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EJECTA PARTICLE SIZE DISTRIBUTIONS FOR SHOCK LOADED SN AND AL TARGETS

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Abstract

When a shock wave interacts at the surface of a metal sample "ejected matter" (ejecta) can be emitted from the surface. The mass, size, shape, and velocity of the ejecta varies depending on the initial shock conditions and the material properties of the target. To understand this phenomena, experiments have been conducted at the Pegasus Pulsed Power Facility (PPPF) located at Los Alamos National Laboratory (LANL). The facility is used to implode cylinders to velocities of many mm/μsec. The driving cylinder impacts a smaller target cylinder where shock waves of many hundreds of kb can be reached and ejecta formation proceeds. The ejecta particle sizes are measured using an in-line Fraunhofer holography technique. Over the years much work has gone into characterizing ejecta mass, but very little has been done to understand the particle size distributions. In this report, ejecta particle size distributions will be presented for shocked Al and Sn targets at pressures of 300 kb and 400 kb respectively. For the first time, particle distributions that results from microjet production will be presented. Results from these experiments will be presented along with predictions from percolation theory

I. INTRODUCTION

Metals under shock-loaded conditions can lead to complex phenomena depending on the properties of the material and initial shock conditions. The phenomena being reported here involves particle ejection which results from a shock wave interacting at a metal vacuum (gas) interface. For these experiments, particle sizes are measured using a holography technique. Ejecta experiments similar to these have been performed at other facilities [1,2,3,4,5] however, only a few measurements of particle sizes have been performed. For the first time, particle size distributions that result from microjet production will be presented. The energy in the microjets will depends on the initial groove angle that was machined into the target. Results from two experimental systems will be presented. These two experiments used Al and Sn targets. The shock pressures were 300 and 400 kb respectively. From the holography data, particle distributions are extracted and are compared to predictions from percolation theory.

II. EJECTA PRODUCTION AND PERCOLATION THEORY

Shock strengths of many hundreds of kb can be obtained in aluminum and tin targets at the Pegasus Pulsed Power Facility (PPPF) located at the Los Alamos National Laboratory. Ejecta produced from these experiments range in velocities up to twice the target free surface velocity. The actual production of ejecta can be a complicated process. Fig.1 shows possible properties of the target material that may contribute to the formation of ejecta. For example, defects such as voids and inclusions give rise density discontinuities. These density discontinuities can then lead to break up of the metal as the shock wave passes through. In addition, grain boundaries can also be possible places for the metal to break up as a shock wave moves through the material. The figure also shows that if there are surface finish variations, microjets will form. These microjets can then break up into fragments forming another source of ejecta. Furthermore, initial shock conditions such as shock pressure and temporal profile can also contribute strongly in determining the properties of ejected material. For example, if the shock wave is strong enough, the material w[illegible]melt which leads to enhanced ejecta production[1,6]. D[illegible]eloping a model that predicts the amount, size, and

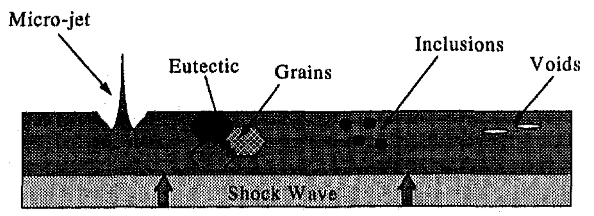

Figure 1: Illustration of possible ejecta formation processes.

velocity of ejecta based on the above micromechanical processes is a difficult problem.

Many phenomena in nature involve fragmentation from very small (nuclei) to large (planets) scale systems[7,8,9,10]. A useful model that has been used to describe the fragment size distributions is percolation theory. For example, fragmentation of heavy nuclei resulting from high-energy nucleus-nucleus interactions [11,12] are described well using this theory. Percolation theory predicts simple power laws with specific values that depend of the dimensionality of the system being investigated. For example, if the system is one, two or three-dimensional, the powers are different[13]. This provides insight into the dimensionality of the phenomena being investigated. This theory is applied to the ejecta data and will be presented in this report.

III. EJECTA PARTICLE MEASUREMENTS

The experiments presented in this report were done at the Pegasus Pulsed Power Facility (PPPF) located at Los Alamos National Laboratory Details of the facility are described in Ref [14]. Fig. 2 shows a view of the target assembly. In the figure an Al cylinder accepts current and is driven cylindrically inward. This cylinder is called the liner driver. The target, a 400-micron thick cylinder measuring 3.0 cm in diameter, is shown inside the liner. For a typical experiment the aluminum cylinder is driven to a velocity such that a shock wave many hundreds of kb is generated inside the target. Finally, a cylindrical tantalum collimator with various cutouts is used to control the number of particles entering the area where the ejecta measurements are made.

Various experimental techniques can be used to measure particles. Holography has the advantage that a three dimensional image of the ejecta is recorded. In particular, the in-line Fraunhofer holography technique was chosen because only one laser beam is required to make the measurement. This technique is described in more detail in Ref. [4,15,16,17,]. Fig.3 shows in more detail the layout of the lens system in its configuration at the PPPF. The first lens element is located just a few centimeters from the region where the ejecta particles are located. This is required if enough scattered light is to be collected for measuring particles with diameters as small as 1.5 microns. The high resolution lens (1000 lp/mm) relays the scattered and unscattered light waves over a cylindrical imaging volume 15 mm in diameter and 6mm in depth. These light waves are relayed 93 cm to where the hologram is placed. After the experiment, the hologram is recovered and a three dimensional image of the ejecta is optically reconstructed. In order to quantitatively determine particle sizes, a hologram reconstruction system has been developed. The reconstruction system converts the optically reconstructed ejecta particles to digital image form. The digital images are then analyzed where particle shapes, sizes, and spatial coordinates are determined. This data is then used to determine particle distributions. Details of this analysis system can be found in Ref [18].

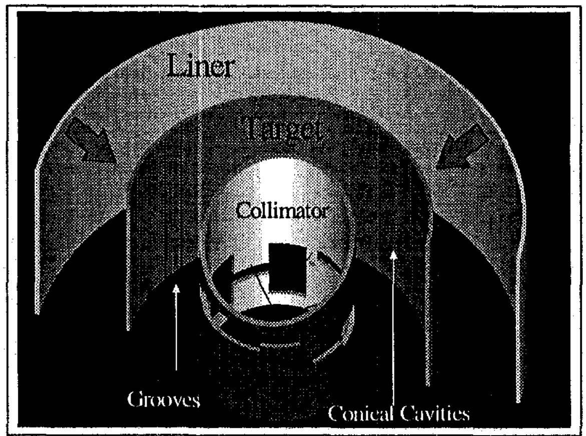

Figure 2: Target assembly. The outer cylindrical liner is what the Pegasus machine drives inward

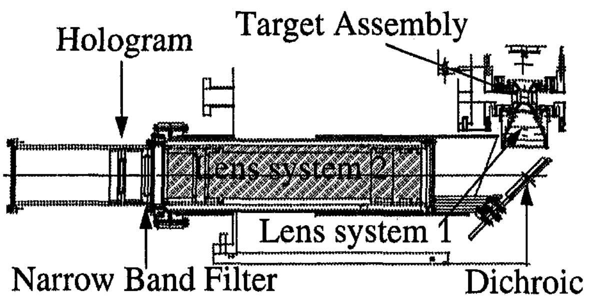

Figure 3: The in-line Fraunhofer holography experiment.

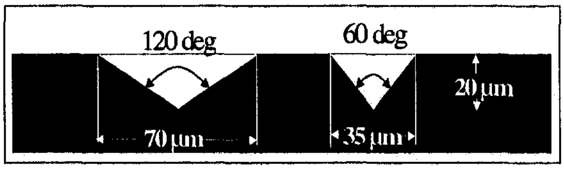

Figure 4: Cross section of the grooves that were used for the experiments

IV. EJECTA PARTICLE SIZE DISTRIBUTION RESULTS

Results from two experiments will now be presented. The first experiment used an Al (6061 T6) target 400 µm thick. The target was prepared initially with a polished finish of 20 µ" RMS. Next, grooves were machined into the target at various locations azimuthally around the target. Fig. 5 shows a cross section of these grooves. Grooves were either 20 or 100 microns deep. The groove angles were 60, 90 and 120 degrees

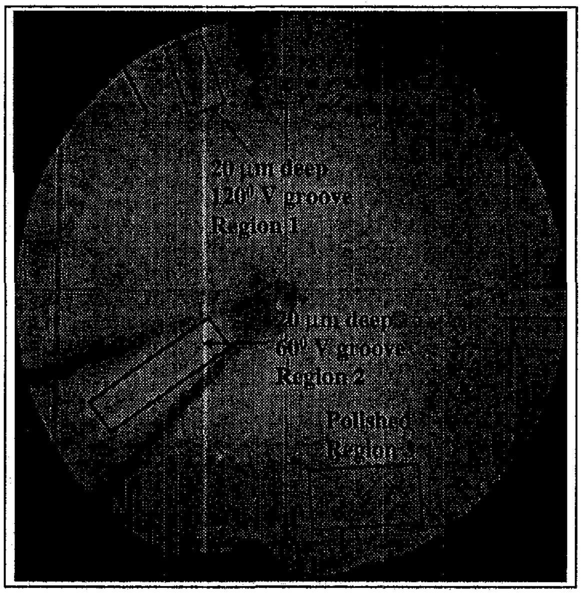

Figure 5: Image of hologram for the shocked Al.

The Pegasus machine was setup to provide current necessary to drive the Al liner driver cylinder to a velocity of 3.4mm/µsec just before the target is impacted. With this velocity, a shock pressure of 300 kb results in the Al target, and 400 kb when a Sn target is used. The holography experiment was performed just before the target impacted the collimator. See Ref [19] for more details about the dynamics of the target assembly. Radiography [20,21] in addition to other diagnostics were performed to measure the radius of the cylinder for different times. Fig. 5 shows an image of the hologram which was obtained for the Al target experiment. The figure is viewing through the collimator. The holographic film records a superposition of the interference patterns which are used to extract the particles, and a shadowgram of the ejecta. The outer part of the image is just inside of the collimator. It is observed that as the groove angle goes from the 60 to 120 degrees the microjet velocity decreases. This is well understood and is discussed in Ref [22]. This feature is exploited in these experiments to change the available energy in the microjet. Thus, for smaller angle grooves more energy is available for the fragmentation process.

V. COMPARISON WITH PERCOLATION THEORY

Data from two targets will be presented and compared to predictions from percolation theory. Fig 6 shows the particle distributions produced from a 120 degree, 20 µm deep V groove (solid circles), and a 60 degree, 20 µm deep V grooves(solid squares). Fig. 7 shows the particle distributions derived from region 1(solid circles) and region 2 (solid squares) in figure 5. These correspond to microjets formed from a 120 degree 20 µm deep V groove and a 60 degree, 20 µm deep V groove respectively. The dots in Fig. 6 and Fig. 7 are the calculations for a single event using percolation theory. The lines are the best power fit to the calculations. We found that a three dimensional lattice near the critical probability worked well in fitting the Sn data, suggesting that the fragmentation is 3-D in nature. However, the Al data shown in Fig 7 can only be fit well using a 2-D lattice.

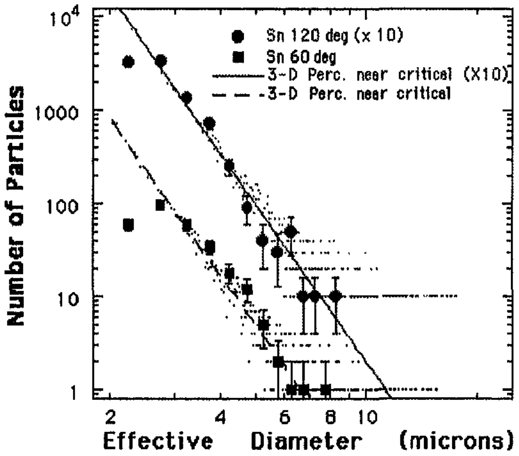

Figure 6: Ejecta particle size distribution for shocked Sn compared with predictions from 3-D percolation theory.

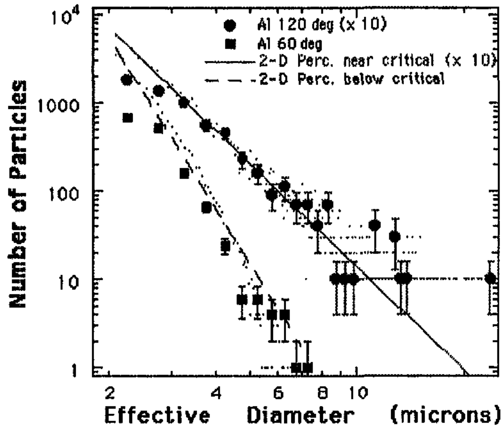

Figure 7: Ejecta particle size distributions for shocked Al compared with predictions from 2-D percolation theory.

VI. CONCLUSIONS

In this report we have presented ejecta particle size distributions for shock loaded Sn and Al samples. The measurements were accomplished using a holography technique. Grooves were machined into the target sample producing well characterized microjets which break up into particles. The shapes of the distributions have been analyzed within the context of percolation theory. The measured distribution shape for shocked Sn at these pressures fit well with predictions from a 3-dimensional lattice. However, the Al data requires a 2-D lattice in order to obtain a fit to the data. This suggests that the nature of the break up for the Al cases are 2-D in nature.

The implications of these results are being further investigated.

VII. ACKNOWLEDGMENTS

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