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GEOMETRY OF DAMAGE IN SHOCK LOADED COPPER AND TANTALUM

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Abstract. Cavities of coalesced voids have been found in recovered samples of Tantalum in gas gun and high-explosive-driven experiments. The boundaries of these cavities are imprinted with details of the coalescence and void growth processes. One way of quantifying these details is to measure the roughness of the surfaces. In this work, we calculate the roughness of 2D cross sections of such cavity surfaces from micrographs by analyzing the images with the box counting technique. Both gas gun samples and explosively driven samples are treated. Different length scale regimes found will be discussed.

Keywords: ductile damage, roughness, spallation, tantalum, copper

PACS: 62.20.Mk; 61.72.Qq; 62.20.Fe; 62.20.Cu

INTRO

Characterizing the nature of a highly evolved ductile damage field is a challenge. Voids and cavities may well have grown to the point that their origin is no longer apparent. One way to make progress is to do box counting over the damage field to see if well defined fractal dimensions exist, perhaps at various length scales. In this paper we perform such analysis of spallation damage fields in copper samples loaded with a flyer plate and in tantalum samples loaded with high explosive. A reasonably well defined exponent was found for each copper sample and several were found for various length scales for the tantalum samples.

BOX ANALYSIS

The box counting method for measuring a fractal dimension is well developed. [1] Here the procedure amounts to dividing the damage micrograph into square boxes of edge length, L , and counting the number, N , that contain damage.

This is done for various box sizes. If the result is that N is a power of L , then the fractal dimension is the exponent, D :

$$N = \text{constant} / L^D. \quad (1)$$

If the results form a reasonable straight line in a log log plot, the power law behavior is established. Often, various regions of the plot each form a different line segment giving a different fractal dimension for each.

We used the image analysis capability of Mathematica 7. One issue is that the family of boxes of a given size does not exactly cover the micrograph. This was addressed by dividing the box hit count by the “area” of the covering boxed to obtain a “box fraction.”

Fig. 1 shows the micrograph for the Cu flyer plate shot 19069 together with the damage boundary edges, together with a set of box images. The box images are useful in understanding the features responsible for establishing the fractal dimension. This sample consists of large “columnar” grains produced by annealing. The

polycrystalline Cu flyer is below the sample. The damage consists of a narrow spall plane of small, nearly coalesced voids.

Figure 1. Top - EBSD scan of Cu shot 19069 sample cross section. Flyer at bottom of image. Bottom – edges of damaged region, used for box count.

The edges of the damaged region (spall layer) were extracted and used for the box count. This procedure is similar to finding the “length of a coastline [1].” The box count results are shown in Fig. 2. Boxes of size 10 through 50 produced a reasonable straight line with a dimension (slope) D of 1.33. A similar damage field from another shot, 19073, produced a dimension D of 1.26. These values indicate a space filling closer to one dimensional than two dimensional. If the damage evenly filled the image and, so, was two dimensional, the dimension D would be two.

Figure 2. Log log plot of the box count fraction versus box size edge length in pixels for shot 19069.

Fig. 3 shows an optical image of a cross section from a tantalum sample with high explosive

(HE) driven damage. The extent of damage is much greater here with a large cavity from coalesced voids. The damage field is more diffuse than the Cu plate impact sample because the tensile stress from the HE drive is less localized spatially.

Figure 3. Damage field from HE Shot Ta Prad 61.

The extracted edge image is not shown for simplicity. The peak pressure in the HE drive was about 20.0 GPa, the high explosive was PBX 9501. Here the box count method was applied to both the entire damage field and the cavity boundary alone.

Fig. 4 shows the box count plot for both the entire damage field and the cavity alone. Several linear regions were found for each. For the all damage case, a D value (slope) of 1.22 was found for the box size range of 10 – 15 pixels; a slope of 1.45 was found for the range 50 – 150 pixels; and a slope of 1.69 was found for the range 100 – 300 pixels. Notice that the dimension D increases with large box size. For the range of smallest boxes, the boxes “see” more linear features with a D value correspondingly closer to 1 (one dimensional). In this case each box contains mostly a small edge of a void or a cavity boundary which “looks” like a straight line. For the range of the largest boxes, each box contains whole features (voids, wrinkles of the cavity boundary) which fill space more and produce a dimension D closer to 2 (space filling).

In the cavity only case, the box size range of 4 – 25 pixels, a dimension D of 1.01 was found, i. e. each box is seeing a straight line. For a box size range of 50 – 150 pixels, a dimension D of 1.16 was found, and for a box size range of 100 – 300, a dimension D of 1.29 was found. Each range corresponds to a roughly linear region in the box count plot, Fig. 4. Again, the dimension increases with larger box size but the D values are significantly smaller than those in the case of all damage. This means that the cavity boundary is

more “linear like” than the whole damage field, which is reasonable.

Figure 4. Box count plot for HE shot Ta Prad 61 showing results for the full damage field and the cavity alone.

Table I. Summary of fractal dimension values D for 5 shots.

Sample	Path character (all damage)	D exponent
Cu, 19069	Plate Impact High density voids	1.33
Cu, 19070	Plate Impact High density voids	1.03 – 1.26
Cu, 19073	Plate Impact High density voids	1.26
Ta, 61	HE Voids + cavity	1.22 – 1.69
Ta, 64	HE Voids + big cavity	1.12

Table I summarized the fractal dimension D values when all damage is included for all shots. The D value for Cu flyer plate shot 19070 is untypically small: 1.03. The reason is probably involved spurious “damage” from regions of large plastic flow in the EBSD scan (not shown). Ta PRad shot 64 was from the same sample as Ta shot 61 but the micrograph analyzed was much smaller in size than that of shot Ta 61. The Ta 64 micrograph was at an effectively “higher magnification” where linear features prevailed. (Smaller scale roughness was not present due to the resolution limit of the optical images.)

Table II. Fractal dimensions D for the cavity only from samples Ta PRad 61 and Ta PRad 64.

Sample	D exponent
Ta, 61	1.01 – 1.29
Ta, 64	0.98

Table II presents the dimension D values for the cavity only analysis of Ta PRad shots 61 and 64. Note that the D value for shot 64 is very close to 1, i. e. “linear.”

CONCLUSIONS

We have analyzed flyer plate driven damage in columnar grain Cu samples and in HE driven Ta samples. We found a well defined fractal dimension for the damage field in the Cu flyer plate case, which consisted of a narrow spall layer of small, almost coalesced voids.

For the HE driven Ta samples, which had more extensive damage including large cavities, we found several length scale regions each with a different value of the fractal dimension. In this case, the fractal dimension of the damage increased as the box size of the box counting method increased, since the larger boxes contain more features that fill the area and the smaller boxes contain just, mostly linear fragments of void and boundary edges.

For the Ta PRad case, when the large central cavity was analyzed alone, a smaller fractal dimension was found than for the complete damage field. This shows that the cavity boundary is more “linear like” than the complete damage field which contains many isolated voids and small cavities, in addition.

In conclusion, the box counting method does find reasonably well defined fractal dimension exponents and, so, we have shown that it can be used as a tool to analyze the geometry of the damage field in ductile spallation damage. More work needs to be done to understand the connection between the fractal exponent value and the underlying damage structures that determine it. For example, the various length scales found in the fractal analysis can be compared to known mesoscale features present in virgin samples, such as grain boundaries and grain boundary clusters. Reed et al [2] provide a good example of such a correlation for samples with special grain engineering.

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