Development and Preliminary Application of Image Filters for Quantitative XCT Damage Analyses

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Abstract

X-ray computed tomography (XCT), is an accurate and powerful way to image and evaluate damage, including cracking in materials due to ballistic impact. However, a clear and consistent algorithm must be applied to XCT image data to determine damage on a quantitative basis. A methodology was developed using a number of software applications to graphically interrogate the physical amount of ballistic meso-damage (>250 μm) in impacted titanium alloy (Ti-6Al-4V) disk samples. The disk samples were sectioned from an imported titanium alloy plate.

Introduction

Segmented binarized (i.e., black and white) XCT images were analyzed using AutoCAD 2000© software. Routines were developed to calculate the physical amount of meso-damage. Within annular rings centered on the middle axis of the penetration cavity the discrete data in each XCT slice was plotted graphically as axi-symmetric damage versus radius. Cumulative damage and unit cumulative damage (i.e., unit volume) plots for each slice were also generated from the axi-symmetric plots. Furthermore, the axi-symmetric data as a function of both radius and depth was graphically plotted showing the 3-D distribution of meso-damage. This paper will describe the procedures used and the methodology developed to quantitatively analyze ballistic meso-damage in the Ti-6-4 sample.

Method

Using a BIR XCT scanning system, sixteen bit unsigned TIFF images having a 70mm x 70mm area with a spatial resolution of a quarter millimeter are created for every .20 millimeter segment of the Ti-6-4 samples. Taking the TIFF images obtained from the XCT scanning system and applying ACTIS software threshold techniques damaged material is distinguished from undamaged material creating binary TIFF images which are exported at twelve bit resolution. The exported twelve bit images serve two purposes: determination of the center of penetration through the Z-axis and use in AutoCAD.

To find the center of penetration within the Ti-6-4 samples a process is used within Surfacer software. All twelve bit images exported from the ACTIS software are imported into the Surfacer software. Doing this creates a 3D point cloud of XY coordinates which represent the damaged-undamaged outline within the object. The region selected is the penetration cavity and the function used determines the center of penetration by averaging the XY coordinates of the undamaged outline. Doing this on several Z-depths – impact face, center of object, exit face – one can then estimate the rest of the centers of penetration throughout the sample.

Using AutoCAD a filter was developed which accurately quantizes the location and amount of ballistic meso-damage throughout the Ti-6-4 sample. In creating a filter the solids-modify-subtraction function was implemented. A 3D rectangular solid was drawn with dimensions 100mm x 100mm x 1mm. Within this rectangular solid another solid, a cylinder, was drawn with its origin at 50mm x 50mm x 0mm with radius of 20.00mm, height 1mm. Using the same origin as the previous 3D solid created, another cylinder with 19.75mm radius, height 1mm was also created. The solids-modify-subtraction function is used to remove the 19.75mm radii cylinder from the 20.00mm radii cylinder. This in turn creates a 3D solid ring. The solids-modify-subtraction function is used again to remove the 3D solid ring from the 3D rectangular solid. One is left with a hollow rectangular solid, the hollow region being a ring between 19.75mm and 20.00mm. This hollow rectangular solid is than moved to its own layer, named 19.75-20.00.

Using the same methodology described in the previous paragraph, these hollow rectangular solids are created down to a .25mm radii, essentially a circle. The 100mm x 100mm x

1mm 3D rectangular solid is always created along with two unique cylinders with radii differing by .25mm. The lesser cylinder is always subtracted from the larger cylinder and the remaining ring is always subtracted from the rectangular solid. This hollow rectangular solid is always moved to its own unique layer name according to the inner and outer radii of the ring created. The rings are also their own unique color, magenta.

Upon completion of all layers between 0mm and 20.00mm alignment lines are made on Z depth 0mm for applying an XY offset at X coordinates 0mm and 100mm extending infinitely in Y directions and at Y coordinates 0mm and 100mm extending infinitely in X directions. Also, alignment lines are created on Z depth 0mm at X coordinates 15mm and 85mm extending infinitely in Y directions and at Y coordinates 15mm and 85mm extending infinitely into X directions for placing the 70mm x 70mm TIFF image into AutoCAD.

Because the center of penetration is not necessarily the center of the 70mm x 70mm binary TIFF image, an offset needs to be applied which corresponds to the Z depth of the current image being worked on and the XY offset obtained from the Surfacer software. To implement this offset, all layers are selected at once and the AutoCAD move function is used, moving the layers from the 0mm x 0mm corner to a select offset. With the layers moved to the proper offset, the TIFF image is imported into AutoCAD and placed accordingly within the 70mm x 70mm alignment lines. Because the alignment lines lie beneath the 3D solid, the TIFF image is placed under the 3D rectangular solid.

With the offset in place one then selects which layers to render within AutoCAD. The layers used depend on whether upon selection of a particular layer both damaged and undamaged pixels are shown within the ring. When a ring is found which meets this criteria, all other rings are hidden, and the current ring is rendered and exported as a Bitmap image from AutoCAD. Bitmap images for all rings which include both damaged and undamaged pixels are created.

The Bitmap images created with AutoCAD ideally would include just the damaged color pixels – black, the undamaged color pixels – white, and the layer color pixels – magenta; however, this is not the case. AutoCAD takes the original imported XCT binary images and converts it to a 24 bit image within AutoCAD, creating several shades of grey. The final rendered image one gets must therefore be reduced to three colors in order to make the processing of the image possible.

Using Paint Shop Pro you import the images created with AutoCAD. Within Paint Shop Pro using the Colors – Decrease Colors – Three Color function, one takes all the images from AutoCAD and decreases the color depth to three. The images are now ready to be used to create quantitative results.

Within the ImageJ software package one can import the three color images created using the previous steps and using the histogram feature, determine the number of damaged and undamaged pixels within the ring. Doing this for all images in the CT scan, one can accurately describe the damage in the object quantitatively using a variety of graphs including the axi-symmetric damage versus radius, the cumulative damage versus radius, the cumulative unit damage versus radius, and the 3D axi-symmetric damage versus radius versus depth plot.

Results

Using this methodology to create quantitative data from what used to be a series of pictures; plots which describe the damage were created for each CT slice. The most useful plot created for representing the data for a particular slice is the axi-symmetric damage versus radius. It takes the percent damage in each ring from the center of penetration out to the edge of the object versus the radius, and shows very clearly where in the object damage is occurring from the projectile.

In describing the damage throughout the entire object, the 3D axi-symmetric unit damage fraction plot was created. It combines the axi-symmetric damage versus radius plots with the addition of depth. In looking at the 3D graph of any particular XCT scans of the Ti-6-4 objects, one can quickly and accurately describe where the damage in the object is occurring. If you look at figure 1 and figure 2, you can see for yourself how, in addition to the usual 3D models of CT data, actual number data of the scans can help to describe the damage in a particular object much better than was possible before. This type of quantitative data makes it possible for damage modelers to more accurately assess the type of damage a certain projectile will inflict and what type of response the object will have upon impact.

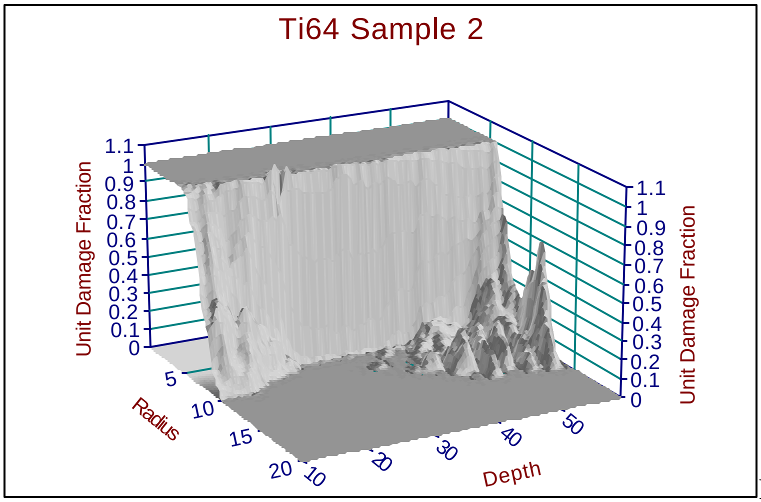

Figure 1

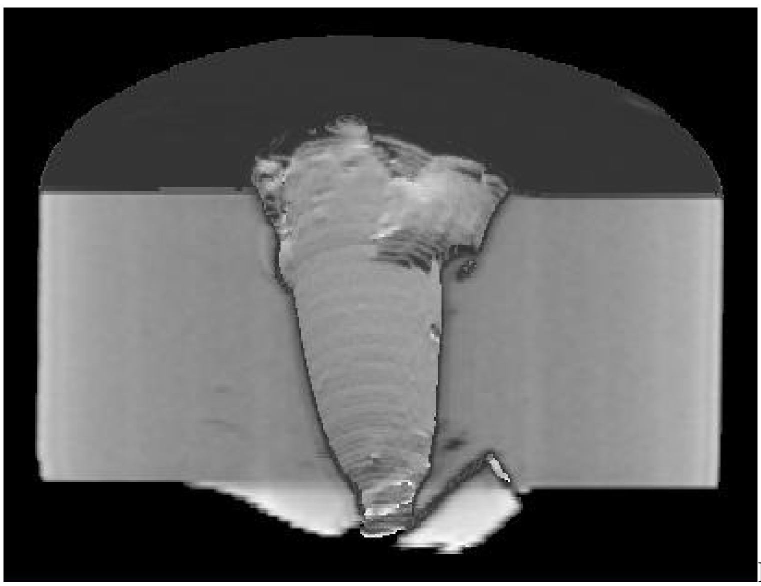
Figure 2