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Quantitative Histogram Damage Assessment Method for Low Velocity Impact of Transparent Materials

by Raymond E. Brennan

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14. ABSTRACT

Projectile impacts to transparent materials used for window and windshield applications have been evaluated nondestructively to determine the degree of damage and the effect on operator visibility. While qualitative imaging methods can provide information on the volumetric damage sustained after an impact event, a quantitative measurement of visible and invisible damage is necessary for accurate comparison of standard and novel materials being fabricated for vehicle protection. For this reason, a quantitative histogram technique has been developed and applied to ultrasound C-scan images to provide a damage assessment value for ranking transparent materials in their ability to withstand damage and maintain visibility.

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1. Introduction

The following method has been developed for quantitatively estimating the percent damage incurred in transparent laminate targets subjected to low velocity impact testing. Ultrasound C-scan imaging has been chosen as the nondestructive evaluation (NDE) technique for obtaining a representative map to contrast damaged and undamaged regions at the surface/near surface as well as through the bulk of transparent targets. This method has been applied to C-scan images in which the bottom surface signal amplitude has been mapped to represent damage through the bulk of each target. The reduction in amplitude of the bottom surface reflected signals indicates the presence of damage, with complete signal attenuation indicating the highest degree of damage. The result is a two-dimensional (2-D) map of damage through the entire volume of the transparent target.

2. Method

The C-scan damage map is processed using an inverted grayscale in which the color white represents the highest degree of damage. While some imaging programs use raw data (*x*-position, *y*-position, and signal amplitude) to generate the map, in this case, the entire image is obtained as its own separate entity in Bitmap format. The edges of the image are cropped to remove any edge effects that may compromise the accuracy of the percent damage calculation.

Once the final image is obtained, it is ready for processing. Origin 8 software from OriginLab Corporation is the program of choice for working with the data because of its ability to effectively convert images into a variety of data formats. The program is used in the following way to determine a damage assessment value:

- Under the File menu, select the New tab to open a new Matrix. The matrix is a grid of data that incorporates the position and amplitude of a given image.

- Under the File menu, use the Import tab to import a selected image. The selected grayscale image appears in the matrix and can be displayed as either an image or converted data.

- Under the Plot menu, choose the Statistics tab and select the Histogram feature. The histogram of the C-scan image is displayed as a function of grayscale levels on the *x*-axis and number of occurrences on the *y*-axis. Creating the histogram also forms a table of the grayscale levels and number of occurrences. On the histogram, the *x*-axis ranges from black on the left side to white on the right side. Typically, there is a large curve or series of curves representing the undamaged region of the target. The damaged region is typically at

the right side of the histogram curve. Any occurrences of "white" or very light colors in the image indicate the damaged portion of the target.

- At this point, choose a threshold on the histogram in which any occurrences to the right represent the damaged regions of the target and any occurrences to the left represent the undamaged regions. The idea is to separate and distinguish the total number of occurrences that represent "undamaged" and "damaged" regions of the C-scan image. This is often the most difficult step in the process, since a definitive threshold value is not always clear. When possible, the grayscale level representing the lowest number of occurrences to the right of the undamaged histogram curve or to the left of the damaged histogram curve is used.

- Once the threshold value is determined, the table of grayscale levels and number of occurrences is referenced. While the columns are named "red," "green," and "blue," the values are identical in each column since the original image is in grayscale. The grayscale level associated with the threshold is located and all occurrences of higher grayscale levels are highlighted, or selected. Copy and paste this set of data, representing the total number of damage occurrences, into a new workbook, by selecting the File menu under the New tab to open a new Workbook.

- Highlight the entire column and use the right mouse button to bring up the associated menu. By choosing the "Statistics on Columns" option, a new set of data is formulated to include the summation of all occurrences in the selected column.

- In order to obtain the summation of all occurrences from the image, use the same procedure on one of the columns of occurrences corresponding to the original set of data (i.e., the "red," "green," or "blue" column).

- To acquire the damage percentage, divide the total number of damage occurrences by the sum total of all occurrences and multiply by 100. The quantitative percent damage value can be used to estimate the amount of damage in the transparent target.

3. Results

The procedure outlined in section 2 was demonstrated on target 740-1, a transparent laminate system impacted with a steel sphere from an air gun. The bottom surface reflected amplitude C-scan image was generated by scanning the target with an ultrasound transducer, as shown in figure 1. The data were processed in inverted grayscale so that the most highly damaged regions were represented by the white areas of the image. After cropping the edges off of the image, it was imported into Origin 8 as a matrix. The data were converted into histogram form, as illustrated in figure 2.
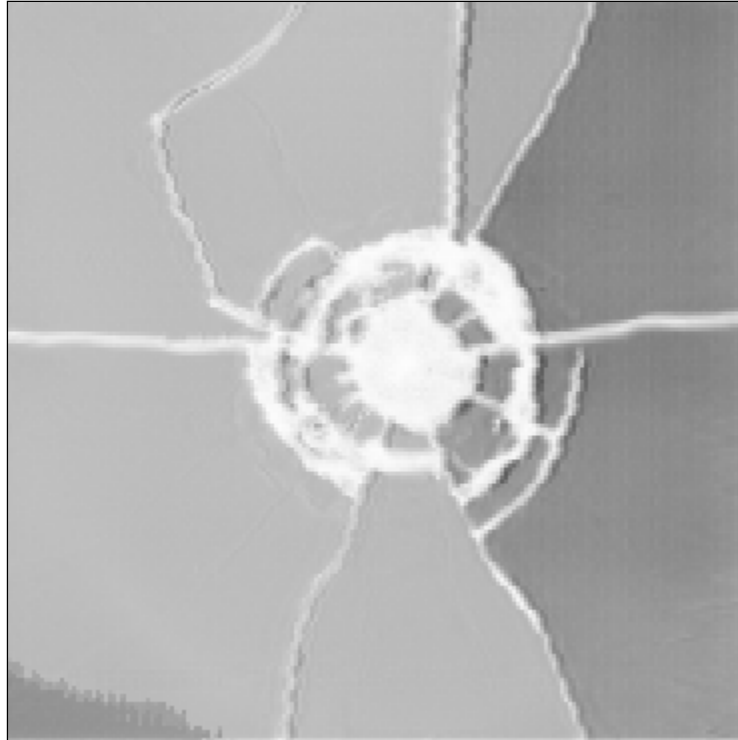
Figure 1. Inverted grayscale C-scan image for the transparent target 740-1
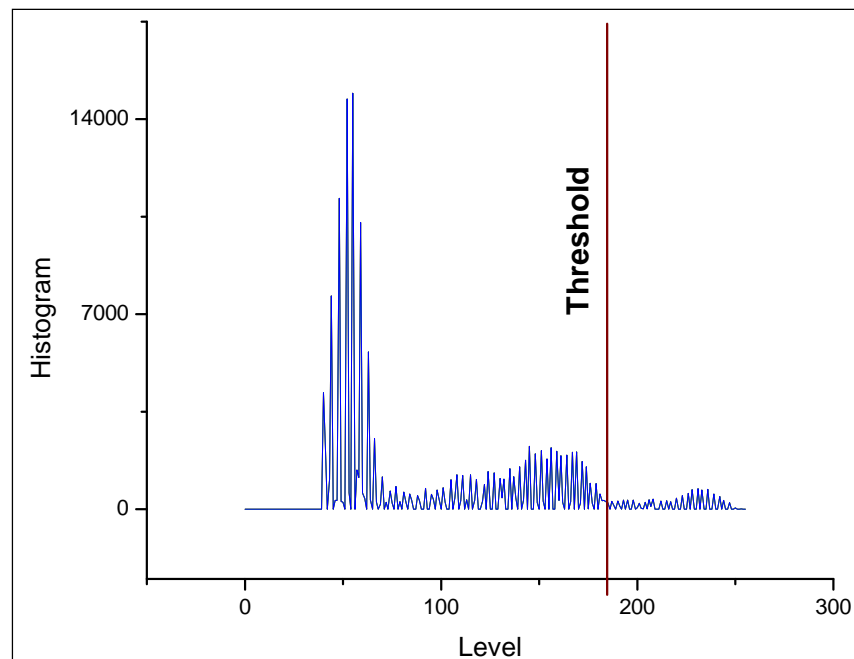subjected to low velocity impact.

Figure 2. Histogram representation of the C-scan image from 740-1 including
demarcation of the selected threshold region.

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The histogram curve showed three distinct zones. The first zone was a narrow, high amplitude area on the left representing the bulk of the sample. These occurrences came from undamaged areas, mostly on the left side of the image. The second zone was a broader, lower amplitude region in the center of the histogram curve. These occurrences came from additional undamaged regions on the right of the sample (and in the lower left corner). Due to the fracture and physical warping of the target after impact, these undamaged regions appeared at a slightly different grayscale level. The third zone was a lower amplitude area on the right of the histogram curve. These occurrences came from the damage at the point of impact and the radial and cone cracks detected in the C-scan image.

The threshold was chosen at the location with the lowest number of occurrences to the right of the second zone (end of the second zone), as indicated in figure 2. To the right of this threshold value (which fully encompassed the third zone), it was estimated that all occurrences represented damaged areas of the transparent target. The threshold value was identified at a grayscale level of 204 in which 242 occurrences were present. All occurrences from grayscale levels of 205 to 256 were selected and transferred to a separate workbook. After running the statistics, the number of damage occurrences was found to be 14,880 out of a total number of occurrences of 136,161. The percent damage for target 740-1 was calculated from this data as 10.9%. This technique was applied to additional transparent laminate targets subjected to low velocity impacts for comparison of damage incurred under varying impact conditions. The results from targets 740-2, 741-1, and 741-2 are shown in figure 3.
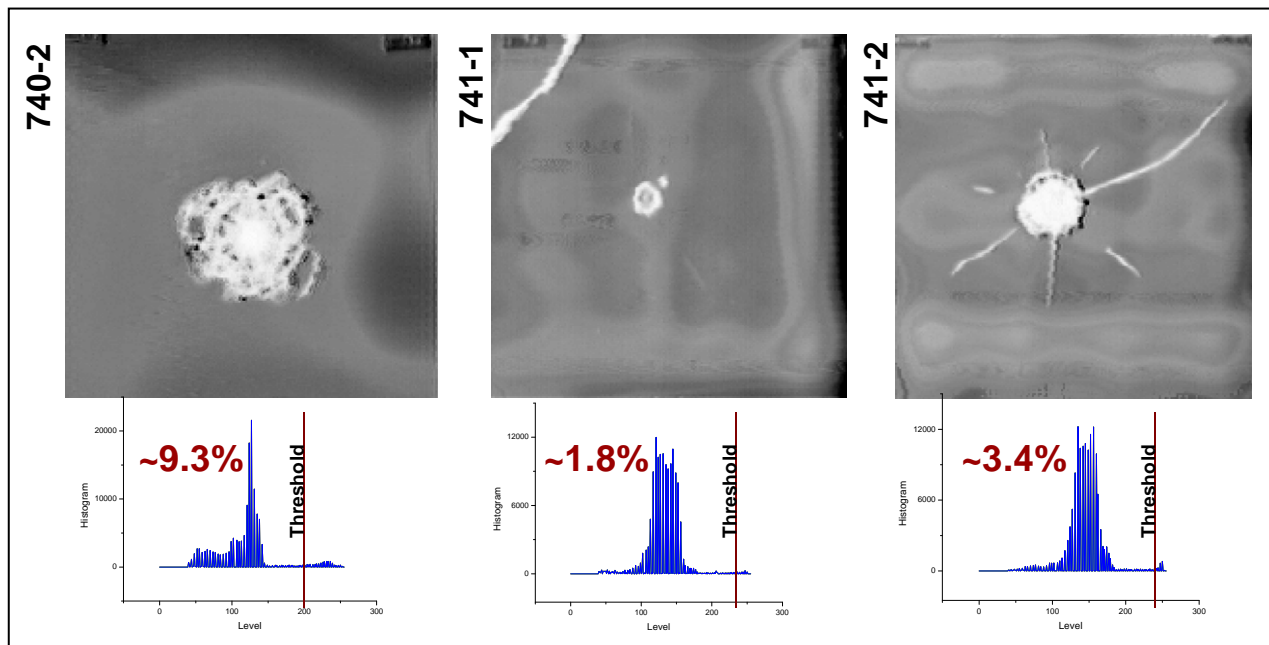

Figure 3. Histogram representations of the C-scan images from 740-2, 741-1, and 741-2 including demarcation of the selected threshold region.

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4. Conclusion

The quantitative histogram damage assessment method is effective at providing an estimate of volumetric damage for direct comparison of various transparent targets. Rather than relying solely on qualitative image interpretation, the quantitative technique supplies a value that can be used to rate impact performance of one target against another. While most of the steps are trivial, it is critical to choose the threshold value in a consistent manner to obtain comparable damage assessment values. The same procedure can be applied to any damaged materials, transparent or opaque, from which a C-scan image can be collected. Future use of the method will include low velocity impact damage comparison of opaque ceramic materials to compare and down-select materials with improved impact resistance for advanced protective systems.

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