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High Performance Shielding Material to Prevent Radiation Leaks

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Abstract: Radiation has become part of our everyday life in nuclear power plants, treatment and diagnostics of nuclear envy, nuclear weapons construction, natural gas and oil exploration, material analysis and many other applications. In addition to the benefits of radiation, there are also major damages if adequate protection is not provided. In this work, high performance alloyed stainless steel specimens were produced to prevent gamma and fast neutron radiation leakage. Before passing through production, rapid neutron macroscopic cross sections and mass absorption coefficients for gamma radiation were determined as an important parameter in radiation shielding using semi-experimental Monte Carlo Simulation GEANT4 code. As a result of these simulations, molybdenum (Mo), tungsten (W), nickel (Ni), chromium (Cr), sulfur (S), manganese (Mn), titanium (Ti), silicon (Si), iron (Fe), using materials three different alloyed stainless steel products were produced by powder metallurgy and the produced samples experimental dose measurements were performed using 241Am-Be fast neutron source with 4.5 MeV average energies. For 7 MeV gamma radiation, mass absorption coefficients were determined semi-experimental. The samples were subjected to the acid wear test and the compressive strength test and were found to have high performance. The results were compared with the stainless steel 316LN which is widely used in nuclear applications. The produced samples were found to have very high properties according to this steel. It has been suggested that the new alloyed stainless steels produced can be used safely in nuclear applications for radiation safety. This study was supported by BAP, TUBITAK projects. Project No: 79/2013, 49 / 2014-111T764.

Key words: Alloyed stainless steel, fast neutron, Monte Carlo Simulation technique, armor.

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1. Introduction

Radiation is fast particles or energy packets traveling in wave form. Radiation used in nuclear energy in medicine, agriculture, material and space research, material analysis and also used in navigation systems to determine direction and location. Radiation not only has benefits but also damages. To prevent these damages a good shield is required in accordance with radiation's type and energy. Materials; such as concrete, paraffin, steel, lead are used to prevent radiation leaks. However, the resistance of these materials to high temperatures, pressures, chemical corrosion is poor. For these reasons, making good armor and its development work continues at a great pace. For example, armor constitutes about 40% of the cost of a nuclear power plant. In the process of radiation shielding the materials must be used according to the type of the radiation. While lead and its compounds are preferred for gamma and X-ray radiation, hydrogen intense materials, such as paraffin, are preferred for neutron radiation. The material to be used in radiation shielding must have both thermal and biological shielding capacity. In particular, it is necessary to prevent radiation leakage at high temperatures such as nuclear reactors. According to gamma and X-ray radiation it is very difficult to shielding neutron radiation. Because the neutron particles do not have an electrical charge, they can reach the core of the material without being affected by the Coulomb gravity of the metal, causing secondary reactions by initiating nuclear reactions. We have produced new alloyed steels to shielding specifically for neutron radiation. In this study, we added chromium (Cr) to the produced steels to create hard carbides such as Cr_7C_3 to increase their resistance to corrosion. We increased the radiation hold up by adding tungsten (W) and rhenium (Re) elements, both of which have high cross-section to gamma rays and neutron particles. Furthermore manganese (Mn) was added to increase tensile strength. When we look at the literature, there are many studies related to this topic, some of which are mentioned below. Alloys such as CS-516, SS-403, SS-410, SS-316, SS-316L, SS-304L, Incoloy-600, Monel-400 and Cupero-Nickel have been used for gamma radiation half-thickness values, mass reduction coefficients and build up factors have calculated. They have been calculated scattering cross sections for fast neutron radiation. They have been founded well shielding cupro-nickel for gamma radiation and SS316 material for neutron radiation at 2-12 MeV energy. (Singh *et.al* 2014). They have produced new shielding material by using neutron and gamma (B_4C) materials using iron (Fe), rhenium (Re), nickel (Ni), chromium (Cr), boron (B), tungsten Iron (Fe), rhenium (Re), nickel (Ni), chromium (Cr), boron (B), copper (Cu), tungsten (W), tantalum (Ta), boron carbide (B_4C). (Aygun. *et.al* 2015). Thermal neutron shielding material has been produced by using 15% B_4C + 1% Gd) / Al material and macroscopic transmission cross section has been calculated by using the MCNP simulation program (Jiang *et.al.* 2016). They have obtained patents by producing corrosion-resistant neutron armor material using gadolinium boron, iron, nickel, chromium and molybdenum elements. (Schmidt. *et.al.* 2016). Austenitic and ferritic stainless steels has been produced, a new material shielding, by adding boron to certain proportions and has been patented. (Kibata. *et.al.* 2016). Tungsten copper and tungsten boron carbide coatings were applied on 321 stainless steel to make armor material for neutron and gamma radiation. (Demir. *et.al.* 2017). Tungsten compounds and their alloys have been calculated the mass reduction coefficient for gamma rays in energies between 1 keV and 100 GeV and the macroscopic effect sections for fast neutrons in energy range (2-12 MeV). They compared the results to lead and experimentally demonstrated that it was better than lead in radiation absorption process. (Singh. *et.al.* 2016). Thermal neutron armor was developed by using high-content boron-containing Fe72-xB25-Mo3Crx (where x = 0, 5, 10, 15 or 20 at%) composite material. They have increased the corrosion resistance by adding Cr into the compound. (Jaewon Moon and Seonghoon Yi 2016).

2. Materials and Methods

Monte Carlo Simulation Codes GEANT4 is a simulation program that helps you to predict the behavior of the rays of the particles entering the material. It has a wide usage area in nuclear physics, high energy physics, space researches. Interactions of neutrons of 0-25 eV-20 MeV energy with matter (Elastic, inelastic scattering, secondary particle or radiation generation, neutron capture and nuclear reactions, etc.) can be simulated. By using the program, gamma mass reduction coefficient and neutron total macroscopic cross sections of the material are calculated and it is possible to save both material and time by predicting the pre-radiation interaction by 95%.

Material Production

Before the production a preparatory work has been done by using tungsten (W), nickel (Ni), chromium (Cr), sulfur (S), manganese (Mn), titanium (Ti), silicon (Si), carbon (C), iron (Fe) elements, and mass reduction coefficients for 7 MeV-14 MeV energetic gamma radiation were determined. In these simulations the mass combination ratios were determined. Powdered materials were blended for 30 minutes using the mixer the nano dimensions given the following table contents and mass percent incorporation ratios. Mixed materials were pelletized by using SPECAC pellet press machine under 600 MPa pressure. The pellet samples were annealed at 1200 ^{0}C for 6 hours. The annealed samples were taken from the oven and hot pressed was carried out to remove the capillary cavities from the unexpanded, which greatly reduced the ductile structure of the material. Thus, the spaces are reduced which radiation passes through the material. The materials produced for the corrosion test were immersed in a full bath of sulfuric acid (H_2SO_4) which has an abrasive effect on metals and allowed to stand for 48 hours in it and no changes has been observed. The materials used in the production of alloyed stainless steels and percent composition by mass are shown in Table 1.

Table 1 Percentage of Alloy Stainless Steels (%)

Material Alloyed Stainless Steel	Nickel	Chroum	Manganesee	Carbon	Molybdenum	Tungsten	Silikon	Titanium	Iron	Vanadium	Sulfur	Rhenium
ASS1	**38**	**10**	**2**	**0.5**	**1**	**15**	**0.1**	**3**	**30**	**-**	**-**	**-**
ASS2	**22**	**18**	**2**	**1**	**-**	**18**	**-**	**2**	**35.975**	**1**	**0.025**	**-**
ASS3	**30**	**15**	**1**	**0.5**	**-**	**20**	**-**	**-**	**32.47**	**0.015**	**0.015**	**1**

Table 2 Monte Carlo simulation (GANT4) Results

Sample Code	4.5 MeV Neutron Total Macroscopic Cross Sections (cm-1)	7 MeV Gamma Cross Sections Per Volume (cm-1)	7 MeV Gamma Cross Sections Per Volume Cross Sections Per Mass (mm2/g)
RNS 316LN	0.3009	0.2692	0.26922
ASS1	0.3347	0.2911	3.2113
ASS2	0.3649	0.2980	3.0259
ASS3	0.3756	0.3434	3.2869

ASS: Alloyed stainless steel

RNS: References nuclear stainless steel

Table 3 Equivalent Dose Rates by Experiments

Sample Code	Equivalent Dose Rates 4.5 MeV Neutron (μSv/h)
Background	9.3855
RNS316LN	0.8781
ASS1	0.7739
ASS2	0.6252
ASS3	0.5126

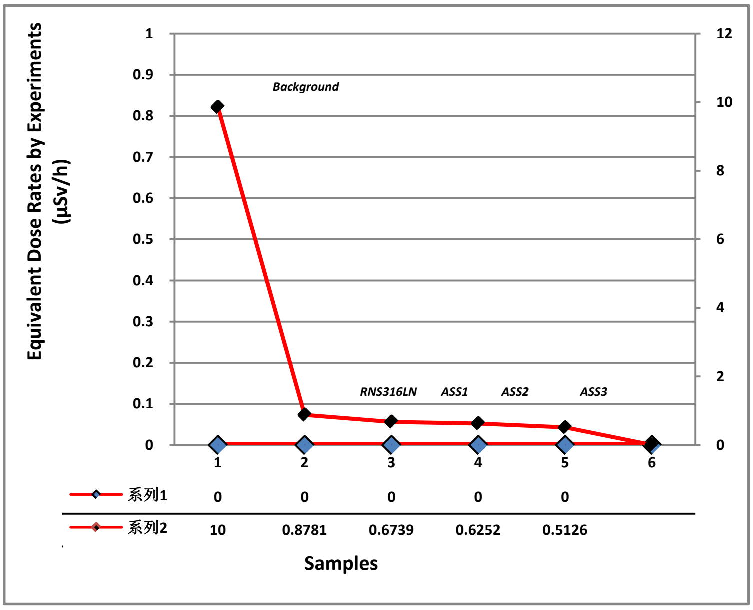

Fig. 1 Equivalent Dose Rates by Experiments

Equivalent Dose Rate Measurements

Equivalent dosing measurements of the produced samples were performed. The measured dosimetry results of the detector are shown in table 3.We used a ^{241}Am / Be source as a fast neutron source and a Canberra NP-100B neutron detector. Measurements have been recorded in computer by RADAC program.

3. Results and Discussion

One of the most important parameters in radiation shielding is the total macroscopic cross section for neutrons. Because this material shows the possibility of interaction with radiation. Also for the gamma rays is the mass reduction coefficient. The higher the value of a material's two values, the better the material can absorb radiation. Nuclear applications generally use 316LN nuclear steel. The alloyed steels we produce have superior properties than the 316LN steel. Because both the cross-section of the effect is higher and experimentally more absorbed neutron radiation. We increased the radiation holding capacity by adding tungsten (W) and rhenium (Re) elements to the structure of alloyed steel. We also added manganese (Mn) to increase tensile strength.

4. Conclusion

The cross-sections of the produced alloyed stainless steels likely to interact with neutron and gamma radiation are higher than the 316LN steel and are shown in Table 2 Experimental measurements showed that the alloyed stainless steels produced absorb more radiation than the 316LN steel, as shown in Table 3 and in Figure 1.

The three alloyed stainless steels produced are resistant to high temperatures, environmental and chemical corrosion. Nuclear power reactors have also been found to be able to use radiation applications such as transporting and storing nuclear materials, radioactive materials.

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