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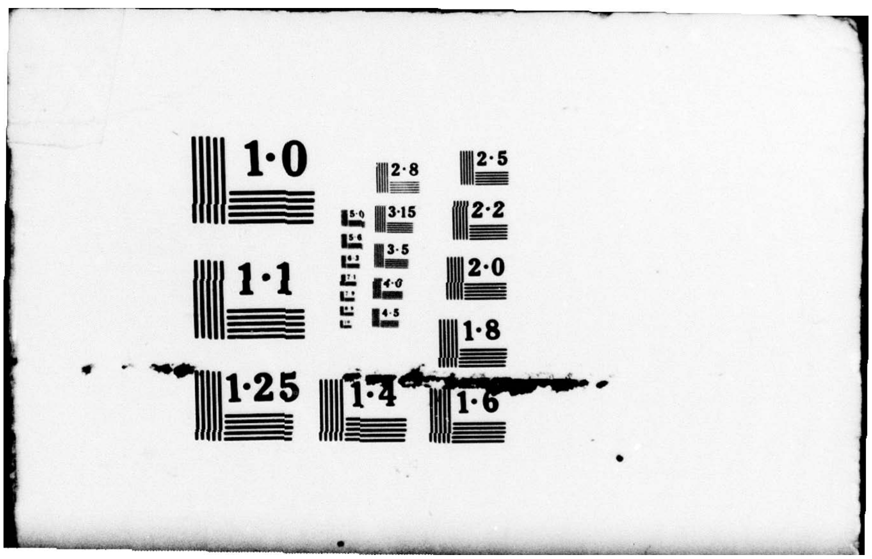
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LEVEL II

EFFECTS OF SHOCK LOADING VARIABLES ON SHOCK-WAVE STRENGTHENING OF METALS

FINAL REPORT

D. E. MIKKOLA

FEBRUARY 12, 1979

U. S. ARMY RESEARCH OFFICE

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The effects of shock pulse amplitude and duration on the hardening response and substructure of Cu-8.7Ge have been studied. By means of flyer plate experiments, very short pulse durations (<0.1μs) have been shown to give unusual and unexpected hardening effects. These have been related to the time dependence of plastic deformation processes. In particular, the sequence of twin formation leads to effective strengthening by twin boundaries. Also, twins form in much shorter times than previously demonstrated. Dislocation generation rates (cont'd)

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20. Abstract (cont'd)

are at least $10^{17}/10^{18}/cm^2/s$ for the conditions studied. Preliminary laser-induced shock pulse studies gave results in agreement with the flyer plate results.

FINAL REPORT

EFFECTS OF SHOCK LOADING VARIABLES ON SHOCK-WAVE STRENGTHENING OF METALS

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Statement of the Problem Studied

The purpose of this research has been to determine the effects of shock loading variables on the microstructure and properties of shock hardened materials and to compare laser-induced shock pulse effects with those associated with mechanically introduced shock pulses. Of particular interest has been the extension of the study of pulse duration effects to very short durations; e.g., less than 0.01μs. Most earlier work had been done with pulse durations of 1μs or greater,[1-3] where, as shown by the current study, the effects are time-saturated. In addition to measurements of the hardening effects, the shock-induced substructures have been characterized in detail with x-ray diffraction and transmission electron microscopy.

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Summary of Results

The hardening effects resulting from subjecting fine-grained Cu-8.7Ge to various shock pulses have been examined in detail. Based on preliminary experiments with various specimen configurations, flyer plates were used to introduce carefully monitored pulses of varying amplitude, 2-47.5 GPa, and duration, 0.004 - 3μs into 1 mm thick 18mm diameter specimens. Unusual hardening effects resulting from changes in pulse duration at constant pulse amplitude were found. A maximum in hardening was observed for all amplitudes at ∿0.07μs, followed by an increase to the same level of hardening at durations greater than 1μs.[3,4] The hardening at high pressures is of the order of that introduced by rolling to reductions of $\sim$50 percent.

Combined analysis by x-ray diffraction[5] and transmission electron microscopy[6] established that twinning plays a dominant role in the hardening at short durations and that both twinning and the dislocation substructures contribute at long durations. Although the volume fraction of twins increases monotonically with pulse duration at constant pressure, the nature of the twins formed is strongly dependent upon pulse duration. At short durations, the twins consist of bundles of fine twins with a large amount of twin boundary area per unit volume of twinned material. The strengthening contribution from twins decreases as the pulse duration is increased because the twin boundary density decreases as the individual twins thicken. The time dependence of this process of twin development has been discussed in detail[5,6] and has been related to the state of stress introduced by the shock pulses. An important finding of this work has been that deformation twins can form in less than 0.01μs, which is much shorter than the commonly quoted time of 1μs.

Dislocations also contribute to the strengthening, but primarily at long durations. At very short durations, the time is not sufficient to permit generation of sufficiently dense dislocation substructures to cause appreciable hardening. The dislocation density increases monotonically with pulse duration at constant pressure and the time dependence is such that the dislocation generation rate is at least 10^{17}-10^{18}/cm^2/s.

These observations have established clearly that short duration shock pulses can be used to provide important information about the time dependence of plastic deformation processes and further, that it may be possible to exploit their hardening effects more easily than long duration pulses because of the much smaller energy input. In addition, these results indicate potential importance of short duration pulses in connection with spallation and fracture.

Preliminary studies of the hardening effects in Cu-8.7Ge specimens with a larger grain size and in pure Cu have been completed and the results show a behavior similar to that described above.

Empirical expressions relating the hardening to the parameters describing the substructure have been developed. For example, the hardening effects associated with a wide range of pulse durations at 20 GPa give the relation:

$$\Delta H = 6.3 \times 10^{-5} \rho^{1/2} + 163 \beta^{1/2}$$

where ΔH = the increment in hardening

ρ = dislocation density

β = twin boundary density

This form is in agreement with the usual expression for strengthening by dislocations as well as with a Hall-Petch type strengthening by the twin boundaries. Analysis of the coefficients of the two terms has enabled us to find agreement with other empirical dislocation density results and to establish the relative effectiveness of twin boundaries in strengthening as compared to grain boundaries in the same material.

A series of laser-induced shock pulse studies of Cu-8.7Ge indicated that the behavior was similar to that for the flyer-plate results in the range 0.03 - 0.07μs. The value of this preliminary laser work has been that it has demonstrated not only the hardening effects, but the importance of the availability of the flyer-plate results to plan future laser work and to interpret the results. Much more work must be done in this area in order to make it possible to take advantage of the unique capabilities of laser shocking.

References:

1. Proc. Conf. on Metallurgical Effects at High Strain Rates, R. W. Rohde, B. M. Butcher, J. R. Holland, and C. H. Karnes, eds., Plenum Press, New York, N.Y., 1973.

2. Proc. 5th International Conference on High Energy Rate Fabrication, Univ. of Denver, Denver, CO, 1977.

3. E. T. Marsh and D. E. Mikkola, Scripta Met., 1976, vol. 10, p. 851.

4. S. LaRouche and D. E. Mikkola, Scripta Met., 1978, vol. 12, p. 543.

5. S. LaRouche, E. T. Marsh, and D. E. Mikkola, submitted to Met. Trans.

6. R. N. Wright and D. E. Mikkola, to be submitted for publication.

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Bradford C. Smith, currently completing M.S. degree requirements.

Publications

"Pulse Duration Effects in the Shock Hardening of Cu-8.7Ge," E. T. Marsh and D. E. Mikkola, Scripta Met., 1976, vol. 10, pp. 851-856.

"Shock Hardening Behavior of Cu-8.7Ge at Very Short Pulse Durations," S. LaRouche and D. E. Mikkola, Scripta Met., 1978, vol. 12, pp. 543-547.

"Strengthening Effects of Deformation Twins and Dislocations Introduced by Short Duration Shock Pulses in Cu-8.7Ge," S. LaRouche, E. T. Marsh, and D. E. Mikkola, Preprint submitted to Metallurgical Transactions.

"Formation of Deformation Twins by Short Duration Shock Pulses," R. N. Wright and D. E. Mikkola, to be submitted for publication.

Presentations

"Effects of Pulse Duration on Shock Hardening of Cu-8.7Ge," E. T. Marsh and D. E. Mikkola, Fall Meeting, TMS-AIME, September, 1976, Niagara Falls, N.Y.

"Substructural Strengthening of Metals," Metals Research Laboratory, Olin Corp., New Haven, CT, December, 1976.

"Laser-Induced Shock Hardening," NSF Workshop on Future Basic Research with Lasers, University of Southern California, Los Angeles, CA, March, 1977.

"Shock Pulse Variable Effects in the Shock Hardening of Cu-8.7Ge," S. LaRouche and D. E. Mikkola, Fall Meeting, TMS-AIME, October, 1977, Chicago, IL.

"Substructures Formed by Various Shock Pulses in Cu-8.7Ge," R. N. Wright and D. E. Mikkola, Fall Meeting, TMS-AIME, October, 1977, Chicago, IL.

"Shock Pulse Variable Effects in the Shock Strengthening of Cu-8.7Ge," R. N. Wright and D. E. Mikkola, American Physical Society Annual Meeting, San Francisco, CA, January, 1978.

"Effects of Pulse Duration on Substructure Development in Shock Deformed Cu-8.7Ge," R. N. Wright and D. E. Mikkola, to be presented at AIME Annual Meeting, February, 1979, New Orleans, LA.

"Changes in Substructure and Properties as a Function of Pulse Duration," to be presented at the Topical Conference on Shock Waves in Condensed Matter, Pullman, WA, June, 1979.