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Comparison of Radiation Properties of Tungsten and Additive Metal Coatings on 321 Stainless Steel Substrate

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In the present work, the gamma and neutron attenuation behaviors of tungsten, tungsten copper, and tungsten boron-carbide coatings on 321 stainless steel substrate were investigated against Cs-137 and Co-60 gamma radioisotopes and Pu–Be neutron source. The experimental results were compared and evaluated with pure 321 stainless steel to obtain gamma and neutron shielding properties of the coating materials. Tungsten, tungsten copper, and tungsten boron-carbide coatings on 321 stainless steel substrate were fabricated by atmospheric plasma spraying technique. Gamma and neutron transmission technique were used in this study to investigate the radiation behaviors of the coated materials. Linear attenuation coefficients of coated samples were carried out for Pu–Be neutron source. Transmittance values for each specimen were calculated at 0.662 MeV and 1.25 MeV gamma energies. The experimental results were evaluated for radiation shielding properties of the coated samples against gamma and neutron source with pure 321 stainless steel.

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1. Introduction

Tungsten (W) is one of the most important materials for nuclear applications, especially fusion reactors which is selected as armor for the divertor region in ITER and DEMO. Tungsten has many advantages for fusion plasma-facing applications due to the high melting point, low erosion for high energy threshold for sputtering, high thermal conductivity and low swelling [1–3]. Furthermore, Tungsten composite materials are used for high gamma radiation shielding applications because of high density and favorable mechanical properties [4]. On the other hand tungsten has some disadvantages as like poor machinability, recrystallization and potential loss of melt layer during transient events. Bulk tungsten has a higher electrical conductivity for this reason that cause some troubles with eddy currents. In addition there are some difficulties of using tungsten as plasma facing component because of its brittleness, hardness and heaviness [5].

Tungsten coatings are considered as the shielding materials for the plasma facing components in order to improve theirs properties. W-Cu composites have been used for many applications due to high thermal and electrical conductivity of copper as well as high density, high melting point and high erosion resistance of tungsten. There are several techniques to produce coating materials such as VPS (Vacuum plasma spraying), PVD (physical vapor deposition), CVD (chemical vapor deposition) and atmospheric plasma spraying technique (APS). In this present work, W coatings were produced atmospheric plasma spraying technique (APS) which is relatively low cost and high deposition rate [6-7]. On the other hand APS-W coatings have some disadvantages such as being handily oxidized, high porosity and comparing with poor physical and mechanical properties [8].

The aim of this paper investigate behaviors of W, W-Cu and WB_4C coatings on 321 stainless steel substrate against gamma radiation and neutron source. Co-60 and Cs-137 were used as gamma radioisotope sources and evaluated for each specimen. Their neutron attenuation were performed against Pu-Be neutron source. Finally all results were evaluated and compared with each other to determine effect of W, W-Cu and WB_4C coatings with pure 321 stainless steel to obtain gamma shielding properties of coating materials.

2. Experimental and material

2.1. Gamma and neutron transmission technique

Experiments were carried out on the basis of transmission technique which is based on penetrating gamma rays and neutrons through the materials [9]. The gamma source or neutron source and detector are placed opposite sides of the material which has shown in figure 1. The gamma ray intensity which comes from the gamma and neutron source are counted by the detector. In the beginning of the experiments, background radiation was measured. Then initial radiation intensity I_0 was measured without any material. After that gamma intensities I were measured for all materials of different thickness. Accumulation time was 600 s both for Co-60 and Cs-137 gamma sources. Each measurements

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was repeated minimum five times and average value of gamma intensity was calculated. Relative intensity I/I_0 values performed for all composites materials to get rational evaluation. Thereupon relative intensity-material thickness graphs were drawn. On the other hand, Pu-Be neutron source which has 5 Ci activity, 10^6 n/cm^{2}s neutron flux, 5 MeV average neutron energy and paraffin wax (2.5 cm thick) was used for neutron transmission experiments. PM1401K model, scintillation detector and multi-channel analyzer (MCA) combined system was used to detect gamma rays and He-3 detector for neutron counting.

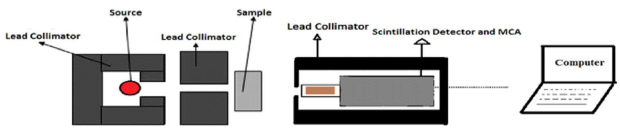

Fig. 1. The schematic view of the transmission technique.

In the experiments Co-60 and Cs-137 gamma radioisotopes were used for gamma source which their half-lives are 5.23 and 30.1 years, respectively [10]. Cs-137 gamma radioisotope has 0.662 MeV gamma energy peak and 7.90 µCi activity. Co-60 gamma source has two energy peaks 1.17 and 1.33 MeV [11] which has 5.79 µCi activity.

In the experiments Canberra Model (802-2X2) NaI Scintillation detector which has 5.5 cm diameter and 14-pin tube was used in the experiments. The detector was placed 4 cm far from the source. Both the detector and gamma radioisotope source are inserted in the lead collimator (5cm thick) which have 7 mm hole on the same axis to see each other and minimize effect of the background radiation and scattering effect.

2.2. Material

Tungsten, tungsten copper and tungsten boron carbide coatings on 321 stainless steel substrate were tested in the experiments. Materials were coded according to number of coating. All coating samples were fabricated with Atmospheric Plasma Technique (APS). The properties of the specimens are shown in Table I.

3. Results and discussion

3.1. Gamma radiation results

Tungsten, tungsten copper and tungsten boron carbide coatings on 321 steel substrate were carried out determination on gamma shielding behaviors for Co-60 and Cs-137 gamma radioisotope sources. Relative count values for all specimens were calculated for both Co-60 and Cs-137 radioisotopes. It can be seen that increasing coating thickness for all samples has improved gamma shielding properties of 321 steel substrate.

Transmittance values of specimens were drawn for Cs-137 and Co-60 gamma radioisotopes according to experimental results. The graphs were divided into three groups which can help us to evaluate and compare with each other the effects of coatings on gamma shielding properties of the composites. Figure 2 shows that comparison of transmittance of the coating samples, it represents a, b and c in the below which are tungsten, tungsten-copper, tungsten boron carbide coatings respectively, against on pure 321 stainless steel substrate for Cs-137 gamma radioisotope.

TABLE I

The properties of W, W–Cu, and W–B_4C coatings on 321 steel substrate. Thickness d [cm]. hickness of coating c [µm], mass m [g], and density ρ [g/cm^3]

Sample	d	c	m	ρ
321 steel	0.1975	—	7.686	7.931
W-30	0.2044	69	7.854	7.965
W-44	0.2066	91	8.014	8.022
W-64	0.2081	106	8.187	8.113
W-Cu_30	0.2096	121	7.863	7.950
W-Cu_44	0.2097	122	7.962	7.977
W-Cu_64	0.2120	145	8.167	8.094
W-B_4C_30	0.2020	45	7.910	8.054
W-B_4C_40	0.2022	47	7.897	8.091
W-B_4C_50	0.2044	69	8.001	8.081

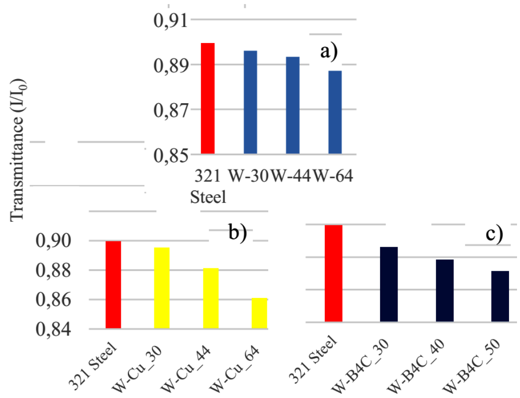

Fig. 2. Transmittance graph of tungsten (a), tungsten copper (b), and tungsten boron-carbide (c) coatings against Cs-137 gamma radioisotope.

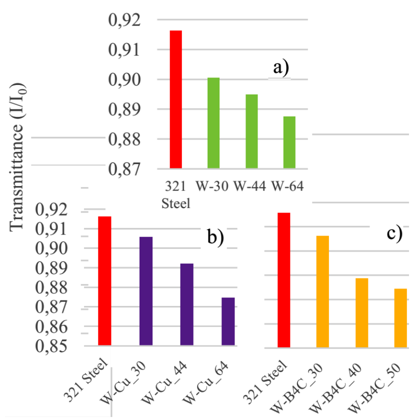

Fig. 3. Transmittance graph of tungsten (a), tungsten copper (b), and tungsten boron-carbide (c) coatings against Co-60 gamma radioisotope.

Figure 3 shows comparison of transmittance of the coating samples against pure 321 stainless steel substrate for Co-60 gamma radioisotope. Tungsten (a), tungsten copper (b) and tungsten boron-carbide coatings (c) can be seen in Fig. 3.

3.2. Pu–Be neutron source

The linear attenuation coefficient of coated samples were calculated for neutron shielding properties. The experimental results of tungsten, tungsten copper, and tungsten boron-carbide coatings on 321 steel substrate were shown in Table II for Pu–Be neutron source. It can be understood from Table II that there is no significant changes for neutron shielding. It may be said that very close thickness of coating values led us to these results.

TABLE II

The linear attenuation coefficient n [cm^{-1}] and correlation coefficient cc [R^2].

Coating material	n	cc
tungsten	0.195	0.8720
tungsten copper	0.203	0.9216
tungsten boron carbide	0.201	0.9092

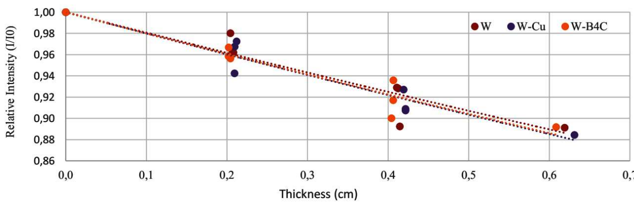

Fig. 4. Relative intensity — thickness graphs for tungsten, tungsten copper, and tungsten boron-carbide coatings on 321 steel substrate against Pu–Be neutron Howitzer (NH-3) neutron source.

Figure 4 shows that relative intensity (I/I_0) — material thickness graphs for tungsten, tungsten copper, and tungsten boron carbide were drawn by using experimental data for Pu–Be neutron source.

On the other hand, there was some theoretical studies which are related to coating materials on stainless steel substrates and which were analyzed with computer programs. MCNP5 program was used to investigate the gamma shielding properties for different materials such as cobalt and titanium on maraging steel. The experimental results in this paper show nearly the same transmittance ratio for gamma shielding properties when compared to the other studies. The results indicate approximately the same transmittance ratio that is calculated as 92% from other related study [12] which is also so close to our consequences (average 90%) for gamma shielding properties.

4. Conclusion

The purpose of this work is to investigate the effects of tungsten, tungsten copper, and tungsten boron-carbide coatings on gamma and neutron radiation shielding properties of 321 stainless steel substrate. Tungsten, tungsten copper, and tungsten boron-carbide coatings on 321 stainless steel substrate were studied for Cs-137, Co-60 gamma radioisotopes and Pu–Be neutron source by using transmission technique. Linear attenuation coefficients of coated samples were carried out for Pu–Be neutron source. Transmittance values for each specimen were calculated at 0.662 MeV and 1.25 MeV gamma energies. From the analysis of the results can be reached as follows:

- The gamma attenuation properties of the all specimens were evaluated and compared with each other. The transmittance ratios were carried out for coated and uncoated samples. Coated samples have lower transmittance ratios than uncoated sample (pure 321 stainless steel) where the ratio was decreased with increase of coating thickness. Hence the coated samples have better gamma shielding properties than the uncoated sample (pure 321 stainless steel).
- The experimental results are generally comparable with the other studies.
- It can be said that tungsten, tungsten copper, and tungsten boron-carbide coatings on 321 steel substrate showed that were no significant changes for neutron shielding.
- W coating on 321 steel substrate has the smallest linear attenuation coefficient of the all studied coated specimens for Pu–Be neutron source.
- According to test results and related studies, it can be said that tungsten, tungsten copper, and tungsten boron-carbide coatings on stainless steel substrate is applicable for gamma shielding materials.

References

[1] G. Pintsuk, *Ref. Mod. Mater. Sci. Mater. Eng., Comprehens. Nucl. Mater.* **4**, 551 (2012).

[2] R. Neu, *Phys. Scr. T* **123**, 33 (2006).

[3] H. Bolt, V. Barabash, W. Krauss, J. Linke, R. Neu, S. Suzuki, N. Yoshida, *J. Nucl. Mater.* **329-333**, 66 (2004).

[4] B. Buyuk, A.B. Tugrul, *Acta Phys. Pol. A* **125**, 423 (2014).

[5] B. Riccardi, R. Montanari, M. Casadei, G. Costanza, G. Filacchioni, A. Moriani, *J. Nucl. Mater.* **352**, 29 (2006).

[6] D.J. Varacalle Jr., L.B. Lundberg, M.G. Jacox, J.R. Hartenstine, W.L. Riggs, H. Herman, G.A. Bancke, *Surf. Coat. Technol.* **61**, 79 (1993).

[7] H. Maier, J. Luthin, M. Balden, J. Linke, F. Koch, H. Bolt, *Surf. Coat. Technol.* **142-144**, 733 (2001).

[8] F. Wang, J. Huang, *Surf. Coat. Technol.* **254**, 61 (2014).

[9] G. Földiak, *Industrial Application of Radioisotopes*, Elsevier, Amsterdam 1986.

[10] G.F. Knoll, *Radiation Detection and Measurement*, University of Michigan, Ann Arbor 2002.

[11] S. Croft, *Ann. Nucl. En.* **33**, 466 (2006).

[12] A.M. Reda, H. Halfa, *Int. J. Phys. Sci.* **10**, 263 (2015).