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Assessment on Gamma Attenuation Behavior of W–VC–C and W–VC–TiC–C Composites for Co-60 Radioisotope

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In this study, tungsten–vanadium carbide–graphite (W–VC–C) and tungsten–vanadium carbide–titanium carbide–graphite composite (W–VC–TiC–C) materials were investigated against Co-60 gamma radioisotope. The composite materials which are used in advanced technological studies and high temperature applications in many various fields especially in the areas of fission and fusion armor materials were produced by mechanical alloying method as in two groups. One of them include 93% tungsten (W), 6% vanadium carbide (VC) and 1% graphite (C) also which has three different alloying times (6–12–24 h). Other group of the samples was composed of 91% tungsten, 6% vanadium carbide (VC), 2% titanium carbide (TiC) and 1% graphite (C) also which has three different alloying times (6–12–24 h) and sintered at 1750 °C. Co-60 gamma radioisotope source and gamma transmission technique were used in the experiments to investigate the properties of the composite materials. The mass attenuation coefficients of the samples were determined by using experimental results and theoretical mass attenuation coefficients were calculated from XCOM computer code. It can be concluded that increasing the tungsten ratio causes higher mass attenuation coefficient and the composite materials have provided us benefits better than lead for radiation gamma shielding.

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PACS/topics: attenuation coefficient, Co-60, radiation shielding material, transmission technique, W–VC–C–TiC composite

1. Introduction

Tungsten (W) based materials are known as refractory materials [1–3]. Adding carbides such as VC and TiC into W matrix is one of the most effective way to grain growth mechanism [4–7]. They have excellent properties such as high melting point, high modules, high resistance of thermal shock, and high temperature strength [1]. Tungsten based materials are important for nuclear applications, especially fusion reactor applications [8]. In addition, tungsten based composites have comparatively high gamma radiation shielding properties [9].

Vanadium and titanium alloys are low activation materials in the nature of things and so have many advantageous properties. Vanadium alloys have more than one advantage particularly in the shielding materials. They have been identified as a promising candidate material for fusion first-wall blanket applications in the fusion systems because of their high thermal stress factor, low activation properties and resistance to irradiation damage [10–15]. Titanium carbide is an extremely high heat resistance ceramic material which has high melting point, low density, high hardness, superior chemical and thermal stabilities [11].

European Union has released a directive in 2002 and recast in 2011 [8] about restriction of the use of some hazardous substances (RoHS) which includes lead (Pb) in electrical and electronic equipment. It has been also reported that there is no economic substitution material instead of lead in these devices and systems for nuclear applications [9]. It is known that the lead is common used radiation shielding material in nuclear applications and devices because of its good shielding properties and low cost. On the other hand, the lead is toxic material, so, there are some studies to get alternative materials which could be used in radiation shielding applications instead of the lead. Steels, tungsten alloys, concrete, aluminum alloys are some of these candidate material [10–18].

In this study tungsten–titanium vanadium composites were produced by mechanical alloying method and investigated against gamma radiation sources. The microstructural and mechanical properties of the composites were investigated. In addition, the gamma attenuation properties were reviewed and compared with the lead and some other candidate materials. The possible uses of the tungsten–titanium vanadium composites instead of lead in radiation shielding applications were evaluated by the view of RoHS Directive.

2. Experimental

Gamma transmission technique was used for observing the behavior of the material that is shown in Fig. 1. In this technique based on gamma rays which are emitted from the source are detected by the detector with/without absorber material between the source and detector [19, 20].

In the experiments Co-60 gamma-emitting radioisotope was used as source. Co-60 has two gamma peaks at 1.17 and 1.33 MeV (1.25 MeV mean) and half-life of

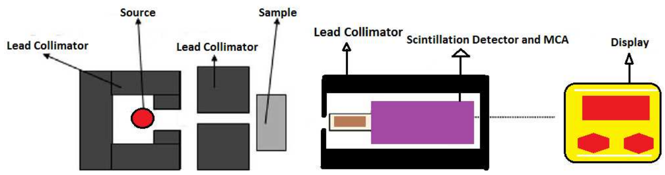

Fig. 1. The schematic view of the gamma transmission technique.

Co-60 is 5.27 years [21–24]. A scintillation detector (Canberra Model (802-2X2) NaI) was placed 14 cm far from the source. Both the detector and source were placed in the lead houses (5 cm thick) which have 7 mm holes on the same axis to coincide with other and minimize the scattering effect. The accumulation time was adjusted as 300 s. At first, the source was placed and gamma radiation (I_0) intensity was measured. Finally, for each material gamma intensities (I) were detected at different material thicknesses. To get rational evaluation, relative intensities (I/I_0) were calculated for different thickness values of the samples.

2.1. Materials

Tungsten–vanadium carbide–graphite (W–VC–C) and tungsten–vanadium carbide–titanium carbide–graphite (W–VC–TiC–C) composites were used in the experiments. The composites were produced by mechanical alloying method at different alloying time values in the Particulate Materials Laboratories of Istanbul Technical University. The composition and densities of the studied samples were given in Table I.

TABLE I

The contents [vol.%], alloying time t [h] and density ρ [g/cm^3] of the studied W–VC–C and W–VC–TiC–C composites.

code	W	VC	C	TiC	t	ρ
6V	93	6	1	–	6	16.80
12V	93	6	1	–	12	16.50
24V	93	6	1	–	24	16.46
6VT	91	6	1	2	6	16.21
12VT	91	6	1	2	12	15.56
24VT	91	6	1	2	24	15.44

3. Results and discussion

The material thickness-relative count graphs of the W–VC–C and W–VC–TiC–C composites were carried out for Co-60 gamma radioisotope source. The mechanical alloying time graphs were drawn for the tungsten–vanadium carbide–graphite (W–VC–C) and tungsten–vanadium carbide–titanium carbide–graphite (W–VC–TiC–C) composites against Co-60 gamma source. They were shown in Table II. The graphs were divided into two groups which can help us to evaluate the effects of alloying time and titanium additive on gamma shielding properties of the composites. Figures 2 and 3 show that the alloying time affects the gamma attenuation properties of the samples for Co-60 gamma sources.

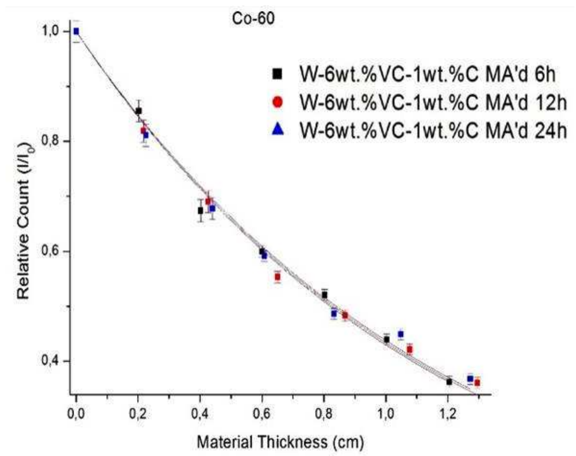

Fig. 2. Gamma attenuation graphs of W–6wt%VC–1wt%C composites against Co-60 gamma radioisotope for different alloying time.

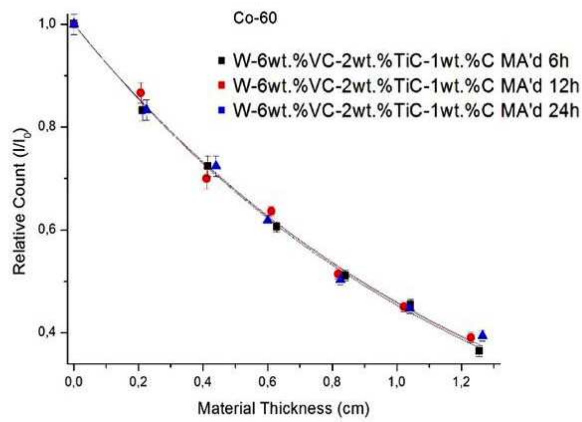

Fig. 3. Gamma attenuation graphs of W–6wt%VC–1wt%C and W–6wt%VC–2wt%TiC–1wt%C composites against Co-60 gamma radioisotope for different alloying time.

Values of the mass attenuation coefficients change alloying time for W–6wt%VC–1wt%C composite materials. It can be said that it is related with density changing of the composites via alloying time. On the other hand, the theoretical mass attenuation coefficients of the samples were determined by using XCOM computer code which was commonly used code in the literature. The experimental and theoretical mass attenuations and difference percentages were given in Table II.

4. Conclusion

The gamma attenuation properties of mechanically alloyed tungsten–vanadium carbide–graphite and tungsten–vanadium carbide–titanium carbide–graphite

TABLE II

The mass attenuation coefficients μ_m [10^{-2} cm^2/g] of the tungsten–vanadium and tungsten–vanadium–titanium composites for Co-60 gamma source.

Material	Exp.	XCOM	Δ [%]
6V	5.024	5.41	7.138
12V	5.045	5.41	6.741
24V	5.012	5.41	7.354
6VT	4.867	5.408	9.997
12VT	5.016	5.408	7.247
24VT	5.032	5.408	6.946

composite materials were investigated against Co-60 gamma radioisotope source. The experimental mass attenuations were close to theoretical ones with the average differences under 10% which come from impurities and production methods. It could be said that W–VC–C composites without TiC have more radiation capabilities than the others for the studied gamma energy. In addition, alloying time has negatively effect on the gamma shielding properties for the all studied W–VC–C and W–VC–TiC–C composites.

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