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SHAPED CHARGE JET FRAGMENTS

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MICROTEXTURAL CHARACTERIZATION OF COPPER SHAPED CHARGE JET FRAGMENTS

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The microstructures of two soft-caught copper shaped charge jet particles were investigated. In particular, the spatial distributions of crystallographic texture within the particles were characterized using point specific measurements of crystallographic orientation. Significant variations in preferred orientation were observed. These results are discussed in light of previous computer simulations of the jetting process which showed significant radial gradients in both strain and strain rate.

INTRODUCTION

The formation of a shaped charge jet from an explosively collapsed metal liner produces very large strains and very high strain-rates. It is, therefore, difficult to experimentally characterize the time and space dependent deformation processes which the material undergoes. One approach to gaining more understanding of the jetting process has been to examine the microstructures of jet particles recovered from low density recovery media such as polystyrene (1). There are several caveats to this approach. Since substantial heating occurs as a result of the plastic work done on the jet material during jet formation, elongation and particulation, the individual jet particles reach elevated (but equilibrated) temperatures before entering the recovery media. It has been shown experimentally, for the specific particles studied here, that the jet particles enter the recovery medium at approximately 500°C and then cool to about 250° C (the melting point of polystyrene) in 15 to 20 seconds (2). Further cooling from 250°C to near ambient temperature is estimated to require another 20 to 30 seconds. With this temperature-time cooling history, the recovered particles may have undergone significant static recrystallization. Thus, the question arises whether the microstructures observed in the retrieved fragments will be the same as those

which existed during and/or after particulation. This question is presently unanswered. Another uncertainty in the interpretation of the microstructures of the soft-caught fragments arises from the fact that, at the time these particles were recovered, the precise locations of the particles in the jet stream were not precisely known. It was, however, known that these particles came from the rear half of the jet. It is worth noting that techniques are now available for more precisely determining the location of individual recovered jet particles along the jet stream. Computer simulations of jet formation using Lagrangian tracer particles to evaluate linear strains and strain-rates (3, 4) indicate that the strain and strain-rate histories of material from jet particles located at different positions along the jet may be quite different.

Despite these potential difficulties in fully understanding data obtained from softly recovered jet particles, several microstructural examinations (5, 6, 7, 8) of such particles have been performed with the aim of extracting information regarding the jetting process. Each of these studies have reported observations of significant microstructural changes (mostly involving grain size reduction) from the original liners to the recovered jet particles. In addition systematic annular radial inhomogeneities were observed in many of the jet particles. An early

56
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study (9) of similar particles with annular rings visible in their transverse sections, using selected area x-ray diffraction with a small spot size, indicated the presence of strongly oriented [100] structures in the central region and in the second annular ring. In a more recent study(10), providing much better resolution, the local distribution of preferred orientation (microtexture) in a softly recovered jet particle was investigated using an automated electron diffraction technique (11, 12). A strong correlation was found between the microstructural inhomogeneities and the microtexture measurements. In this work, microtexture measurements obtained from still another softly recovered particle (sample B), compared to the results previously reported in (9) (sample A).

EXPERIMENTAL RESULTS

Soft-caught fragments of ETP (electrolytic tough pitch) copper shaped charge jets were characterized using optical microscopy and electron diffraction in the scanning electron microscope. The section planes examined were approximately normal to the long axes of the fragments. Individual measurements of crystallographic orientation were made using an automatic technique based on computer indexing of electron backscatter diffraction patterns (11, 12). Point-by-point measurements of crystallographic orientation were made on sample A on a $2000\text{ }\mu\text{m} \times 1200\text{ }\mu\text{m}$ hexagonal grid with $10\text{ }\mu\text{m}$ spacing between measurement points ($\sim 28,000$ measurements). Measurements on sample B were made on a $1000\text{ }\mu\text{m} \times 1200\text{ }\mu\text{m}$ hexagonal grid with $10\text{ }\mu\text{m}$ spacing ($\sim 14,000$ measurements). At each measurement point, the orientation, the grid coordinates and a parameter (IQ) describing the quality of the diffraction pattern were recorded.

Optical Microscopy

In both fragments, a fine-grained region ($\sim 10\text{ }\mu\text{m}$) was observed near the center surrounded by a ring of coarser grains. Another ring of finer grains (although not as fine as the center region) encloses this coarser-grained region. However, the shape and size of these regions are quite different in the two samples.

The central fine-grained region in sample A is approximately $400\text{ }\mu\text{m}$ in diameter; whereas, in sample B it is less than $100\text{ }\mu\text{m}$. The average grain diameters in the coarse-grained regions are $\sim 25\text{ }\mu\text{m}$ in sample A and $\sim 100\text{ }\mu\text{m}$ in sample B. In addition, a void exists at the center of the fine-grained region in sample A.

Crystallographic Texture

Sample A was partitioned into three zones, labeled zones 1, 2 and 3. Zone 1 corresponds to the fine-grained central region, zone 2 to the coarse-grained ring surrounding zone 1 and zone 3 refers to all measurements outside zone 2. Orientation distribution functions (ODFs) were calculated for each zone using the harmonic series expansion method (13) to an order of $l=16$. Each orientation was represented as a Gaussian with a 5° half-width (14, 15).

Sample A exhibited a fiber texture approximately aligned with the long axis of the particle. Inverse pole figures determined from the ODF calculations are shown in FIGURE 1. Inverse pole figures give the distribution of crystal directions aligned with a particular sample direction (in this case a direction approximately normal to the transverse plane). The texture in zone 1 is a strong (100) fiber texture (the other weaker features are an artifact of using harmonics to resolve this sharp texture). Zone 2 shows a mix of (100) and (211) fibers and zone 3 shows primarily a weak (100) fiber texture with some (111).

Sample B did not lend itself to such convenient partitioning as sample A. However, the measurements on sample B were interrogated according to "grain" size. A "grain" was defined by grouping together neighboring orientation measurements which did not differ in orientation by more than 15° . The measurement set was then partitioned into a set of large "grains" (containing more than four orientation measurements per "grain") and small "grains" (containing at most four measurements). Inverse pole figures for the large and small "grains" are shown in FIGURE 2. These pole figures show that both the large and small "grains" have a (211) type texture. However, the small-"grain" texture is considerably weaker. The central fine-grained region contained only 125 measurement points. An inverse pole figure for these measurements is

FIGURE 1. Inverse pole figures for sample A.

FIGURE 2. Inverse pole figures for sample B.

also given in FIGURE 2 and exhibits, in contrast to sample A, a weak (111) type texture.

DISCUSSION

The textures observed in the fragments are consistent with recrystallization textures observed in drawn copper wires (16) where a mix of $\langle 100 \rangle$, $\langle 111 \rangle$ and $\langle 112 \rangle$ texture components generally develops during annealing. The $\langle 100 \rangle$ fiber is greatly enhanced after annealing. The $\langle 112 \rangle$ texture has been observed to be a coarsening texture which is in direct agreement with the microtexture results for the coarse-grained regions in both samples.

Computer simulations of the jetting process (3, 4) predict strong radial gradients in both strain and strain rate. In general, the simulations predicted the strain at the center of the jet to be extremely large and to decrease rapidly with increasing distance from the jetting axis. The strains varied in magnitude and

direction from nearly axial to nearly radial depending on location (in both the jetting and radial directions). A direct one-to-one correlation of the jet fragments to these simulations can not be made as the relative positions of the fragments along the jet axis are unknown. However, an indirect correlation to the simulations can be made; namely, the center of a jet particle undergoes more strain than the outer regions. In addition, the material at the center of a particle undergoes axial stretching; whereas, the predicted strains in the material away from the jet axis varied to near radial directions.

No indications of the sharp microstructural boundaries observed in the fragments exist in the simulated radial strain gradients. However, there is evidence in the literature that suggests that relatively slight increases in deformation can produce sharp changes in recrystallization texture. Necker et al. (17) rolled OFE copper samples to height reductions of 58%, 73% and 90% (Von Mises strains of 1.0, 1.5 and 2.7) and then fully recrystallized the samples. The

deformed samples exhibited rolling textures of increasing strength. ODFs measured on the recrystallized materials reduced 58% and 73% deviated somewhat from the rolling textures with intensities at cube orientations, {001}(100), of 1.2 and 2.1 times random; however, the material reduced 90% exhibited a nearly complete cube texture with a cube intensity of 20 times random. These results indicate that a dramatic change in recrystallization texture can be achieved once a critical amount of strain has been reached. This observation suggests that the large strain gradients predicted by the simulations could produce the distinct changes in recrystallization texture observed in the fragment.

This explanation only seems to hold for the change in texture from zone 1 at the center of sample A to zone 2. The simulated strains in zones 2 and 3 were much smaller than the those in zone 1. It could be argued that the inertial confinement of the jet will produce a stress state with a significant shear component in the peripheral zones. However, no preferred alignment of any crystal axes with the radial direction nor any other evidence of shear-type textures was observed.

The absence of the strong (100) type texture in the fine-grained region in sample B suggests that this fragment comes from a position along the axis of the jet where the critical strains required to generate the (100) type recrystallization texture were not reached.

CONCLUSIONS

The inhomogeneities observed in the microstructures of soft-caught copper shaped charge jet fragments can be correlated to the spatial distribution of crystallographic orientation. The strong (001) fiber texture observed at the center in one of the fragments seems to confirm previous numerical predictions of extreme strain in the central region of the jet. In addition, the distinct changes in texture and microstructure in the radial direction observed in the fragment may be due to large radial strain gradients generated during jet formation.

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