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RESEARCH ARTICLE

DEVELOPMENT OF SILICONE RUBBER/LEAD OXIDE COMPOSITES AS GAMMA RAY SHIELDING MATERIALS

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Abstract

Silicone rubber composite sheets filled with different concentrations (15-42wt. %) of lead oxide was fabricated inhouse to be used as γ-radiation shielding materials. The shielding properties of the composite (linear attenuation coefficient (μ) and total mass attenuation coefficient (μ/ρ)) have been evaluated using three radioactive point sources (^{232}Th, ^{137}Cs and ^{22}Na) in the energy range (238 to 1275keV). When compared with the theoretical values which have been calculated by means of WinXcom program (version 3.1), a good agreement has been observed between the experimental and the theoretical results. The mechanical properties, such as tensile strength (σ_R), elongation at break (ε_R), Young's modulus (E) and hardness (H) have been studied and discussed. It was found that, adding filler into the rubber matrix is one of the main factors that improve the physico-mechanical properties and the best results have been observed at 35 wt. % of lead oxide concentration.

INTRODUCTION

In the field of gamma ray shielding, polymeric materials such as silicone rubber composites are going to replace the ordinary shielding materials (concrete shields and developed glass) because of their great properties (elasticity, light weight, durability)[1, 2]. Due to these advantages and its ease of manufacturing and shaping, silicone rubbers are used in our daily life in different fields such as medical devices, electronics, food storage products, automotive applications and in home repair with products such as silicone sealants. In nuclear applications such as γ-radiation shields, silicone rubbers cannot be used without additives because of their low atomic numbers (Z). So, Lead oxide with higher atomic number (Z) has been used as filler to improve the shielding properties and the physico-mechanical properties [3, 4]. Commercially, Lead oxide is available, cheap and one of the most effective materials used in shielding.

Rubber composites could be used in the medical field as a garment to protect patients and the operating personal from exposure to nuclear radiation during diagnostic treatment or imaging in hospitals, and to protect personnel working in the vicinity of airport scanners or similar devices [5, 6].

In this work, silicone rubbers/lead oxide composites were investigated for their γ-radiation shielding properties such as linear attenuation coefficient and total mass attenuation coefficient for different gamma energies ranged from (238 to 1275 KeV) by using three radioactive point sources (^{232}Th, ^{137}Cs and ^{22}Na).

2- THEORY

Shielding properties

The attenuation of mono-energetic gamma ray photons in matter can be calculated according to Lambert-Beer law [7, 8]

$$I(X) = I_O e^{-\mu x} \quad (1)$$

Where

I(x) is the photons that penetrates the sample of thickness x

I_O is the initial photon density

μ is the total linear attenuation coefficient

X is the thickness of the absorber

The mass attenuation coefficient could be written in the form:

$$\frac{\mu}{\rho} = \frac{ln\left(\frac{I_o}{I}\right)}{\rho x} \quad (2)$$

Where ρ is the density of the sample.

3-EXPERIMENTAL PROCEDURES AND TECHNIQUES

3.1. Materials

- Silicone rubber was supplied by SONAX (Neuburg -Germany).While Lead Monoxide of minimum assay (98 %) was supplied by Oxford Laboratory (Mumbai- India).
- Zinc oxide (ZnO), Strearic acid and Peroxide (IPBP) were supplied by Aldrich Company, Germany.

3.2. Sample preparation.

All rubber ingredients presented in Table 1 were prepared on two roll-mixing mills (outside diameter 470 mm, working distance 300 mm, speed of slow roll 24 rpm and friction ratio of (1:1.4) in accordance with ASTM D3182-07. The rubber compounds were vulcanized in an electrically heated hydraulic press at 152 ± 1 °C and a pressure of about 4 MPa for the optimum cure time (Tc_{90}). The rheometric behavior of the rubber compounds was determined using an oscillating disc, Monsanto rheometer model 100, according to ASTM D2084

Table1. : Formulations of silicone rubber compounds

Lead concentration, weight% / Ingredient, phr*	S0	S1(15%)	S2 (27%)	S3 (35%)	S4 (42%)
Lead Oxide	—	20	40	60	80
Silicone rubber	100	100	100	100	100
Stearic acid	2	2	2	2	2
Zinc oxide	5	5	5	5	5
Peroxide	3	3	3	3	3

*** Part per hundred parts of rubber.**

3.4. Mechanical properties

The mechanical properties (*e.g.* tensile strength (σ_R), elongation at break (ε_R) and Young's modulus (E)) of the rubber compounds were determined according to standard methods using an electronic Zwick tensile testing machine, model 1425 (Munchen, Germany) in accordance with ASTM D412.

Hardness (H) was measured using a Shore A durometer (Akron, Ohio, USA) according to ASTM D2240.

3.5. The mass attenuation coefficient

The vulcanized sheets prepared for radiation tests were vulcanized in square mold into four individual square shaped specimens (3x3cm). The linear attenuation coefficient of gamma radiation was measured in a narrow beam array using gamma spectroscopy technique in the physics department, Faculty of science, Ain shams university, Cairo, Egypt. The arrangement of the device consists of hyper pure germanium (HPGe) detector with relative efficiency ~30% relative to a 7.62 x 7.62cm NaI(TI) detector connected to multichannel pulse height analyzer. The necessary power for the detector as well as the acquisition of gamma spectra was achieved by an integrated spectroscopic system at 2900 volt. This system is controlled by a personal computer. The control of the acquisition parameters and analysis of the collected spectra are carried out using MAESTRO-32 software package. The detector is surrounded by Lead blocks (5cm thickness) as shield to smooth the background gamma radiation. The experiment was operated at liquid nitrogen temperature (~77K°).The sample was placed between the standard gamma point source and the detector. The experiment was repeated with and without the sample for 300s. The samples were irradiated by photons emitted from ^{232}Th, ^{137}Cs and ^{22}Na radioactive point sources in the energy range (238 to 1275keV).

4-Results and Discussions

Shielding properties.

The linear attenuation coefficient (μ) for silicone rubber samples filled by different concentration of lead oxide have been calculated as the slope of the relation between ln I/Io and the thickness of the sample at different photon energies. The linear attenuation coefficient (μ) and the total mass attenuation coefficient (μ/ρ) dependence on lead oxide concentration are both illustrated in Fig.1.and 2.

Fig.1: Linear attenuation coefficients as a function of lead oxide concentration

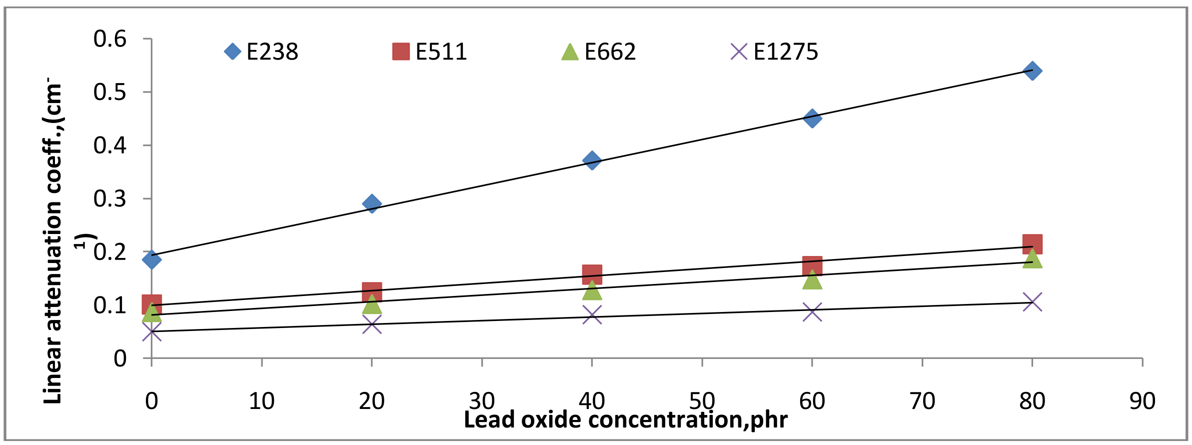
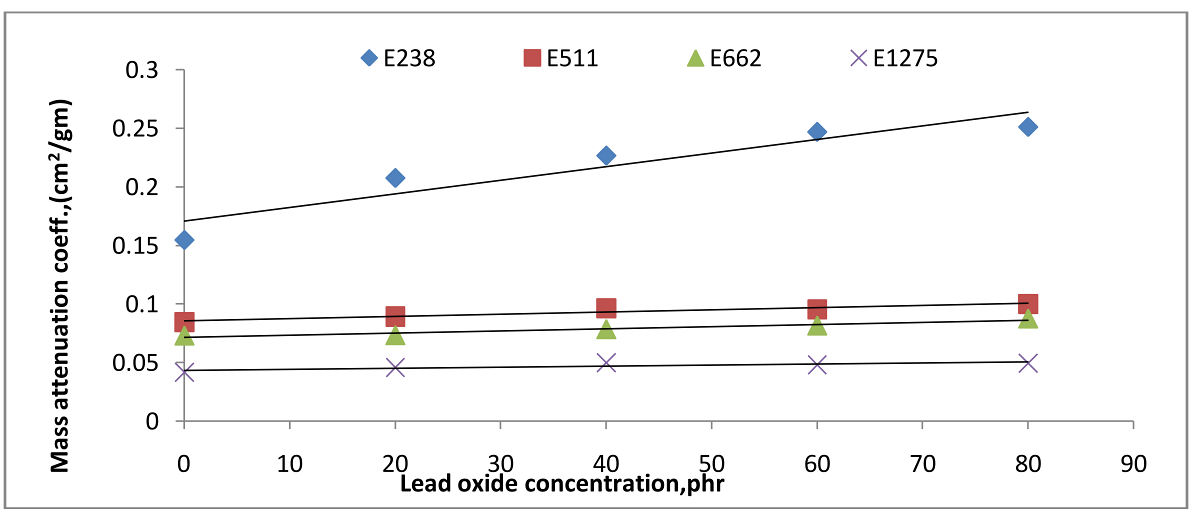


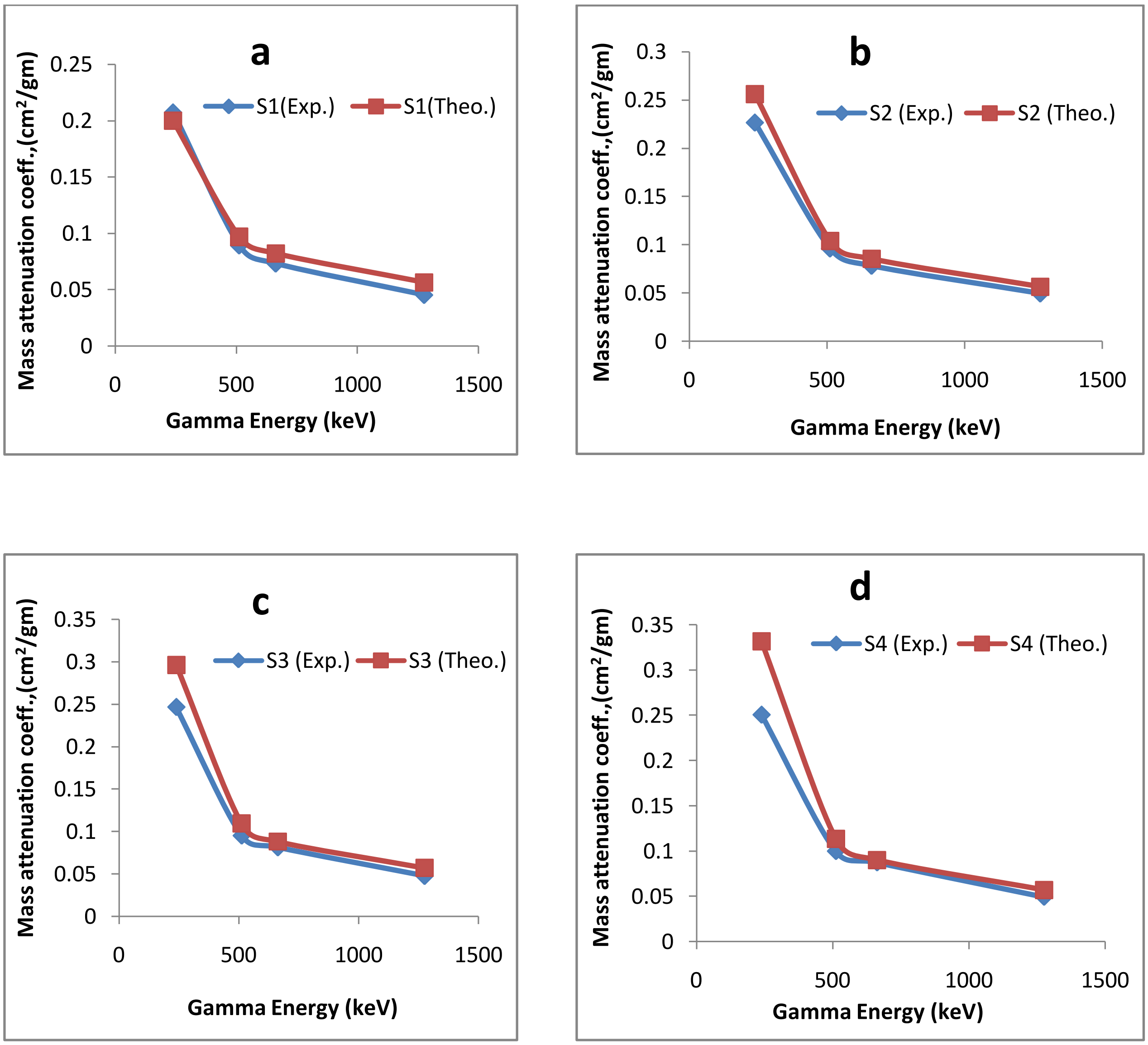
Fig.2: Total mass attenuation coefficients as a function of lead oxide concentration



It was shown that the linear attenuation coefficients of all silicone rubber composites increase with increasing lead oxide concentration at different energies due to the higher atomic number and density of lead oxide

The experimental mass attenuation coefficient of all silicone rubber samples filled by different concentrations of lead oxide (15 wt. %, 27 wt. %, 35 wt % and 42%wt) for different γ-ray energies were evaluated from the linear attenuation coefficient and compared with the theoretical values which are calculated by WinXCom program [9, 10]. Experimental and theoretical mass attenuation coefficients as a function of γ-ray energies for all samples are illustrated in Figs. 3 (a-d), a good agreement between the experimental and the theoretical calculations has been observed.

Fig.3: Experimental and theoretical mass attenuation coefficient as a function in gamma energy

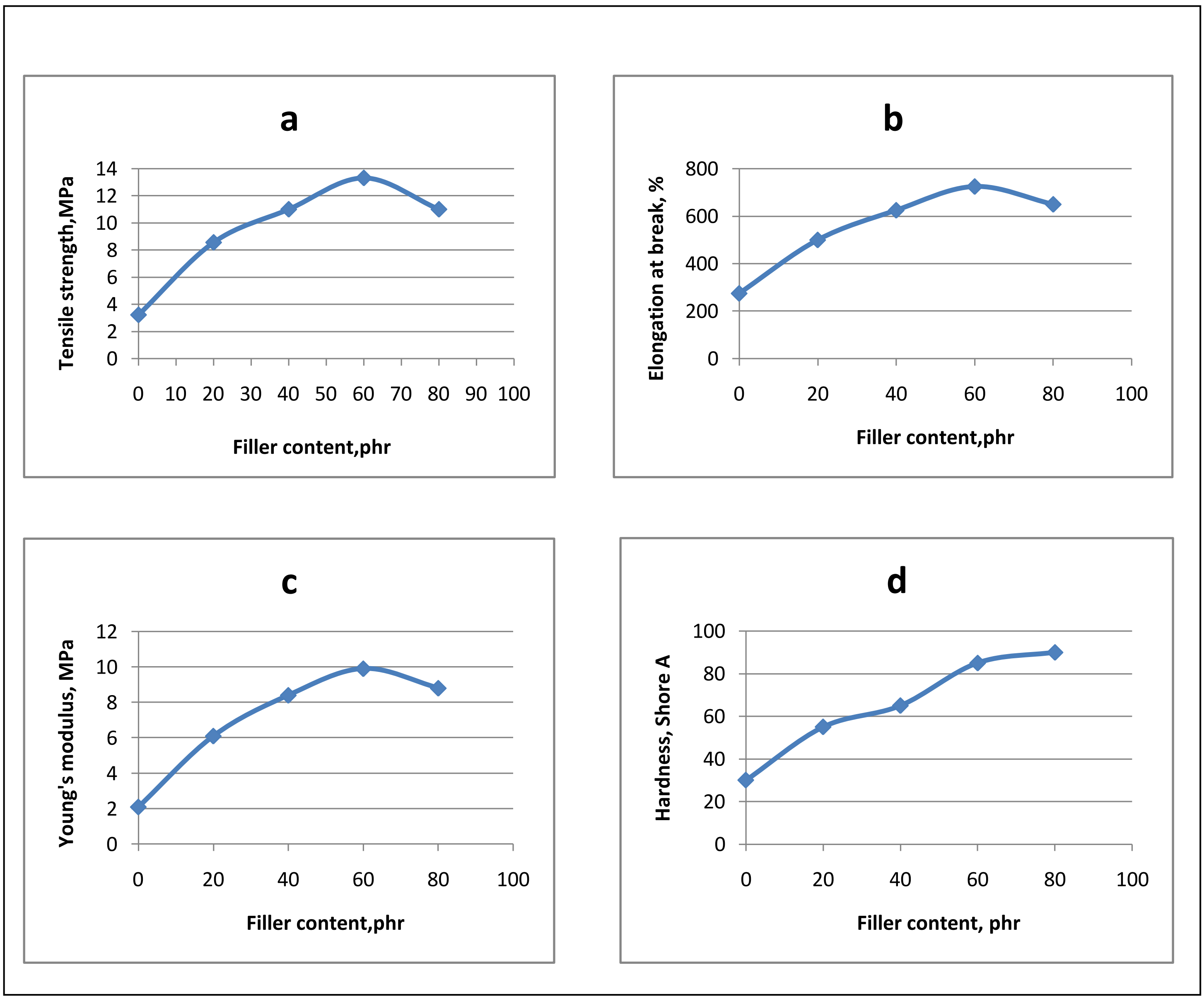


a) 15 Wt. % of lead oxide, b) 27 Wt. % of lead oxide, c) 35 Wt. % of lead oxide, d) 42 Wt. % of lead oxide

Mechanical properties:

In absence of reinforcing fillers, the mechanical properties of silicone rubber composite are relatively poor. The mechanical properties of this silicon rubber/lead oxide composite are summarized in figs.4a-d. These figures show the variation of the mechanical properties (tensile strength **(σ_R)**, elongation at Break **(ε_R)** and Young's modulus **(E))** with different concentrations of lead oxide as filler. It is clear that, an increase in the filler loading resulted in pronounced increase in the tensile strength **(σ_R)**, elongation at break **(ε_R)** and Young's modulus **(E)** up to 35 wt. %,. The improvements in tensile strength **(σ_R)**, elongation at break **(ε_R)** and Young's modulus **(E)** can be explained by the interactions at the phase boundaries on incorporating the lead oxide, as a result of the filler dispersion [11]. On the other hand, further addition of lead oxide leads to decrease in the previous properties. This finding denotes that about 35%wt of added lead oxide is the optimum loading which gives the best mechanical reinforcement for these composites. The decrease of the mechanical properties above 35 wt. % filler content is most probably due to the aggregation of the filler in different rubber layers [12]. Therefore, hardness increases because it is well known that the addition of filler in rubber compounds leads to an increase in the materials hardness linearly. Furthermore the hardness increasing rate is found to be reduced after 35 wt. % of lead oxide concentration.

Fig.4. Mechanical properties as a function of lead oxide content
a) Tensile strength **(σ_R)** **b)** Elongation at break **(ε_R),** **c)** Young's modulus **(E)** **d)** Hardness



5-Conclusion

In the present study, the radiation shielding properties such as linear attenuation coefficient and mass attenuation coefficient of silicone rubber composites filled with different concentrations of lead oxide were evaluated and compared with the theoretical calculations. A good agreement has been found between the experimental values and the theoretical values calculated by WinXcom program (version 3.1). The linear attenuation coefficients and the mass attenuation coefficients were found to be increased with the increase of lead oxide content.

The effect of lead oxide content on the mechanical properties (tensile strength (σ_R), elongation at break (ε_R), Young's modulus (E) and hardness (H)) has been studied and discussed. From the obtained results it is found that the mechanical properties (tensile strength (σ_R), elongation at break (ε_R), Young's modulus (E) and hardness (H)) increase with the increase of filler content up to 35 wt. % by weight and then decrease except the hardness. The hardness of silicone rubber composites increases as the lead oxide concentration increase because the addition of filler in rubber compounds leads to an increase in the materials hardness linearly. The present work shows a strong advantage of rubber composite shield for its low weight and elasticity compared with the standard shielding concrete.

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