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ORIGINAL PAPER

Gamma-ray-shielding properties of composite materials made of recycled sport footwear

Z. Parlar[1] · A. Abdlhamed[2] · İ. Akkurt[2]

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Abstract
Radiation has been one of the realities in our life. Even though it exists naturally in the universe, there are additional forms, which we use in our daily life. As it is used in many different fields, radiation shielding becomes vital nowadays, and thus the main purpose of this study is to evaluate the characteristics and performance of composite materials obtained by recycled sport footwear. Jute fibre was used to obtain composite material in different compositions. The prepared materials exposed by gamma sources ^{60}Co and ^{137}Cs in order to test their shielding capabilities. It can be concluded that recycled rubber is suitable to use as radiation protection material with appropriate additives.

Keywords Composite materials · Radiation protection · Radiation shielding · Recycling · Rubber

Introduction

Radiation is a reality of our life as it has been existed since the creation of the universe due to the long lifetime of radionucleus. There are many studies in the literature to determine radiation levels of natural materials (Akkurt et al. 2015a; Mavi and Akkurt 2015). Besides the natural radiation, artificial radiation becomes important for the development of technology. Even though several applications use radiation, its hazardous effects require special care. It is important to determine the extent or level of radiation (Tekin et al. 2018). There are three basic rules in order to be protected from radiation. These are time, distance, and shielding where the latter is the most important (Akkurt et al. 2015b; Özavci and Çetin 2016). To shield a gamma ray, the linear attenuation coefficient μ (cm^{-1}) should be known. The linear attenuation coefficient μ (cm^{-1}) is defined as the probability of radiation interacting with the material per unit path length (Woods 1982). For radiation shielding, many different types of materials developed and tested which include biological materials, elements, compound, and some building materials (Chitralekha et al. 2005; Baltas et al. 2007; Akkurt 2009; Akkurt et al. 2006). To reduce the hazardous effect of radiation, the selection of suitable shielding material is crucially important. Traditional radiation-shielding materials such as lead and mercury are not very suitable due to their high cost, high density, and adverse effects on the environment. Polymer materials are very attractive as shielding material due to their low weight and low cost (Harish et al. 2009; Mann et al. 2015; Sayyed 2016; Mirji and Lobo 2017). To improve the shielding properties of polymer materials, some natural fibres such as basalt, bamboo, and jute can also be used (Abdo et al. 2003; Li et al. 2017).

Natural resources have been decreasing since the world's population has been increasing. The rapid fashion trends and marketing strategies result in an increase in the consumption of products. Used shoes are one of the most common waste products that can be recycled. Shoes are very complex products which consist of 40 different materials like leathers, rubber, polymers (Lee and Rahimifard 2012). However, the sole is usually made of rubber, PVC, and PU which makes it easier to shred and use in granulated size. Since purification of these materials from each other is not feasible with today's technology, they should be used as homogenised composite structure. In a previous study, the sound insulation properties of composite materials prepared by the granules soles were investigated by Yıldız et al. (2017). In this study, to reduce fuel oil consumption, composite panel for radioactive shielding was prepared by recycling used shoes. For this purpose, linear attenuation coefficients of

Editorial responsibility: İskender Akkurt.

✉ Z. Parlar
parlarze@itu.edu.tr

1 Istanbul Technical University, Istanbul, Turkey

2 Suleyman Demirel University, Isparta, Turkey

four different composite samples have been studied for different gamma energies (662, 1173, and 1332 keV).

Materials and methods

In this study, composite materials were prepared using granules obtained from waste shoe soles. Different types of used shoes were collected. First, sole of each shoe was separated by manual sorting. During manual sorting, the special care was taken to not to leave any leather or metal residues. All soles were granulated by using shredder with 10-mm mash diameter. At the end homogeneous mixture of rubber granules, 8–10-mm-diameter granules were obtained. Polyurethane binder, A391, supplied by DUAYEN was used to obtain homogeneous composite panels. Polyurethane rubber binder is preferred to gain rigid and flexible structure. During moulding process, 3 bar pressure was applied by using hydraulic press. Then, for curing it was taken to reheating furnace at 150 °C in 15 min as shown in Fig. 1.

In addition, granules were mixed with 8–10-mm-long jute fibres to investigate the effect of different material compositions. The detailed composition of materials is given in Table 1. Binder amount was kept constant for all material compositions to investigate the effect of jute fibre. Amount of jute fibre was calculated in terms of mass percentage. The reference, R, only includes sole granules. Based on the amount of jute in the composition, jute samples are named, for 10% jute R90-J10, for 20% jute R80-J20, and for 30% jute R70-J30. Three specimens were prepared for each experiment.

Prepared materials have been tested against gamma ray in order to determine radiation-shielding properties. The measurements have been noted at Gamma spectroscopy Laboratory in Suleyman Demirel University (Akkurt et al. 2014). The spectrometer contains 3″×3″ in size NaI(Tl) detector connected to multichannel analyser. The schematic view of experimental design is displayed in Fig. 2. One collimator with a lead block of 5 cm radius and 2 cm width, and a central hole of 0.3 cm radius is used. This system is controlled by a personal computer, and the control of acquisition parameters and analysis of the collected spectra are carried out using MAESTRO-32 (version6.06) software package. To investigate shielding properties of composite, the linear attenuation coefficients of four different samples have been measured at gamma ray energies of 662 keV obtained from a ^{137}Cs source, and 1173 and 1332 keV obtained from a ^{60}Co source.

Table 1 Details of developed materials

No.	Sample	Rubber %	Jute %	Thickness (cm)
1	R100	100	–	2
2	R90-J10	90	10	2.1
3	R80-J20	80	20	2.1
4	R70-J30	70	30	2.2

The linear attenuation coefficients (μ) have been evaluated comparing N and N_0, which are the measured count rates in detector, respectively, with and without the absorber of thickness by the following equation:

$$N = N_0 e^{-\mu x} \tag{1}$$

where N and N_0 are transmitted and incident gamma ray intensities recorded by detector, respectively, and x is the material thickness.

The transmitted (N) and incident (N_0) gamma ray intensities gamma rays are obtained from the energy spectrum as shown in Fig. 3.

Fig. 1 Cutting and compressing devices

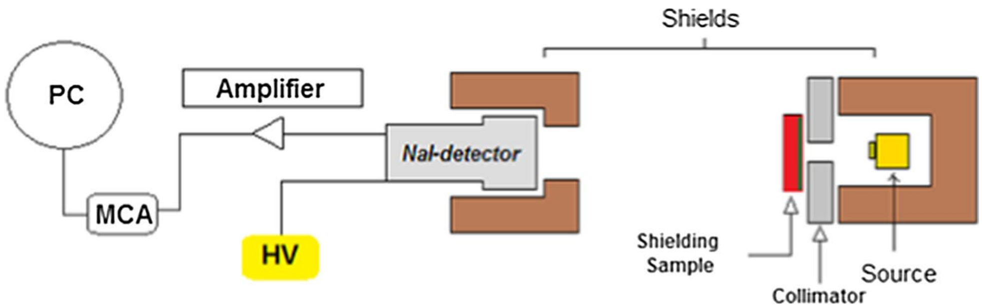

Fig. 2 Schematic view of experimental setup

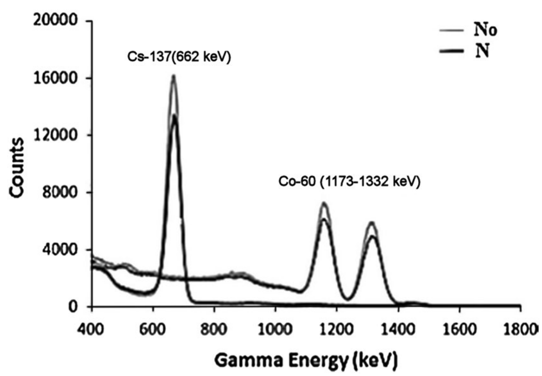

Fig. 3 Intensity of gamma rays with and without materials for ^{60}Co and ^{137}Cs sources

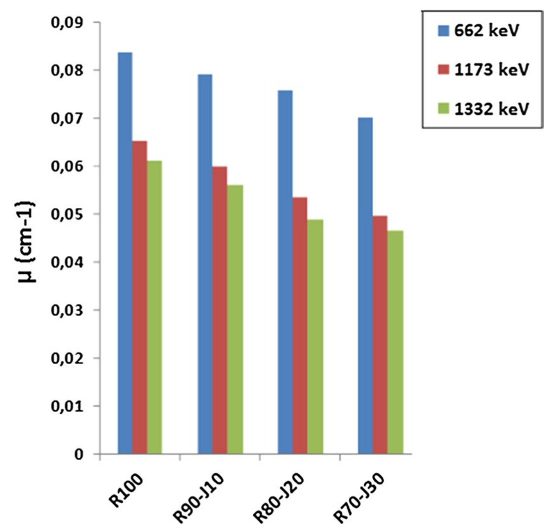

Fig. 4 Linear attenuation coefficients of all materials

Results and discussion

The linear attenuation coefficients (μ, cm^{-1}) were measured for rubber containing jute composite in different rates (0, 10, 20, and 30%), and results are given in Fig. 4.

The linear attenuation coefficients as a function of gamma ray energies were given in Fig. 5. It can be seen from this figure that the linear attenuation coefficients (μ, cm^{-1}) decreased with the increasing gamma ray energies. This is due to the different interaction mechanism of gamma rays with the matter depending on energies, and it was in good agreement with the previous measurements (Davraz et al. 2017; Mavi and Akkurt 2015). In order to see the effect of jute rate in composite, the results are given in Fig. 6 as a function of jute rate for three different energies and four different rates (0, 10, 20, 30%). It can be seen from this figure that a significant decrease has been obtained for the linear attenuation coefficients (μ, cm^{-1}). With increasing rubber rate, the linear attenuation coefficients (μ, cm^{-1}) are also increased (Fig. 7).

The desired properties such as light weight, easy manufacturing, and effective radiation reduction increase the interest in polymer materials. However, the chain breaking in many polymer materials exposed to radiation leads to degradation. For this reason, it is possible to obtain more efficient polymer materials for radiation shielding by selecting the appropriate additive.

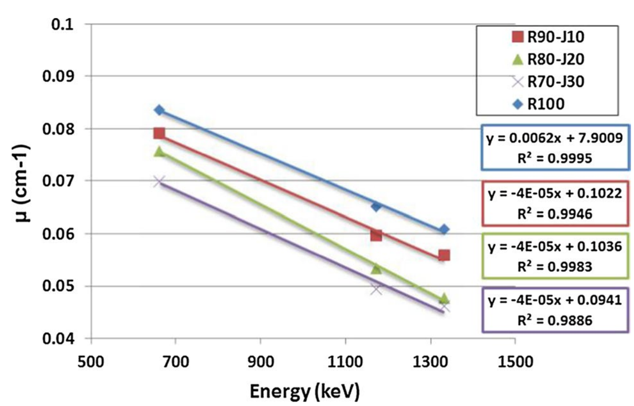

Fig. 5 Linear attenuation coefficients as a function of gamma energy

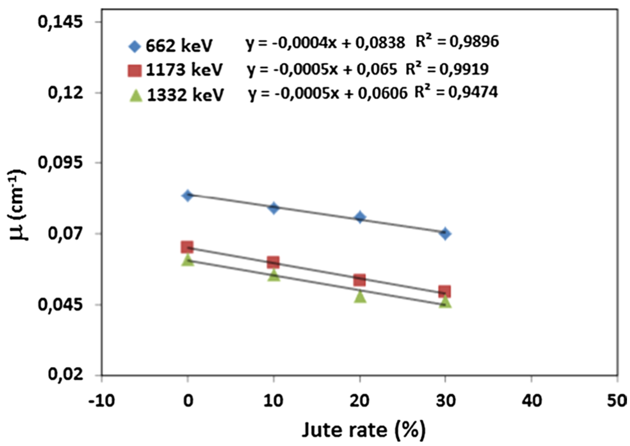

Fig. 6 Linear attenuation coefficients as a function of jute rate in composite

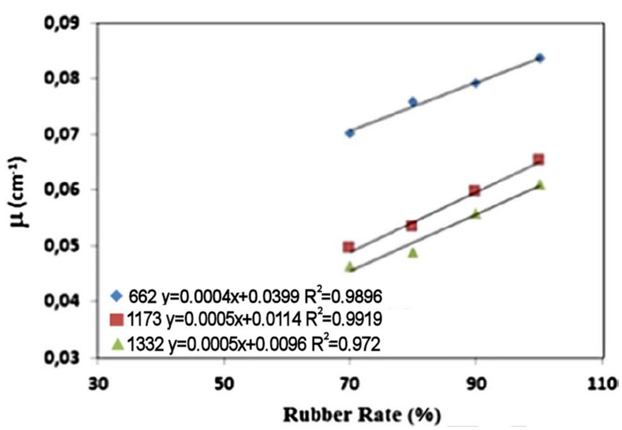

Fig. 7 Linear attenuation coefficients as a function of rubber rate in composite

Conclusion

In the recent years, many researchers have investigated better materials for radiation shielding. For this purpose, composite materials consisting of rubber as the main material and jute as the additive were tested for radiation shielding. The samples manufactured were tested against gamma ray of 662, 1173, and 1332 keV energies. The measurements showed that the jute do not have a significant effect to shield gamma rays when added to rubber. With the increasing jute rate in the composite material, the linear attenuation coefficient is decreased. This leads that rubber without jute is more useful for shielding against gamma rays.

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References

Abdo ES, Ali MAM, Ismail MR (2003) Natural fiber high-density polyethylene and lead oxide composites for radiation shielding. Radiat Phys Chem 66:185–195

Akkurt I (2009) Effective atomic and electron numbers of some steels at different energies. Ann Nucl Energy 36(11–12):1702–1705. https://doi.org/10.1016/j.anucene.2009.09.005

Akkurt I, Basyigit C, Kilincarslan S, Mavi B, Akkurt A (2006) Radiation shielding of concretes containing different aggregates. Cement Concr Compos 28(2):153–157. https://doi.org/10.1016/j.cemconcomp.2005.09.006

Akkurt I, Gunoglu K, Arda SS (2014) Detection efficiency of NaI(Tl) detector in 511–1332 keV energy range. Sci Technol Nucl Install. https://doi.org/10.1155/2014/186798

Akkurt I, Uyanik NA, Günoğlu K (2015a) Radiation dose estimation: an in vitro measurement for Isparta-Turkey. IJCESEN 1(1):1–4. https://doi.org/10.22399/ijcesen.194376

Akkurt I, Emikönel S, Akarslan F, Günoglu K, Kilinçarslan S, Üncü IS (2015b) Barite effect on radiation shielding properties of cotton-polyester fabric. Acta Phys Pol A 128:53. https://doi.org/10.12693/APhysPolA.128.B-53

Baltas H, Celik S, Cevik U, Yanmaz E (2007) Measurement of mass attenuation coefficients and effective atomic numbers for MgB2 super conductor using X-ray energies. Radiat Meas 42:55–60

Chitralekha Kerur BR, Lagare MT, Nathuram R, Sharma DN (2005) Mass attenuation coefficients of saccharides for low-energy X-rays. Radiat Phys Chem 72:1–5

Davraz M, Pehlivanoglu HE, Kilinçarslan S, Akkurt I (2017) Determination of radiation shielding of concrete produced from portland cement with boron additives. Acta Phys Pol A 132:702. https://doi.org/10.12693/APhysPolA.132.702

Harish V, Nagaiah N, Prabhu TN, Varughese KT (2009) Preparation and characterization of lead monoxide filled unsaturated polyester based polymer composites for gamma radiation shielding applications. J Appl Polym Sci 112:1503–1508

Lee MJ, Rahimifard S (2012) An air-based automated material recycling system for postconsumer footwear products. Conserv Recycl 69:90–99. https://doi.org/10.1016/j.resconrec.2012.09.008

Li R, Gu Y, Zhang G, Yang Z, Li M, Zhang Z (2017) Radiation shielding property of structural polymer composite: continuous basalt fiber reinforced epoxy matrix composite containing erbium oxide. Compos Sci Technol 143:67–74

Mann KS, Rani A, Heer MS (2015) Shielding behaviors of some polymer and plastic materials for gamma-rays. Radiat Phys Chem 106:247–254

Mavi B, Akkurt I (2015) Investigation of radiation absorption properties of some India granites. Acta Phys Pol A 128:370–371. https://doi.org/10.12693/APhysPolA.128.B-370

Mirji R, Lobo B (2017) Computation of the mass attenuation coefficient of polymeric materials at specific gamma photon energies. Radiat Phys Chem 135:32–44

Özavci S, Çetin B (2016) Determination of radiation attenuation coefficients in concretes containing different wastes. Acta Phys Pol A 130:316. https://doi.org/10.12693/APhysPolA.130.316

Sayyed MI (2016) Investigation of shielding parameters for smart polymers. Chin J Phys 54:408–415

Tekin HO, Cavli B, Altunsoy EE, Manici T, Ozturk C, Karakas HM (2018) An investigation on radiation protection and shielding properties of 16 slice computed tomography (CT) facilities. IJCESEN 4–2:37–40

Woods J (1982) Computational methods in reactor shielding. Pergamon, New York

Yıldız F, Parlar AG, Parlar Z, Bakkal M (2017) Sound panel application by using recycled footwear tread. Acta Phys Pol A 132(3-II):936–940. https://doi.org/10.12693/aphyspola.132.936