International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 55 No. 1 January 2026, pp. 130-134

Effect Of Silicone Rubber–Tungsten Bolus On Surface Dose In Photon Radiotherapy

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Abstract: This study investigates the characteristics and dosimetric performance of a Silicone Rubber-Tungsten (SR-W) bolus synthesized with 10 wt% tungsten. Material characterization included density measurement, Energy Dispersive X-ray (EDX) analysis, and relative electron density (RED) evaluation. The SR-W bolus demonstrated a physical density and RED comparable to soft bone tissue. Surface dose measurements using a photon beam LINAC showed a significant increase in surface dose when the SR-W bolus was applied compared to no-bolus conditions. The enhancement is attributed to the high-Z tungsten content, which increases secondary electron production and shifts the dose build-up region toward the surface. These results indicate that the SR-W bolus has strong potential as an effective surface dose modifier in photon radiotherapy.

Keywords: Bolus, Radiotherapy, Silicone Rubber, Tungsten

1. INTRODUCTION

Cancer is a leading cause of death worldwide. In Indonesia, breast cancer is the most prevalent cancer among women. In 2020, approximately 30.8% of all cancer cases were breast cancer, and 20.4% of these cases resulted in death [1].

Linear Accelerators (LINAC) generate electron or photon beams for radiotherapy. Photon beams have a skin-sparing effect, which can result in a surface dose lower than needed. To address this, a bolus is used as a compensating material [2].

Various tissue-equivalent bolus materials have been widely used, including paraffin wax, elasto-gel pads, superflab, thermoplastic sheets, dental wax, polypropylene, and rayon blend. Despite their effectiveness, the availability of these materials in Indonesia remains limited, and most must be imported. In response to this limitation, Silicone Rubber (SR), a synthetic polymer that is readily available in Indonesia, has gained attention due to its advantageous properties such as heat resistance, chemical stability, low toxicity, abrasion resistance, and moldability, making it a promising bolus material [2], [3]. Furthermore, incorporating high-density metals into SR has been shown to increase surface dose. Materials with high atomic numbers (high-Z) generate significant electron scattering and thus have strong potential for enhancing surface dose [4].

This study synthesizes a Silicone Rubber–Tungsten (SR–W) bolus by combining silicone rubber (SR) with tungsten (W), a high atomic number element. The material was characterized by measuring its physical density and relative electron density, and by performing compositional analysis using Energy Dispersive X-ray (EDX). Additionally, surface dose measurements were conducted with photon beams using a LINAC.

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2. RESEARCH METHOD

The study began by synthesizing a bolus material composed of Silicone Rubber (SR) and 10 wt% tungsten (W). Tungsten powder was first added to a PEG4000 and distilled water solution, then homogenized ultrasonically. This solution was mixed with Silicone Rubber and further processed in an ultrasonic bath to disperse the tungsten particles evenly. A catalyst was added, and the mixture was molded into a 17×17×0.5 cm^3 sheet. The process used to synthesize the bolus is shown in Figure 1.

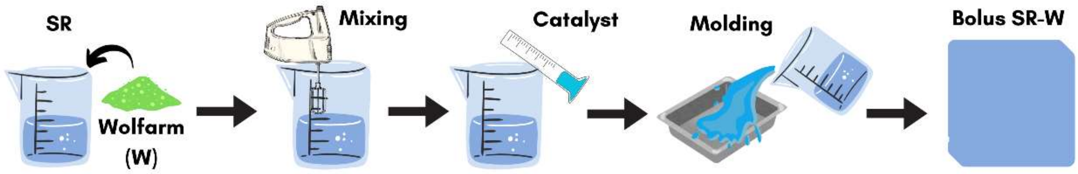

Figure 1. SR-W Bolus Synthesis Step

Three types of material characterization were performed: physical density measurement, Energy Dispersive X-ray (EDX) analysis, and relative electron density (RED) evaluation. Density measurement was conducted by weighing the sample and determining its volume. The resulting density was then calculated as shown in Equation (1):

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

where m is mass bolus SR-W (gr) and V is SR-W volume (cm^3).

The EDX analysis was conducted using a Shimadzu EDX-7000 system. The sample did not require sectioning and was placed directly into the CMOS camera chamber of the instrument. The scan was performed using the "easy" mode.

Subsequently, RED analysis was conducted by acquiring CT-scan images of the bolus to obtain CT numbers. These CT-numbers were measured using the Region of Interest (ROI) method in RadiAnt DICOM Viewer. ROI measurements were taken 10 times from different slices, and the relative electron density was calculated using Equations (2) and (3) [5].

$$\rho = 1.052 + 0.00048N_{CT} \qquad for\ N_{CT} > 100 \quad (2)$$

$$\rho = 1.000 + 0.001N_{CT} \qquad for\ N_{CT} < 100 \quad (3)$$

where ρ_e is the relative electron density and N_{CT} is CT-*Number.*

Surface dose measurements were performed using a photon-beam LINAC with energies of 6 MV and 10 MV. First, the field size was set to 15 × 15 cm^2. Then, measurements were obtained under two conditions: without bolus and with the SR–W bolus. Radiation doses were measured using a Farmer-type ionization chamber. The collected charge was read in nanocoulombs (nC) using an electrometer, and the absorbed dose was calculated using Equation (4) [6]. The procedure for acquiring surface dose data is illustrated in Figure 2.

$$D_{w,Q} = M_Q N_{D,w,Q_0} \quad (4)$$

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where M_Q is the corrected electrometer reading and N_{D,w,Q_0} is the calibration factor of the ionization chamber for absorbed dose to water at the reference beam quality. M_Q was calculated using Equation (5):

$$M_Q = Q_{read} k_{TP} k_{elec} k_{pol} k_s \quad (5)$$

where Q_{read} represents the charge reading measured by the electrometer, k_{TP} is the temperature-pressure correction factor, k_{elec} is the electrometer calibration correction, k_{pol} is the polarity correction, and k_{pol} is the ion recombination correction factor.

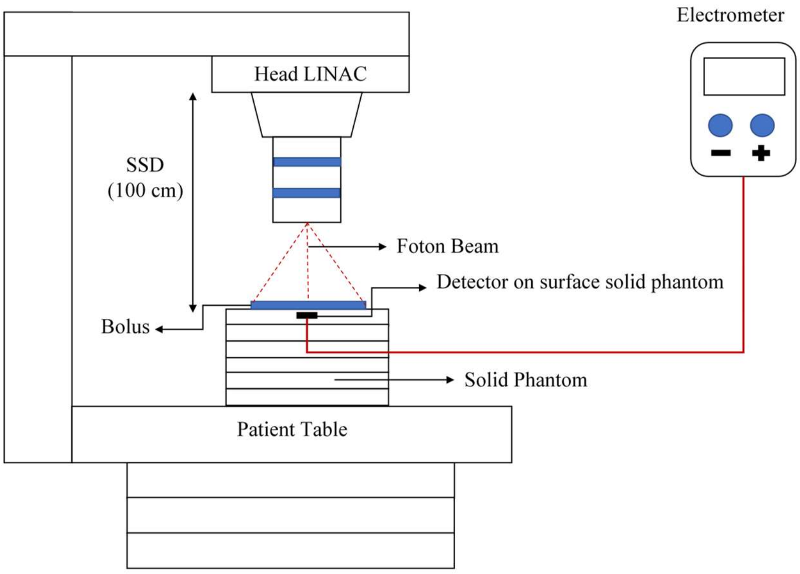

Figure 2. Surface Dose Data Collection Scheme

3. RESULT AND DISCUSSION

The density measurement of the SR–W bolus was conducted to evaluate the material's physical compactness. The density of the SR–W bolus containing 10 wt% tungsten was 1.19 ± 0.0005 g/cm³. This value, based on ICRU data (1989 and 1992), indicates that the SR–W bolus is suitable for applications requiring equivalence to soft bone tissue. The comparison with TPU and PLA bolus materials [7] was performed to demonstrate that the SR–W bolus achieves a density on par with other commonly used bolus materials.

EDX analysis was conducted to verify tungsten incorporation in the synthesized SR–W bolus. The EDX results for the 10 wt% tungsten sample showed a composition of 82.40% SR and 17.60% tungsten. The observed tungsten content differed from the nominal synthesis value. This variation is attributed to the localized nature of EDX, which examines only a micrometer-scale surface area, not the full sample volume. Since tungsten distribution may be non-uniform in the SR matrix, the analyzed region can have a higher or lower tungsten concentration than the overall average.

The RED value, which reflects the magnitude of radiation scattering within the bolus material, is widely used to characterize the radiological properties of dosimeters, human tissues, and water [8]. Specifically, the RED represents the relative electron density within the synthesized bolus. The SR–W bolus containing 10 wt% tungsten exhibits a RED value of 1.15 ± 0.031, indicating equivalence to soft bone tissue according to ICRU 1989 and 1992 data. Additionally, this RED value is similar to that of SR–Si bolus materials [9]. An ideal bolus should mimic the properties of soft tissue to replicate skin–radiation interactions, and it must be flexible and conformable to minimize air gaps and ensure a homogeneous dose distribution.

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The measured surface dose without a bolus for a 15 × 15 cm² field size was 96.653 cGy at 6 MV and 86.718 cGy at 10 MV. In comparison, the SR–W bolus with 10 wt% tungsten gave a surface dose of 122.798 cGy at 6 MV and 120.376 cGy at 10 MV. The surface dose result are shown in Figure 3. These results show that the SR–W bolus increases the surface dose. Adding tungsten, a high-Z material, boosts interactions near the surface by generating more secondary electrons, which moves the build-up region closer to the skin. A higher RED value means more attenuation, so less photon fluence reaches deeper tissues, while more is absorbed and scattered at the surface—raising the surface dose. A larger field size also increases scatter and the surface dose. Similar experimental findings have been reported, where bolus materials such as shape-tunable rubber containing tungsten (STR) with thicknesses of 0.5–1 cm produced higher surface relative doses (D_0) compared with conditions without a bolus [10], [11].

The SR-W bolus with 10 wt% tungsten produced a higher surface dose than paraffin, paraffin wax, plasticine, natural rubber, playdoh, SR+Al, and SR+Bi [5], [12]. Overall, the SR-W bolus can increase the surface dose to more than 100% of the prescription dose, while commercial boluses typically increase it to only 95–100%.

The SR-W bolus is suitable for radiotherapy cases requiring enhanced surface dose, but its use should consider field size and beam energy, as excessive dose enhancement may lead to hotspots. Additionally, its ability to reduce the depth dose offers an advantage for deeper-seated tumors by lowering radiation exposure to surrounding organs.

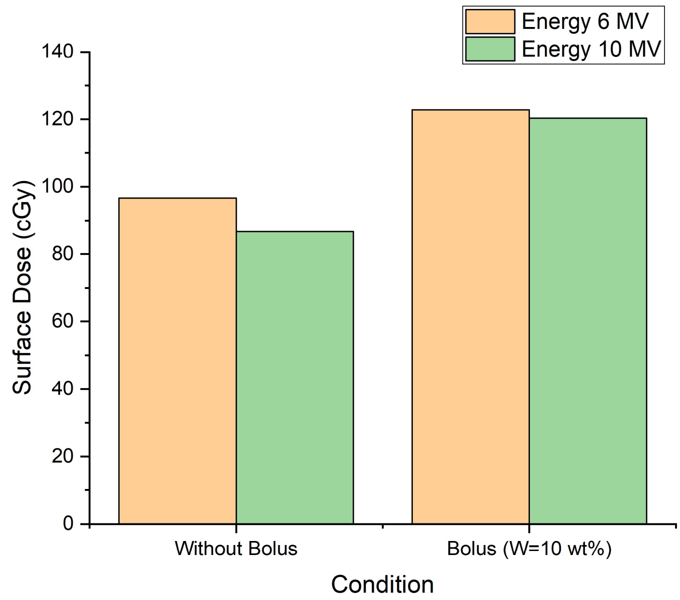

Figure 3. Surface Dose Without Bolus and With Bolus

4. CONCLUSION

Based on the results of this study, it can be concluded that the Silicone Rubber–Tungsten (SR–W) bolus containing 10 wt% tungsten exhibits density characteristics comparable to soft bone tissue. Furthermore, EDX analysis confirmed the presence of tungsten within the SR–W bolus. As a result, the surface dose achieved with the SR–W bolus increased significantly compared with the dose without a bolus. This enhancement is strongly influenced by the relatively high RED value of the SR–W material. Specifically, the incorporation of a high-Z element (tungsten) increases the production of secondary electrons, including backscattered electrons, thereby contributing to a higher surface dose.

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