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Gamma radiation induced effects of compressed silicone foam

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The effects of gamma radiation on mechanically-compressed, silica-reinforced silicone foam at various levels of absorbed dose and temperature were investigated in this study. The results show that irradiation temperature does not have an obvious influence upon the material morphology and properties. SEM characterization shows collapsed or deformed microstructures with increasing doses of irradiation, consistent with decreased sample thicknesses. The tensile strengths of irradiated samples increase significantly with dose level, eventually decreasing slightly with extreme exposure. Elongation at break decreases monotonically with irradiation, from a control value of 136.1 ± 4.0% to 27.0 ± 2.0% for samples exposed with a dose of 500 kGy at 45 °C. DSC studies show dose dependent crystallization phenomena and melting behaviors. The molecular weight of soluble materials decrease slightly with increasing absorbed doses. The property and morphology changes are probably attributed to the irradiation-induced crosslinking and radiolysis, the likely mechanisms for which are proposed.

1. Introduction

Silicone rubbers are synthetic polymers with silicon and oxygen in their backbones, exhibiting outstanding performance, including wide service temperature ranges [1], biocompatibility [2,3], chemical, oxygen and sunlight resistance [4], and good electrical insulation properties [5,6]. These useful properties have been further expanded by the addition of silica as a reinforcing agent [7]. Foams produced from silica-reinforced silicone rubber serve to reduce density and the volumetric cost of these materials. Silicone foams are generally produced using an excess of blowing agent and a peroxide crosslinker [8,9]; the blowing agent decomposes under heating, producing a porous structural material when cross-linked. Silicone foams produced in such a manner are promising for applications in extreme environments, such as exist in aerospace and nuclear power plant applications. Once exposed to gamma rays, polymers generally undergo chemical changes. The high-energy rays or particles cause formation free radicals which then lead to crosslinking or radiolysis, influencing the property and lifetime of the materials [10]. Many investigations of the effects of radiation on silicone rubber have been reported, but few studies on the effects of radiation on compressed silicone foams have been published to the best of our knowledge [11–16].

In this study, we examine the effects of absorbed dose and temperature on the morphological structure and properties of a silicone foam. The silicone foam was compressed when irradiated, to imitate the application environment of cushion material. ^{60}Co was used as the high-energy irradiation source to evaluate its effects on the mechanical, thermal, molecular weight and microstructural properties of a silicone foam. The general mechanisms of the microstructure change of the compressed silicone foam are also proposed.

2. Experimental

Materials. The silicone foam used in this study was methyl vinyl silicone foam, prepared as reported in previous publications [17,18], in which N,N′-Dinitrosopentamethylenetetramine (blowing agent H) is used as blowing agent, dibutyltin dilaurate is used as catalyst, and peroxide (dicumyl peroxide and benzoyl peroxide) is used as crosslinking agent. The gel fraction of the obtained silicone foam is about 95–97%.

Methods. Irradiation of the samples was carried out using a ^{60}Co source at Institute of Nuclear Physics and Chemistry, China Academy of Engineering Physics, China. Dog-bone shaped samples were sandwiched between two stainless steel plates, and clamped with a screw. The compression ratio was about 55% (Fig. 1). The samples

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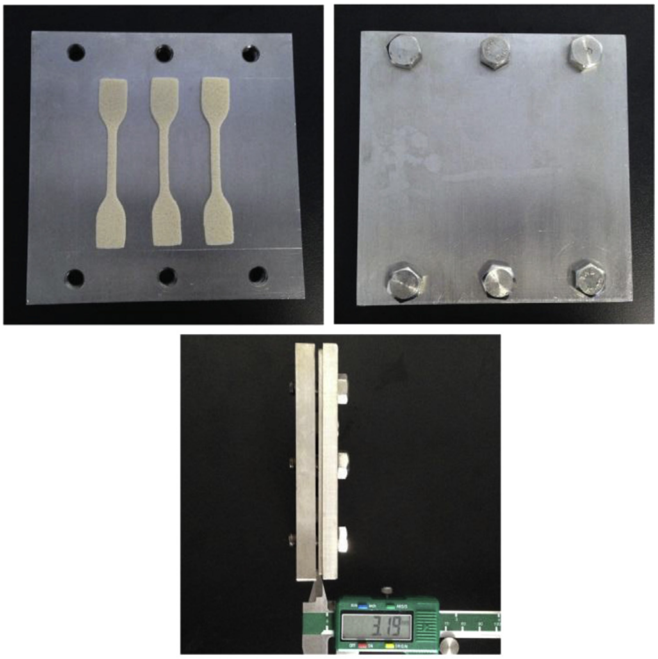

Fig. 1. Dog-bone shaped silicone foam sandwiched between two stainless steel plates.

were then placed in a steel container filled with air at temperatures of 45, 60 or 80 °C. The samples were irradiated at about 100 Gy min^{-1}, for times necessary to expose the samples from 50 to 500 kGy. The dose rate was determined by a $Ag_2Cr_2O_7$ standard dosimeter which was placed at sample position between two stainless steel plate. Then the total dose was calculated by dose rate and the accumulative radiation time. The samples obtained in this matter are denoted as A-B, where number A means the absorbed dose, number B denotes irradiation temperature.

3. Characterization

The microstructures of the samples were characterized using a ZEISS EVO 18 special edition scanning electron microscope at acceleration voltage of 10 kV. Both the surfaces and profiles of the samples were characterized for comparison.

Tensile strength and elongation at break measurements were carried out with using a SANS CMT7000 testing machine, fitted with a 1 kN load cell, at a crosshead of 10 mm/min. Five samples for each composition were tested for reproducibility.

DSC curves were obtained with TA Q200 DSC apparatus, calibrated with pure indium and zinc standards, with a liquid nitrogen cooling attachment. The 5.0 ± 0.5 mg samples were placed in the aluminum pans to test their thermal behaviors. The samples were first heated from −135 to 100 °C at 10 °C/min, and kept at 100 °C for 3 min to erase any thermal history, then cooled to −135 °C at 10 °C/min. The testing curves and corresponding data were recorded.

The molecular weights of the extracted samples were characterized with PL-GPC-220 high temperature chromatograph. Trichlorobenzene was used as solvent, with concentration of about 0.2 wt%.

4. Results and discussion

With its excellent chemical resistance and low glass transition temperature, silicone foam is widely used in cold regions as cushion material. The application of silicone rubber in special applications requires good resistance to irradiation as well. In this study, the irradiation effect of silicone foam under pressure at various temperatures was investigated using gamma irradiation.

The morphological microstructures were characterized and are illustrated in Fig. 2. On both its surface and profile, the control sample shows two different types of pores, with sizes of several hundred microns and several microns, respectively. The aggregation of silica is also observed with size of several microns. The larger pores flatten with an absorbed dose of 50 kGy under mechanical

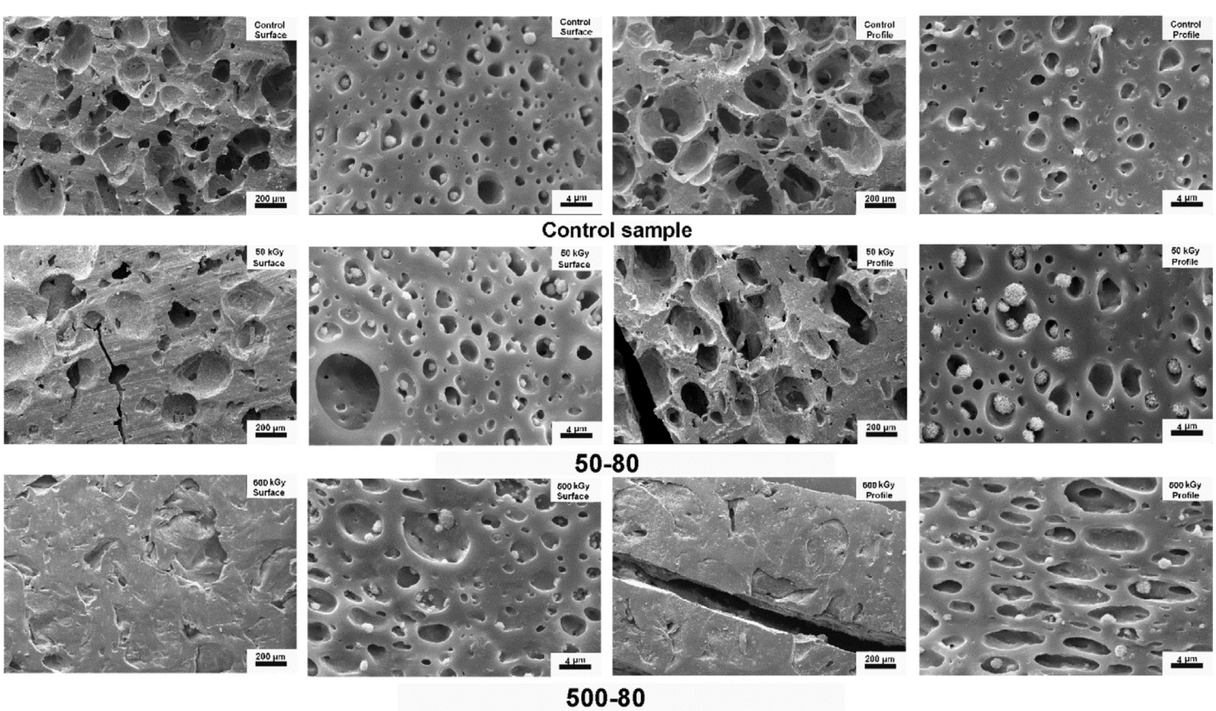

Fig. 2. SEM micrographs of irradiated silicone foams under pressure.