STUDY OF TL AND OSL DOSIMETRIC PROPERTIES OF ELECTROFUSED ALUMINA PELLETS

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ABSTRACT: The aluminum oxide composes the modern TL and OSL radiation dosimeters. The TL and OSL phenomena are related to chemical elements present in the crystalline structure of the α-Al_2O_3. The aim of this work was to study the TL and OSL dosimetric properties of white electrofused alumina commercially available as abrasive material to be applied as dosimetric material. Sintered pellets of electrofused alumina were obtained using soda-lime glass, a relatively inexpensive, chemically stable, reasonably hard, and extremely workable material, capable of being re-softened and re-melted numerous times. The electrofused alumina and soda-lime glass powders and EAG samples were analyzed by X-rays diffraction. The fracture micrographs of the EAG pellets were also obtained. The electrofused alumina-glass pellets (EAG) showed significant TL and OSL signals. Preliminary results on TL glow curves, OSL decay curves and dosimetric properties such as repeatability, dose response curves and useful dose range were evaluated.

Keywords: thermoluminescence, optically stimulated luminescence, aluminum oxide, dosimetric materials, radiation dosimetry.

INTRODUCTION

For a long time TL has been an important method for radiation dosimetry. The theory about TL phenomenon and its properties are abundantly available in the literature [1]. Recently the OSL has gained significant importance and both of these methods are applied to in many radiation dosimetry fields, including personal, environmental, retrospective, space, neutron and medical dosimetry [2,3,4].

The carbon-doped aluminum oxide represented by α-Al_2O_3:C was introduced as a highly sensitive thermoluminecent detector [5] and, afterwards, this material showed to be also an OSL dosimeter [6].

The aluminum oxide (Al_2O_3) exhibits a variety of forms and characteristics. It may have adsorbent, abrasive, dielectric or refractory properties depending on the obtaining process.

The abrasive Al_2O_3 commercially available as electrofused alumina is a very cheap material obtained by electrofusion of bauxite or alumina in an electric furnace at temperatures higher than 2000 ºC, which are produced in blocks that are gradually crushed and milled, setting the size distribution and morphology of the grains, which have a chemical purity guaranteed by a rigorous decontamination process through powerful magnetic separators and after a rigorous quality control (physical and chemical analysis) the material is available [7]. There are two types of alumina produced for abrasives: brown and white. The basic difference between the brown and white is the chemical composition, in which brown presents approximately 97.0% Al2O3 and 2.50% TiO2 and white 99.5% Al2O3. Therefore, the difference in the chemical composition has a direct influence on product applications. Table 1 presents the main physical and chemical properties of the two materials.

Table 1 – Physical and Chemical main properties of electrofused alumina.

Alpha alumina	Hexagonal system	
% Al_2O_3	**White** – 99.5%;	**Brown** – 96.70 %
Composition	[**SiO_2** 0.20% ; **Na_2O** 0.60% ; **Fe_2O_3** 0.20%] min. **Al_2O_3** 99.00% mín.	
Hardness	9.0 Mohs scale	
Specific gravity	**White** - 3.65 g/cm^3;	**Brown** - 3.85 g/cm^3
Melting point	**White** 2,040ºC	**Brown** 2,000ºC

The Al_2O_3 commercially available as white electrofused alumina is a very cheap material and was found to show interesting TL and OSL properties.

Sintered pellets, named EAG, were obtained using soda-lime glass as binder material. Soda-lime glass is a relatively inexpensive, chemically stable, reasonably hard, and extremely workable material, capable of being re-softened and re-melted numerous times.

Soda-lime glass (soda-lime-silica glass) is divided technically into glass used for windows, called flat glass, and glass for containers, called container glass. The two types differ in the application, production method (float process for windows, blowing and pressing for containers), and chemical composition. Flat glass has a higher magnesium oxide and sodium oxide content than container glass, and lower silica, calcium oxide, and aluminum oxide content [8]. From this follows the slightly higher quality of container glass for chemical durability against water, which is required especially for storage of beverages and food.

The typical compositions and some physical properties of soda-lime glasses are presented in Table 2 [8].

Table 2- Composition and physical properties of soda-lime glasses

Properties	Soda-lime glass for containers	Soda-lime glass for windows
Chemical composition wt%	74 SiO_2; 13 Na_2O; 10.5 CaO; 1.3 Al_2O_3; 0.3 K_2O; 0.2 SO_3; 0.2 MgO; 0.04 Fe_2O_3; 0.01 TiO_2	73 SiO_2; 14 Na_2O; 9 CaO; 4 MgO; 0.15 Al_2O_3; 0.03 K_2O; 0.02 TiO_2; 0.1 Fe_2O_3
Glass transition T_g	573 °C (1,063 °F)	564 °C (1047 °F)
Density 20 °C g/cm^3	2.52	2.53
Liquidus temperature	1,040 °C (1,900 °F)	1,000 °C (1,830 °F)

The obtained sintered pellets of fused alumina using soda-lime glass as binder material were characterized with the purpose of being applied as radiation detectors [9] .

Preliminary results on TL glow curves, OSL decay curves and dosimetric properties such as repeatability, dose response curves and useful dose range were evaluated.

MATERIALS AND METHODS

The white electrofused alumina supplied by Elfusa Geral de Eletrofusão Ltda. was sieved and grains with sizes between 75 and 180 μm were selected. The certificate of analysis of the white electrofused alumina indicates that the main impurities are Ca, Fe, K, Mg, Na, Si and Ti (Table 3).

The alumina powder was mixed with polyvinyl alcohol solution (10%) and soda-lime glass powder with particles size smaller than 75 μm, in the 1:1 ratio by weight. Table 4 presents the soda-lime glass composition obtained by X-ray fluorescence. The mixture was cold pressed and sintered in air using a microwave muffle furnace (MAS-7000 ™ model, CEM Corporation) in three temperature steps 90 ºC, 600 ºC and 732 ºC, during 40 minutes.

The electrofused alumina and soda-lime glass powders and EAG pellets were analyzed by X-rays diffraction using an X-ray diffractometer RIGAKU, model Multiflex (copper anode; Cu-Kα radiation; 40 kV and 20 mA).

The fracture electron microscopy images of the EAG pellets were obtained by a Scanning Electron Microscope (SEM) Philips model XL-30.

Table 3- Composition of white electrofused alumina supplied by Elfusa

Componente	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	Na_2O	SiO_2	TiO_2
% peso	99,39	0,02	0,02	0,05	0,02	0,50	0,04	0,01
% mol	-	0,04	0,03	0,11	0,05	1,66	0,07	0,01

Table 4 - Soda-lime glass composition obtained by X-ray fluorescence

Element	%	Oxide	%
Si	60,24 ± 0,06	SiO_2	60,87 ± 0,21
Ca	22,28 ± 0,03	CaO	8,68 ± 0,04
Na	13,42 ± 0,25	Na_2O	26,6 ± 1,2
Al	2,41 ± 0,03	Al_2O_3	2,60 ± 0,11
K	1,14 ± 0,01	K_2O	0,15 ± 0,03

Irradiation systems

- ^{60}Co Panoramic Irradiator – 1.346 10^{13} Bq - irradiations performed free in air at electronic equilibrium conditions;
- ^{90}Sr/^{90}Y beta source – 1.4 10^9 Bq – dose rate of 0.1 Gy s^{-1} – irradiations performed inside the OSL reader.

TL and OSL Reader

The TL and OSL responses were performed using a RISØ reader TL/OSL-DA-20 model. The OSL measurements were performed in reading mode CW-OSL (Continuous Wave OSL) using blue *LED*s as a light source and a Hoya filter U-340.

Each presented value corresponds to the average of four measures and the error bars the standard deviation of the mean (1σ).

RESULTS AND DISCUSSION

EAG pellets

The general characteristics of EAG pellets obtained are summarized in Table 5. The apparent density and the volume were calculated by their weight and external dimensions.

Table 5. General characteristics of EAG pellets

Composition	
Weight	(51.4 ± 0.4) mg
Diameter	(5.53 ± 0.02) mm
Thickness	(1.04 ± 0.02) mm
Volume	(25.1 ± 0.3) mm^3
Density	(2.05 ± 0.03) g cm^{-1}
Sintering temperature	732 ºC

X-rays diffraction and fracture surface micrograph of AEG pellets

Figure 1 presents the X-ray diffraction pattern obtained to the soda-line glass (a) and electrofused alumina (b) powders and AEG pellets (c).

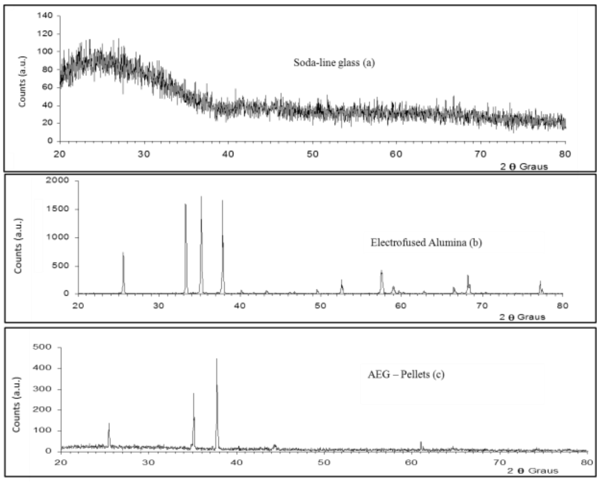

Figure1- X-ray diffraction pattern obtained to the soda-line glass (a) and electrofused alumina (b) powders and AEG pellets (c)

The soda-lime glass profile is typical of vitreous materials. Figure 2 presents the fracture surface electron microscopy image of the EAG sintered pellet.

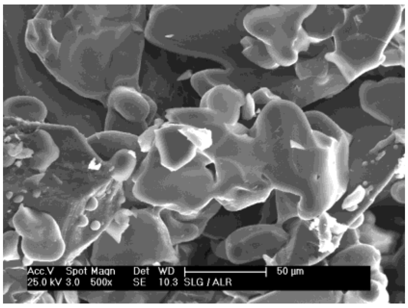

Figure 2- Fracture surface electron microscopy image of the EAG sintered pellet

TL and OSL glow curves

The typical TL glow curve obtained to electrofused alumina powder irradiated with ^{60}Co gamma radiation at electronic equilibrium conditions free in air presents two peaks, the first at 123 ^{o}C and the second at 226 ^{o}C, using a heating rate of 10 $^{o}C\ s^{-1}$ (Figure 3).

The typical TL glow curve of EAG pellets to the same irradiation conditions and using a heating rate of 5 °C s^{-1} is shown in Figure 4. The first peak appears at 175 ^{o}C and the second at 307 °C (Figure 4 a). The first peak can be easily eliminated by a post-irradiation heat treatment of 120ºC during 15min (Figure 4 b).

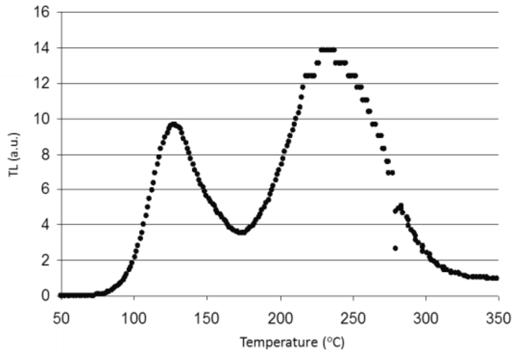

Figure 3- Typical TL glow curve of ELFUSA white eletrocfused alumina powder irradiated with ^{60}Co gamma radiation.

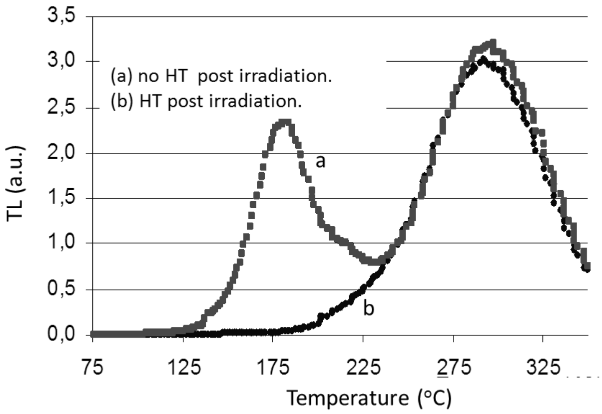

Fig. 4. Typical TL glow curve of EAG pellet obtained using white electrofused alumina irradiated with ^{60}Co gamma radiation (a), glow curve after heat treatment post irradiation of 120ºC/15min (b).

The OSL response curves of EAG pellets irradiated with $^{90}Sr/^{90}Y$ beta radiation source with absorbed doses between 0.1 and 2 Gy are shown in Figure 5. The OSL readout was performed using blue LEDs, with 10% luminous power, one second per point and CW-OSL illumination.

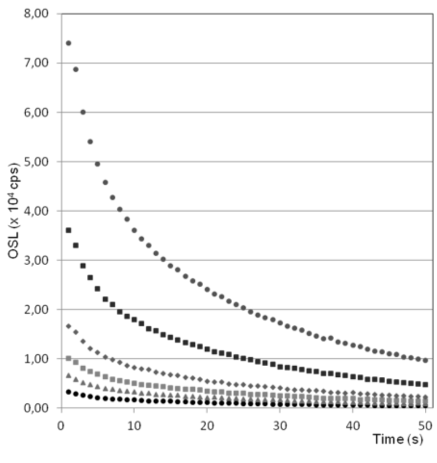

Fig 5. Typical OSL curves of EAG pellets irradiated with $^{90}Sr/^{90}Y$ beta radiation with absorbed doses between 0.1 and 2 Gy.

Repeatability of TL and OSL response

In order to verify the repeatability of TL and OSL responses a batch of ten pellets selected with TL and OSL response better than ± 5% was submitted to ten cycles of heat treatment at 400ºC / 1h , irradiation with the same standard beta dose and read out. The TL responses presented a standard deviation of the mean (1σ) of ± 2.8% and the OSL response ± 3.5%.

Dose Response

The TL response of EAG pellets irradiated with ^{60}Co gamma radiation at electronic equilibrium conditions with doses ranging from 0.2 to 10 Gy are presented in Figure 6, where can be observed a linear behavior to doses up to 2 Gy. For doses higher than 2 Gy a supra linear tendency is observed. The average TL reading of non-irradiated samples was subtracted of each presented point.

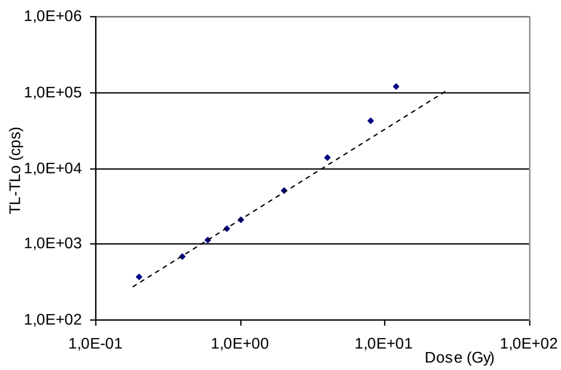

Fig. 6- TL dose response of EAG pellets irradiated with ^{60}Co gamma radiation.

The OSL dose response curve presents similar behavior, with a same linear response region between 0.1 and 2 Gy.

CONCLUSIONS

The soda-lime glass is a transparent and convenient material for sintering electrofused alumina at a temperature as low as 732 ^{o}C. This cold press and sintering procedure made possible to study TL or OSL properties of the electrofused alumina in pellet form.

The TL and OSL responses present interesting characteristics. The dose response curves present a desired linear behavior in a dose range between 0.2 and 2 Gy.

The EAG pellets are promising dosimeters, the obtained results indicate that EAG pellets can be used as an alternative detector in TL and OSL dosimetry, since characteristics such as thermal and optical fading, energy dependent response be analyzed.

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