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Teflon Examination

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Executive Summary

In this document, we outline an experiment performed at LLNL to evaluate the radiation sensitivity of polytetrafluoroethylene (PTFE) and a PTFE isomer, fluorinated ethylene propylene (FEP). We demonstrate that PTFE, a material currently used for assessing MicroCT system stability, shows higher radiation-dependent change in x-ray attenuation than FEP. Specifically, for a dose of approximately 1.44×10^3 Gy, the linear attenuation coefficient (LAC) of PTFE changes by 0.8 ± 0.1 %. During the same irradiation period, the LAC for FEP changes by 0.02 ± 0.1 %, which is within the statistical uncertainty of the measurement. Due to its higher resistance to radiation damage, we recommend that LLNL and partner labs operating under the Department of Homeland Security's Explosives Division (DHS EXD) transition to the use of FEP as a reference material in place of PTFE.

1. Introduction

MicroCT systems are an integral part of homemade explosive (HME) characterization and quality control (QC) in support of efforts sponsored by the Department of Homeland Security's Explosives Division (DHS EXD). In this role, it is important that MicroCT systems provide stable characterization results over time. During HME characterization, MicroCT system health is assessed for system drift by scanning known reference materials concurrently with a specimen [1]. Specifically, after dual-energy scans, verification is done by assessing if reference material attenuation values as well as ratios of attenuation values measured from the dual-energy scans lie within predetermined reference material quality control bounds.

One such reference, PTFE, often referred to by the trade name Teflon, has been shown to exhibit changes in x-ray attenuation with irradiation [2], [3]. This is problematic because drifting PTFE response may, over time, indicate MicroCT system health problems in the absence of actual system drift. As PTFE was discovered to exhibit radiation damage, we decided to evaluate an isomer that is more resistance to radiation damage, FEP [2], [3].

Section 2 describes the experimental setup and CT technique to compare the attenuation stability as a function of radiation dose for PTFE and FEP. Section 3 presents the effect of radiation dose on the stability of the linear attenuation coefficients of PTFE and FEP. We end with a conclusion in section 4.

2. Experimental Procedure

a. Setup

The MicroCT system's main components include a Perkin Elmer XRD 1620 flat-panel amorphous-silicon detector and an Yxlon 450 kV D09 x-ray tube head as well as a two-level holder or "carousel" and double-slit collimator which were designed in-house (Figure 1). The upper part of the carousel holds the specimen, while the lower part contains the six reference materials: graphite, water, silicon, magnesium, polyoxymethylene (POM), and PTFE. The two narrow slits in the double slit collimator define two projection regions. The top slit allows x-rays to pass through a specimen, while the lower slit gives access to the six reference materials. A 360-degree carousel rotation of stepped projections produces radiographs that are reconstructed into two sets of cross-sectional images of the specimen and reference materials [4] .

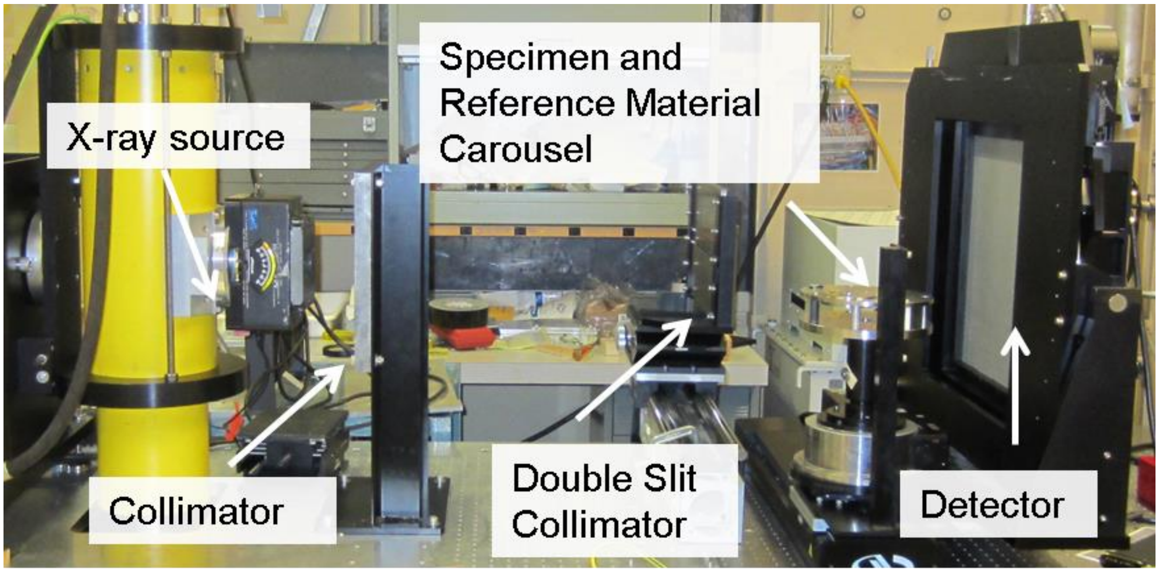

Figure 1 Photograph of the microCT system.

b. Acquisition Procedure

Two half-inch diameter PTFE and two half-inch diameter FEP specimens were considered. Set 1, which consisted of one PTFE specimen and one FEP specimen labeled $PTFE_1$ and FEP_1, respectively, served as the control specimens. Set 2, which consisted of one PTFE specimen and one FEP specimen labeled $PTFE_2$ and FEP_2, respectively, served as irradiation specimens. Each of the control and irradiation specimens were acquired and cut from the same respective uniform rods. All four specimens were individually placed in the upper carousel for CT acquisition. To confirm CT settings remained consistent before and after irradiation, control specimens were scanned individually as well as the irradiation specimens. After the 1st set of four CT scans was acquired, $PTFE_2$ and FEP_2 were irradiated 19 cm away from the x-ray source for 8 hours, with the x-ray source operated at a voltage of 100 kV with 2 mm of aluminum filtration and current of 15 mA. The dose to $PTFE_2$ and FEP_2 during the 8-hour irradiation phase is estimated to be 1.44×10^3 Gy. This dose is equivalent to the dose accrued over 711 dual-energy MicroCT scans. Following irradiation, CT scans were again taken of all four specimens.

The CT scan parameters used to determine the attenuation change as a function of dose are shown in Table 1, and follow the Livermore Explosive Detection Program (LEDP) MicroCT Acquisition Standard Operating Procedure (SOP) [1]. Linear attenuation coefficients (μ) were normalized by the linear attenuation coefficient of water (μ^w) from the reference data set. Normalization was done to account for any systematic drift of linear attenuation coefficient values.

Parameter	Value	Parameter	Value
Scanner	450 kV Test Bed	Source Spot (mm)	1 mm
Detector	XRD 1620 AN	Anode Type	W
Source	Yxlon 450 kV	Detector Elements	2048 x 2048
Number of Angles	720	Detector Pitch (mm)	0.2
Angular Range	360 Deg.	Detector Frame Averages	4
Source Energy	100 kV	Source-Object-Distance	1095 mm
Source Current	7.5 mA	Object-Detector-Distance	308 mm
Source Filter(s)	2 mm Al	Source-Detector-Distance	1403 mm

Table 1 Technique parameters used to scan PTFE and FEP.

3. Results

a. Comparison of μ^w values

For each specimen, the percent change between the normalized linear attenuation coefficient from the first CT scan and the second CT scan was calculated as:

$$Percent\ change\ for\ specimen\ x\ (\%) = 100\ \frac{\mu^w_{2nd\ CT\ scan\ of\ x} - \mu^w_{1st\ CT\ scan\ of\ x}}{\mu^w_{1st\ CT\ scan\ of\ x}}\ [Eq.1]$$

where x is the specimen (e.g. $PTFE_1$, FEP_1, $PTFE_2$, FEP_2), $\mu^w_{1st\ CT\ Scan\ of\ x}$ is the normalized linear attenuation coefficient calculated from the 1st CT scan for specimen x and $\mu^w_{2nd\ CT\ scan\ of\ x}$ is the normalized linear attenuation coefficient from the 2nd CT scan for specimen x.

Table 2 list μ^w values and Figure 2 graphs the percent change. While $PTFE_2$ and FEP_2 both received 1.44×10^3 Gy, change of the linear attenuation coefficient as a function of radiation dose is only apparent in $PTFE_2$.

	μ^w	
Sample ID	**1st CT Scan (mm^{-1})**	**2nd CT Scan (mm^{-1})**
FEP_1	2038.7 ± 10.5	2039.4 ± 10.4
FEP_2	2038.9 ± 10.2	2039.4 ± 10.3
$PTFE_1$	2058.2 ± 10.1	2057.5 ± 10.5
$PTFE_2$	2058.7 ± 10.1	2074.8 ± 10.2

Table 2 List of μ^w values for FEP and PTFE specimens. Mean and standard deviation were determined from voxels included in the segmented region of interest in the CT reconstruction.

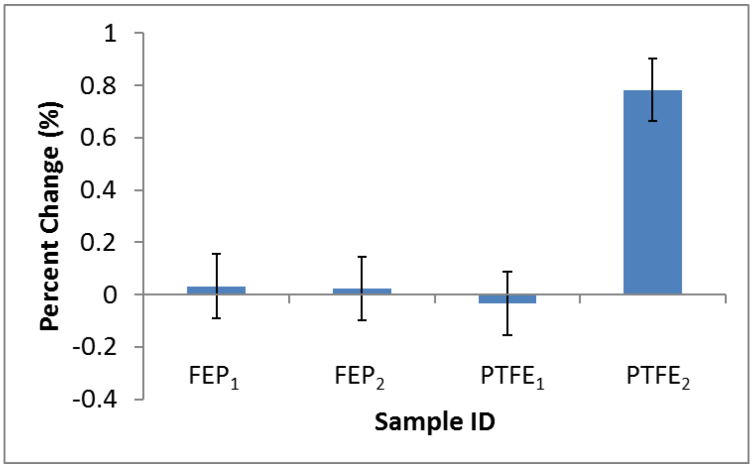

Figure 2 Graph of percent change given by Eq. 1 for each specimen. Error bars correspond to the standard deviation of the mean. Negative percent change measured for $PTFE_1$ is not statistically significant as the measurement is within the noise.

b. Estimation of dose per dual-energy CT scan

Dividing the observed percentage change in $PTFE_2$ attenuation by the estimated scan equivalence of the 8-hour irradiation yields an estimated per dual-energy scan change in μ^w of 0.0011% (ignoring source-intensity reduction through the sample thickness). In comparison, empirical measurements from MicroCT scans taken over a two-year period at LLNL suggest an increase in μ^w of ~0.0015 % per scan for a PTFE reference rod (Figure 3). These numbers are consistent within the limited accuracy of the measurements.

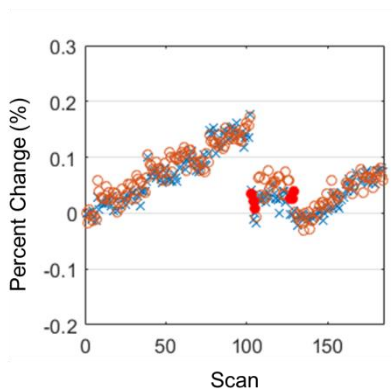

Figure 3 Measured percent change in μ^w during a set of dual-energy scans. Slope suggests percent change per dual-energy scan of 0.0015%. Jump discontinuities (marked by solid red dots) indicate events where the Teflon reference was physically manipulated (flipped upside-down) or replaced [2].

4. Conclusion

The measurements of specimen LAC increase for PTFE are consistent with the μ^w increases seen in recorded MicroCT data over a two-year period. The μ^w increase for FEP was less than for PTFE and below the statistical sensitivity of the experiments. Due to its higher resistance to radiation damage, we recommend that LLNL and partner labs operating under the Department of

Homeland Security's Explosives Division (DHS EXD) transition to the use of FEP as a reference material in place of PTFE.

References

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