The Effect of Boronizing on the Radiation Shielding Properties of Steel

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The radiation shielding properties of steel and its variation with the boronizing process have been investigated. For this purposes the linear attenuation coefficients of steel have been measured before and after boronizing the steel at the photon energy of 662 and 1250 keV. The measured results before boronizing were compared with the theoretical calculation. It was clearly seen that boronizing improved the radiation shielding properties of steel.

Key words: Steel; Boron; Radiation; Shielding.

1. Introduction

Photons are widely used in different fields such as in medical application, agriculture, air industry, energy station. Ionizing radiation is known to be harmful to human health, and the attenuation of radiation can be achieved by three main rules, i. e. time, distance and shielding. Shielding is the most effective technique and it is mostly required against X-rays and gamma rays, which are very penetrating [1, 2]. Gamma radiation is best absorbed by dense materials consisting of heavy atoms such as lead and barium [3] or some building materials such as marble [4], and also barium sulfate (baryte) is used as an aggregate in concrete [5].

Boron can be used almost in all branches of industry and it is estimated that about 54% of the known boron reserves of the world are in Turkey [6]. As it is important to shield radiation especially in the fields where radiation is being used, boronizing can be an alternative method to improve the radiation shielding properties of materials. Although boron is widely used for neutron shielding Gromov et al. [7] tested boron-loaded for gamma radiation years ago.

In this study the radiation shielding properties of three different types of steel, namely stainless steel (SS), carbon steel (CS) and speed steel (VS), have been determined and the effect of boronizing on this properties have been investigated.

2. Materials and Methods

In Table 1 the chemical composition of steels is tabulated. The linear attenuation coefficients (μ) were obtained via mass attenuation coefficients (μ/ρ) of steel, computed using the XCOM code which uses chemical parameters of a mixture of materials, providing total cross-sections as well as partial cross-sections for various interaction processes and the database at photon energies of 1 keV to 100 GeV [8]. The XCOM is a database running on a PC which was prepared by combining pre-existing databases for interaction processes such as scattering (both coherent and incoherent), photoelectric absorption and pair production. As detailed in [9] photon interaction with materials depends on incoming photon energies and the number of target materials (Z). The linear attenuation coefficients were measured at the photon energies of 662 keV and on average of 1250 keV obtained from ^{137}Cs and ^{60}Co γ-ray sources, respectively. If N and N_0 are the measured count rates in detector (G-M tube), respectively, with and without the absorber of thickness x (cm), the linear attenuation coefficients can be extracted by the standard equation

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

Plotting $\ln(N_0/N)$ versus x would give a straight line, and μ can be obtained from the value of the slope.

In order to test the effect of boronizing on the radiation shielding properties of steel, all samples were boronized by using the powder pack method [10]. In this method, a commercial Ekabor-II boron source and activator (ferrosilicon) were thoroughly mixed. The packed test samples were heated in an electrical furnace for 4 h at 1210 K under atmospheric pressure. Once the bonding process was completed the samples

Table 1. Chemical composition of the specimen.

	C	Si	Mn	P	S	Cr	Mo	Ni	Co	Cu	W	Fe
Stainless steel (SS)	0.12	0.37	1	0.024	0.005	17	0.63	6.86	0.07	0.21	–	73.7
Carbon steel (CS)	0.12	0.05	0.28	0.06	0.008	0.020	0.005	0.013	–	–	–	98.5
Speed steel (VS)	0.9	–	–	–	–	4.1	5.0	–	–	–	6.4	83.7

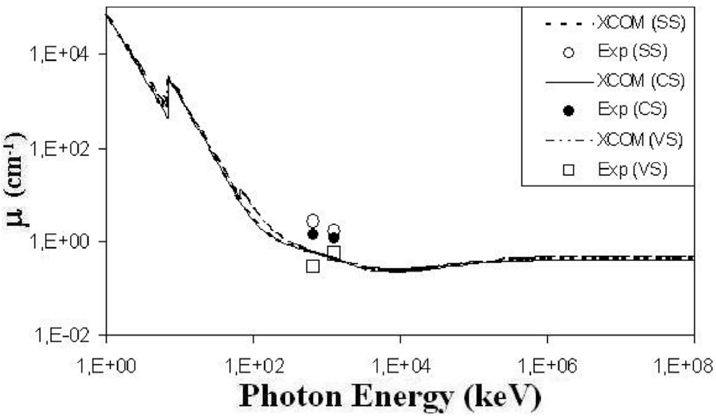

Fig. 1. Measured linear attenuation coefficients of three different steels and comparison with the calculation.

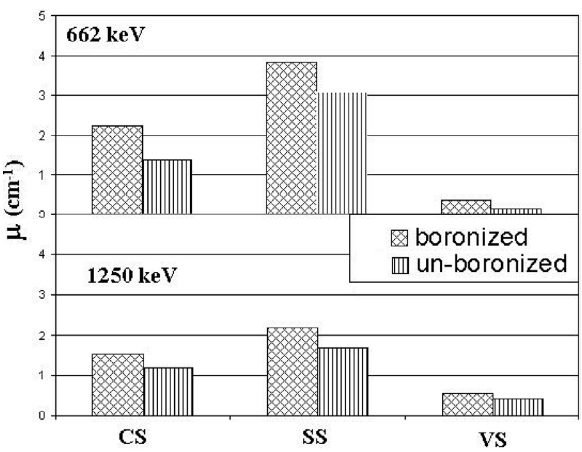

Fig. 2. Measured linear attenuation coefficients for three different steels before and after boronizing.

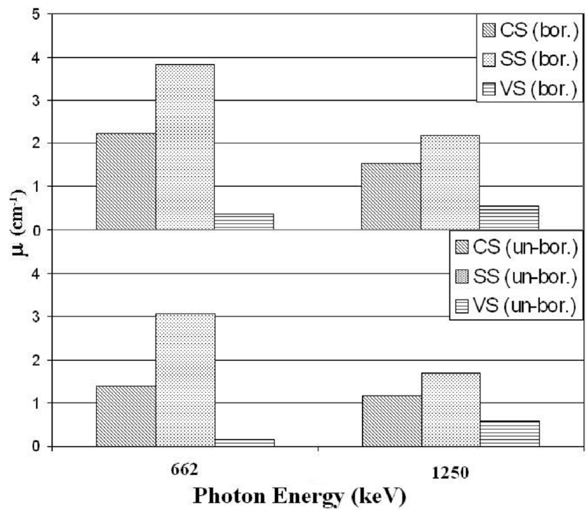

Fig. 3. Measured linear attenuation coefficients of the different steels as a function of photon energy before and after boronizing.

were cooled at a rate of 15 °C/min to room temperature before removal from the chamber. Boronized samples were sectioned from one side and prepared metallographically up to a 1200-grid emery paper and then polished, using 0.3-Am alumina paste.

3. Results and Discussion

The linear attenuation coefficients (μ) for all types of steel (SS, CS, VS) have been calculated at photon energies of 1 keV to 100 GeV and the results were compared with the measurements for photon energies of 662 and 1250 keV. This is displayed in Fig. 1, where it can be seen that the calculated and measured results are in good agreement for all types of steel. It can also be clearly seen from this figures that the linear attenuation coefficients depend on the incoming photon energies as the interaction mechanism of photons with the matter is different for different photon energies [9]. By comparing the linear attenuation coefficients of the different steels, it is clear that the highest linear attenuation coefficient was found for SS while the lowest value for VS. This could be the results of the different components of the steels.

The effect of boronizing on the radiation shielding properties of steel was investigated. This was done by measuring the linear attenuation coefficients of steel after boronizing and comparing with the results obtained before boronizing. The results are displayed in Fig. 2 for 662 keV photon energy (upper) and for 1250 keV photon energy (lower) for all types of steel. It can be clearly seen from this figure that the linear attenuation coefficient of all types of steel has increased after boronizing. This can also be seen from Fig. 3 where the measured linear attenuation coefficients of the different steels before and after boronizing are shown as a function of photon energy.

4. Conclusion

It can be concluded from this work that the linear attenuation coefficient is the highest for stainless steel. This means that using stainless steel can provide more advantage in terms of radiation shielding than other types of steel. Additionally it is also clearly seen from this work that the radiation shielding capability of steel can be improved by boronizing. This would lead to an extra-advantage in fields where radiation is commonly used.

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