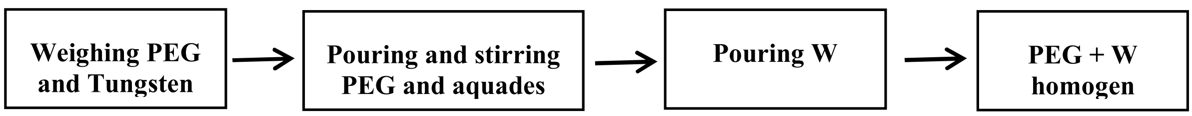

Figure 1. PEG+W dissolution scheme

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Figure 1. shows the stages of the PEG–W solution manufacturing process starting from weighing the material, dissolving PEG with aquades, adding tungsten powder, to obtaining a homogeneous PEG–W solution. This process is important because it determines the level of dispersion of tungsten within the silicon rubber matrix at the next stage of mixing. The PEG–W solution that has been formed is then mixed with silicone rubber (RTV-52) using a mixer for 30 minutes until a homogeneous SR–W mixture is obtained. The mixture is then processed with an ultrasonic bath for 30 minutes to increase homogeneity through the sonication process. After that, the SR–W mixture is stirred again for 7 minutes, and a bluesil catalyst is added to speed up the hardening process. The final mixture is poured into a mold that has been coated with silicone oil so that it does not stick, then flattened and allowed to harden at room temperature. The scheme of making shielding can be seen in Figure 2.

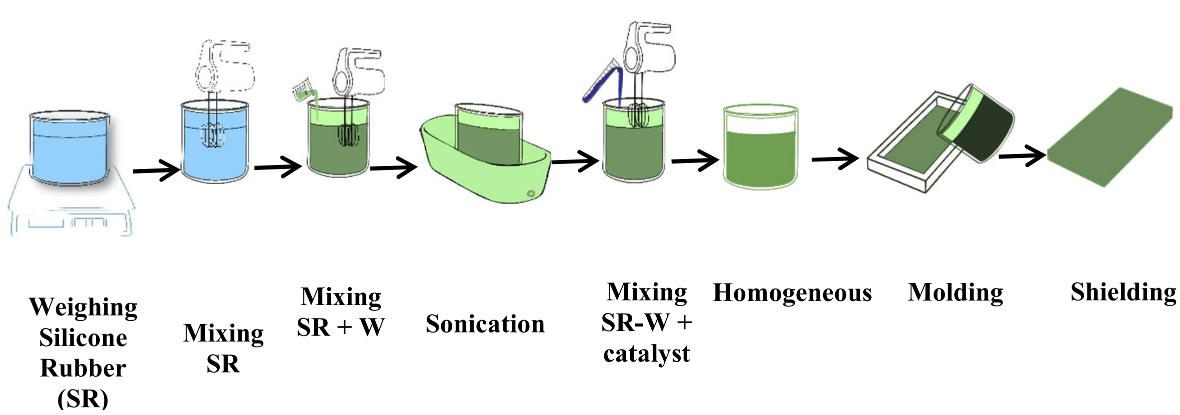

Figure 2. SR–W shielding manufacturing scheme

Figure 2. shows the sequence of the SR–W composite manufacturing process starting from weighing silicone rubber, mixing with tungsten, sonication process, adding catalysts, to molding. This stage produces SR–W composite sheets with an even distribution of tungsten particles, smooth surfaces, and a dense structure, making it ready for use for testing density and element composition characteristics using the EDX method.

2. Density

Density measurements were carried out to determine the density of the radioprotector variation using the ratio between mass and volume. Mass can be known using a digital balance, while volume can be known by measuring the dimensions of the radioprotector. As formulated as follows:

$$\rho = \frac{m}{v} \quad (1)$$

With is the density of the radioprotector (kg/m3 ρ), m is the mass (kg) and v is the volume (m3) [13].

3. Energy Dispersive X-Ray

In this study, the characterization of energy dispersive X-ray atay commonly known as EDX was carried out. The sample is inserted into the Shidmazu EDX 7000 device and stored the sample on the EDX device's Cmos camera and then fired at the desired point or spot, in this case intermalic, silicon eutectic. The characterization of the EDX test was carried out to determine the elements and chemical composition contained in the radioprotector sample, so that it can be known that the constituent elements are evenly distributed homogeneously or not as seen in Figure 3.

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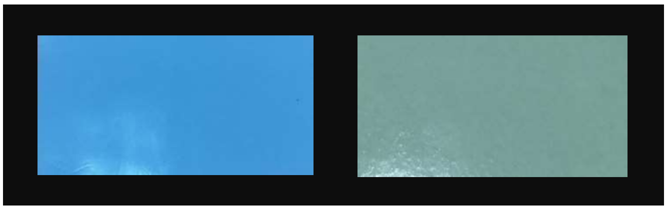
Figure 3. EDX Testing

III. RESULTS AND DISCUSSION

1. SR-W Shielding Synthesis Results

The use of sillicone rubber (SR) material combined with tungsten powder (W) in the manufacture of shielding has been successfully carried out using a simple mixing method. Variations in the percentage of SR and W have been used in the process of making shielding The results of the synthesis of silicon rubber–tungsten composite (SR-W) shielding show a fairly obvious visual change in each variation in the concentration of tungsten powder (W). These changes are seen in the different color and brightness levels of the shielding surface as the W level increases. This indicates that tungsten particles have been evenly dispersed in the rubber silicon matrix and form a homogeneous composite material. These visual differences can be observed in Figure 4.



(a) (b)

Figure 4. The results of the synthesis of SR-W shielding; (a) 0; (b) 15 wt%

From Figure 4. It is seen that each increase in the weight fraction of tungsten results in a consistent visual change. Sample (a) with a 100% SR composition appears the lightest because it does not contain W powder, while sample (b) with the highest W composition (15 wt%) appears darkest and more opaque. This difference is due to the increased optical density due to the addition of tungsten, which has a dark gray color and high light-absorbing properties. These visual results indicate that the mixing process using hot plate stirrer, mixer, and ultrasonic bath is effective in distributing W particles throughout the SR matrix. Thus, each variation of the resulting composition has homogeneity and physical characteristics suitable for the next stage of testing.

2. SR-W Shielding Density

Density measurements were carried out to evaluate the change in density of silicon rubber-based shielding materials (SR) with the addition of tungsten (W) particles at various concentrations using Archimedes principle to obtain volume values [14]. Then the shielding density is calculated based on equation 1. Changes in the density of a material are one of the important characteristics that need to be considered to understand the level of bond density of the constituent material. The density value of a material is closely related to the attenuation capacity of X-ray radiation, so the higher the density, the greater the material's ability to absorb or inhibit radiation. Figure 5 shows the relationship between the variation in tungsten particle concentration

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(%wt) and the resulting SR-W composite density value. This graph illustrates the trend of density change from the sample without the addition of W to the sample with the highest concentration (15%), and shows the fluctuation in density values that occur between these ranges.

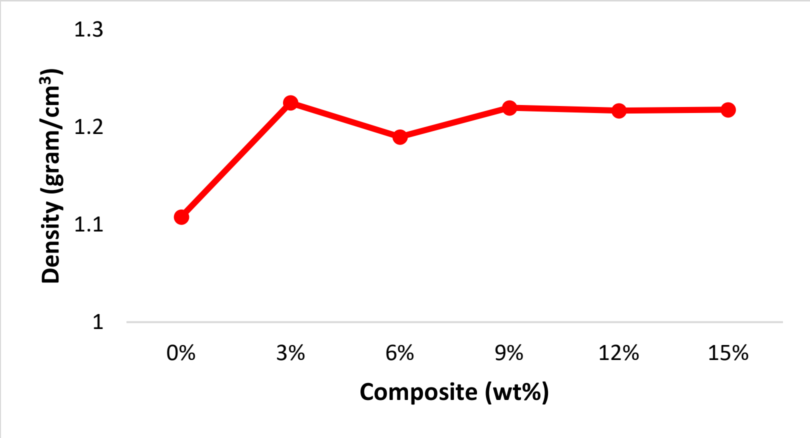

Figure 5. Shielding density graph with various percentage variations

In general, the addition of tungsten increases the density of the material, as expected based on the high intrinsic density of tungsten, which is 19.3 g/cm^3. Based on the graph in Figure 5, it can be seen that the increase in density did not occur linearly but experienced a significant increase from 1.1076 g/cm^3 (without W) to 1.2254 g/cm^3 at a W concentration of 3% which shows the main message of the addition of tungsten to the increase in density. However, at the 6% concentration there was a slight decrease to 1.1899 g/cm^3 before increasing again at the concentration of 9% and stabilizing to 15%, although it did not exceed the value at 3%.

These fluctuations indicate that an increase in the weight fraction of tungsten does not necessarily guarantee a direct and consistent increase in density. Several technical factors are the cause, such as the homogeneity of the mixture, the size and distribution of W particles in the rubber silicon matrix, as well as the possibility of the formation of micro-voids (cavities) between particles due to uneven dispersion as described in the study [16]. In addition, manual and mechanical mixing methods also affect the quality of particle distribution. At certain concentrations, tungsten particles may not be optimally distributed throughout the entire volume of the material. Despite small fluctuations, the overall density increase trend was maintained and showed an increase in density compared to pure SR of 1.1076 grams/cm^3, indicating that tungsten remains a dominant role in forming composites with radioprotective characteristics. However, these results also confirm the importance of mixing method optimization, homogeneous filler distribution, and control of process parameters in composite-based shielding material synthesis.

3. Energy Dispersive X-Ray (EDX)

The test was carried out with a variation in the percentage of SR-W, namely 0-15 wt% by mixing tungsten silicone rubber material.

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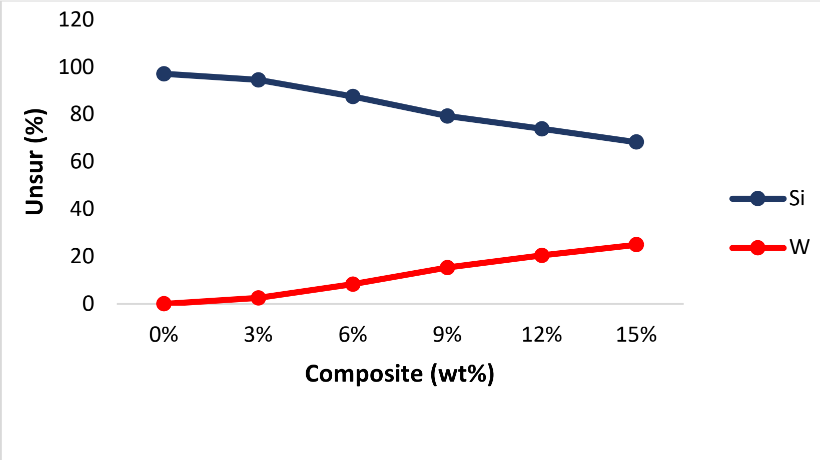

Figure 6. Graph of the content of the Si and W elements in the SR-W shielding percentage

It can be seen in Figure 6 showing the results of EDX testing on the shielding sample, which indicates a significant composition of silica (Si) and W elements. The results of the analysis showed that the content of the element silicon (Si) decreased consistently with the increase in the weight fraction of tungsten, while the content of the element W showed the opposite trend. In shielding samples with a percentage of SR-W of 85:15 wt%, silica element (Si) with a small relative amount of 68.371% in mass percentage, while element W had a higher percentage of mass at SR-W 85:15 percentage of 25.023%. In contrast, in the SR-W sample 100:0 wt% the largest silica element with a mass percentage of about 97.236% while the W element was not detected. These results show that the composition of the majority of atoms is consistent with the composition of SR-W. The element silica (Si) appears to be the main element in the sample, which suggests that the distribution of heavy elements in the composite is proportional to the fraction of the weight added during synthesis. This result is in line with the basic principle of composite materials, where the increase in the mass fraction of the filler will be directly reflected in the results of the chemical composition analysis, especially if the mixing method used is able to produce even dispersion of particles [16]. In addition to Si and W, there are other elements such as S, Al, Ge, Ti, K, Fe, Cu, Ag, Ca, Sn, and Zr each have a very small percentage of elements less than 1%.

The mixture between sillicone rubber and W materials produces two main elements, namely silica (Si) and tungsten (W). The presence of tungsten elements in the mixture gives the sample the ability to function as a shielding. An increase in the W content in the SR-W composite will increase radiation attenuation because W has a high atomic number that is highly effective in absorbing x-ray photons through photoelectric interaction mechanisms, especially at the energy <100 keV commonly used in diagnostic radiography [2,10].

The results of this EDX are an important parameter to confirm that the ratio of the blended mixture has theoretically been distributed in the actual form of the final material. The increasingly rich composition of elements W supports the main goal of material development, which is to produce radioprotective materials that are lightweight, flexible, and still have high attenuation efficiency. An increase in W levels needs to be balanced with an evaluation of other parameters such as mixture homogeneity, mechanical properties, and material printing capabilities, given that the addition of high amounts of heavy metal particles has the potential to lead to particle aggregation and decrease interphase cohesion in the polymer matrix. Thus, the EDX data not only serves as a validation of the success of the synthesis process, but also provides a preliminary picture of the dispersion quality and efficiency of the incorporation of tungsten particles in the sillicone rubber matrix as an early indicator of the success of the formulation of SR-W radioprotective materials.

III. CONCLUSION

The results showed that the silicon shielding rubber–tungsten (SR-W) composite was successfully synthesized using a simple mixing method, resulting in a homogeneous, flat, and air bubble-free surface. An increase in tungsten's weight fraction was shown to affect the increase in material density from 1.1076 g/cm³ to 1.2254 g/cm³, reflecting an increase in density and X-ray attenuation ability. The results of the EDX analysis also confirmed the presence of the main elements silicon (Si) and tungsten (W) with a distribution comparable to the theoretical mixture ratio, indicating an even dispersion of the particles. Overall, the combination of synthesis results, density testing, and EDX proves that SR-W composite has the appropriate physical and chemical characteristics for use as an effective radioprotective material in protection in radiography.

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