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Card-Gap and Projectile Impact Sensitivity Measurements, A Compilation

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by

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ABSTRACT

Card-gap and projectile impact sensitivity data are presented for a wide variety of explosive compositions tested at the Bureau of Mines in more or less standard test geometries. The results of both tests are in good agreement in that they provide the same sensitivity ordering for different subclasses of explosives. Least sensitive were homogeneous liquids that did not exhibit a tendency to undergo low-velocity detonation, ammonium nitrate-fuel oil, and most cast military explosives. Of intermediate sensitivity were pressed and powdered military explosives, cast pentolite, permissible and nonpermissible water-based explosives, and one commercial two-component explosive. The most sensitive were permissible and nonpermissible dynamites and explosives susceptible to low-velocity detonation.

INTRODUCTION

The Bureau of Mines has accumulated data relating to the card-gap sensitivity and the projectile impact sensitivity of a large variety of explosive substances. Many of the individual results have appeared in outside publications and formal and informal internal reports. Additional data have been compiled for a number of new explosives that have recently appeared on the commercial scene. This document consolidates these results in a single report for the convenience of those involved in the manufacture, transportation, and use of explosives in the United States.

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[1] Research supervisor.

EXPERIMENTAL METHODS

Card-Gap Test

The card-gap test results to be presented are limited to experiments conducted using the Bureau's standard test procedure which has been fully described elsewhere (2-3).[2] Summarized briefly, the donor charge consists of two pressed tetryl pellets, each having a diameter of 1-5/8 inches and a length of 0.5 inch. The pellets are pressed to a density of 1.57 g/cm^3 and individually weigh 25 g, making the total donor weight 50 g. The donor is initiated with a No. 8 electric blasting cap. The shock attenuator also has a diameter of 1-5/8 inches and is made from a machined Plexiglas[3] rod having nearly the desired length. Adjustments are made in the total length of the attenuator by adding 1/4-inch-thick by 1-5/8-inch-diameter Plexiglas disks or 0.010-inch-thick cellulose acetate cards also having a diameter of 1-5/8 inches. The peak shock pressure generated by this system has been determined as a function of attenuator length; the results are reported by Gibson (1). The explosive under test is confined in a 1-inch-inside-diameter schedule 40 seamless steel pipe ordinarily having a length of 16.0 inches and a nominal wall thickness of 0.133 inch. In certain cases, lengths as short as 8.0 inches were used, as will be indicated in the tabulation of test results. When determining the card-gap sensitivity of liquids, gels, slurries, or powders, a 0.003-inch polyethylene diaphragm is used to seal the shocked end of the acceptor tube.

Projectile Impact Test

The procedure for determining the sensitivity of explosives to projectile impact is fully described by Weiss (4). In essence, a cylindrical charge of the test explosive is impacted with a 0.5-inch-long by 0.5-inch-diameter brass projectile fired from a smooth-bore 50-calibre gun. The projectile is directed along the axis of the charge and impacts at normal incidence on the unconfined surface of the test explosive for the case of solid explosives. In testing liquids, gels, and powders, a 0.003-inch polyethylene film is used to cover the ends of the charge container; the confining effect of this diaphragm is negligible. Several different charge geometries, container sizes, and materials have been used in the impact work conducted at Bruceton. The particulars of the charge confinement geometry are given in the data tabulation. At present, 1.5-inch-diameter schedule 40 steel pipe nipples are used for this purpose; they have a length of 3.0 inches and a nominal wall thickness of 0.145 inch.

EXPERIMENTAL RESULTS

The card-gap test results for 55 different explosive compositions are presented in table 1. Threshold gap values are given for both high-velocity

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[2] Underlined numbers in parentheses refer to items in a list of references preceding a list of related publications.

[3] Reference to specific trade names is made for identification only and does not imply endorsement by the Bureau of Mines.

and low-velocity detonations whenever the latter occur. In rigorous card-gap testing, the Bruceton up-and-down technique is usually used to define the gap length corresponding to a 50-percent probability of initiation. From 25 to 50 test firings are required to adequately determine this value. Many of the data in table 1 are based on a smaller number of observations, usually 10 to 15. For this reason, threshold gap limits are used to define the relative sensitivities of the various explosive systems. The limits represent the largest gap for which detonations occurred and the smallest gap resulting in failures. High-velocity detonations were distinguished from low-velocity detonations by means of detonation velocity probes (3), witness plate damage, and size of fragments from the acceptor containers.

The results of the projectile impact tests are presented in table 2. In the majority of tests the Bruceton "up-and-down" method was used for estimating the projectile velocity corresponding to a 50-percent initiation probability (V_{50}). However, in certain cases, due to a limited number of firings, rough estimates of V_{50} were made by averaging the highest projectile velocity for which detonations were not observed and the lowest velocity resulting in detonations. In these cases, the values of V_{50} presented in table 2 are preceded by the symbol ($\sim$). Three different methods were used to determine if initiation of the explosive had occurred. The first was the use of a length of Primacord butted against the surface of the explosive below the line of flight of the projectile. The initiation of the Primacord as evidenced by a witness plate was taken as a positive result. The second method utilized an aluminum foil blast gage placed in proximity to the test sample, while the third method was based on the complete fragmentation of the containers used to confine the charges. An examination of the test site for explosive remnants was also employed to supplement the other methods.

SUMMARY

The results of card-gap tests and projectile impact tests are presented for a variety of explosive compounds. The results of both tests are in good agreement in that they provide the same sensitivity ordering for different subclasses of explosives. Homogeneous liquids that did not exhibit a tendency to undergo low-velocity detonation, cast military explosives (with the exception of Pentolite), and ammonium nitrate-fuel oil were the least sensitive. Pressed and powdered military explosives, cast Pentolite, permissible and nonpermissible water gels, and one commercial two-component system were of intermediate sensitivity. Permissible and nonpermissible dynamites and explosive compositions susceptible to low-velocity detonation were the most sensitive.

TABLE 1. - Summary of card-gap test results

Donor: 1-5/8-inch diameter by 1.0-inch-long pressed tetryl
Attenuator: 1-5/8-inch-diameter Plexiglas
Confinement: 1.0-inch-ID by 0.133-inch-wall by 16-inch-long steel

Explosive	Density, g/cm^3	Composition, weight-percent	Threshold gap length (ℓ), inches: High-velocity detonations	Threshold gap length (ℓ), inches: Low-velocity detonations
GELS AND SLURRIES				
Commercial two-component:				
X-1334	1.38	Proprietary	$1.75 < \ell < 2.0$	None observed
X-1406	1.38	do	Not determined	$\ell > 10$
Experimental gels:				
Mix-21	1.46	36 ammonium perchlorate, 39 aluminum, 22.5 nitromethane, 2.5 nitrocellulose.	$\ell < 1.0$	$\ell > 10$
270-C	1.26	65 ammonium nitrate, 12 aluminum, 10.5 water, 6 sodium nitrate, 6.5 other.	$1.5 < \ell < 1.75$	None observed
Dynamite: X-1351 (semigel)	1.76	Proprietary	$\ell > 10$[1]	None observed
Permissible explosives:				
P-1399 (nitroglycerin-sensitized semigel).	1.44	do	$\ell > 10$[1]	None observed
P-1340 (water-based)	1.17	do	$1.75 < \ell < 2.0$	None observed
GRANULAR MIXES AND POWDERS				
Ammonium nitrate	0.85	100 AN prills	No sustained reaction at zero gap.	None observed
Commercial AN-FO (X-1250)	.93	Proprietary	$1.25 < \ell < 1.50$	None observed
Permissible explosive P-1393 (nitroglycerin-sensitized granular).	.83	do	$\ell > 10$[1]	None observed
Pressed tetryl[2]	1.57	Neat tetryl	$2.0 < \ell < 2.5$	None observed
CAST SOLIDS				
Composition B	1.72	60 RDX, 40 TNT; 1 D-2 wax added.	$1.25 < \ell < 1.50$	None observed
H-6[2]	1.71	45 RDX, 30 TNT, 20 Al, 5 D-2 wax, 0.5 CaCl.	$1.1 < \ell < 1.2$	None observed
HBX-3[2]	1.81	31 RDX, 29 TNT, 35 Al, 5 D-2 wax, 0.5 CaCl.	$1.0 < \ell < 1.1$	None observed
Minol 2	1.68	40 TNT, 40 AN, 20 Al	$0.75 < \ell < 1.0$	None observed
Pentolite	1.61	50 PETN, 50 TNT	$2.0 < \ell < 2.25$	None observed
TNT[2]	1.57	Neat TNT	$1.0 < \ell < 1.2$	None observed
Tritonal[2]	1.72	80 TNT, 20 Al	$1.0 < \ell < 1.1$	None observed

LIQUIDS				
Ethyl nitrate	1.10	Neat EN	$0.10 < \ell < 0.25$	$1.0 < \ell < 2.0$
Ethylene glycol dinitrate	1.48	Neat EGDN	$\ell < 1.0$	$\ell > 10.0$
Hydrazine-hydrazine nitrate	1.11	75 H, 25 HN	No sustained reaction at zero gap.	No sustained reaction at zero gap.
Do	1.13	70 H, 30 HN	$\ell < 1.0$	None observed
Do	1.20	55 H, 45 HN	$\ell < 0.75$	$\ell > 0.75$
Do	1.23	50 H, 50 HN	$0.25 < \ell < 0.75$	$5.0 < \ell < 8.0$
Do	1.28	40 H, 60 HN	$0.13 < \ell$	$\ell > 10$
Do	1.34	30 H, 70 HN	$0.5 < \ell < 1.0$	$\ell > 10.0$
Do	1.42	20 H, 80 HN	$0.25 < \ell < 1.5$	$\ell > 10.0$
Hydrazine nitrate-monomethyl hydrazine-hydrazine.	[3]1.06	31.4 HN, 45.3 MMH, 23.3 H	No sustained reaction at zero gap.	No sustained reaction at zero gap.
Do	[3]1.08	35.0 HN, 42.9 MMH, 22.1 H	No sustained reaction at zero gap.	No sustained reaction at zero gap.
Do	[3]1.11	40.0 HN, 39.6 MMH, 20.4 H	$\ell < 0.5$	None observed
Do	[3]1.14	45 HN, 36.3 MMH, 18.7 H	$\ell < 0.5$	None observed
Do	[3]1.18	50 HN, 33 MMH, 17 H	$\ell < 0.5$	$0.5 < \ell < 2.0$
Do	[3]1.25	60.0 HN, 26.4 MMH, 13.6 H	$\ell < 0.25$	$8.0 < \ell < 10.0$
Do	[3]1.34	70.0 HN, 19.8 MMH, 10.2 H	$\ell > 0.13$	$\ell < 10.0$
Do	[3]1.43	80.0 HN, 13.2 MMH, 6.8 H	$\ell < 0.25$	$\ell > 10.0$
Do	[3]1.54	90.0 HN, 6.6 MMH, 3.4 H	$\ell < 0.13$	$\ell > 10.0$
Isoatomic mix for nitromethane	[3]1.08	51.6 nitric acid, 33.6 acetonitrile, 14.8 water.	$0.5 < \ell < 0.75$	None observed
Nitrobenzene-nitric acid	[3]1.40	28 NB, 72 WFNA	$10 < \ell < 15$	None observed
Nitromethane with 50/50 nitroglycerin-ethylene glycol dinitrate.	[3]1.19	80 NM, 20 NG-EGDN	$\ell < 0.5$	None observed
Do	[3]1.23	70 NM, 30 NG-EGDN	$\ell < 0.5$	None observed
Do	[3]1.26	60 NM, 40 NG-EGDN	$\ell < 0.5$	$\ell > 0.5$

[1] Sustained reaction with velocity lower than normal.
[2] Charge length 8.0 inches.
[3] Calculated density.

TABLE 1. - Summary of card-gap test results--Continued

Donor: 1-5/8-inch diameter by 1.0-inch-long pressed tetryl
Attenuator: 1-5/8-inch-diameter Plexiglas
Confinement: 1.0-inch-ID by 0.133-inch-wall by 16-inch-long steel

Explosive	Density, g/cm^3	Composition, weight-percent	Threshold gap length (ℓ), inches: High-velocity detonations	Threshold gap length (ℓ), inches: Low-velocity detonations
LIQUIDS--Continued				
Nitroglycerin-ethylene glycol dinitrate.	1.54	50 NG, 50 EGDN	$0.4 < \ell < 0.5$	$\ell > 10.0$
Nitroglycerin	1.59	Neat NG	$0.38 < \ell < 0.50$	$\ell > 10.0$
Nitromethane-tetranitromethane.	[3]1.31	55.5 NM, 44.5 TNM	Not determined	$\ell > 10.0$
Do	[3]1.27	65.1 NM, 34.9 TNM	Not determined	$\ell > 10.0$
Nitroisobutane triol trinitrate-acetone-ethyl centralite.	1.22	78 NIBTN, 20 AC, 2 EC	$\ell < 0.25$	None observed
Nitroisobutane triol trinitrate-ethyl centralite.	1.61	98 NIBTN, 2 EC	Not determined	$\ell > 10$
Nitromethane	1.13	Neat NM	$0.15 < \ell < 0.30$	None observed
Nitromethane-ethylene diamine.	1.12	95 NM, 5 ED	$0.5 < \ell < 0.63$	None observed
Nitropropane-nitric acid	[3]1.29	32 NP, 68 WFNA	$0.05 < \ell < 1.0$	$2.0 < \ell < 5.0$
Trimethylolethane trinitrate	1.47	Neat TMETN	$0.05 < \ell < 0.10$	$\ell > 10.0$
Tetranitromethane-acetonitrile	[3]1.24	70.5 TNM, 29.5 A	$\ell > 10.0$	None observed
Tetranitromethane-benzene	[3]1.47	86.3 TNM, 13.7 BEN	$\ell > 10.0$	None observed
Tetranitromethane-octane	[3]1.41	87.7 TNM, 12.3 OCT	$\ell > 10.0$	None observed
Triethylene glycol dinitrate-2-nitro-diphenylamine.	1.32	99.75 TEGDN, 0.25 2-NDPA	$\ell < 0.13$	None observed

[3]Calculated density.

TABLE 2. - Summary of projectile impact tests

Explosive	Composition, weight-percent	Density, g/cm^3	Charge size, inches		Confinement		V_{50}, m/sec
			Length	Diameter	Wall thickness, inches	Material	
LIQUIDS							
m-Dinitrobenzene	Neat DNB	1.4	3.0	1.5	0.145	Aluminum	1,150
Ethyl nitrate	Neat EN	1.11	3.0	1.5	.145	do	1,280
Hydrogen peroxide-glycerin.	74 H P (90 pct), 26 GL	1.4	3.0	1.5	.145	do	100
Nitroglycerin-ethylene glycol dinitrate.	50 NG, 50 EGDN	1.55	3.0	1.5	.145	do	132
Nitromethane	Neat NM	1.13	2.5	1.5	.145	Steel	>1,650
Nitromethane-ethylenediamine.	95 NM, 5 ED	1.12	2.5	1.5	.145	do	1,250
GELS AND SLURRIES							
Commercial gels (water-based):							
X-1336	Proprietary	1.49	3.0	1.5	0.145	Steel	~720
X-1337	do	1.32	3.0	1.5	.145	do	~438
Commercial two-component:							
X-1334	do	1.38	3.0	1.5	.145	do	~538
X-1406	do	1.38	3.0	1.5	.145	do	<146
Experimental gels:							
PB-1	39 AN, 34 Al, 27 NM	1.66	3.0	1.5	.145	do	~969
270-C	65 AN, 12 Al, 10.5 H_2O, 6 SN, 6.5 gelling agent and stabilizers.	1.26	3.0	1.5	.145	do	~384
272-C	65 AN, 12 Al, 15 H_2O, 3 SN, 5 gelling agent and stabilizers	1.27	3.0	1.5	.145	do	~264
Gelled dynamites:							
D-1316	Proprietary	1.68	3.0	1.5	.145	do	~140
D-1351	do	1.75	3.0	1.5	.145	do	~170
D-1370	do	1.63	3.0	1.5	.145	do	~160
D-1371	do	1.52	3.0	1.5	.145	do	~175
Liquid hydrogen-solid oxygen.	7.5 H_2, 92.5 O_2 (approximate)	.20	~2.0	5.0	1.5	Urethane foam.	~510
Liquid oxygen-solid butane.	Unknown	.96	~2.0	5.0	1.5	do	~116
Permissible gels (nitroglycerin-based):							
N-670	Proprietary	1.58	2.5	1.5	.145	Steel	170
N-770	do	1.37	2.5	1.5	.145	do	155
N-967	do	1.41	2.5	1.5	.145	do	120

TABLE 2. - Summary of projectile impact tests--Continued

Explosive	Composition, weight-percent	Density, g/cm^3	Charge size, inches		Confinement		V_{50}, m/sec
			Length	Diameter	Wall thickness, inches	Material	
GELS AND SLURRIES--Continued							
Permissible gels (nitroglycerin-based)--Continued:							
N-939	Proprietary	1.13	2.5	1.5	0.145	Steel	157
P-1037	do	1.40	2.5	1.5	.145	do	125
Permissible gels (water-based):							
P-1257	do	1.08	3.0	1.5	.145	do	~336
P-1340	do	1.17	3.0	1.5	.145	do	~410
P-1392	do	1.19	3.0	1.5	.145	do	~402
GRANULAR MIXES AND POWDERS							
Ammonium nitrate-fuel oil	95 AN, 5 FO	0.88	3.0	1.5	0.145	Aluminum	>1,700
Commercial AN-FO:							
X-1247	Proprietary	.89	3.0	1.5	.145	Steel	~1,000
X-1250	do	.93	3.0	1.5	.145	do	~900
Black powder	73 SN, 16 S, 11 C (approximate)	1.05	2.5	1.5	.145	do	615 (burns) 1,020 (explodes)
Granular permissibles (nitroglycerin-based):							
N-771	Proprietary	.85	2.5	1.5	.145	do	215
N-772	do	1.12	2.5	1.5	.145	do	173
N-863	do	1.23	2.5	1.5	.145	do	175
N-934	do	.92	2.5	1.5	.145	do	250
P-1088	do	.79	2.5	1.5	.145	do	290
P-1095	do	.77	2.5	1.5	.145	do	270
P-1124	do	1.08	2.5	1.5	.145	do	250
Granular permissibles (nitrostarch-sensitized):							
P-1116	do	.96	2.5	1.5	.145	do	330
P-1137	do	.97	2.5	1.5	.145	do	330
HMX	Neat HMX	1.27	3.0	1.5	.145	Aluminum	445
Nitroguanidine	Neat NGD	.38	3.0	1.5	.145	do	1,000
RDX	Neat RDX	.80	3.0	1.5	.145	do	300
Tetryl	Neat tetryl	1.0	3.0	1.5	.145	do	310

PRESSINGS							
PETN	Neat PETN	1.48	1.0	1.5	0	Unconfined	310
RDX-stearic acid (composition A-5).	99 RDX, 1 SA	1.62	1.0	1.5	0	....do....	455
Tetryl	Neat tetryl	1.57	1.0	1.5	0	....do....	425
TNT	Neat TNT	1.54	1.0	1.5	0	....do....	780
CAST SOLIDS							
Composition B	60 RDX, 40 TNT; 1 D-2 wax added.	1.67	1.0	1.5	0	Unconfined	1,470
Do	.....do	1.67	3.0	1.5	.145	Steel	~787
H-6	45 RDX, 30 TNT, 20 Al, 5 D-2 wax; 0.5 CaCl added.	1.71	2.5	1.5	.145	....do....	960
HBX-3	31 RDX, 29 TNT, 35 Al, 5 D-2 wax; 0.5 CaCl added.	1.81	2.5	1.5	.145	....do....	885
Minol 2	40 TNT, 40 AN, 20 Al	1.68	2.5	1.5	.145	....do....	>1,530
Pentolite	50 PETN, 50 TNT	1.61	1.0	1.5	0	Unconfined	440
Do	.....do	1.61	3.0	1.5	.145	Steel	~437
TNT	Neat TNT	1.55	1.0	1.5	0	Unconfined	>1,740
TNT	.....do	1.55	3.0	1.5	.145	Steel	~1,271
Tritonal	80 TNT, 20 Al	1.72	2.5	1.5	.145	....do....	1,360

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