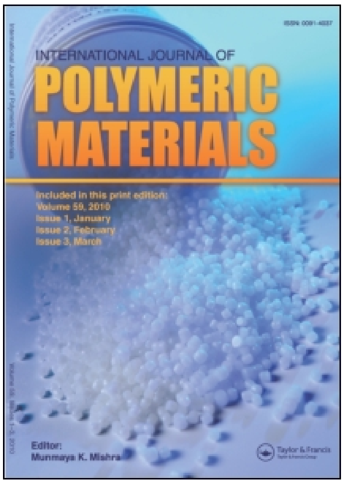

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Studies on the Interaction of Alpha Particles with Polycarbonate Materials

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The interaction of alpha particles irradiation with different commercial polycarbonate foils, from different suppliers was studied, aiming to test the foils as alpha particle detectors, analyzing the effect to the energy to the particles and the response of each material to the chemical etching aimed to reveal latent track.

The sensitivity to varying energies and the average backgrounds, which are important parameters to environmental measurements. The efficiency to alpha particles registration and the linearity of the different materials, as referred to the corresponding track density, were compared.

Keywords: Polycarbonates; alpha particles; irradiation; chemical etching

1. INTRODUCTION

The study of the interaction of all types of radiation with matter has been an active field of research and technological development in the past 70 years at least, not only due to the interesting scientific questions remaining to be answered, but also because of the practical applications that these phenomena represent. In particular, the formation of nuclear tracks in polymeric materials is known from about 20 years and still lacks a unifying model to explain many of the characteristics of the interaction of different types of radiation with polymers. The use of a number of polymeric materials as radiation detectors, through the measurement of the density, diameter and spatial distribution of the tracks, has been a powerful tool for applications ranging from medical instrumentation and dosimetry to soil contamination and exploration [1 – 9].

Among the polymeric materials employed as radiation detectors for the different applications, Poly Allyl Diglycol Carbonate (PADC), generally known in the radiation field as CR-39, represents one of the best examples of how a well-spread and employed technology rests on a very scarce fundamental scientific knowledge. Indeed, PADC is regarded among the specialists as one of the most sensitive materials for recording alpha particles [10] and has been employed in medicine, hydrogeology, materials science, in-situ monitoring of soils and radon detection [11, 12] and many arguments still exist on what is the main driving mechanism which leads to the formation of those latent tracks in the first place, which are subsequently revealed by a number of different methods, and theories based on a total or partial energy loss of the particle to the detector, or others which regards the process as elastic strain caused in the material by the ionization produced by the incoming particle, have not been able to explain successfully all the experimental information available. One interesting aspect of this discussion is the fact that relatively very few researchers from the Polymer Science and Technology area have been interested in these phenomena and, as a consequence, most of the theories proposed seem to forget that the macromolecular nature of PADC is certainly related to its effectiveness as particle detectors as compared to other solid state and gaseous materials [13, 14].

Accordingly, in this work, a study of the properties of various commercial PADC foils, with different characteristics, as alpha particles detectors is carried out, aiming to characterize the sensitivity, average background, efficiency of alpha particle registration and linearity of the response of the different materials analyzed.

2. EXPERIMENTAL

Materials from three different commerical manufacturers were chosen for this study, as follows: Polycarbonate materials from American Acrylics and Plastics Inc. (one CR-39 brand), Landtrack® from

Fukuvi Chemicals (CR-39 commercial grade), and five varieties of CR-39 from Pershore Moulding Ltd. Table I, contains, a summary of the relevant physico-chemical characteristics of the materials employed, according to the corresponding supplier. In every case five specimens of each material, from the same production set were analyzed. Laser beam was used for cut and coding the material, aiming to avoiding any handling contamination, physical damages and to introduce stress to the material.

The original material is produced in sheets in different sizes, depending basically on the manufacturer.

The sheets were cut into 19 mm×10 mm chips, and a total of 15 chips were employed for each measurement for each material to ensure a meaningful statistics.

The following alpha sources were utilized to irradiate the coded chips: Pu-239 (5.16, 5.11 MeV), Am-241 (5.49, 5.44 MeV) and Cm-244 (5.81, 5.77 MeV). The sources were conveniently calibrated and certified according to their disintegration rates in dpm and over a 2π geometry.

After irradiation, all the samples were chemically-etched in a single stage process [10–12], by using a 6N KOH solution at a constant temperature of 60±1°C. The pH of the solution was constantly measured and kept constant to obtain reproducibility in the etching. Additionally the etching solution was circulated through the detectors to ensure a uniformity of the track developing process.

Figure 1, shows an actual photograph of both the polycarbonate chip and the typical track etche.

3. RESULTS AND DISCUSSION

Figure 2 contains the information of the decrease in thickness of the polycarbonate foil as a function of the etching time, that is, the bulk etching rate of the material studied. It is extremely interesting to notice a number of facts from the figure. First, the clearly linear dependence of the amount of the material etched with the corresponding etching time, with different bulk rates for the different process on the PADC preparation. This behavior, for all the materials studied, falls within one out of four possible bulk rates and all of them are linear.

TABLE I Characteristics of various PADC used in this analysis

Detector Material and Code	*Dioctyl Phthalate (%)*	*Curing time (h)*	*Protective cover (μm)*	*Optical transmission before etching (%)*	*Optical transmission after etching (%)*	*Type*
American Acrylics (AA)	Unknown	Unknown	350	90	20	Commercial
Lantrack (Fukuvy)	0.3	32	250	91–92	91–92	Commercial
Pershore (PH-355)	0.0	32	200	91	78	Super Grade I
Pershore (PH-500)	0.0	16	200	92	78	Super Grade II
Pershore (PS-0.2%)	0.2	32	200	93	93	Special
Pershore (PS-1%)	1.0	32	200	92	92	Special
Pershore (PS-32)	0.3	32	200	90	25	Commercial

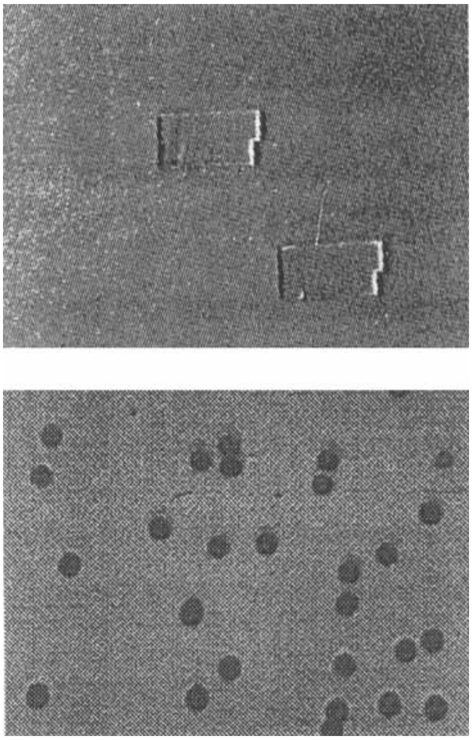

FIGURE 1 CR-39 chip and a typical track etched.

Notice also that this linear dependence goes up to nearly 300 μm, which constitutes a considerable percentage of the whole thickness of the foils. This result indicates that, at least from a chemical dissolution standpoint, the foils are very homogeneous, which allows to rule out possible artifacts when counting meaningful nuclear tracks. In fact, the likely causes reported in the literature of polymer artifacts in these applications, are the chemical impurities, surface scratches during the preparation, or even atmospheric radon. Therefore, it is important to rule out those artifacts from the very beginning.

As can be observed in Table I, some of the suppliers add Dioctyl Phthalate to their formulations, as plasticizer, since the flexibility of the foils is a requirement for most practical applications and this is

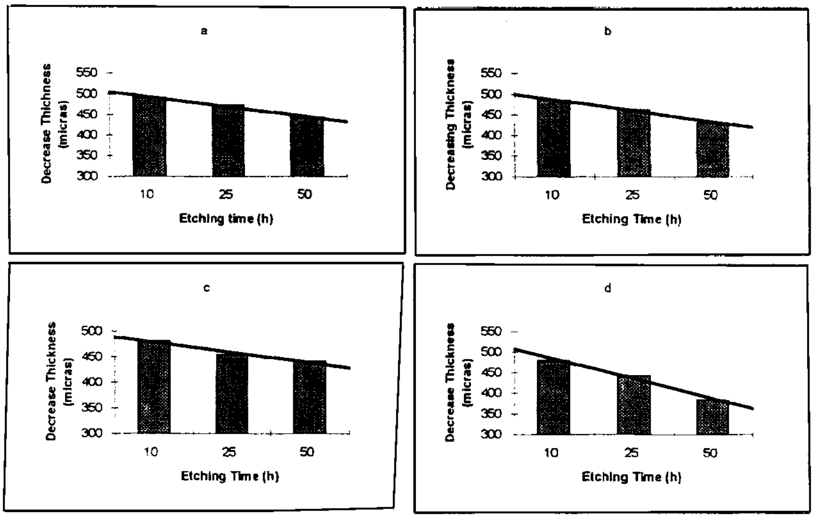

FIGURE 2 Bar graph of the decrease thickness as a function of the etching time. a) Pershore (PS-32); b) Landauer (Fukuvy); c) Pershore (PS-0.2%) and Pershore (PS-1%); d) Pershore (PS-500), Pershore (PS355) and American Acrylics.

surely to be related to the changes in the corresponding mechanical properties of the material, which in turn would be reflected on the etching behavior of the materials.

It is a well known fact that free radicals in materials, especially of organic nature, have a strong influence on their degradation processes. Indeed, a couple of possible phenomena could take place while irradiating a double bond-containing material. One is the polymerization of molecules into larger ones, especially for $C{=}C$ and $C{=}O$ double bonds, and the second the scission of relatively large molecules into smaller ones, likely to occur in oxygen-containing double bonds, such as the hydroxyl group [15].

In the PADC case, both degradation phenomena are likely to occur, given the molecular structure of the material, schematically depicted in Figure 3. Moreover, the dielectric breakdown of PADC materials after been subjected to irradiation, shows an interesting fractal-like behavior which has been qualitatively associated to the possible paths of the ionizing radiation into the material [16].

$C_{12}H_{18}O_7$

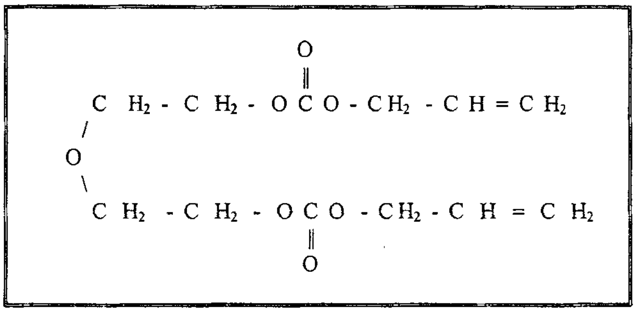

FIGURE 3 Chemical Structure of PADC.

It is accepted now that ion beam-induced scission of polymeric chains produces an effective charge redistribution along the skeletal backbone of the macromolecule. This would cause chemically-unsaturated bond in a variety of topologies of crosslinked rearrangements of the fragments produced during the irradiation. Therefore, the addition of rheological agent would allow to modify the concentration of nucleation centers for the development of latent tracks, which are subsequently revealed through the etching process.

On the other hand, the efficiency of the materials studied shows a moderate dependence on both the energy of the incoming alpha particle and on the specific material utilized. It is important to mention that the alpha particles coming near grazing angles are not detected as etched tracks, since tracks oriented nearly parallel to the surface are eliminated by the bulk etching of the materials. Hence, 100% registration efficiency is commonly achieved as function of the different chemical characteristics of the polymer, as shown in Figure 4, with a planar emitting source or particle accelerator beam. In a practical monitoring situation, where the emitting surface are rough, dirty and, as in the case of applications, such as soils, composed of inhomogeneous grains, the effective energy of the alpha particles will be significantly degraded. Under those circumstances, the relationship

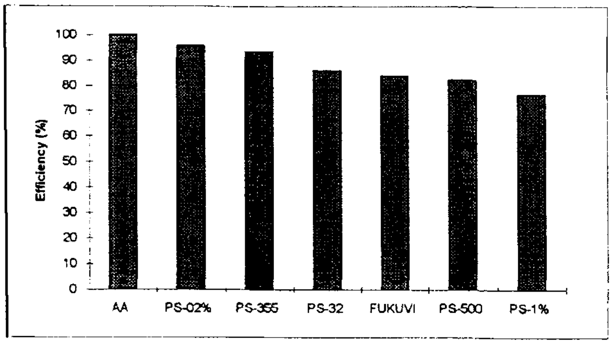

FIGURE 4 Response of the different materials.

counting efficiency-parent isotope will be less clear than one could desire for identification and/or quantification purposes.

4. CONCLUSIONS

The results of the analysis of different commercials PADC from various suppliers, show that, in spite of all materials having basically the same molecular formula, the details of the fabrication process have a strong influence on the degradation behavior while subjected to alpha particles irradiation. In particular, the use of plasticizers clearly affect the efficiency of the materials as radiation track detectors, area poorly studied and which certainly deserves more attention, especially if a fundamental knowledge of the radiation-matter interaction in these polymeric materials is to be achieved.

Acknowledgements

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