DNA/SNLA COMMONALITY PROGRAM (U)

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SUMMARY

The purpose of the "Commonality" program, initiated by DNA in 1978, was to evaluate e-beam material testing procedures and techniques by comparing material stress and spall data from various U.S. and U.K. e-beam facilities and experimenters. As part of this joint DNA/SNL/UK Commonality effort, Sandia and Ktech used four different electron-beam machines to investigate various aspects of e-beam energy deposition in three materials. We varied the deposition duration and the deposition profiles, and measured the resulting stresses produced. The materials studied were: 1) a low-Z material (Al), 2) a high-Z material (Ta), and 3) a typical porous material, a cermet. We irradiated aluminum and tantalum using the DNA Blackjack 3 accelerator (60 ns pulse width), the DNA Blackjack 3' accelerator (30 ns pulse width), and the SNLA REHYD accelerator (100 ns pulse width). Propagating stresses were measured using X-cut quartz gauges, carbon gauges, and laser interferometry techniques. Data to determine the influence of deposition duration were obtained over a wide range of energy loadings. The cermet material was studied using the SNLA REHYD and HERMES II accelerators. The e-beam from REHYD generated propagating stresses which were monitored with quartz gauges as a function of sample thickness and energy loadings. The HERMES II accelerator was used to uniformly heat the cermet to determine the Grüneisen parameter and identify the incipient spall condition. Results of these experiments will be presented.

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DISCLAIMER

INTRODUCTION

The objectives of this joint DNA/SNLA program were to obtain valid and reproducible data on material responses to electron irradiation from differing electron beam facilities. The "Commonality" program, of which this work is a part, was initiated in 1978 by DNA to provide a common data base so that comparisons between facilities would be independent of the particular testing and dosimetry techniques utilized. Each experimental group used its preferred diagnostic techniques. Common-supply materials were used to eliminate test result variations due to material differences.

The work reported herein was performed by a group of Ktech and SNLA experimenters and utilized four electron beam machines: Blackjack 3 and 3 prime (BJ3, BJ3') at Maxwell Laboratories, Inc., San Diego, and Rehyd and Hermes II at SNLA. Table 1 summarizes the pertinent machine characteristics along with those of U. S. machines used by the other "commonality" experimenters.

For the tests at Sandia and Maxwell, Ktech Corporation performed the beam characterization and materials irradiation experiments and SNLA provided the data acquisition techniques and instrumentation.*

The materials, aluminum (Type 1100), tantalum, and a 50VJ2 cermet, were supplied by SRI, Menlo Park, and SNLA. The Al and Ta samples were prepared, respectively, from one original material piece by D. Schallhorn at Harry Diamond

*Data acquisition work was performed by J. Romine, M. Ruebush, and G. Hansen of Division 1126.

Laboratories (HDL). Ktech procured its own supply of aluminum (Type 6061-T6) and tantalum for some of the initial experiments.

Phase I of this program involved the study of aluminum using the BJ3, BJ3' and Rehyd machines. Al was chosen as a standard material for technique checkout because its equation-of-state is best known. Also, because of Al's low density, there was little stress relief during the deposition time. The three machines yielded similar deposition profiles in Al (range 0.5 gm/cm^2, $\sim$ 0.2 cm) but differed in deposition times (between 30 nsecs and 120 nsecs FWHM). The parameters studied were the deposition profiles, the resulting stresses and their propagation characteristics. For Phase I the aluminum samples were 0.110" thick, greater than the deposition range. Energy loadings of 50-900 cal/gm and deposition times of 30-120 nsecs were used. This dose range covered behavior through melt and just beyond incipient vaporization ($\geq$ 718 cal/gm).

Phase II was the study of the tantalum, again using BJ3, BJ3' and Rehyd. The deposition range of about 0.5 gm/cm^2 for this high density material involves a very shallow depth (0.03 cm), and with these machines the peak induced stresses depend significantly on deposition time and the consequent stress release effects. The tantalum samples were 0.030" or 0.050" thick, greater than the deposition range. The Ta was subjected to energy loadings of 50-900 cal/gm and deposition times of 30-120 nsecs. The higher loadings induced significant partial vaporization ($\geq$ 260 cal/gm).

Phase III was the study of a porous shielding material, 50VJ2 cermet. For this material only Rehyd and Hermes II were used to investigate the sample behavior as a function of thickness and energy loading. The cermet has an effective intermediate Z ($\equiv 22$) and a density of 3.26 gm/cm^3. The intent of the Rehyd tests was to keep constant the deposition profile and timing while investigating the stress dependence as a function of the sample thickness (0.050", 0.080", 0.110") and energy loading. All three sample thicknesses were greater than the Rehyd deposition range. The 0.050" sample was marginal. The stress relief depth was 0.05 cm for the Rehyd 120 nsecs deposition time; this depth was comparable to the electron range, so some stress relief occurred during deposition. The stress profiles were expected to display a strong attenuation with distance that is usual for porous materials. The propagated stress waves were measured with quartz gauges, using fused silica buffers for the thinnest samples to avoid electron deposition directly into the gauge.

Direct measurements of the Grüneisen parameter and the spall strength were also made for this cermet using the Hermes II machine. Hermes II at 8-10 MeV yields a large deposition range (~ 5.0 gm/cm^2) and, consequently, produces uniform deposition profiles in the samples used.

This report summarizes briefly the experimental techniques used and the types and quality of data obtained. Although some specific numerical results are presented, all results

are preliminary at this time. Complete data reduction and analysis of the results have not yet been completed. Detailed hydrocode calculations of predicted stress histories for comparisons with these data, and with the data by other commonality experimenters, are in process at SRI. These commonality correlations and conclusions will be reported separately.

EXPERIMENTAL TECHNIQUES

Figures 1 and 2 illustrate typical calorimetry arrays for both spatial dosimetry (using total stopping carbon calorimeters) and dose-depth measurements (using thin carbon foils). Also indicated is the manner of mounting samples and gauges. For the material irradiations by the e-beams, the dose-depth stack was replaced by the appropriate sample/gauge configuration. For all shots the diode characteristics were recorded using the Sandia 7912-PDP11 data recording and reduction system. This system recorded V and I (voltage and current) and computed the diode impedance, the diode power, the pulse duration, and the time-integrated electron energy spectrum. This information allows deposition calculations to be performed using the Monte Carlo transport codes ELTRAN and TIGER. Figure 3 illustrates a typical dose-depth analysis using BJ3'.

The material response monitoring techniques used by Ktech included quartz and carbon gauges, and laser velocity and displacement interferometry (LVI and LDI). The quartz gauges were usually placed directly on the specimen, whereas the carbon gauges and LVI generally included the use of a PMMA (Plexiglas) or fused silica material in which the gauge or mirror was

embedded. For a thin specimen, a fused silica buffer was also used to protect quartz gauges from direct electron deposition.

EXPERIMENTAL RESULTS

Figures 4, 5, and 6 illustrate typical Al stress measurements taken with the three monitoring techniques of quartz and carbon gauges, and LVI. For the carbon gauges and LVI conditions the influence of the buffers of PMMA and fused silica, respectively, must be taken into account. The PMMA "shocks-up" the stress wave profile giving the steep observed rise. The long-lived tail on the carbon gauge record resulted from the impedance mismatch between Al and PMMA, and represented the "ring down" of the stress reflecting back and forth in the thinner Al piece. The fused silica buffers mostly smooth the stress profiles, lessening the steepness of the front of the original material wave.

To allow evaluation of the stress records it is essential to ensure one-dimensional conditions for as long as possible. Great care was taken with the choice of irradiation area, sample thickness, and buffer/monitor geometry to guarantee one-dimensional situations. Typically the beam fluence varied by less than 20% across a sample irradiation diameter (about 0.7"). Figure 7 illustrates the consideration involved in this one-dimensional determination. Indicated on Figs. 4, 5, and 6 are the calculated limits to one-dimensionality times for these experimental conditions.

Due to the non-flat deposition profiles coupled with stress propagation during energy deposition, the peak induced stresses are less than the direct Grüneisen stresses for instantaneous

energy deposition. The magnitude of this stress relief effect depends on the deposition profile width, the deposition time and the material sound speed. Figure 8 gives the generalized effects for Al and Ta as a function of deposition timing using these e-beam machines. It is seen that where Al exhibits only a relatively small dependence on time, Ta is very dependent.

Figure 9 gives a direct comparison of Al stress profiles normalized to gauge stress per unit material specific energy loading. Despite the wide range of energy loadings and deposition times, very little variation in the normalized peaks is observed, as expected.

Figure 10 gives a direct comparison of Ta stress profiles normalized to gauge stress per unit material specific energy loading. A dramatic dependence in peak stress is observed as a function of deposition time, as expected, while the influence of deposition profile widths, due to differing mean electron energies, can also be seen.

Figure 11 illustrates the observed gauge stresses for the three cermet thicknesses exposed at Rehyd. It is seen that at constant energy loading the thinner sample gives the higher peak stress, as expected for a porous material.

To directly study the Grüneisen Γ and spall strength of the cermet, Hermes II was chosen for the electron irradiation since it gave a reasonably uniform deposition within the samples (0.080" thick) and had a short enough deposition time (70 nsecs) to give only minor through-the-thickness stress relief. Energy loadings of up to 85 cal/gm were achieved.

The Grüneisen Γ was determined using LDI and employing the stress matching technique with fused silica as the reference material having a free surface mirror. Figure 12 illustrates the position-time (x:t) and stress-particle velocity (P:u) analysis appropriate to the experimental arrangement. Figure 13 gives a typical LDI interpretation showing clearly the first three velocity states which allow extrapolation to the initial cermet thermal stress, and hence determination of the Grüneisen parameter (i.e., via $P = \Gamma\rho E$). Also evident is the influence of the finite deposition time and the jump incurred due to the thin epoxy bond between the porous sample and fused silica reference.

Figure 14 summarizes the stress inferred versus energy loading and indicates a mean value of $\Gamma \sim 0.05$ over the range of 0-60 cal/gm.

To determine the spall strength of the cermet, a triple stack of free-surface samples (0.080" thick) were irradiated in a common shot. Figure 15 illustrates the arrangement, gives mean energy loadings, and shows the observed modes of damage. A variation from complete spall to no damage was obtained, and incipient spall loading of about 70 cal/gm was identified. Figure 14 suggests a corresponding tensile strength of about 0.55 kbars, assuming a simple release path inversion of initial thermal stress into tension, appropriate for approximate uniform energy loading. The small non-uniformity in the deposition profile is the reason why the spall plane is towards the rear of the samples.

SUMMARY AND CONCLUSIONS

The ability to load, monitor, and understand the response of three classes of materials exposed to electron beam irradiations from four different electron beam machines has been demonstrated. Aluminum, tantalum and a cermet were successfully irradiated over the loading range 50-900 cal/gm and with deposition times from 30-120 nsec. The aluminum exhibited only slight dependence on deposition duration, as expected; the tantalum stress exhibited the anticipated strong dependence on deposition time. For the cermet, the Grüneisen parameter was determined to be about 0.05. The spall strength for uniform heating was found to be one-half kilobar, and stress generation, propagation, and attenuation were recorded as a function of thickness and loading. Detailed correlation between measurements and calculations are in progress.