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ON THE BULLET SENSITIVITY OF COMMERCIAL EXPLOSIVES AND BLASTING AGENTS

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Summary

This paper presents the results of experiments conducted to compare the projectile, cap, and bullet sensitivity of a number of commercial explosives and blasting agents. It was found that No. 8 electric blasting caps having either aluminum or copper shells yield essentially equivalent results in cap sensitivity testing. It was also found that the results of projectile impact tests could be correlated with the results of cap sensitivity measurements in the sense that a projectile velocity could be defined that represented the approximate threshold between cap sensitivity and cap insensitivity. The most important finding was that under ordinary conditions of confinement expected in the transport and storage of explosives, materials that were not sensitive to a No. 8 blasting cap were not observed to be sensitive to rifle-fired bullets.

Introduction

In 1963, the Bureau of Mines published the results of studies on the bullet sensitivity of ammonium nitrate—fuel oil (ANFO) mixtures [1]. It was found that certain ANFO mixtures could be initiated to detonation by high-powered rifle fire, especially if the mixtures were confined.

In a more recent Bureau publication [2] it was noted that certain experimental ANFO mixtures exhibited a fairly wide range of sensitivity as defined by the Bureau's projectile impact test. In addition, one of the mixtures was observed to be sensitive to a No. 8 blasting cap, a test used in the United States for delineating blasting agents from high explosives [3]. These observations raised questions concerning the relative sensitivity of more modern commercial blasting agents, particularly with regard to bullet impact, since these materials may be stored in non-bullet-resistant structures [4]. Since results from the projectile impact tests and the cap sensitivity test are not easily equated to bullet sensitivity, additional experiments have been conducted to compare the projectile, cap, and bullet sensitivity of a number of commercial explosives and blasting agents. The ANFO mixtures described in ref. 2 were also tested in parallel experiments. Because of less restrictive storage requirements, emphasis was placed on materials sold as blasting agents and classified as oxidizers (Nitrocarbonitrates) or Propellant Explosives, Class B for transport.

Test procedures

Projectile impact test

The procedure for determining the sensitivity of explosives to projectile impact was fully described by Weiss [5] and later by Mason [6]. In essence, a cylindrical charge of the test explosive is impacted with a 0.5-in.-long × 0.5-in.-diam brass projectile fired at various velocities from a smooth-bore 50-calibre gun. The explosive sample is contained in a 1.5-in.-diam schedule 40 steel pipe nipple having a length of 3.0 in. and a nominal wall thickness of 0.145 in. 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-in. polyethylene film is used to cover the ends of the charge container; the confining effect of this diaphragm is negligible. For precise work the Bruceton "up-and-down" method is used for estimating the projectile velocity corresponding to a 50% initiation probability (V_{50}). For the work reported here 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. Complete fragmentation of the steel container was used as a criterion for detonation.

Cap sensitivity test

In the cap sensitivity test currently conducted at Bruceton, the material is placed in a $3\frac{3}{8}$-in.-diam × $6\frac{5}{8}$-in.-long cardboard container (a 1-quart ice cream container) and placed on a 9- × 16-in. oak board which is $1\frac{5}{8}$ in. (nominal 2-in. board) thick. The board is supported at the ends at a level 12 in. above the floor. A copper-cased No. 8 instantaneous electric blasting cap is fully inserted into the material and fired from a 110-volt line source. The criteria for detonation are complete destruction of the oak board and lack of explosive residue after the firing.

Since an aluminum-shelled No. 8 blasting cap is being considered by other organizations as a "standard cap" for cap sensitivity determinations, parallel trials were run with No. 8 instantaneous electric blasting caps having aluminum shells. In these trials the same cardboard containers that were used in trials with copper-shelled caps were also used, but the containers were placed on a 2-in.-diam × 4-in.-long lead cylinder which serves as a witness. The material is considered to have detonated if the lead cylinder is foreshortened by $\frac{1}{8}$ in. or more. A similar witness is used in classification tests for explosives and blasting agents in the United States.

Bullet impact tests

Bullet impact trials were conducted at Bruceton with laboratory-sized samples of explosives and in field trials with the materials in their original shipping packages, ranging from 10-lb. polyethylene bags to 50-lb. paper sacks. In the trials with small-sized samples, the materials were contained in $3\frac{3}{8}$-in.-diam × 4-in.-long cardboard containers capped with cardboard lids. The filled cartons were backed with $\frac{1}{4}$-in. steel plates in some instances and with $1\frac{5}{8}$-in. wood boards in others. Firings were conducted from a distance of 10 ft. with the rifle placed behind a reinforced concrete wall and fired through a small opening at the center and along the axis of the charge. In the field trials the rifle was mounted 75 ft. from the test sample and aimed at the approximate center of the packaged explosive, which was backed with either a 12- × 12- × $\frac{1}{4}$-in. steel plate or a 16- × $9\frac{1}{2}$- × $1\frac{5}{8}$-in. oak board. The rifle was remotely triggered from a bunker some 300 feet away. In both the laboratory and field trials the occurrence of detonation was based on the noise produced, damage to the backup material, and absence of any unconsumed explosives.

The rifles used were the 300 Weatherby Magnum Mark V, the 200 Swift Model 70 (Winchester), and the 30-06 Springfield Model 700 (Remington). The Weatherby Magnum represents the highest-powered weapon likely to be used by hunters and is intended for big game. The 200 Swift is widely used as a "varmint rifle" and conceivably could be used in illicit target practice on storage magazines. Rifles chambered for 30-06 ammunition are also very popular among hunters and are used for both big and small game hunting.

Table 1 gives the weights and measured velocities of the various bullets and the brass projectile. The bullet velocities represent 10-shot averages for the 300 Weatherby Magnum and the 200 Swift and a 5-shot average for the 30-06. The velocity measurements were made with a high-speed chronograph and two "break" grids spaced 50 cm apart with the closest grid 50 cm from the muzzle end of the rifle. The measurements are in reasonable agreement with advertised values.

TABLE 1

Characteristics of the various bullets and projectile used in impact sensitivity trials

Type	Weight, grains (grams)	Velocity, m/sec (ft/sec)	Kinetic energy, joules
½ in. × ½ in. brass cylinder	208 (13.5)	100—1500 (328—4920)	67.5—15,187
300 Weatherby Magnum "soft point"	110 (7.127)	1128 (3700)	4534
30-06 "soft point"	125 (8.099)	917 (3007)	3405
220 Swift "soft point"	48 (3.110)	1249 (4096)	2425

Materials tested

The projectile impact sensitivity of a wide variety of military explosives and relatively sensitive commercial explosives was recently reported [7]. The experimental efforts described here were therefore concentrated on the less sensitive commercial explosives and blasting agents. Prepackaged blasting agents and explosives were selected from those available on the commercial market and are believed to represent a reasonable cross-section of the products of this type used in the United States. Included were nine commercial products classified as Nitrocarbonitrates, consisting of various ammonium nitrate—fuel oil mixtures made from prilled AN, crushed AN, mixtures of crushed and prilled AN, ANFO's containing aluminum powder or ferrosilicon or carbonaceous material, and several slurry blasting agents. Eight other slurry or water-gel compositions classified as Class A or Class B explosives were also studied. In addition, the 95/5 ANFO mixtures reported in ref. 2 were re-examined for cap and bullet sensitivity.

Experimental results

Table 2 contains the results of the projectile and bullet impact and cap sensitivity trials conducted both in the laboratory and in the field. Since the number of different test conditions used in the bullet impact studies was rather large, a simple code, explained at the bottom of the table, was used to describe the outcome of the experiments. In most cases the bullet impact results are based on single observations for any given test configuration; however, in marginal situations replicate trials were performed to provide an unambiguous result; this also applied to the cap sensitivity trials. In the projectile impact tests, 10—15 firings were usually performed to obtain a reasonable estimate of V_{50}.

From the results of Table 2 it will be noted that the copper and aluminum caps produce essentially equivalent results. There was only one case of disagreement between the two measures of cap sensitivity (Key No. 1635). Here the aluminum cap produced a positive result and the copper cap a negative one. Repeat trials yielded the same result, indicating that the aluminum cap is a slightly stronger initiation source, at least for the particular explosive in question; the different criteria for detonation (lead *vs.* wood witness) may have influenced the results to some degree.

One other area of disagreement, not evident from the data of Table 2, bears mentioning. In the sensitivity studies reported in ref. 2, the experimental ANFO designated 1486 was the only ANFO mix observed to be sensitive to a No. 8 copper cap. However, in these studies two other mixes (Nos. 1487 and 1488) were also observed to be cap sensitive, even though they failed the earlier cap tests. The exact reason for this discrepancy is not known, but the AN prills used in these mixes had been exposed to rather severe temperature cycling during the interim between the two test series and of course had undergone aging. These factors may have influenced the sensitivity of the ANFO mixes,

TABLE 2

Results of sensitivity trials

Explosive Key No.	Loading density, g/cc	V_{50}, m/sec	Cap sensitivity		Bullet sensitivity*
			No. 8 Al	No. 8 Cu	
Experimental ANFO mixtures					
1486	0.84	638	Yes	Yes	Yes (L1W, L2W, L3W)
1488	0.83	765	Yes	Yes	Yes (L1W); No (L2W, L3W)
1487	0.85	771	Yes	Yes	Yes (L1W, L3W); No (L2W)
1485	0.89	849	No	No	No (L1W, L2W, L3W)
1490	0.94	990	No	No	No (L1W, L2W, L3W)
Nitrocarbonitrates					
1632	0.63	695	Yes	Yes	Yes (F1W); No (L1W, L1S, F1S)
1590	0.92	872	No	No	No (L1W, L1S, L2W, L3W, F1W, F1S, F2S, F3S)
1635	1.03	918	Yes	No	No (L1W, L1S, F1W, F1S, F2S, F3S)
1633	1.01	1006	No	No	No (L1W, L1S, F1W, F1S, F2S, F3S)
1625	0.48	1112	No	No	No (L1W, L1S, F1W, F1S, F2S, F3S)
1612	1.23	1191	No	No	No (L1W, L1S, F1W, F1S, F2S, F3S)
1634	1.52	1250	No	No	No (L1W, L1S, F1W, F1S, F2S, F3S)
1624	0.99	1262	No	No	No (L1W, L1S, F1W, F1S, F2S, F3S)
1613	1.27	1382	No	No	No (L1W, L1S, F1W, F1S)
Explosives, Class B					
1654	1.35	891	No	No	No (L1W, L1S, F1W, F1S, F2S, F3S)
1623	1.47	1355	No	No	No (L1W, L1S, F1W, F1S)
Explosives, Class A					
1571	1.25	326	Yes	Yes	Yes (L1W, L3W); No (L2W)
1552	1.29	382	Yes	Yes	Yes (L1W, L3W); No (L2W)
1553	1.36	479	Yes	Yes	No (L1W, L2W, L3W)
1653	1.35	561	Yes	Yes	No (L1W, L2S, F1W, F1S, F2S, F3S)
1657	1.43	650	Yes	Yes	No (L1W, L1S, F1W, F1S, F2S, F3S)

*Bullet Impact Code: L = Laboratory Test; F = Field Test; 1 = 300 Magnum; 2 = 30-06 Remington; 3 = 220 Swift; S = Steel Backing; W = Wood Backing.

which are made-up 24 hours prior to testing in order to maintain some control over lot-to-lot variability.

On comparing cap sensitivity with projectile impact sensitivity, we find that cap-sensitive materials (aluminum or copper caps) had V_{50}'s ranging from 326 to 918 m/sec, while cap-insensitive materials exhibited V_{50}'s ranging from 849 to 1382 m/sec. If we consider only the trials with the copper caps, the threshold for cap sensitivity is more distinct in terms of V_{50}, with cap-sensitive materials exhibiting V_{50}'s of 771 m/sec or lower and cap-insensitive materials having V_{50}'s of 849 m/sec or higher. Averaging these two values yields 810 m/sec as an approximate threshold velocity for cap sensitivity.

Turning to the bullet impact data, it is interesting to compare the effectiveness of the three different bullets used, on the basis of their kinetic energy. From Table 1 we see that the kinetic energy of the bullets are ranked as follows: Weatherby Magnum > 30-06 > 220 Swift. The data in Table 2 show that the initiating effectiveness of the bullets ranks as follows: Weatherby Magnum > 220 Swift > 30-06. Thus there does not appear to be a direct relationship between the kinetic energy and the initiating effectiveness of the bullets used here. The results of experiments in ref. 1 also indicated that the Weatherby Magnum and 220 Swift were more effective than the 30-06, but the 220 Swift was observed to be slightly more effective than the 300 Weatherby Magnum. However, the velocity reported in ref. 1 for the Weatherby Magnum was lower than the velocity reported here.

The relative effectiveness of the three bullets can also be compared to that of the cylindrical projectile on the basis of equivalent energy. From the mass and velocity data in Table 1, simple calculations show that the cylindrical brass projectile travelling at 819 m/sec has the same kinetic energy as the 110-grain Weatherby Magnum bullet travelling at 1128 m/sec. Projectile velocities providing energies equal to the other two bullets are 710 m/sec for the 30-06 and 599 m/sec for the 220 Swift bullet. If missile energy (projectile or bullet) was the controlling factor in the impact initiation process, we would expect the Weatherby Magnum to be capable of initiating materials having V_{50}'s below 819 m/sec, and the 30-06 and 220 Swift to be capable of initiating materials with V_{50} below 710 and 599 m/sec, respectively. If we limit our considerations to the data in ANFO mixes and NCN's, we find that the 300 Weatherby Magnum did initiate materials having V_{50}'s of 638, 695, 765, and 711 m/sec but failed to initiate materials exhibiting V_{50}'s of 849 m/sec or higher; this is in good agreement with the premise that energy controls the initiation. Similarly, the 30-06, with a "V_{50} equivalent" of 710 m/sec, was capable of initiating a material having a V_{50} of 638 m/sec but failed to initiate materials having V_{50}'s of 765 m/sec or higher. These results are also in good agreement with the premise of energy-controlled initiation. However, the 220 Swift, having a "V_{50} equivalent" of only 599 m/sec, appears to be too effective to conform to the postulate of energy equivalence and was capable of initiating materials having V_{50}'s as high as 771 m/sec. If we include the data from the Class A explosives, which were for the most part water gels (one was a nonaqueous slurry), the premise of an energy-dependent initiation process breaks down completely, since none of the bullets were capable of initiating Class A explosives with V_{50}'s as low as 479 m/sec. The fact that several of the ANFO mixtures having appreciably higher V_{50}'s were observed to be sensitive to fire from the Weatherby Magnum and the 220 Swift, and in one case (Key No. 1486 the 30-06, suggests some difference in the initiation mechanism for the two types of explosives; elucidation of this point must await further work.

Perhaps the most important result of these experiments is the observation that those materials that were not cap-sensitive could not be initiated by any of the bullets used here. It must be emphasized that the test conditions were not the most stringent that could be imposed in terms of confinement [1], but it is felt that they are representative of the conditions that do exist in the transport and storage of these materials. On the other hand, the use of the 300 Weatherby Magnum ammunition does represent a severe test since the kinetic energy of the 110-grain bullet with a muzzle velocity of over 1100 m/sec is about the highest available in sporting ammunition.

Conclusions

The experiments reported here lead to the following conclusions:

(1) Commercial No. 8 electric blasting caps having either aluminum or copper shells yield essentially equivalent results in cap sensitivity testing.

(2) Results of projectile impact tests can be correlated with the results of cap sensitivity measurements in the sense that a projectile velocity can be defined that represents with reasonable precision the threshold between cap sensitivity and cap insensitivity.

(3) Under ordinary conditions of confinement expected in the transport and storage of explosives, materials that are not sensitive to a No. 8 blasting cap do not appear to be sensitive to rifle-fired bullets from even very high-powered commercial ammunition. Thus, the cap sensitivity test does provide meaningful information concerning the relative hazards of high explosive and blasting agents.

(4) Experimental ANFO mixtures and certain NCN's tested at low packing densities are observed to be cap-sensitive and prone to initiation by high-powered rifle fire.

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