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EFFECT OF PARTICLE MORPHOLOGY ON INPUT AND PROPAGATED STRESS WAVE PROFILES FOR TWO HIGHLY-POROUS POLYTETRAFLUOROETHYLENE POWDERS

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Piezoelectric polymer stress gauges in copper fixtures were used with the Sandia 2.5-inch bore gas gun to obtain time-resolved pressure measurements for two polytetrafluoroethylene powders having significantly different particle morphologies. The powders had approximate average particle sizes of 534 microns and 28 microns, respectively, and scanning electron microscopy revealed differences in the appearances of representative particle surfaces. The range of input stresses was from 0.13 GPa to 2.81 GPa, and the initial densities were 57% of the solid density. The "crush strength" (pressure required to compress the porous compact to solid density) was close to 1.0 GPa for the coarse material as compared to 0.6 GPa for the finer material. At an input stress of about 0.6 GPa, the risetime of the propagated stress waves in the coarse material was approximately 240 nsec compared to 50 nsec for the finer material. These measurements show the strongly rate-dependent deformation of the powders and that particle morphology has a significant effect on the shock compression.

INTRODUCTION

The effect of initial particle morphology on the shock compression behavior of polymers is of interest as a part of an over all study of the shock compression of highly-porous powder systems¹⁻⁴. Time-resolved pressure measurements have been obtained for two polytetrafluoroethylene (PTFE) powders having significantly different particle morphologies. The powders had approximate average particle sizes of 534 microns⁵ (coarse grain) and 28 microns⁶ (fine grain) respectively. Figure 1 shows scanning electron microscopy (SEM) photos of the as-received, coarse-grain particles, and, the deagglomerated fine-grain particles. The coarse-grain particles do not appear to be agglomerates of smaller particles. The as-received fine-grain material showed a tendency to agglomerate into fragile larger particles,

and was deagglomerated in a blender prior to use in the shock compression experiments.

FIGURE 1. SEM photos of PTFE particles. (a) As-received coarse-grain particles. (b) Deagglomerated fine grain particles.

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EXPERIMENTAL TECHNIQUE

The time-resolved shock compression technique used in the present study subjects the powder sample to controlled shock loading. Pressed samples of PTFE powder (all $56.8 \pm .05\%$ of 2.15 gm/cm^3 solid density) were held in cylindrical copper fixtures¹. A two-step pressing procedure was used to help ensure uniformity of the powder sample. Each fixture incorporated three piezoelectric polyvinylidene fluoride (PVDF) film stress gauge packages for time-resolved measurements of the stress in different parts of the fixture. The gauges were insulated with 25-micron-thick PTFE film. A Kel-F⁷ polymer disk formed the closure of the fixture on the impact end. A gauge on the impact surface of the Kel-F measured the input stress to the fixture. A second gauge, on the opposite surface of the Kel-F, measured the input stress to the powder sample. A third gauge, mounted on a disk of TPX⁸ polymer that forms the other closure of the fixture, provided a measurement of the stress wave after propagation through the powder sample. The TPX material provided a low-shock-impedance support for the gauge.

The Sandia 2.5-inch (63.5-mm) bore gas gun was used for these experiments. Copper disks (9.6 mm thick) impacted the copper fixtures at speeds from 0.164 to 0.997 km/s to produce selected input shock stress levels. The PVDF gauges were operated in the current mode¹. The current pulses were recorded on digital oscilloscopes and the current versus time profiles were converted to stress versus time using the PVDFSTRESS computer code⁹. Wave speeds and impact speeds are known to 0.1%. Loading tilt is 200 microradians or less.

RESULTS AND DISCUSSION

Six time-resolved shock compression experiments were performed, four with the 534 micron powder and two with the 28 micron powder. Table 1 is a summary of the experiments and results.

The stress dependence of the measured wave speeds was similar for both the coarse- and fine-grain powders. Figure 2 shows the very significant

TABLE 1. Summary of Experiments and Results.

Experiment Number	Particle Size (microns)	Impact Speed (km/s)	Input Stress ^a (GPa)	Wave Speed ^b (km/s)	Prop. Risettime ^c (nsec)	Output Stress ^d (GPa)	Relative Volume ^e
2591	534	0.164	0.13	0.541	395	0.25	1.132
2581	534	0.381	0.57	1.092	259	0.92	1.067
2586	534	0.624	1.22	1.509	79	1.80	0.985
2584	534	0.996	2.81	2.149	95	3.23	0.884
2587	28	0.400	0.65	1.095	52	0.32	0.981
2579	28	0.997	2.47	2.189	40	f	1.017

^aPVDF measurement at Kel-F/sample interface. ^bWave speed toe-to-toe. ^cPropagated wave toe-to-peak (10-90%). ^dPVDF measurement at sample/TPX interface. ^eCalculated using PVDF input stress, toe-to-toe wave speed, and solid density of PTFE material. ^fTransit time measurement only.

FIGURE 2. Effect of particle morphology on the stress-dependence of the risetime of the propagated wave.

differences in the risetime versus stress behavior of the two powders for stress levels less than about 1 GPa. Figure 3 shows the differences in the crush-up behavior from the initial highly porous state with a relative volume of 1.75 to the ambient solid density at relative volume of 1.0. This "crush strength" (pressure required to compress the porous compact to solid density) was close to 1.0 GPa for the coarse-grain powder as compared to 0.6 GPa for the fine-grain powder. At higher stress levels, the coarse-grain material continues to decrease in volume, while the fine-grain powder shows a slight increase in volume. Figure 4 provides an example of the difference in propagated wave risetimes for the two powders (Experiments 2581 and 2587). The input stress levels for these experiments were similar (0.57 GPa for the coarse-grain powder and 0.65 GPa for the fine-grain powder). From the curves of Fig. 2, for a stress level of about 0.6 GPa, the risetime of the propagated wave was approximately 240 nsec for the coarse-grain powder and 50 nsec for the fine-grain powder.

The observed differences in the shock compression behavior of these powders is consistent with the model of the larger particles having opportunity for greater total shear deformations while filling the

FIGURE 3. Propagated wave stress dependence on relative volume for the two powder morphologies.

FIGURE 4. Stress-time profiles for two powder morphologies at similar input stress levels.

interparticle voids during compression. The propagated wave risetimes would be expected to be larger for the larger particles as they deform more extensively in response to the applied stresses.

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5. This material (designated DuPont "Teflon" 8A PTFE) was obtained from DuPont Fluoroproducts, Wilmington, DE. An average particle size of 534 microns was obtained from the supplier.
6. This material (designated Fluon "G" Series G170 PTFE) was obtained from ICI Americas, Inc., Wilmington, DE. An average particle size range of 25-30 microns for the received material was obtained from the supplier. An average value of 28 microns will be used in this paper.
7. Vinylidene chloro-chloro-trifluoro ethylene copolymer, 4-methylpentene-1 polymer.
8. D. E. Wackbarth, M. U. Anderson, and R. A. Graham, SAND92-0046, February 1992, Sandia National Laboratories.

While the wave propagation speeds are similar for the two powders (resulting from transmission of stress in the stress levels attained can be related to the different times required for void closure, and to corresponding differences in propagated wave risetimes. If longer times are required to attain a certain stress level in the coarse-grain powder, then it would be expected that during the limited time of the experiment, a lower maximum stress level would result for the propagated wave.

CONCLUSIONS

This study shows for the first time, the shock compression features of highly-porous PTFE. The observed differences in the propagated wave risetimes for coarse- and fine-grain powders indicate that the time dependence of the compression processes are strongly affected by particle size. Differences in the crush strengths indicate that the smaller particles are compressed to ambient solid density at lower stress levels than for the larger particles. These observed differences in the shock compression response of the two PTFE powders demonstrate the significant effects of particle morphology on stress wave propagation in these materials, and the importance of including these effects in stress calculations and modeling efforts.

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