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Tungsten-ethylene vinyl acetate (EVA) composite as a gamma rays shielding material

Onur Alp Ersoz, Fatma Yurt Lambrecht* & Hale Melis Soylu
Department of Nuclear Applications, Institute of Nuclear Science, Ege University, Bornova, 35100, Izmir, Turkey

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Lead is a highly toxic metal, also heavy in personal shielding. This negative aspect decline us to search for alternative shielding material that is free of toxic effect, environment friendly, lighter and easy to use individually. Polymer, being lighter, may constitute an alternative to lead, but it has a much lower density and does not serve in gamma shielding by it. Therefore, high density tungsten could be added to polymer in order to shield gamma rays. In this study ethylene vinyl acetate (EVA) and tungsten were mixed in certain amounts and thus discs have been produced from this mixture. The results show that EVA-Tungsten composite is an effective shielding material for gamma shielding.

Keywords: Gamma radiation, Shielding, Tungsten, Polymer, Ethylene vinyl acetate

1 Introduction

Ionizing radiation is a hazard to human health. Thus, people need protection against the hazard of ionizing radiation. There are three basic methods in order to be protected from radiation; time, distance and shielding. The amount of radiation exposure is reduced if the distance from the radiation source is increased. Exposure follows inverse square law. Shielding is the best method for radiation protection. There is no requirement of shielding material for alpha particles because of their very small range. Even thin paper or human skin could easily block alpha particles. Ranges of beta particles are smaller than alpha particles; therefore, they penetrate human body easily. Thus, we need special shielding materials against beta particles. Beta particles could lead to bremsstrahlung in the elements of the highly atomic number and for this reason the elements of the low atomic number like aluminum should be used for beta radiation shielding. Hydrogenous polymers are effective for neutron shielding[1-4]. Thus, gamma rays could penetrate materials of low density. Materials with high density and high-Z such as lead, concrete could block gamma rays when gamma energy increases and the thickness of materials should increase in order to stop gamma rays[5-8].At the present time, generally lead plays an important role in radiation shielding because of its cost and shielding potential. Lead is used frequently in the fields of nuclear medicine, industry and defense industry to protect radiation workers. However, lead is a highly toxic metal and very heavy for personal shielding[9-11]. For this reason, non-toxic and light materials are required for radiation shielding. Polymers are very light weight materials and they have no toxic effect. But they are inadequate and they cannot stop gamma rays because of their low density and low-Z[12,13]. However the mixture of high atomic number with polymer would improve the shielding properties. Tungsten is an element with a high atomic number with high density and also tungsten is non-toxic[14,15]. In this paper, we aimed to produce light, formable, thin and non-toxic shielding material using mixture of polymer with tungsten. Micro sized tungsten powder and ethylene vinyl acetate (EVA) have been chosen to produce new shielding material.

2 Experimental Method

2.1 Materials

The composite discs which are used to determine the efficiency of radiation shielding have been made from ethylene vinyl acetate (EVA) and micro sized tungsten powder. EVA (density: 0.94 g/cm^3) has contents of 19% vinyl acetate which was supplied by DuPont. Micro sized tungsten powder (density= 19.3 g/cm^3) was supplied by Sigma-Aldrich.

2.2 Preparation of the EVA-Tungsten composite discs

The new shielding material was prepared by EVA and micro sized tungsten powder. It was mixed in

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*Corresponding author: (E-mail: ftmyurt@gmail.com)

15 mL in a DSM Xplore Micro compounder device. The proportions of the tungsten powder in the composite were 50%, 60% and 70% by weight, respectively. The mixing process was carried out at a temperature of 120 °C and at a rate of 120 rpm for two minutes. After the mixing process, the melted mixture was cut for the pallets and it determined the density of tungsten in the mixture. Samples were extruded at a temperature of 120 °C. Thus 5 cm in a diameter and 1 and 2 mm thick discs have been obtained from the sample. The W–EVA composites list whose contents on different *W* rates are shown in Table 1 with their codes.

2.3 Mechanical tests

Shore-D test was applied to discs to determine the elasticity of discs with a LX-D Analog Shoremetre at the Department of Mechanical Engineering of the DokuzEylul University.

2.4 Test of homogeneity

After mechanical tests, the discs were sent to the Advanced Technology Education, Research and Application Center of the Mersin University. The homogeneity of the samples was analyzed with a scanning electron microscope (SEM).

2.5 Use of the EVA-Tungsten composite discs in radiation shielding

1 and 2 mm of the thickness composite discs D1, D2 and D3, 1mm of the thick pure EVA disc and a lead disc shave have been located in front of Geiger-Muller (GM) detector window and sodium iodide detector [NaI(Tl)] to determine the shielding efficiency of these discs. Also, the discs which were located at distances of 2, 6 and 10 cm from the detector were exposed to Cs-137point source and I-131 source. Each disc was exposed to radiation sources for 300 sec and this process was repeated five times. Thus countings were obtained when discs were used in both detectors. Same radiation sources were counted without discs for 300 sec. The obtained countings when discs were used were compared with the countings without the use of the shielding material and lead discs.

Table 1 – Codes of EVA–WC composites by percent contained

Composite	W (%)	EVA (%)
D1	50	50
D2	60	40
D3	70	30
EVA	0	100

3 Results and Discussion

3.1 Results of the mechanical testing

There is an inverse relation between hardness and machinability. Numeric values of the test are shown in Table 2, the values of Shore hardness are low (<40). Thus, it is shown that the material has properties as elasticity and easy shapeable.

3.2 Results of the test of homogeneity

According to the scanning electron microscope (SEM) images (Fig. 1), each sample that includes tungsten powder at the proportions of 50%, 60% and 70% by weight are homogenous. SEM analysis showed that tungsten powder spreads homogeneously in the polymer. In the case of the above, with the 70% proportion of tungsten powder, it is very difficult to prepare homogenous material.

3.3 Shielding potential of the EVA-Tungsten composite discs

Shielding efficiencies of discs have been calculated as follows equation for both GM and NaI(Tl) counters:

$$100\text{-}\left(100\times\frac{1}{1_0}\right)=\mathit{Shielding\ Efficiency}(\%)$$

where

I=Dose rate with shielding material

I_0=Unshielded dose rate

The shielding of the EVA-Tungsten composite discs were determined when they were compared with countings with the use of the shielding material and with countings without the use of shielding material. Firstly, 1 mm thick composite discs were exposed to Cs-137 (5 µCi, 662 keV) point source. According to the obtained counts of the in GM detector, a 1mm thick disc D1, D2, D3 and their shielding potentials are relatively 89,98±0,28 , 92,00±0,37 , 92,25±0,29% respectively in Fig. 2. When 2 mm thick composite disc was exposed to Cs-137, minimum transmittance was observed as 8%at the D3 that included tungsten powder 70%and maximum transmittance was 10% at the D1 at all distances. When Cs-137 point source was used, the tungsten-polymer composite efficiency was higher than lead efficiency in 1 and 2 mm thick

Table 2 – Shore-D hardness test results of EVA-W composites

Composite Disc	Shore-D test
EVA	27
D1	29
D2	31
D3	32

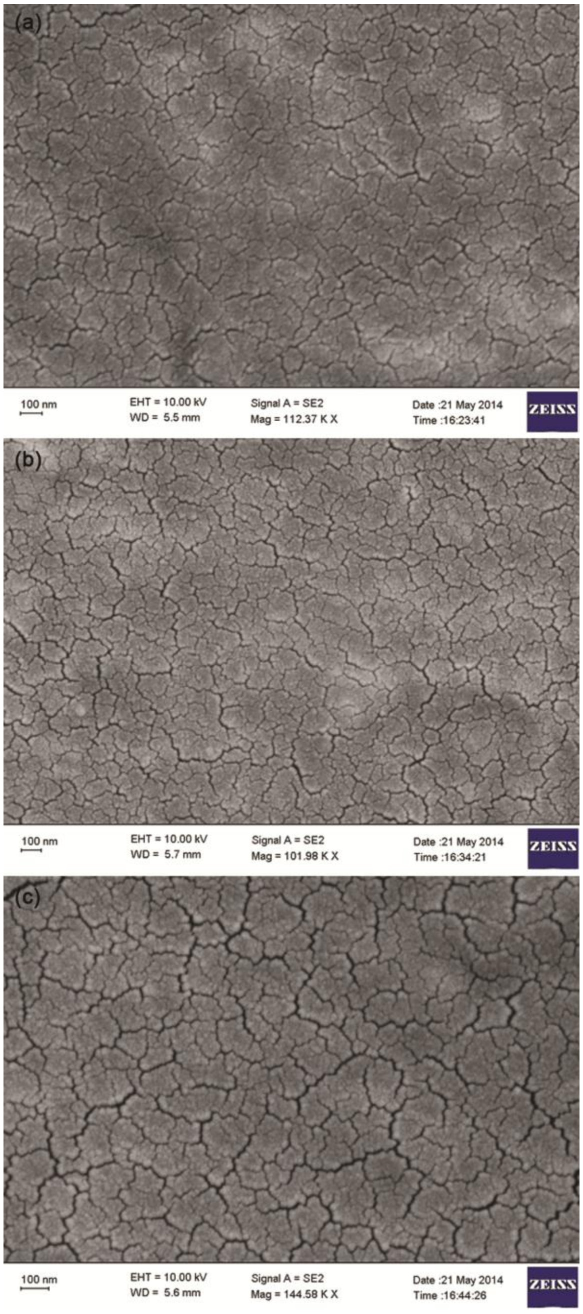

Fig. 1 – SEM micrographs of composites (a) D1, (b) D2 and (c) D3

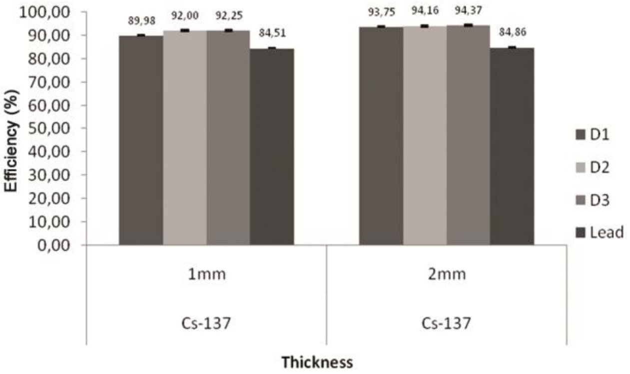

Fig. 2 – Change of efficiency of composite and lead discs for Cs-137 depending to distance (1mm and 2 mm)

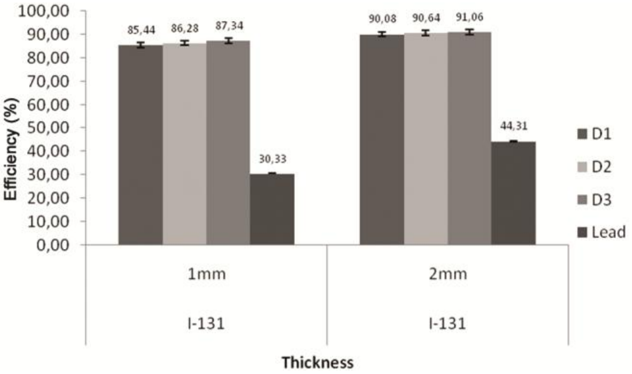

Fig. 3 – Change of efficiency of composite and lead discs for I-131depending to distance (1mm and 2 mm)

(Fig. 2).The shielding efficiencies were quite close to each other. Nevertheless the efficiencies of the composite material were better than lead. Also, the results were similar with the use of the NaI (Tl) detector. When I-131 (5 µCi, 364 keV) was used as gamma source, the results were summarized in Fig. 3. According to the obtained countings in GM detector, the shielding efficiencies of D1, D2, D3 discs (thick 1 mm) were determined to be 85.44±0.07 , 86.28±1.18 , 87.34±1.27%, respectively. 2 mm thick discs showed similar results as 1 mm thick discs. The absorbed radiation yield of metal-polymer composite was better than lead's when I-131 sources were used. For the NaI (Tl) detector, the results showed similarity with the GM detector. On the contrary, EVA the polymer shielding efficiency was obtained as 2.5±0.05 for Cs-137 and as 3.9±0.50% for I-131 sources. A new radiation shielding composite material showed the best efficiency against Cs-137 point source in both 1 and 2 mm thick. For every distance and source, the shielding efficiencies of all the composite discs showed no big difference. Hence it is observed that the tungsten-EVA composite is a more effective shield for the source than lead. Although Cs-137 has higher gamma energy when compared with Cs-137 (E_{γ}= 662 keV) and I-131 (E_{γ}= 364 keV) sources, it was determined that the shielding efficiency was better for the Cs-137 source. So, it shows a weakness against low-energy gamma rays because of secondary radiation. In the low-energy gamma rays, tungsten is susceptible to secondary radiation[16].

Shielding potentials of discs including 70% and 60% tungsten powder are similar. For this reason, we can choose a new shielding material that includes 60% tungsten powder by weight because of cost and lightness. In this study, Yue *et al.*[17] had obtained new shielding materials including SEBS co-polymer with tungsten instead of lead and used Monte Carlo method. They had determined the efficiency of shielding by using 0.3 between 2.7 cm thick materials against 9-12 MeV at the energy range. According to results, they had decide that a new shielding material is more effective than lead against electron shielding and Bremsstrahlung[17].Guetersloh *et al.*[18] had used Monte Carlo method in order to simulate the efficiency of the shielding of polyethylene in cosmic rays' environment. Although polyethylene is not a long-living material, polyethylene showed effective shielding effect against cosmic radiation[18]. Kim *et al.*[19] had studied barium compounds for the shielding effectiveness in medical radiation. They had produced six types of shielding material by combining tungsten, molybdenum, rubber and silicone with barium sulfate. In this study, these materials were exposed to X-rays and the materials had been determined as 0.3 mm lead equivalents. According to results, they suggested that barium compounds could be used instead of lead[19]. Soylu *et al.*[20] had studied the efficiency of tungsten carbide doped polymer composites against gamma ray shielding. In this study, composite discs including tungsten carbide powder at the proportions of 50%, 60% and 70% had been produced and exposed to various gamma sources. According to the results, composite shielding materials had showed better shielding efficiency in middle and high gamma energies than low gamma energies[20]. Shore-D test proved that the new composite material is elastic and that it is characterized by machinability. Thus, this composite material is wearable in the field of nuclear applications like nuclear medicine. Also the composite material is approximately 70% lighter than lead when used at the same size and with thick discs. Also the composite material is non- toxic. Actually it is very important for people and the environment. In this way, this shielding material could be used as personal shielding equipment.

4 Conclusions

Metal-polymer (W-EVA) composite could be candidate for the use of gamma ray shielding applications. This material has better shielding efficiency against high-energy gamma rays like Cs-137 and I-131 than lead. In conclusion, the obtained composite is elastic, soft and easily shapeable. Moreover, it is non-toxic and lighter than lead. For this reason, the material might be chosen for gamma shielding equipment in commercial utilization.

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