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INITIAL TEMPERATURE EFFECTS ON THE SHOCK COMPRESSION AND RELEASE PROPERTIES OF DIFFERENT ALUMINA-FILLED EPOXY COMPOSITIONS

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Abstract. Alumina-filled epoxies are composites having constituents with highly dissimilar mechanical properties, resulting in complex behavior during shock compression and release. Two distinguishing characteristics are amplitude-dependent wave structures and high release wave velocities. Recent studies examined the effects of various compositional changes on these shock properties. As expected, the strongest effects were observed when the total alumina volume fraction was reduced in steps from a nominal 43% to 0%. In the present study, compositions prepared over the same range of alumina loadings were examined at initial temperatures that were nominally -55 °C or 70 °C. Experimental configurations were identical to previous room-temperature experiments. Laser interferometry and wave timing were used to obtain transmitted wave profiles, Hugoniot states, and release wave velocities. Initial densities were determined from thermal expansion coefficients measured for each composition. Although initial density changes are very small, significant temperature effects on shock properties were observed.

Keywords: composites, alumina-filled epoxy, temperature effects
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INTRODUCTION

Alumina-filled epoxy (ALOX) has constituents with highly dissimilar mechanical properties, resulting in complex behavior during shock compression and release. Previous studies (1-3) examined in some detail the shock properties of particular compositions consisting of Epon 828 resin (4), Epi-Cure Z curing agent (5), and various volume fractions of alumina powder (6). Transmitted wave profiles showed extended rise times that increased with decreasing wave amplitude, and dispersive rounding near peak values. Release waves displayed unusually high velocities compared to shock velocities. These distinguishing characteristics were enhanced by increasing the volume fraction of alumina powder. In the current study, the effects of initial temperature changes on these characteristics were examined in the same ALOX compositions. Elastic properties of the unfilled epoxy are known to vary considerably with temperature (7), suggesting that temperature effects on the shock properties of ALOX compositions could be significant.

EXPERIMENTAL CONFIGURATION

Figure 1 shows the experimental configuration used in the current study. An ALOX disk backed by silicon carbide foam impacts a target consisting of a sample of the same ALOX composition bonded to a fused silica buffer/window assembly. The temperature of the ALOX sample is monitored using embedded thermocouples. A 0.025-mm-thick piezoelectric PVDF gauge is

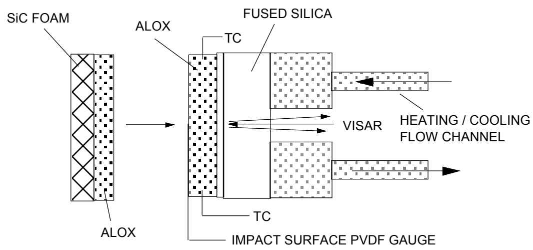

FIGURE 1. Projectile and target configurations for experiments conducted at hot or cold initial temperatures.

attached to the impact surface to provide accurate impact timing. VISAR instrumentation is used to record the profiles of the transmitted compressive wave and the subsequent release wave. A copper flow channel is incorporated into the target through which either heated water or chilled ethanol is circulated. Final target temperatures are achieved over a 4-5 hour period.

In order to determine initial densities for heated or cooled ALOX samples, linear coefficients of thermal expansion were measured for each of the compositions over the temperature range of interest. Coefficients increased linearly with temperature, with values at 20 °C varying from 5.04×10^{-5} to 2.40×10^{-5} mm/mm/°C for unfilled epoxy and for 43% by volume alumina, respectively. Calculated initial densities over the range -60 to 80 °C vary from room temperature values by only 1.10% and 0.55% for the unfilled and 43% cases, respectively.

RESULTS

ALOX impactor and target dimensions, as well as impact velocities, were chosen to match conditions used in previous room-temperature experiments (2,3). The first case examined used ALOX with 43% by volume alumina and an impact condition that produced relatively low peak stresses and long wave rise times. Figure 2 shows transmitted wave profiles at the ALOX/window interface recorded in experiments at initial temperatures of 75 °C and -55 °C, together with a profile obtained previously at room temperature. To facilitate comparisons, the profiles are plotted versus time from wave arrival. Details of the

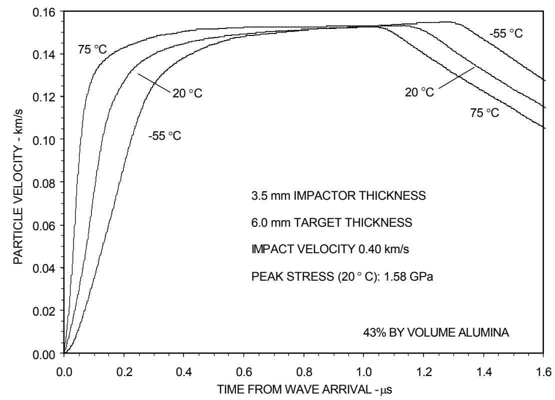

FIGURE 2. Transmitted wave profiles in samples with 43% alumina loading for a lower peak stress case.

experimental conditions are listed on the figure. The most striking temperature effect is the increase in wave rise time with decreasing temperature. A possible mechanism for this effect has been discussed previously (2). The same wave profiles are plotted versus time from impact in Figure 3. Because impactor and sample dimensions were the same in each experiment, these profiles show initial temperature effects on the velocity of the shock and release waves. Shock velocities increase substantially with decreasing temperature, but only a very small increase in release wave velocities is apparent. The peak stress values listed on Figure 3 are the product of the calculated initial density, the average velocity of the half-maximum

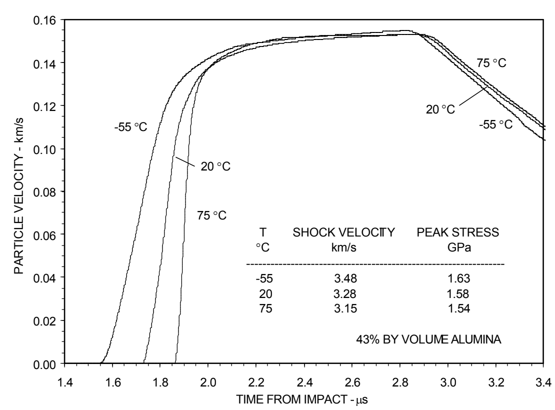

FIGURE 3. Transmitted wave profiles from Fig. 2 plotted versus time from impact.

point on the wave profile, and a calculated value for the impact interface velocity. The resulting values increase steadily with decreasing temperature.

The second case examined used ALOX with 43% by volume alumina and an impact condition that produced much higher peak stresses, resulting in much shorter wave rise times. Figure 4 shows profiles recorded in experiments at initial temperatures of 73 °C and -46 °C, together with a corresponding room-temperature profile. The

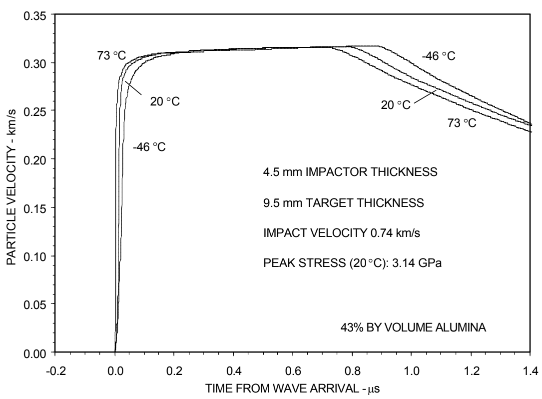

FIGURE 4. Transmitted wave profiles in samples with 43% alumina loading for a higher peak stress case.

impactor and target dimensions were larger in this case, as listed in the figure. Temperature effects on wave rise times are not as apparent, and the most noticeable feature is an increase in dispersive rounding in the -46 °C profile. Figure 5 shows the same wave profiles plotted versus time from impact. As in the previous case, decreasing temperatures result in noticeable increases in shock velocities and peak stresses, but very small changes in release wave velocities.

The peak stress results shown in Figs. 3 and 5 can be compared to an early study of temperature effects in the same ALOX containing 43% by volume alumina (8). In this study, projectile-mounted quartz gauges were used to obtain Hugoniot states for heated or cooled ALOX samples in gas-gun targets. Using the reported Hugoniot curves, calculations for our impact conditions give peak stresses that are roughly 1% lower for the cold experiments, 2% lower for the

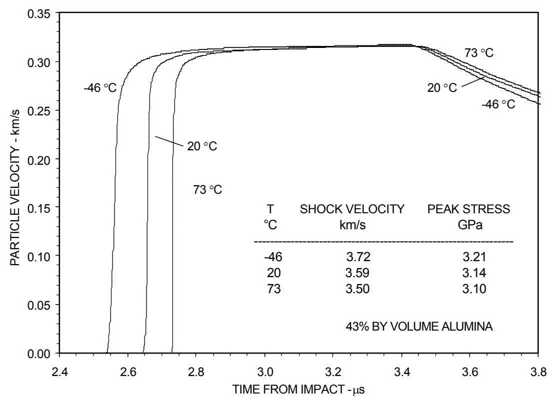

FIGURE 5. Transmitted wave profiles from Fig. 4 plotted versus time from impact.

room-temperature experiments, and 3% lower for the hot experiments.

The next case examined used ALOX containing only 20% by volume alumina. Impactor and target dimensions, as well as impact velocity, were the same as in the last case with 43% alumina loading. Room temperature experiments in these two cases resulted in shock states at nearly the same strain (3). Figure 6 shows the transmitted wave profiles recorded for this case plotted versus time from impact. Wave rise times are very short in all cases, and the primary difference due to temperature changes is greater dispersive rounding in the -51 °C profile. Shock velocities and peak stresses show the same trends with temperature, but the relative changes are larger than the last case with

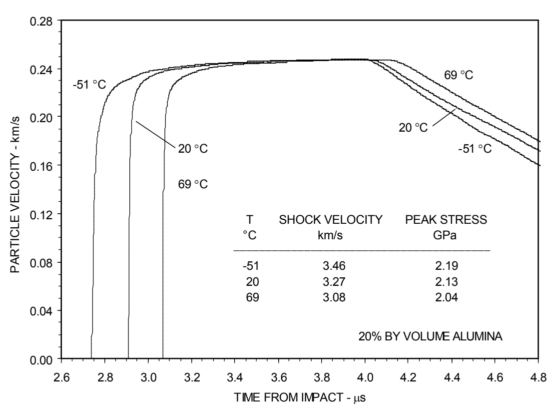

FIGURE 6. Transmitted wave profiles in samples with 20% alumina loading.

43% alumina loading. In addition, differences in release wave velocities are more pronounced.

The final case examined was the limiting case of unfilled epoxy. Impact velocity and sample dimensions were the same as in the last two cases, with the shocked state at room temperature very close in strain to the corresponding strains in these cases. Figure 7 shows the wave profiles recorded in this case plotted versus time from impact. The start of each wave profile is an abrupt shock jump, followed by dispersive rounding that increases with decreasing temperature. The relative changes in shock velocity and peak stress are slightly larger than in the last case with 20% alumina loading. Larger increases in release wave velocities with decreasing temperature are apparent. Equilibrium states were not achieved in this case, as the recorded particle velocities are still rising steadily at the time of release wave arrival.

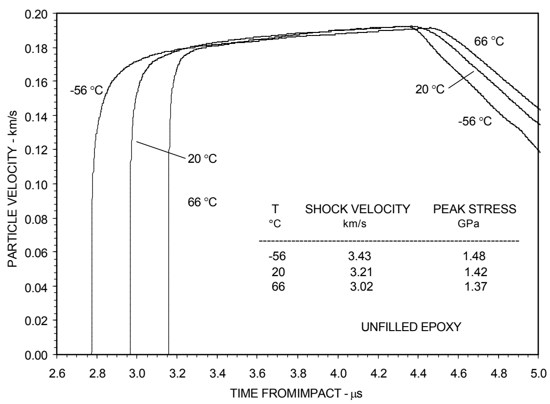

FIGURE 7. Transmitted wave profiles in unfilled epoxy samples.

SUMMARY

Shock compression and release experiments have been conducted on several alumina-filled epoxy compositions to examine initial temperature effects. Although changes in initial density were small, significant changes in shock properties were observed. A lower peak stress condition was used to observe a large increase in wave rise time with decreasing temperature. Other cases used common sample dimensions and impact velocities to observe temperature effects as the volume percent of alumina was reduced. Shock velocities and peak stresses were found to increase substantially with decreasing temperature, with much smaller changes observed in release wave velocities. These effects increased with decreasing alumina loading.

In each case, peak particle velocities recorded for different initial temperatures were nearly the same. These states result from wave interactions at the VISAR window, and temperature effects in fused silica properties could be involved.

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REFERENCES

1. Munson, D. E., Boade, R. R. and Schuler, K. W., *J. Appl Phys.* **49**, 4797-4807 (1978).
2. Setchell, R. E., and Anderson, M. U., *J. Appl Phys.* **97**, 083518 (2005).
3. Setchell, R. E., Anderson, M. U., and Montgomery, S. T., *J. Appl Phys.* **101**, 083527 (2007).
4. A product of Resolution Performance Products.
5. Previously available from Shell Chemical Company.
6. Ground tabular alumina from Alcoa Industrial Chemicals Division.
7. Adolf, D., Childress, C. and Hannum, D., "Bulk and Shear Moduli of Epoxy Encapsulants," Sandia Laboratories Report SAND89-0748 (1989).
8. Lee, L. M.,Jenrette, B. D., and Greb, A., "Alumina-Filled Epoxy Shock Response as a Function of Temperature," Air Force Weapons Laboratory Report AFWL-TR-87-133 (1987).