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Gd_2O_3 ve La_2O_3 Katkılı Atık Ambalaj Camının Radyasyon Zırhlama Uygulamalarında Kullanılabilirliğinin Araştırılması

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Anahtar kelimeler
Cam; Radyasyon; Zırhlama; Gd_2O_3; La_2O_3.

Öz

Bu çalışmada, Gd_2O_3 ve La_2O_3 olarak iki farklı oksitle ayrı ayrı katkılandırılmış atık ambalaj camının radyasyon zırhlama özellikleri üzerine kullanılabilirliği araştırılmıştır. Her iki katkı % 0.005, % 0.05 ve % 0.5 kütlece oranlarında ayrı ayrı eklenmiş ve homojen karışım sağlanarak ergitme süreci gerçekleştirilmiştir. Daha sonra yoğunluk, molar hacim ve doğrusal zayıflama katsayısı ölçümleri yapılmıştır. Sonuç olarak, 2.8033 g/cm^3 yoğunluk değeri ve 8.11 cm^{-1} doğrusal zayıflatma katsayısı değeri % 0.5 katkılı Gd_2O_3 cam kompozisyonu ile elde edilerek atık ambalaj camının düşük enerjili radyasyon zırhlama uygulamalarında kullanılabilirliği görülmüştür.

An Investigation on Usability of Waste Container Glass with Gd_2O_3 and La_2O_3 Addition in Radiation Shielding Applications

Keywords
Attenuation; Glass; Radiation; Gd_2O_3; La_2O_3.

Abstract

In this study, the usability of soda-lime-sand glass added separately with two different oxides as Gd_2O_3 and La_2O_3 in radiation shielding applications was investigated. Both additives were added separately at 0.005 %, 0.05 % and 0.5 % by weight and the melting process was achieved by providing homogeneous mixture. Then, density, molar volume and linear attenuation coefficient measurements were carried out. As a result, the density value of 2.8033 g/cm^3 and linear attenuation coefficient value of 8.11 cm^{-1} were obtained with 0.5 % Gd_2O_3 addition and therefore the usability of waste packaging glass in low energy radiation shielding applications was observed.

1. Introduction

With technological advances, the utilization rate of radiation-induced devices has increased and is expected to increase in many areas. For example, mammography, X-ray, computed tomography, etc. used in medical diagnostic centers or x-ray

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diffraction, x-ray fluorescence, etc., used for characterization purposes within research institutions and moreover, there is a great deal of radiation and radiation in the energy processes produced in nuclear power plants [1].

Hazardous radioactive substances emitted as a result of radiation (e.g. alpha, beta or gamma) adversely affect individual health, and may, however, cause irreversible health problems depending on the time, intensity and distance of radiation exposured [2].

Many measures are applied in the related devices and processes in order to minimize and even eliminate the radiation. The most important of these measures is to use shielding materials. As a result of the determination of the area where the radiation occurs and the determination of the emission level, the selection of the shielding material that can absorb the intensity of the relevant radiation is made. In this direction, lead metal and heavy concretes have extensively been implemented [3].

Traditionally shielding can be performed with these high density materials, but search for alternative materials have been conducted on performance expectations and environmental impacts from these materials.

The toxic effects of lead based materials, which are one of the traditional materials mentioned, to human health and the environment have shown negativity as the subject of many studies [4], [5], [6]. Likewise, the heavy concrete materials have some limitations due to the destruction of natural resources and their high greenhouse gas emissions. Further, transparent appearance can not be achieved by using lead based materials as well as heavy concretes [7], [8], [9]. Therefore, a direct need for glass material usage in that field is of importance.

In order to overcome mentioned difficulties, research activities have been paid attention on glass materials which are environmentally friendly, offering compositional flexibility and providing a transparent appearance.

Within the scope of this study, the usability of soda-lime-silica glass doped with two different oxides as Gd_2O_3 and La_2O_3 on radiation shielding properties was investigated.

2. Experimental Procedure

2.1 Glass Synthesis

In the present study, waste flint container glass having composition of *71.5*SiO_2*-14.2*Na_2O*-7.9CaO-4.1MgO-1.7*Al_2O_3*-0.05*Fe_2O_3 in wt.% was obtained from municipal waste storage area. The glass sample was firstly crushed, and then milled at plenatary ball mill for 1h until having average particle size of lowering than 125 microns. The chemicals of Gd_2O_3 (99.00%) and La_2O_3 (99.99%) supplied from Sigma Aldrich with the particle size of lowering than 5 microns were used as received. The mix designs of glass compositions were carried out as given in Table 1. Sample code of G1 represented waste flint container glass without any addition of oxides whereas G2 to G7 were based on Gd_2O_3 and La_2O_3 contents. Besides that, density values (ρ) and molar volumes (V_m) of mix designs were given, accordingly.

Table 1: Mix designs, values of density (ρ), molar volume (V_m) and oxygen molar volume of glass samples.

Glass Code	Gd_2O_3 (%)	La_2O_3 (%)	ρ (g/cm³)	V_m (cm³/mol)
G1	0	0	2.4930	23,93
G2	0.005	0	2.5539	23,36
G3	0.05	0	2.5602	23,20
G4	0.5	0	2.8033	21,93
G5	0	0.005	2.5290	23,59
G6	0	0.05	2.5352	23,45
G7	0	0.5	2.7583	22,22

As shown in Fig. 1, as soon as precisely weighing and homogeneously mixing the respective reagents for having 10 g batch was performed, the mixtures were then put in a Au-Pt crucible and melted in a conventional electrical furnace at 1250 – 1350 °C for 1h.

Fig. 1: Images of glass sample preparation routes.

The melt was kept in the crucible till it was cooled, and afterwards the glass samples were removed from the crucible. The glass samples produced were shown in Fig. 2.

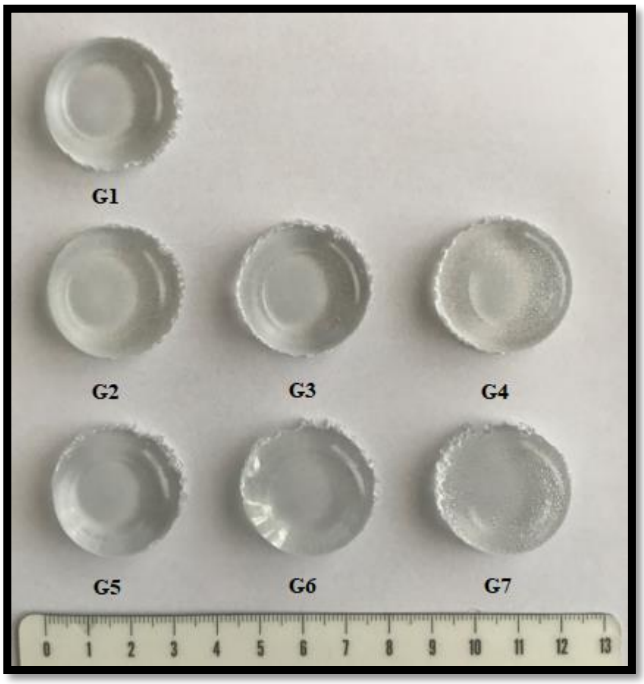

Fig. 2: Images of glass samples produced.

2.2 Characterisation

Physical characteristics of samples produced were determined by conducting Archimedes' principle for denstiy measurement. The Eq. 1 where X_{air} and X_{liquid} are the weights of samples in air and ethanol, respectively was used for calculation of values of densities.

$$\rho_{glass} = (X_{air}) / (X_{air} - X_{liquid}) \qquad \text{Eq.1}$$

Molar volume, V_m, of the samples produced was determined by applying the following formula:

$$V_m = (M_{glass}) / (\rho_{glass}) \qquad \text{Eq. 2}$$

where M_{glass} is the molecular weight of glasses as a function of each component and ρ_{glass} is the density of glass sample.

Radiation shielding measurements of glass samples were performed using a conventional X-ray diffraction device which is capable of 40 kV voltage, 30 mA current and copper target. The experimental set up is illustrated in Fig. 3. [10][11]. At first, the spectrometer was calibrated, and then measurement of glass samples was initiated.

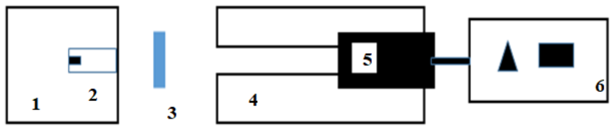

Fig.3: Experimental Set Up (1: lead shield, 2: X-ray source, 3: glass sample, 4: lead shield, 5: detector, 6: PC monitor).

The linear attenuation coefficients were calculated by using Eq. 3 which is also known as Lambert-Beer law:

$$I = I_0 \times (e^{-\mu t}) \qquad \text{Eq. 3}$$

where I_0 and I are the initial and transmitted intensities, respectively and μ is the linear attenuation coefficient of the glass sample, and t is the thickness of samples produced.

3. Results & Discussion

In the scope of this study, a total number of 7 different glasses were produced to observe the radiation shielding properties. As can be appreciated from the Fig. 2 that glass samples visually appear as transparent. No color change due to the addition of Gd_2O_3 and La_2O_3 was observed. This is very important because transparency was provided without any yellowish or brownish color hue. Since there was no addition of any refinement agent like sodium sulphate or sodium nitrate, a number of seeds, bubbles or the like in sample glasses can be visibly observed.

The density values as well as molar volumes of glass samples were listed in Table 1. The density values were found between 2.4930 and 2.8033 g/cm^3. That means, as both Gd_2O_3 and La_2O_3 addition ensured an increase in glass density compared to as-cast glass sample of G1. As stated in the studies of [12] and [13], Gd_2O_3 and La_2O_3 showed an increase in glass density due to replacing of main glass former (SiO_2 or B_2O_3, etc.). Further, G2 to G4 glass samples showed higher glass density values in comparison to G5 to G7 due to the fact that Gd_2O_3 (7,41 g/cm^3) has higher density value than La_2O_3 (6,51 g/cm^3). As found in the studies of [1], [14], [15], the higher the density value of glass system the better the radiation shielding properties will.

For molar volume calculations, it was found to be in the range of 22.81 and 23.91 cm^3/mol. One can say that an increase in oxygen amount will cause to very much free volume in glass structure, which will deteriorate the radiation shielding performance of glass system.

The linear attenuation coefficients for glass samples were measured at 40 kV as given in Fig. 4. For as-cast glass, G1, the linear attenuation coefficient was measured as 6.32. For Gd_2O_3 added glass samples, G2 to G4, the coefficient of linear attenuation was achieved as 6.80, 7.33 and 8.11, respectively. That means, as the amount of Gd_2O_3 in glass system was increased the radiation shielding properties was enhanced. Similarly, for La_2O_3 added ones, G5 to G7, it was obtained as 6.46, 6.53 and 6.96 for linear attenuation coefficient, respectively. However, one can state that Gd_2O_3 added glass system showed better radiation shielding performance compared to La_2O_3 added glass systems. This is because the higher density values with lower molar volumes provided to have such better properties for Gd_2O_3 addition.

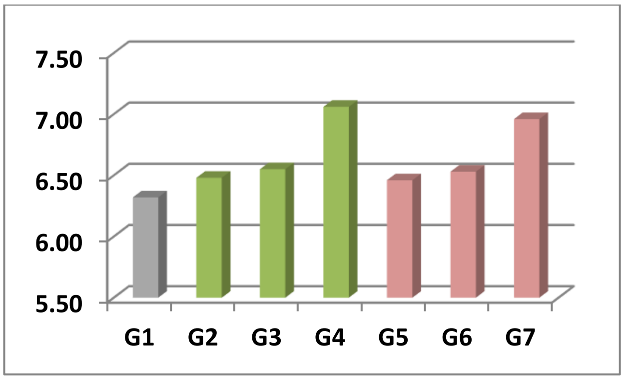

Fig. 4: The measured linear attenuation coefficients (cm^{-1}) of glass samples.

Both linear attenuation coefficient values obtained by adding Gd_2O_3 and La_2O_3 can also be compared with a commercial product of Nippon LFX (lead-free) used in mammography diagnosis centers [16]. That is, nearly 0.04 % X-ray transmission can be achieved at 50 kV X-ray tube voltage with LFX-9 while averagely 0.03 % X-ray transmission was obtained with G2 to G7 glass samples of the present work.

4. Conclusions

In summary, soda-lime-silica glass system was studied by adding two different oxides of Gd_2O_3 and La_2O_3 in order to see the radiation shielding properties. It can be concluded that soda-lime-silica glasses with no addition of oxides shows worst radiation shielding properties whereas doping with 0.5 % Gd_2O_3 will provide to have greatest radiation shielding ability. Moreover, such kind of glass systems doped with Gd_2O_3 and La_2O_3 can effectively be used in mammography diagnosis centers which utilize relatively lower energy levels for monitoring.

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