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Abstract. The size (diameter) effect and the Cylinder test results for Kinepak (ammonium nitrate/nitromethane), Red Dot and Bullseye shotgun powders, Semtex 1, Semtex H and urea nitrate will be presented. Cylinder test data appears normal despite faster sound speeds in the copper wall. Most explosives come to steady state in the Cylinder test as expected, but Kinepak shows a steadily increasing wall velocity with distance down the cylinder. Kinepak appears to have a late-time reaction about one hundred times slower than the initial detonation.

Keywords: Size effect, diameter effect, detonation velocity, detonation energy, Cylinder test
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INTRODUCTION

The size (diameter) effect for detonation velocity [1] and the copper-wall Cylinder test for detonation energy density [2-4] are basic measures of detonation.

Kinepak is a commercial mixture nominally of AN 79 wt%/NM 21. The old version contained 2.9 wt% glass microballoons and the new (from shot 750 on) 4.0%. The old AN was 30-150 µm with a peak at 60 µm and the new is coarser. The liquid is added just before shooting and the absorption appears uniform.

Semtex 1A is PETN 83.5, semtexoil 12.4, and rubber 4.1. Semtex H or 1H is RDX 60.5, PETN 25.0, semtexoil 11.6, rubber (styrene/butadiene) 2.9. Red Dot is a shotgun powder made up of NG 20, NC-13.2 77.5, diphenylamine 0.7, carbon black 0.5, potassium nitrate 0.3, graphite 0.3, acetone/ethanol 0.5, water 0.2. Bullseye is a shotgun powder made of NG 40, NC-13.2 58, ethyl centralite 0.7, potassium sulfate 0.3, graphite 0.3, acetone/ethanol 0.5, and water 0.2.

EXPERIMENTAL PROCEDURE

The detonation velocities were measured with shorting pin rings. The standard deviation comes from comparing two rings with 6 pins each.

The Cylinder Tests measure wall velocity with PDV (photon Doppler shift or heterodyne) [5]. A heavy aluminum rack is now used to hold the probe angles constant. In Table 2, all wall velocities are at scaled 1-inch diameters for displacements of 6, 12.5 and 19 mm. These correspond to relative volumes in the cylinder of 2.4, 4.4 and 7.0 [4].

RESULTS/DISCUSSION

Table 1 lists the size effect data for three explosives. The average detonation rate, ν, is inversely proportional to the slope by way of

$$\nu \approx \frac{-D^2}{dU_s / d(1/R_o)} \qquad (1)$$

where U_s is the detonation velocity at radius R_o and D is the detonation velocity at infinite radius. The Kinepak rate is 4.0 μs^{-1} in metal and 1.2 μs^{-1} in plastic, and the confined Red Dot rate is 4.2 μs^{-1}. These are low, ANFO-like, non-ideal values. The Semtex rate cannot be quanitified, but it is clearly large, perhaps 200 μs^{-1}.

Table 2 lists the Cylinder test results. Today's Cylinder test analysis calculates the detonation energy density while accounting for the angle of the PDV probe [4], with the energy varying as the cosine of the probe angle. Table 2 lists results for Semtex H with six probes at the same distance down the cylinder but with probe angles from 5 to 10°. The velocities are the same within error, showing that the effect of angle error is indeed small.

With many probes with modern accuracy, we may check two other issues regarding the Cylinder test. One is whether anything unusual occurs because the detonation velocity of the explosive is less than the sound speed in the copper wall. Our best example is the pure component urea nitrate, which was measured at 0.746 and 0.944 g/cc with a 25.4 mm diameter and gave detonation velocities of 3.28 and 4.41 mm/μs. As shown in Figure 1, both came to the expected steady state conditions despite the probable run-ahead in the copper wall.

The second issue is whether the Cylinder test really comes to steady state in the length allowed. Previously, we measured only a single value 72% of the way down the tube. We now find that wall velocities suitable for conversion to energy densities may be measured from 46 to 87% of the way down the tube. Figure 2 shows the results for Red Dot, and steady state appears achieved by the second probe. The Bullseye appears to have reached steady state by the first probe, although we do not show the figure.

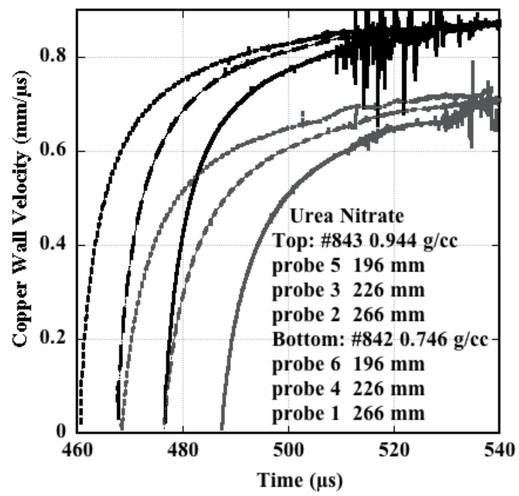

Figure 1. Wall velocities of urea nitrate at two densities, showing normal Cylinder behavior.

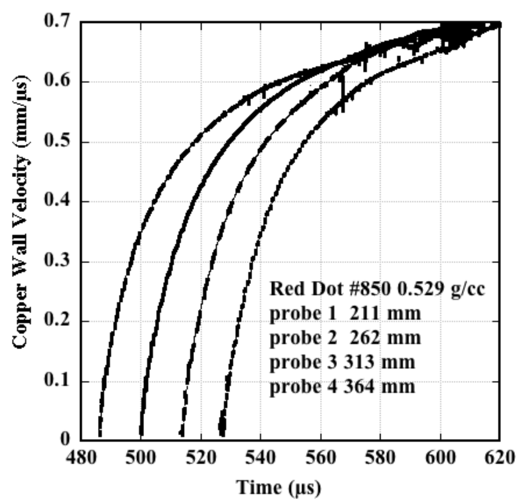

Figure 2. Cylinder test for Red Dot showing steady state by the second probe.

TABLE 1. Size (diameter) effect data.

Density, g/cc	Radius, mm	Detvel, mm/µs	stdev, mm/µs	Wall material	Wall, mm	Length, mm	Shot No.
Kinepak							
1.25	25.85	5.46	0.021	steel	2.83	508	666
1.24	25.38	5.29	0.008	steel	5.22	458	851
1.20	12.71	5.13	0.014	copper	2.61	305	657
1.16	6.56	4.62	0.046	steel	2.90	254	665
1.05	6.35	3.92	0.014	copper	1.36	152	750
1.25	4.76	4.00	0.034	steel	1.54	257	668
1.17	3.98	3.17	0.028	steel	2.37	254	681
1.24	3.97	4.15	0.054	copper	3.18	153	792
1.12	3.12	2.49	0.117	steel	1.70	254	670
1.38	3.09	1.87		steel	3.27	254	669
1.17	2.61	2.94	0.052	steel	3.72	254	703
1.17	6.42	4.12	0.242	steel	9.46	254	679
1.31	6.38	4.66	0.132	steel	19.00	253	672
1.22	3.20	3.53	0.226	steel	9.49	254	674
1.33	2.80	1.18		steel	9.90	254	678
1.23	2.38	0.62		steel	10.31	254	677
1.23	25.40	4.61	0.010	Lucite	3.20	509	671
1.20	15.94	3.99	0.014	Lucite	3.12	509	661
1.14	12.73	3.37	0.010	Lucite	0.50	254	675
1.20	11.17	3.23	0.015	Lucite	1.68	257	660
1.20	8.03	2.68	0.016	Lucite	1.57	254	662
1.20	6.39	fail		Lucite	1.54	254	664
Red Dot							
0.53	25.39	3.641	3.64	steel	6.37	457	821
0.52	12.71	3.468	3.35	copper	2.61	305	651
0.49	12.71	3.282	3.36	copper	2.61	304	653
0.52	6.43	3.248	3.12	steel	1.56	254	715
0.52	3.98	2.827	2.70	steel	0.83	153	828
0.49	3.10	2.562	2.60	steel	1.64	254	717
0.47	2.29	2.480	2.64	steel	1.71	152	820
Semtex 1A							
1.451	13.54	7.575	0.041	steel	2.34	252	815
1.395	12.71	7.489	0.054	copper	2.61	305	647
1.446	9.97	7.648	0.093	steel	2.81	229	832
1.423	6.44	7.502	0.050	steel	1.55	254	718
1.421	6.31	7.580	0.045	steel	1.65	153	831
1.420	3.10	7.604	0.050	steel	1.62	254	719

TABLE 2. Cylinder test data at the three standard wall displacements: 6, 12.5 and 19 mm.

Explosive	radius, mm	thick, mm	probe no.	angle, deg	view, mm	length, mm	wall 6	velocity, 12.5	mm/µs 19
Semtex H	12.706	2.599	1	5	240	305	1.260	1.380	1.435
#814			2	5	240	305	1.276	1.386	1.442
1.527 g/cc			3	7	240	305	1.268	1.397	1.450
7.88 mm/µs			4	7	240	305	1.249	1.373	1.428
			5	10	240	305	1.272	1.395	1.448
			6	10	240	305	1.250	1.366	1.426
Bullseye	25.382	5.225	1	7	211	458	0.662	0.765	
#849			2	7	263	458	0.672	0.780	0.838
0.703 g/cc			3	7	314	458	0.677	0.780	0.831
4.35 mm/µs			4	7	364	458	0.671	0.776	
Kinepak	25.384	5.216	1	7	211	458	0.857	0.983	1.003
#851			2	7	262	458	0.878	0.980	1.029
1.237 g/cc			3	7	314	458	0.914	1.030	1.078
5.29 mm/µs			4	7	364	458	0.980	1.089	1.134
Red Dot	25.382	5.225	1	7	211	458	0.512	0.594	0.630
#850			2	7	262	458	0.524	0.610	0.655
0.529 g/cc			3	7	313	458	0.532	0.626	0.669
4.35 mm/µs			4	7	364	458	0.535	0.620	0.660

Figure 3 shows the results for Kinepak and the curves rise steadily as the detonation progresses down the cylinder. This could be evidence of a second slower reaction.

We next convert wall velocities to detonation energy densities and plot them as a function of the detonation front time down the tube in Figure 4 [3]. The curves are at the three standard relative volumes that go with the scaled displacements in Table 2. It is difficult to judge the later reaction because it is not leveling off but appears to be increasing. We also plot the calculated points using CHEETAH V6, and the final measurements have reached these values.

The times in Figure 4 suggest a rate of perhaps 0.02 μs^{-1}, which is one hundred times slower than the primary rate. This would require a two-rate reactive flow model and explains why the one-rate model was

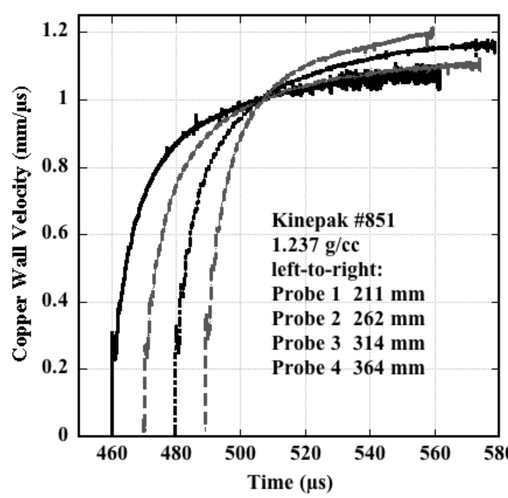

Figure 3. Cylinder test for Kinepak showing continued reaction down the cylinder.

inadequate. The other answer is that this behavior comes from large density gradients. The shot was fired upward, so that denser material would be expected at the bottom of the cylinder if settling occurred. At present, this result is mysterious.

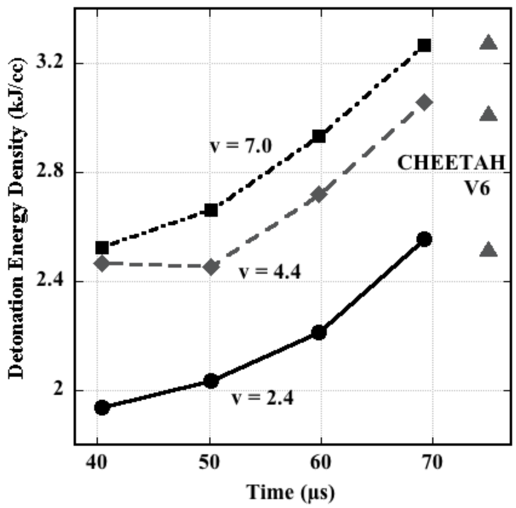

Figure 4. Detonation energy densities for Kinepak at the three standard Cylinder test relative volumes.

CONCLUSIONS

The Cylinder test gives good information on low-detontion-velocity explosives.

ACKNOWLEDGEMENTS

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