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REPORT OF INVESTIGATIONS/1994

Method of Comparing Initiating Strength of Detonators Using Adjustable-Sensitivity Liquid Explosive

By T. S. Bajpayee and J. Edmund Hay

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

U.S. Department of the Interior
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Bruce Babbitt, Secretary

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Library of Congress Cataloging in Publication Data:

Bajpayee, T. S.

Method of comparing initiating strength of detonators using adjustable-sensitivity liquid explosive / by T.S. Bajpayee and J. Edmund Hay.

p. cm. — (Report of investigations; 9503)

Includes bibliographical references.

1. Detonators—Testing. 2. Explosives—Testing. I. Hay, J. Edmund. II. Title. III. Series: Report of investigations (United States. Bureau of Mines); 9503.

TN23.U43 [TN279] 622 s—dc20 [622' .2] 93-28423 CIP

CONTENTS

ILLUSTRATIONS

TABLE

METHOD OF COMPARING INITIATING STRENGTH OF DETONATORS USING ADJUSTABLE-SENSITIVITY LIQUID EXPLOSIVE

By T. S. Bajpayee[1] and J. Edmund Hay[2]

ABSTRACT

The U.S. Bureau of Mines (USBM) has developed a test procedure to compare the initiating strength of detonators by using adjustable-sensitivity liquid explosives. Various tests of detonator strength are currently used by the industry, but many of them do not quantify the ability of detonators to initiate detonation reactions in an explosive charge. The USBM used mixtures of nitromethane and ethylene diamine, the sensitivity being "fine-tuned" by 2-nitropropane. Military standard J-2, commercial No. 6, and commercial No. 8 detonators were evaluated using three test configurations: (1) axially immersed in the test explosive, (2) tip just touching surface of the explosive, and (3) immersed transversely in the explosive. Markedly different results were obtained for these three configurations, indicating that the directional effects are important. This explains why different detonator strength tests do not correlate well with each other. Some tests, such as the sand bomb and underwater, measure the total energy output, while other tests, such as the plate dent, test measure the energy in the axial direction. The USBM's test data indicate the importance of conducting the experimentation in the manner in which the detonator is actually intended to function.

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INTRODUCTION

Misfires and poor performance of explosives are not only costly, but can result in unsafe conditions. In some cases, misfires might be due to inadequate detonator strength, particularly with the proliferation of less sensitive explosives and the availability of detonators (e.g., imports) that may not, in some cases, be subject to the exacting standards of domestic explosive suppliers. Therefore, in accord with its mission to improve safety and efficiency in mining, the U.S. Bureau of Mines (USBM) developed a test procedure to assess detonation performance.

A detonator is used to initiate a high explosive charge, and a successful initiation depends on the characteristics of the detonator and the acceptor charge. Primary high explosives (initiating explosives) are sensitive to initiation by shock, flame, friction, spark, and impact. Secondary high explosives are generally initiated by shock and impact. The interaction between the detonation wave of the base charge and the acceptor explosive is critical in determining whether an acceptor charge will detonate or not. The shock output characteristics of a detonator play a paramount role in initiating an acceptor charge. According to a commonly accepted criterion for the initiation of detonation, the product of the square of the detonation pressure and the duration of the shock produced by the base charge of the detonator must equal or exceed a value that is characteristic of the acceptor charge.[3] It is very difficult to measure the detonation pressure directly because of its transient nature and exceedingly high magnitude. The mass of the base charge, its geometrical configuration, and specific shock energy output are important considerations in characterizing the initiating efficiency of a detonator. Researchers have advocated various methods to evaluate tip strength of detonators. Depending on the laboratory situation, purpose of test, cost involved, and level of accuracy desired, an appropriate test method can be selected.

Hopler[4] has classified test methods broadly under two categories: direct and indirect. Some of the tests listed as direct methods are (1) charge weight, (2) lead, aluminum, or iron plates, (3) lead block, (4) sand bomb, and (5) underwater. Important tests listed as indirect methods are (1) lead-block compression, (2) explosion by influence, (3) desensitized picric acid, (4) TNT-talc, and (5) miniature cartridge.

Any test method should ideally (1) be economical to perform, (2) provide reproducible results, and (3) give results with a meaningful relation to the physical property being evaluated. In this case, the physical property is the ability of a detonator to initiate detonation reactions in an explosive. Although the direct methods satisfy criteria 1 and 2 above, there is no evidence known to the authors of this report to indicate that the measure of detonation strength determined by these methods correlates with the ability of a detonator to initiate explosives.

Since there are so many tests for detonator strength that produce poorly correlating results and that, for the greater part, do not directly represent the initiation of an explosive by a detonator, it was decided that it would be of interest to test the strength of detonators in the manner in which they are intended to function; i.e., to test their actual ability to initiate detonation in an explosive. Accordingly, it was decided to attempt development of a test that specifically determines the latter property. For this purpose, an explosive system of graded sensitivity is required; i.e., an explosive whose sensitivity to initiation by a detonator can be controlled so that it is near its initiation threshold for the detonators that are to be tested.

Previous research by the USBM attempted to achieve this goal using mixtures of pentaerythritol tetranitrate (PETN) and potassium chloride (KCl). In this work, very little discrimination was obtained. While the critical range (the spread in PETN concentration in which the results for a particular detonator changed from reliable initiation to reliable noninitiation) was small, all the detonators tested seemed to have the same range. This was thought to be the result of uncontrolled variables. Using a granular two-component explosive such as PETN-KCl, these potential uncontrolled variables include the particle sizes, the bulk density, and the uniformity of mixing (homogeneity). While these variables can be controlled to an extent (one can sieve the ingredients to a narrow range of particle sizes and measure the overall bulk density), it is difficult to guarantee that the mixing process does not cause attrition of the particles into finer particles, or that the finer particles of one ingredient will not sift downward through the coarser particles of the other, or that the act of inserting the detonator into the mixture will not cause poorly reproducible local compression.

For this reason, although the TNT-talc test, the desensitized picric acid test, and the miniature cartridge test all involve the ability of a detonator to initiate detonation reactions in an explosive material and thus might be

[3]Foan, G. C. W., and G. D. Coley. Shock Initiation in Gap Test Configurations. Paper in Seventh Symposium (International) on Detonation (Annapolis, MD, June 16-19, 1981). Nav. Surf. Weapons Cent., Dahlgren, VA, 1981, pp. 278-284.

[4]Hopler, R. B. The Historical Development of Commercial Detonators and a Review of the Methods Used To Compare Their Ability To Initiate High Explosives. Pres. at Second High-Tech Seminar on State of the Art Blasting Technology, Instrumentation and Explosives Applications, Orlando, FL, June 10-15, 1990, 30 pp.; available from R. B. Hopler, Dyno Nobel Inc., Salt Lake City, UT.

considered to be good candidate tests, it was decided to use a liquid system, in which the above-mentioned variables are not a problem (miscible liquids are relatively easy to mix and do not segregate afterwards). Since it is well known that nitromethane (NM) can be sensitized into the detonator-sensitive range by small quantities of acids, bases, or oxidizing agents, sensitized NM systems seemed to be an attractive choice. The sensitizer chosen was ethylene diamine (EDA). The NM was taken from a single batch obtained from Angus Chemical Corp.[5] and had the following analysis: NM, 98.71%; nitroethane (NE), 0.65%; propionitrile, 0.47%; 2-nitropropane (2-NP), 0.08%; acetonitrile, 0.07%; and water, 0.02%. The specific gravity was 1.1314. The EDA was Fisher Certified ACS anhydrous (99% EDA, 1% water).

The original plan was to simply control the EDA concentration to obtain the needed sensitivities. Early results, however, showed that every detonator initiated a mixture of 1% EDA, while no detonator initiated the straight NM; i.e., the critical range of EDA is small. To the authors' knowledge, the sensitivity of the NM+EDA system at very small concentrations of EDA has not been published. Data that have been published suggest that the variation of sensitivity with EDA concentration might be very nonlinear at low EDA concentrations. Therefore, it was decided to start with a "base mix" of 1% EDA in NM, and to adjust the sensitivity by desensitizing the sensitized mix with 2-NP. The rationale for this is that the published data show that the variation in the sensitivity of the NM+2-NP system varies nearly linearly with the 2-NP concentration. The 2-NP was obtained from Eastman Kodak Co., Rochester, NY.

EXPERIMENTAL SETUP AND TEST PROCEDURE

The initial experimental arrangement used is shown in figure 1. The NM+EDA/2-NP mixture was contained in a 12.7-centimeter (cm) length of 1¼-inch (in) schedule 40 steel pipe (inside diameter, 3.51 cm; wall thickness, 0.36 cm). The bottom was sealed with a 0.01-cm thick polyethylene diaphragm, and it was placed on a 15-cm-square, 0.32-cm-thick witness plate that, in turn, was mounted on a steel tube, 10-cm inside diameter and 5-cm long with a wall thickness of 0.64 cm. The detonator was immersed into the liquid to a depth of 2.5 cm and held in place by a perforated cork disk. The choice of charge length was somewhat arbitrary. The only absolute criterion is that the charge length be sufficient so that an incipient detonation has sufficient runup distance to establish itself as a recognizable detonation (in this case to punch a hole in the witness plate and to shatter the steel pipe into small fragments). In our tests it was found that this charge length resulted in a clean separation between detonations and nondetonations.

The charge length of 12.7 cm was retained throughout the testing. The critical diameter of the mixtures was checked using a booster to ensure that failures to detonate were the result of insufficient initiation stimulus rather than insufficient diameter of the explosive. A hole punched in the witness plate and complete fragmentation of the pipe indicated detonation of the liquid explosive mixture. A base stock of NM+EDA in the proportion of 99:1 was prepared and variable quantities of 2-NP were added to the base stock to select the desired sensitivity level. Three types of detonators were chosen for this study: military standard J-2 (Army Engineers Special), commercial No. 8 aluminum shell, and commercial No. 6 copper shell. These detonators were thought to represent the range of strengths of most commercial detonators.

It was thought prudent to study the directional effect of detonators. Consequently, two additional test configurations, illustrated in figures 2 and 3, were utilized. Figure 2 illustrates the experimental setup to test detonators in end-on mode and figure 3 the side-on mode.

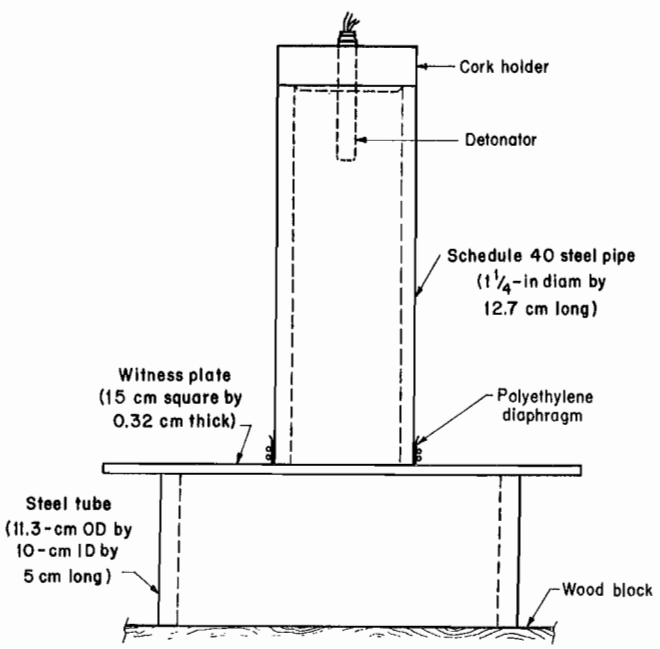

Figure 1.—Test setup for detonators in immersed configuration. (ID = inside diameter; OD = outside diameter.)

[5]Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

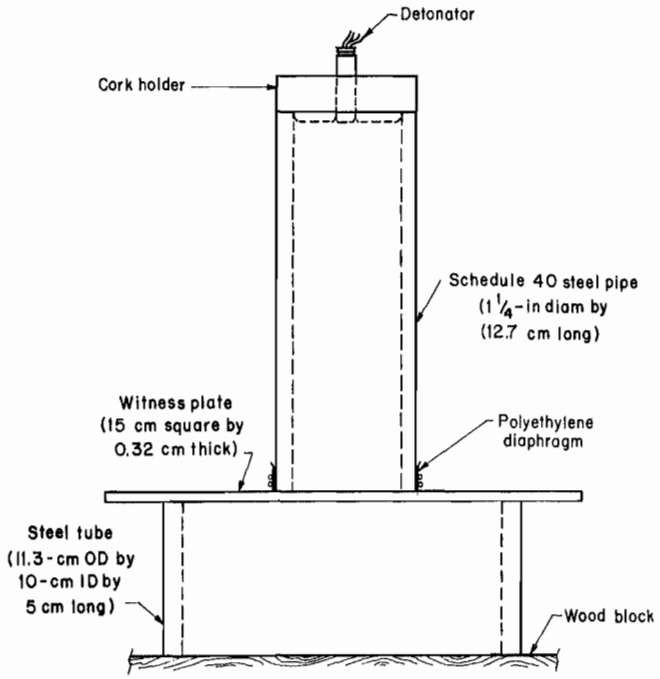

Figure 2.—Test setup for detonators in end-on configuration. (ID = inside diameter; OD = outside diameter.)

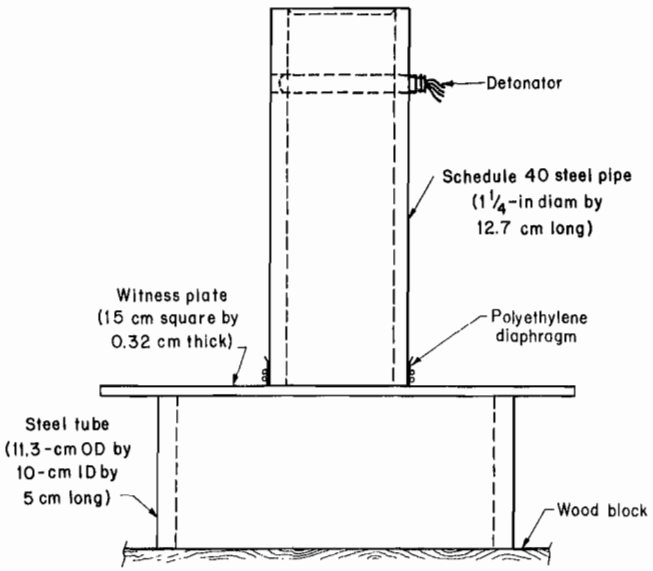

Figure 3.—Test setup for detonators in side-on configuration. (ID = inside diameter; OD = outside diameter.)

RESULTS AND DISCUSSION

The results of the initial tests were surprising in that the J-2 detonator, always thought to be the strongest because of its ability to initiate composition C-4, did not appear to be the strongest in these tests. This observation, together with the observations alluded to above (namely, that various other tests of detonator strength do not correlate well) added to the suspicion that the explosive energy output of detonators is not a simple, single parameter.

If one assumes that the critical parameters that determine whether an explosive is detonated by a shock wave are both the shock pressure and the duration of the shock, then one could conceive that a given detonator might produce a stronger shock wave, but with a shorter duration, while another detonator might produce a weaker shock, but with a longer duration. The first detonator would be more effective than the second in initiating explosives that required a higher shock pressure but did not require a longer duration shock, while the reverse would be true for explosives that required a longer duration shock, but did not require as great a shock pressure. Similar results would hold in many detonator strength tests since some of the explosives are primarily shock-pressure dependent, while others are impulse dependent. Since detonation is a directional process, it was thought that such differences in shock pressure and duration might show up as effects of the orientation of the detonator in the explosive.

To this end, the arrangements shown in figures 2 and 3 were tried. In the end-on case, the detonator tip just touched the surface of the liquid, although the detonator axis still coincided with the axis of the explosive sample. Whereas in the side-on case, the detonator was inserted through holes drilled in the wall of the pipe so that the detonator was transverse to the axis of the explosive, with the axis of the detonator 2.5 cm below the surface of the liquid.

Table 1 lists the concentrations of NM+EDA/2-NP in liquid mixtures and the results that were observed for the three test modes: (1) immersed in the liquid, (2) end-on, and (3) horizontal side-on. Data in table 1 indicate that, in the immersed mode, commercial No. 8 detonators can initiate a 99:01 NM+EDA mixture desensitized by 24% 2-NP. Corresponding values for commercial No. 6 and military standard J-2 detonators are 16% and 0%, respectively. From the test data it is evident that a No. 8 detonator is stronger than a No. 6 detonator. This statement corresponds to the fact that a No. 8 detonator contains more PETN in the base charge than a No. 6 detonator.

Table 1.—Initiating strength of detonators using liquid explosive mixtures

Detonator tested	NM+EDA/2-NP[1]	Test results
DETONATORS FIRED IN IMMERSED MODE		
Military standard J-2	100:00	D
	99:01	ND
	99:01	ND
	99:01	ND
Commercial No. 8	84:16	D
	80:20	D
	78:22	D
	78:22	ND
	76:24	D
	76:24	D
	74:26	ND
	74:26	ND
	74:26	ND
Commercial No. 6	90:10	D
	88:12	D
	88:12	D
	86:14	ND
	86:14	ND
	84:16	D
	84:16	ND
	82:18	ND
	82:18	ND
	82:18	ND
DETONATORS FIRED IN END-ON MODE		
Military standard J-2	97:03	D
	98:02	ND
	98:02	ND
	98:02	ND
Commercial No. 8	90:10	D
	86:14	D
	84:16	D
	84:16	D
	84:16	ND
	82:18	ND
	82:18	ND
	82:18	ND
Commercial No. 6	92:08	D
	90:10	D
	88:12	D
	86:14	D
	86:14	ND
	84:16	D
	84:16	D
	82:18	ND
	82:18	ND
	82:18	ND

Detonator tested	NM+EDA/2-NP[1]	Test results
DETONATORS FIRED IN SIDE-ON MODE		
Military standard J-2	96:04	D
	94:06	D
	92:08	ND
	90:10	ND
	88:12	D
	88:12	ND
	86:14	ND
	84:16	ND
	82:18	D
	80:20	ND
	80:20	ND
	80:20	ND
Commercial No. 8	86:14	D
	84:16	D
	82:18	ND
	80:20	D
	80:20	D
	78:22	ND
	78:22	ND
	78:22	ND
Commercial No. 6	96:04	D
	94:06	ND
	92:08	ND
	90:10	ND
	88:12	ND
	86:14	D
	86:14	ND
	84:16	D
	84:16	ND
	82:18	D
	82:18	ND
	82:18	ND
	80:20	ND
	80:20	ND
	80:20	ND

D Detonation.
ND No detonation.
[1]NM+EDA mixtures in the proportion of 99 to 1 were used with variable proportions of 2 NP.

Test data also reveal that a No. 8 or No. 6 detonator can initiate insensitive mixtures that a J-2 detonator fails to initiate. This is contrary to expectations. USBM's previous test data using the sand-bomb and underwater methods indicate that a J-2 detonator is stronger than a No. 8 or No. 6 detonator. However, No. 8 and No. 6 detonators have indentations on the end that create a Munroe effect, which may explain why they can initiate a desensitized mixture that a J-2 detonator fails to initiate. Test data reveal that a No. 8 detonator has the capability of initiating the least sensitive mixture, and it may be construed as the strongest detonator as far as this method of comparison is concerned.

In the end-on firing mode, the No. 8 detonator initiates the least sensitive mixture and the J-2 detonator initiates only the most sensitive mixture. Test results show that No. 8 detonators are generally stronger in this test mode than J-2 detonators and that the difference in initiating strength between the No. 8 and No. 6 detonators was negligible. Table 1 shows that, in the immersed mode, No. 8 detonators initiate a less sensitive mixture (76:24) than in the end-on mode (84:16). Table 1 also shows that J-2 detonators initiate less sensitive mixtures in the side-on mode than in the immersed or end-on modes. This may be due to the hypothesis that, in the immersed mode, the shock wave emanating from the cylindrical surface contributes to the initiation process of the liquid explosive. In the end-on mode, the shock wave radiating from the cylindrical surface propagates to the air above the liquid and probably does not contribute to the initiation process.

CONCLUSIONS

The test data indicate that the suspicion that motivated the development of this test is well founded: At least some of the direct tests do not correlate well with the ability of a detonator to initiate explosives, and thus they cannot be accurately used for the purpose of measuring this property. This appears to be due at least in part to the geometrical effects that are not accounted for in certain types of tests that quantify only the total energy output of the detonator.

The test procedure described in this report appears to discriminate well between various detonators with regard to their initiating strength. The same type of detonator can show different initiating strengths in different geometries of insertion in the sample, and this effect varies between different detonators; i.e., some are more effective in the side-on mode than the end-on mode, while for others the reverse is true. Thus, the lack of symmetry in the delivery of energy by detonators is important and must be accounted for in the development of practical tests for detonator strength.

The test methods described in this report compare the relative ability of detonators to initiate an explosive and are relatively practical to use as such, or they may be used to validate and/or calibrate other indirect tests of detonator strength.

In the side-on configuration, the J-2 detonator seems somewhat more effective than in the other two configurations, but the experimental statistics are worse for this configuration. The reasons for this are not readily apparent.

The No. 8 aluminum shell detonator appears to be somewhat stronger than the No. 6 copper shell detonator in the immersed and side-on configurations, although the difference appears to be negligible in the end-on configuration.

Test results indicate that success in developing an adjustable sensitivity liquid explosive mixture suitable for comparing the initiating efficiency of detonators was achieved.