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Spatially Resolved Analysis of Material Response to Destructive Environments Utilizing Three-Dimensional Scans

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Abstract

The response of a material to destructive environments is difficult to quantify experimentally. In thermal environments, the size and shape of the material changes as it pyrolyzes, warps, and chars. Quantitative descriptions of such material responses are valuable for data reporting and model validation. In this work, a three-dimensional scanner is evaluated for non-destructive material analysis. The scans spatially resolve the response of materials to a high-heat-flux environment. To account for the effect of distortion induced in thin materials, back-side scans of the sample are used to characterize the displacement of the bulk material. Data spanning the area of the sample, rather than using a net or average quantity, enhances the evaluation of the crater formed by the incident flux. The 3D reconstruction of the sample also provides the ability to perform volumetric calculations. The data obtained from this new methodology may be useful for characterizing materials exposed to a variety of destructive environments.

Preliminary Results

3D scans were obtained using a NextEngine 3D Scanner Ultra HD. The scanner uses 650 nm lasers to scan the sample and captures data using two 5.0 Megapixel CMOS image sensors. The sample surface was reconstructed using three separate scans. One scan was taken normal to the surface; two were taken after rotating the sample 36 degrees in either direction. The advertised accuracy of the scanner is 0.005 in, but the device is not commonly used on predominately flat objects, such as the samples in this test series. The accuracy of the scanner may need to be independently validated. The scanner is sensitive to color variations, which are erroneously measured as depth variations in some cases. The manufacturer recommends coating the sample if these errors become significant.

The 3D scanner proved to be a useful tool for quantifying the effect of the concentrated solar energy on the materials tested; however, the resulting data were complicated for materials that distorted upon heating. The depth of the crater formed (~1 mm) was relatively small compared to the displacement of the bulk material (~1 cm). As a result, the data generally do not reveal effects

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of pyrolysis and charring. The distortion also prevents quantitative analysis of the crater that might otherwise spatially resolve the mass flux from the sample.

To obtain sufficient quality data for analyzing the crater depth, a second 3D scan was taken of the backside of the sample. Assuming the backside of the sample was initially flat, the resulting scan reveals how much the material warped during heating. Using the back as the reference surface, the back-side distortion is subtracted from the front-side data. Effectively, this process yields the thickness of the material, negating the impact of distortion.

However, distortion was not the only issue experienced in the 3D scans. Varying surface color biased the depth of the sample. Additionally, reflective surfaces could not be resolved. Both issues were addressed using by spray coating the sample with a white, matte layer. Following recommendations of the 3D-scanner manufacturer, Magnaflux Spotcheck SKD-S2 Solvent-Based Developer was used for this purpose.

For example, results for a polystyrene sample are provided in Figure 1. The sample, which was originally flat, distorted significantly; the depth of the crater is not discernable from the scan of the front surface. After accounting for distortion with the backside scan, the crater is clearly visible and is about 0.4 mm deep.

Incorporating the backside scan helped significantly; however, the color variations are still having a notable effect. For example, the streaks well outside the crater are merely darkening of the sample from smoke deposits. Repeating the process for a spray-coated sample, the distortion-corrected scan (Figure 2) was produced again. The thickness is much more uniform outside of the crater; the blackening from the smoke is no longer evident. The data in the crater also appear less noisy.

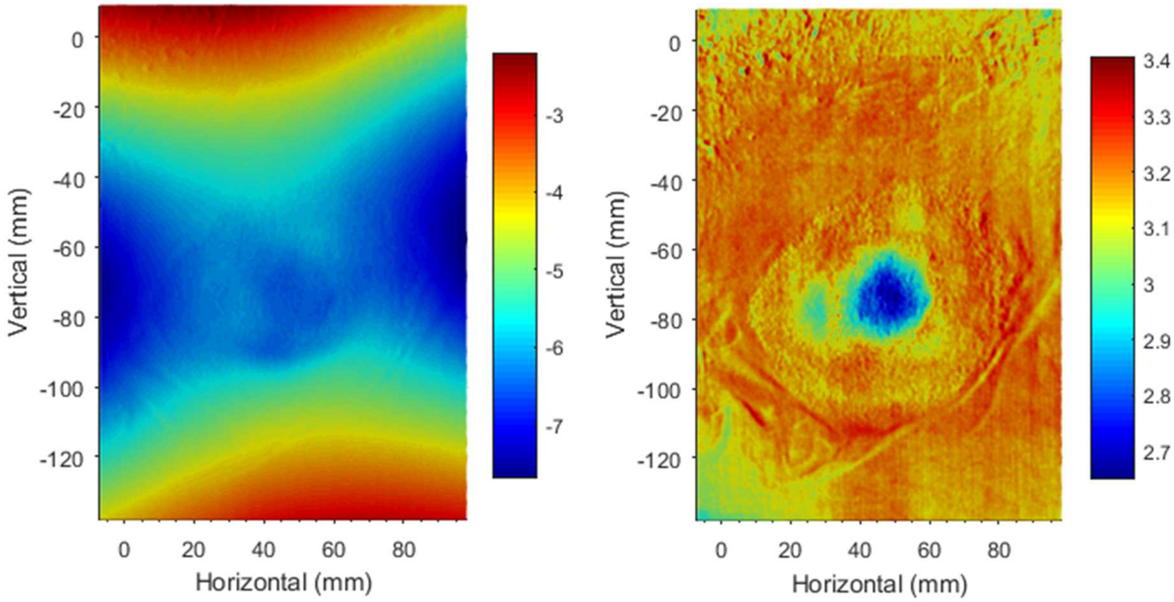

Figure 1. 3D Scans of an uncoated high-impact polystyrene sample including front surface (left) and calculated thickness of material using back-surface scan (right). Note that the zero-value on the color bar is arbitrary for the left scan.

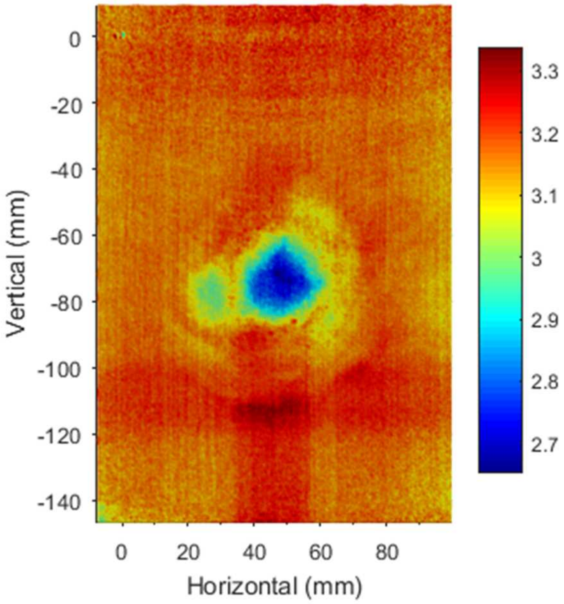

Figure 2. Calculated thickness of a high-impact polystyrene sample coated with Magnaflux Spotcheck.

PMMA is examined next. In addition to distorting upon exposure, the material was very reflective; the original series of scans often could not resolve the surface. Scans were obtained on a coated sample and are presented in Figure 3. The reflective surface is now correctly identified, but the distortion of the front surface still necessitates correction using a backside scan. After the distortion is accounted for, the crater is well-defined. The crater is very large and uniform.

Using the density of high-impact polystyrene (1.04 g/cm^3), the net volume change is calculated by numerically integrating the difference between the calculated thickness to the original thickness across the surface of the material. Using the density of the material, the net volume change is then compared to the mass-loss data. Limiting the analysis to the area within the crater, the reconstructed thickness indicates the sample volume changed by 0.25 cm^3; consequently, the estimated mass loss is 0.26 g. This is roughly half the mass loss recorded in the experiments. Possible explanations for the difference include:

- The material on the crater surface may have a different density than virgin material, such as if the material swelled, charred, deposited soot, or lost volatiles beneath the surface.
- The depth of the crater obtained by the 3D scanner may be inaccurate.

Following the same procedure, the density of PMMA (1.18 g/cm^3) is used to predict its mass loss. The sample volume changed by 5.25 cm^3, yielding an estimated mass loss of 6.2 g; the actual mass loss for this sample was 6.0 g. The level of agreement is promising, suggesting that volume change can reasonably represent the mass loss for PMMA. If this assumption is true, the 3D scans can spatially resolve the mass flux from the PMMA samples. With these data, we can better validate model predictions.

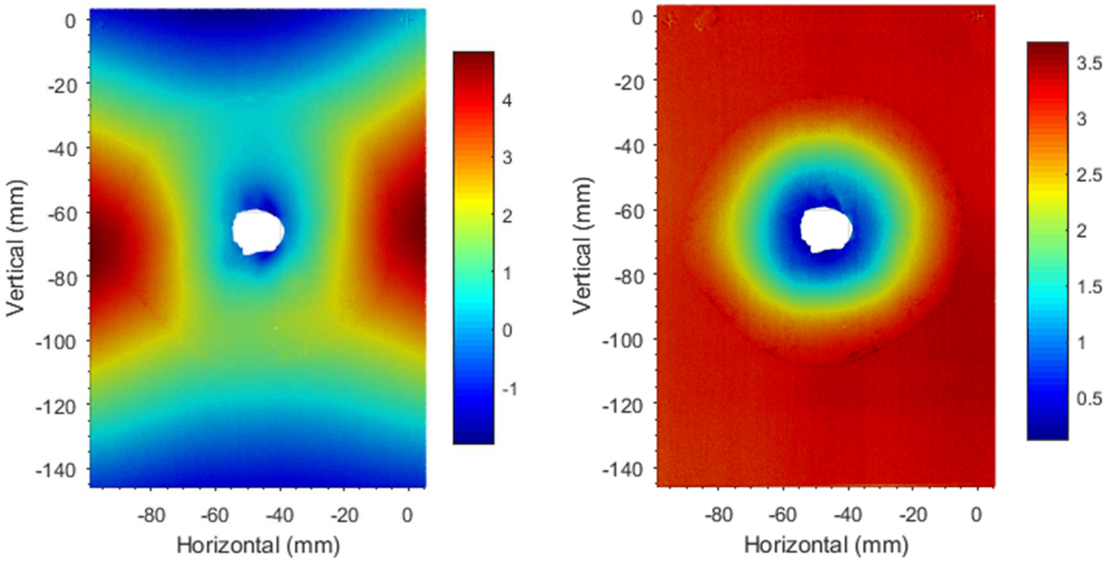

Figure 3. 3D Scans on PMMA including front surface (left) and calculated thickness of material using back-surface scan (right). Note that the zero-value on the color bar is arbitrary for the left scan.