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RESEARCH ARTICLE

RADIATION SHIELDING PROPERTIES OF BORIDED Fe-Ni ALLOYS.

Nazim Ucar¹, Cihan Ekinci¹, Adnan Calik² and Serdar Karakas³.

1. Faculty of Arts and Sciences, Physics Department SuleymanDemirel University, Isparta, Turkey.
2. Faculty of Technology, Machine and Manufacturing Engineering Department, SuleymanDemirel University, Isparta, Turkey.
3. Faculty of Engineering, Department of Metallurgical and Materials Engineering, Selcuk University, Konya, Turkey.

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Abstract

In this study, the radiation shielding properties of borided Fe-Ni binary alloys (Ni-60 wt.% and Ni-80 wt.%) have been investigated. For this purpose, linear attenuation coefficients at photon energy levels of 662 keV, 1173 keV and 1332 keV have been measured. The results showed that this alloy can be considered as an ideal material for radiation shielding against gamma radiation.

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Introduction:-

In areas where people are likely to encounter ionizing radiation, it is often necessary to provide shielding to reduce exposure to gamma radiation [1]. The studies showed that the degree to which gamma radiation is attenuated is dependent upon the energy of the incident gamma radiation, the atomic number and density of the elements in the shielding material, and the thickness of the shielding [1-6]. Carbon steels or stainless steels, as lead (Pb), have been commonly used as materials for thermal and radiation shields [2,3,7-9]. Corresponding to this, it has been found that the measured effective linear attenuation coefficient (μ) of carbon steel gives an average value of 0.340 cm^{-1} [2]. On the other hand, in recent years, boron has been used as an alternative for radiation shielding, although heavy metals such as Pb have been used for this purpose [4,5,10,11]. In relation to this, it has been shown that the borided AISI 316L and microalloyed stainless steels, especially in the middle energy region, have radiation shielding properties that are similar to those of Pb, the standard shielding material [3,4]. In these studies, it was clearly seen that the radiation shielding properties of steels were improved with a boriding process.

Magnetic iron-nickel (Fe-Ni) alloys, generally called permalloys, are of great interest in many industrial applications due to their ductility and versatility as soft magnetic alloys [12]. Although many papers on the magnetic properties of permalloys and the effect of boriding on the microstructure and microhardness profiles of borided permalloys have been published [13-15], especially, the radiation shielding behaviour has not yet been reported in the literature. The purpose of the present paper is to investigate the radiation shielding behaviour of borided Fe-Ni binary alloys (Ni-60 wt.% and Ni-80 wt.%).

Corresponding Author: NazimUcar

Address: Physics Department, Faculty of Arts and Sciences, SuleymanDemirel University, Isparta, Turkey

Experimental Method:

The substrate materials used in this study were prepared from Fe-Ni binary alloys (Ni-60 wt.% and Ni-80 wt.%). Test samples were cut from a 5 mm plate to dimensions of approximately $5 \times 10 \times 10$ mm. Fe-Ni binary alloys with two different Ni concentrations were borided in an electrical resistance furnace for exposure times of 2, 4, 6 and 8 h at 1223 K and a series of borided samples in the temperature range 1073–1373 K for 5h under atmospheric pressure. The μ is the probability of a radiation interacting with a matter per unit path length, depends on the intensity of the incident photons, atomic number and density of absorber. To investigate the radiation shielding properties of the borided Fe-Ni binary alloys, the μ was measured at the photon energy of 662 keV, 1173 keV and 1332 keV obtained from the ^{137}Cs , and ^{60}Co γ -ray sources, respectively. For this purpose, γ -rays transmitted through the samples of borided and unborided Fe-Ni binary alloys were detected using a gamma spectrometer that consists of a 3×3 -inch NaI(Tl) detector connected to a multichannel analyzer (MCA). If N and N_0 are the measured count rates in the detector with and without the absorber of thickness x (cm), respectively, then the μ can be extracted by the standard equation:

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

Plotting $\ln\left(\frac{N}{N_0}\right)$ versus x would give a straight line and thus μ can be obtained from the value of the slope. Detailed information on radiation measurements can be obtained from Ref. 16.

Results and Discussion:

The radiation shielding is based on the principle of attenuation, which is the ability to reduce a wave's or ray's effect by blocking or bouncing particles through a barrier material. Charged particles may be attenuated by losing the energy to the reactions with electrons in the barrier, while gamma radiation is attenuated through the scattering or pair production [1,17,18]. In this study, the μ for Fe-Ni binary alloys (Ni-60 wt.% and Ni-80 wt.%) was calculated as a function of photon energies and boriding parameters (temperature and time). The results are displayed in Fig.1 and 2.

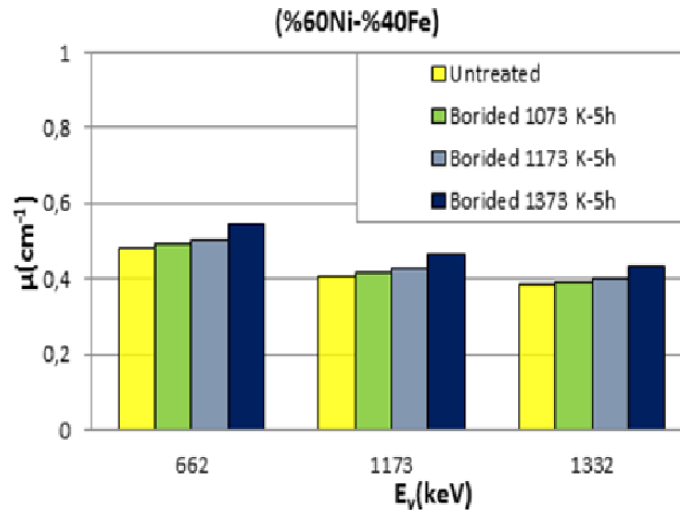


Fig. 1: Measured linear attenuation coefficients of the Fe-Ni binary alloys (Ni-60 wt.%) as a function of photon energy and boriding temperature.

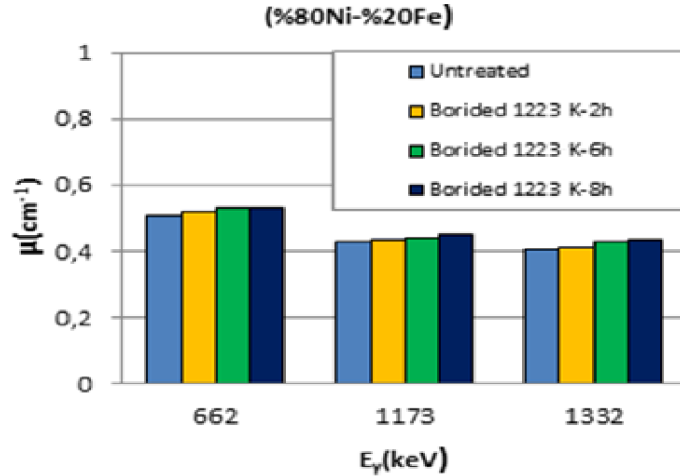


Fig. 2: Measured linear attenuation coefficients of the Fe-Ni binary alloys (Ni–80 wt.%) as a function of photon energy and boriding time.

It can be observed from the Fig 1 and 2 that the μ values depend on the photon energy and decrease with increasing photon energy. In addition, from these figures, it is clear that the μ is decreasing rapidly at low energy but in high energy it decreases slowly for borided binary alloys at the same time and temperature due to the energy dependence of photon interaction with material. On the other hand, it can be noticed that the μ for borided binary alloys is higher than unborided binary alloys. And also, it increases with the increasing boriding time and temperature. This result has been explained with the boride layer thicknesses and boride phases at the borided binary alloys. It is well known that a boride layer on the upper surface of the specimen forms as a result of boron diffusion into the surface in the boriding process. In literature [12,18-21], it has been shown that hard boride phases (Ni_4B_3 and Ni_6Si_2B phases) occur in the boride layers of borided Fe-Ni binary alloys. The boride layer thickness increases with increasing boriding time and temperature due to increasing boron diffusion. In the present study, the thickness of the boride layer is in the range of $55\mu m$ to $130\mu m$ for 1073-1373 K at 5 h whereas the thickness of the boride layer is in the range of $60\mu m$ to $115\mu m$ for 2-8 h at 1323 K. To sum up, the μ increases with increasing boriding time and temperature due to increasing boron content. It means that the μ depends on the photon energy and density of borided Fe-Ni alloys.

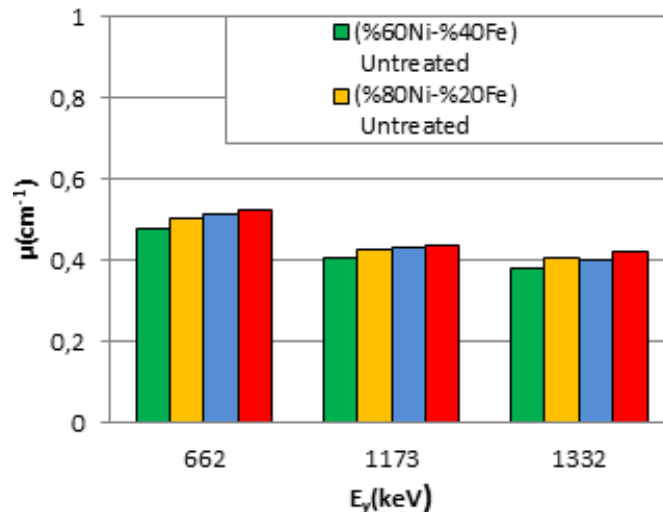


Fig. 3: Measured linear attenuation coefficients of the Fe-Ni binary alloys as a function of photon energy and Ni content.

The same results can be seen in Figure 3. Fig. 3 shows the dependence of radiation absorption properties as a function of different combinations of components in Fe-Ni binary alloys. From this figure, we say that the μ

increases with increasing Ni content due to changing the of borided Fe-Ni binary alloys. The same results for μ have been reported in the other studies [5,6]. They showed that attenuation coefficient depends on the chemical composition of materials.

In literature, the μ values of Pb were measured as 0.618 cm^{-1} [3] and 0.616 cm^{-1} [22] for 1.33 MeV ^{60}Co γ -ray source. In this study, the μ value for 1.33 MeV ^{60}Co γ -ray source is slightly over 0.4 cm^{-1} and boriding treatment and Ni concentration increases μ . From these results, one concluded that the borided Fe-Ni binary alloys show an appropriate radiation shielding performance. What is needed is to make the μ value of borided Fe-Ni binary alloys close to the μ value of the Pb by selecting an appropriate boriding process besides the boring parameters and concentration.

Conclusions:

In this work a new material has been tested for radiation shielding applications. The results reveal that the investigated Fe-Ni binary alloys provided similar protection as pure Pb. If these borided alloys used as a radiation shielding materials against gamma radiation, they have a shielding feature that is very close to the Pb, especially in the low photon energy.

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