 Volume 7 Issue 10, 2021
DOI: 10.6919/ICJE.202110_7(10).0068

Preparation and Properties of a Composite Material for γ-ray Protection

Miaomiao Fan, Xianghong Ren, Yizhi Zeng, Yue Shen

Xi'an Gaoxin Research Institute, Xi'an 710025, China.

Abstract

In view of the demand of a certain type of personal radiation protection products for new flexible lead-free radiation protection materials, a new flexible lead-free γ-ray shielding composite material was prepared by using tungsten (W) powder, bismuth oxide (Bi_2O_3) powder and natural rubber (NR) as basic raw materials. The preparation process of the material and the influencing factors of γ-ray shielding performance, section morphology, mechanical properties, permeability and heat transfer performance were studied. In addition, the differences of X-ray shielding performance, cross-sectional morphology, mechanical properties, air permeability and heat transfer performance between the newly developed lead-free radiation protection materials and W/NR composites, Bi_2O_3/NR composites and PbO/NR composites with the same filler mass fraction were studied and compared, and the influencing factors of performance differences were analyzed.

Keywords

Nuclear Radiation; Protection; Gamma Rays; Neutrons.

1. Introduction

The most powerful, traditional choice, to select the appropriate thickness of concrete or lead plate to effectively block. In fact, any substance can block the rays, which is different from the blocking ability. Its blocking ability mainly depends on two aspects: one is the atomic number, and the other is the density of the substance. The traditional shielding materials such as concrete and lead plate are of high density. The atomic number of lead is 82, which is a substance with high atomic number in nature. Therefore, the ability to block gamma rays is strong, and it is also often used. But later, because lead is toxic, it is not suitable to continue to be used as shielding materials. According to GJB3176, the effective attenuation materials should be evenly distributed and contain elements with high atomic number. The elements with high atomic number in the same cycle near lead include cesium, barium, lanthanide elements, tantalum, tungsten, rhenium, osmium, iridium, platinum, gold, mercury, thallium, bismuth, polonium, adenum, radon. Cesium is toxic, and barium is active in chemical properties. Barium has never been found in nature which is not a necessary element for the human body, but a toxic element. Lanthanum elements..., gold, silver, platinum, ruthenium, palladium, osmium and iridium belong to precious metals [1]. The toxicity of thallium to human body exceeds that of lead and mercury, which is similar to arsenic. Nonessential trace elements in human body can be enriched by drinking water, food and breathing. Polonium element is radioactive, itself can radiate a ray [2]. Therefore, in the selection of materials, the selected metal elements are tungsten, rhenium, osmium, lead and bismuth [3]. The osmium metal element is very stable in the air, but it is easy to oxidize in the form of powder. At room temperature, it is easy to react with oxygen to form osmium oxide (OSO_2) [4].

γ-ray is also called gamma ray. Short wavelength, 10^{-8}cm below, often in the form of light speed of 3 * 10^5km/s electromagnetic wave or photon flow movement, without charge, when the nucleus from high energy instability, without changing the composition of the case into a stable or stable low energy state, often emit gamma rays [5]. In the process of radioactive decay, γ rays are often released together with α and βrays. No charge, no mass, weak ionization, but strong penetration. Natural nuclide 40 K and artificial nuclide 239 plutonium and 137 cesium are the main sources of γ-rays in the environment. As potential external hazards, they can cause serious harm even if they are quite round away from the γ-ray source. γ-ray can easily penetrate the human body, which is extremely harmful to the human body. Therefore, in order to reduce or prevent the harm of γ-ray to the human body, in most cases, γ-ray should be shielded and protected [6].

2. Preparation of test samples

2.1 Blending Process of Natural Rubber and Powder

Natural rubber and powder blending can be called mixing or refining rubber. Mixing process is to say that a variety of agents are uniformly dispersed in the rubber, in order to form a rubber as a medium or rubber and some can dissolve with its components (agents, other polymers) mixture as a medium, and rubber can not dissolve with the agents (such as powder fillers, zinc oxide, pigments, etc.) as the dispersed phase of the multiphase dispersion system.

2.2 The specific ratio of W / Bi / Bi_2O_3 to NR composites

Table 1. Basic Formula of Natural Rubber (ASTM) [56]

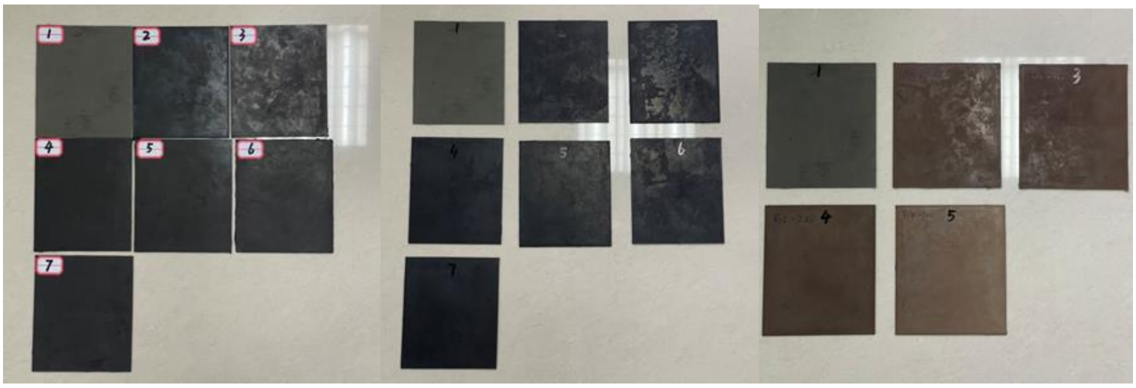
Name of raw materials	NBS Standard Sample Number	Quality
NR	-	100
ZnO	370	5
stearic acid	372	2
antideteriorantPBN	377	1
acceleratorDM	373	1
sulphur	371	2.5

Table 2. Component ratios of different samples of γ-ray-composite shielding materials

numbering	W	Bi	Bi_2O_3	NR	ZnO	sulphr	stearic acid	Captax M
1	0	0	0	100	6	3.5	0.5	0.5
2	100	50	50	100	6	3.5	0.5	0.5
3	200	100	100	100	6	3.5	0.5	0.5
4	300	200	200	100	6	3.5	0.5	0.5
5	400	247	300	100	6	3.5	0.5	0.5
6	480	300	400	100	6	3.5	0.5	0.5
7	600	400	-	100	6	3.5	0.5	0.5

2.3 The specific ratio of W / Bi / Bi_2O_3 to NR composites

The plate vulcanizer was started and preheated to 150 °C. After the temperature was stable, the 1 mm and 2 mm molds were taken out, respectively, and the demoulding agent was coated. The pre-weighed NR and W / Bi / Bi_2O_3 blend materials were placed in batches in the mold. The mold was pressurized at 15 MPa and heated to 150 °C for about 15 min. The solidified samples were taken out and cooled. The samples are 1mm, 2mm thick flakes, smooth surface, non-foam rubber materials. As shown in Fig. 1, a, b and c are W / NR composite, Bi / NR composite and Bi_2O_3 / NR composite, respectively.



a b c

Fig. 1 a, b and c are W / NR composite, Bi / NR composite and Bi_2O_3 / NR composite, respectively.

3. γ-ray shielding performance test

When γ-ray interacts with matter, when the incident energy is not too high, there are mainly three ways : photoelectric effect, Compton effect and electronic effect. The linear weakening coefficient of γ-ray interaction with matter is:

Material for a single element

$$\mu = \frac{6.023 \times 10^{23}}{A} \rho b$$

ρ is the density of matter (g / cm3), is the molar mass of its constituent elements (g), is the total cross section (cm2) of the atomic effect on γ-ray, that is, the sum of the photoelectric effect of atoms, Compton effect, and electron pair effect cross sections.

The W / NR composites with mass fractions of 100, 200, 300, 400, 480 and 600 were tested. The Bi / NR composites with mass fractions of 50, 100, 200, 247, 300 and 400 were tested. The Bi2O3 / NR composites with mass fractions of 50, 100, 200, 300 and 400 were irradiated by 185 keV energy. The γ-ray shielding properties of three different materials were tested. Mainly according to its mass gram weight and metal content gram weight to analyze its shielding performance results. As shown in the figure.

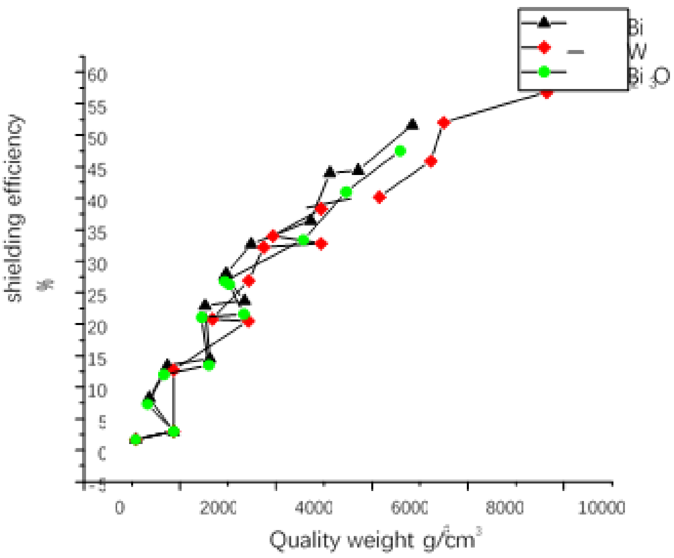


Figure 2. Total mass weight - shielding efficiency of Bi, Bi_2O_3, W at 185 keV

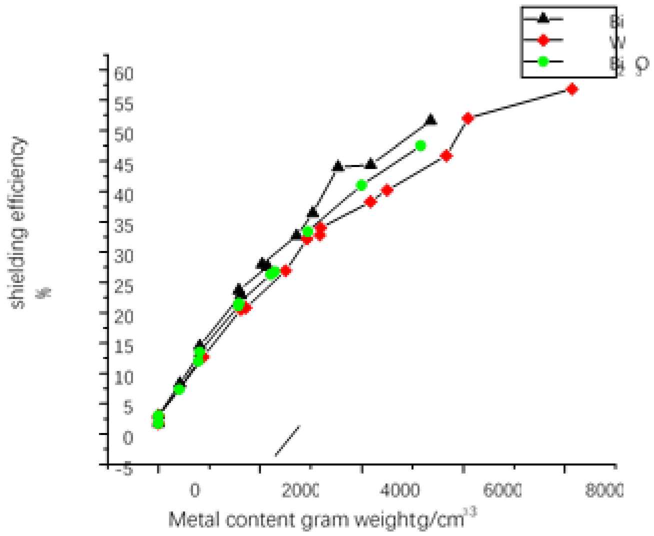


Figure 3. Total mass weight - shielding efficiency of Bi, Bi_2O_3, W at 185 keV

It can be seen from the figure that when the mass fraction of functional materials is 0, the measured shielding rate is about 2 %, that is to say, pure natural rubber has a certain shielding effect on γ-ray, but the influence is small. The shielding performance of Bi / NR composites is obviously better than that of Bi2O3 / NR composites and W / NR composites. From the practical application, the price of bismuth powder is also lower than that of tungsten powder and bismuth oxide powder, so it is a better choice to select bismuth powder as shielding filler.

4. Conclusion

On the basis of considering economy, the selection of this new type of protective material comprehensively compares the blending of bismuth powder, tungsten powder and bismuth oxide powder with natural rubber respectively, and tests its shielding constant energy. Simple judgment shows that metal bismuth powder as a filler for shielding γ-ray can improve the comprehensive performance of the protective material and the shielding efficiency. Then, according to the basic performance of the rubber, other materials can be added to enhance the flame retardancy, strength, soft comfort and other properties of the composite material.

Acknowledgments

Natural Science Foundation.

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