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The performance testing of permitted explosives for coal mines*

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SYNOPSIS

Permitted explosives in South Africa are those explosives approved by the relevant State authority for use in fiery coal mines. The main tests that an explosive must pass for this approval are the gallery tests derived from the Buxton (U.K.) classification. These tests are described briefly.

In addition, the safety of permitted explosives is affected by their ability to deflagrate, and to produce a naked flame after blasting, rather than to detonate fully. Tests done on this phenomenon are discussed.

A further potential hazard of explosives is after-blast fume. The testing and behaviour of several permitted explosives in this respect are covered, both in the laboratory and in the field. Performance testing of permitted explosives, specifically the double-pipe, underwater, and ballistic mortar tests, and their relationship to field use, are considered in some detail. The application of traditional and new tests to permitted explosives leads to guidelines for the safe and efficient formulation and use of these products.

SAMEVATTING

Veroorloofde springstowwe in Suid-Afrika is dié springstowwe wat deur die betrokke staatsowerheid goedgekeur is vir gebruik in brandgassteenkoolmyne. Die vernaamste toets wat 'n springstof vir hierdie goedkeuring moet deurstaan, is die galerytoetse wat van die Buxton-klassifikasie (V.K.) afgelei is. Hierdie toetse word kortliks beskryf.

Verder word die veiligheid van veroorloofde springstowwe geraak deur hul vermoë om snel te verbrand en na die ontploffing 'n oop vlam af te gee in plaas van volledig te detoneer. Toetse wat in verband met hierdie verskynsel uitgevoer is, word bespreek.

Nog 'n potensiële gevaar van springstowwe is die dampe na die ontploffing. Die toetsing en gedrag van verskeie veroorloofde plofstowwe in hierdie verband, in sowel die laboratorium as in die veld, word gedek. Werkverrigtingstoetse op veroorloofde springstowwe, spesifiek die dubbelpyp-, onderwater- en ballistiese mortiertoetse, en hul verband met veldgebruik, word uitvoerig bespreek. Die toepassing van tradisionele en nuwe toetse op veroorloofde springstowwe lei tot riglyne vir die veilige en doeltreffende formulering en gebruik van hierdie produkte.

Introduction

Coal is won in South Africa by the common methods of mining: underground bord-and-pillar, underground (mechanized) longwall, opencast strip, and opencast bench mining. Despite the recent growth of opencast and mechanized mining, the long-established bord-and-pillar method still produces over 40 per cent of South Africa's coal. In the long term, the competitiveness of this type of mining depends upon continuing improvements in safety and efficiency. The optimum formulation, choice, and use of explosives and accessories for the blasting of coal are some of the more important technical requirements for successful bord-and-pillar mining.

This paper deals with the main factors affecting the safety and results of blasting in collieries. Over many years, as knowledge of the relevance and importance of various features of permitted explosives has increased, new tests have been devised for the characterization and comparison of explosives and their methods of use.

The properties of permitted explosives that affect their safety in use are as follows:

(a) incendivity, i.e. the likelihood that mixtures of methane and air, or of coal dust and air, will be ignited by the action of blasting;
(b) deflagration, i.e. a naked flame after blasting as a result of the explosives burning rather than detonating, which is extremely undesirable in an underground coal mine;
(c) impact and friction sensitivity; and
(d) after-blast fumes.

The designing and conducting of tests aimed at the potential hazards of explosives is difficult owing to the very low probability of an event in practice. It is impossible to discover from controlled laboratory or field tests what the actual probability of a hazardous event is. Instead, hazards have to be inferred from tests done under extreme conditions, where the magnitudes of the potential causes are grossly exaggerated. On the other hand, these potential causes are often easy to identify, and tests that exaggerate them can usually be set up. In this way, useful comparative data can be gathered and, with time, test results can be correlated with the statistics of undesirable events from the user industry.

The problems in the designing and conducting of performance tests for explosives are somewhat different. There is a variety of tests, which in themselves are well understood. In fact, more test procedures for explosives

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are described in the literature than the explosives and mining industries can handle. Equally, the desired results of blasting—fragmentation, heave, advance, etc.—can easily be specified. However, the relationship between one or more parameters of explosives measured in the laboratory and their likely performance in blasting is almost always poorly understood. Blasting is a complex process, not only because of the heterogeneity of most rocks and minerals, but because of strong interactions between the energies available for fragmentation and for heave, e.g. between the explosion product gases and the target materials.

For these reasons, the main thrust of the performance tests described here has been towards the quality of detonation. Detonation in a borehole is not a simple go–no go situation. Tests designed to mimic the conditions of use as far as possible show that the detonation behaviour of commercial explosives can vary widely. The approach has therefore been to use laboratory tests to ensure good-quality detonation in a borehole by the improved formulation and use of explosives. The frequency and consistency of blasting in bord-and-pillar mining mean that explosives can be compared in terms of practical blasting results fairly easily and accurately.

Permitted Explosives Studied

The following commercial and experimental compositions were examined, all the explosives being produced by AECI Explosives & Chemicals Limited:

Ajax	An ammon gelatine dynamite (or 'gelignite')
Coalex 1	Waterproof powder, nitroglycerin-based
Sinex 905	Watergel, sensitized by paint-grade aluminium
Energex 140/150	Watergels, sensitized by mono-methylamine nitrate.

Safety Testing of Permitted Explosives

At present, the only testing gallery in South Africa belongs to AECI Explosives & Chemicals Limited and is situated at Modderfontein. Before explosives are scheduled as permitted explosives in South Africa, they must pass the incendivity tests on this gallery or the one from which it is copied, the British gallery at Buxton. (In due course, the testing of permitted explosives will become the responsibility of the South African Bureau of Standards.)

British standards specify six classes of permitted explosives: P1, P2, P3, P4, P5, and P4/5. In South Africa, only P1 is used. Brief definitions and descriptions of the tests for P1 explosives are given below.

Definitions

Methane–Air Mixture. The mixture into which a test shot is fired shall contain combustibles equivalent to 9,0 ± 0,25 per cent of methane in air. A methane–air mixture is most sensitive in these proportions.

Coal Dust. Wankie Coal ground to such a degree of fineness that 85 per cent by mass will pass through a 0,066 mm sieve.

Cannon. A cylinder of special steel with a diameter of 457 mm or more and having an axial bore that, when new, is 55 mm in diameter and 120 cm long.

Cartridges. Waxed paper shells 36,5 to 37,5 mm in diameter.

Priming. By means of a Carrick detonator inserted flush with the end of the primer cartridge.

Loading and Stemming. A dry fireclay plug is inserted into the cylinder first. When inverse initiation is specified, the primer cartridge is inserted with the detonator to the back, followed by the remainder of the charge. When direct initiation is specified, the primer cartridge is inserted last with the detonator to the front. When stemming is specified, a single dry fireclay plug is pushed onto the charge but not with such force as to distort the cartridges. The plugs are made of unfired fireclay, and are 51 mm in diameter and 25 mm in length.

Coal-dust Tests. A steel platform 305 mm wide by 3,0 m long is placed in the gallery with one end touching the end plate through which the shot is fired, and with its surface 12,5 mm below the bore of the cannon. According to the laid-down rules, 2,27 kg of coal dust is scattered onto the table.

Tests for P1 Explosives

Series (i) 26 shots, each 140 g, inversely initiated, without stemming, into methane–air mix.
Series (ii) 5 shots, each 800 g, directly initiated, with stemming, into methane–air mix.
Series (iii) 5 shots, each 800 g directly initiated, with stemming, over coal dust.

To pass the P1 test, the explosive must

- result in not more than 13 ignitions in series (i), and
- result in no ignitions in series (ii) and (iii), and
- display satisfactory detonation throughout the tests.

Deflagration

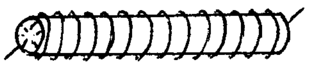
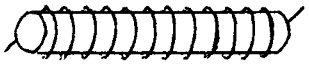
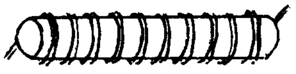
Under certain circumstances, explosives can fail to detonate completely in a borehole. The residual explosive can be ignited by being subjected to gases at high pressure and temperature from the part of the charge that detonated. This phenomenon has been known around the world for many years[1]. Deflagration is most likely, and has occurred in South Africa on a few occasions, with nitroglycerin-based powder explosives.

There are two approaches to the testing of an explosive for possible deflagration in use. Firstly, tests can be conducted to show the aspects of formulation or the conditions of use that can cause partial misfires. Secondly, the propensity of an explosive cartridge to be ignited, and to sustain combustion at atmospheric pressure, can be investigated in idealized laboratory tests.

Various experimental set-ups have been used in different laboratories to study the burning characteristics of explosives[1,2]. These studies have concluded that the probability of ignition and sustained burning is increased when the explosive is a nitroglycerin-based powder, and there is excessive wax on the end of the cartridge.

At AECI, the ease with which a nitroglycerin powder

TABLE I
DEFLAGRATION TESTS ON COALEX USING SLOW IGNITERCORD

Test no.	Experimental arrangement	Result
1	 Wrapped* with incendiary cord	No ignition
2	 Wrapped* with incendiary cord—cartridge wrapper removed	No ignition
3	 Doubly wrapped* with incendiary cord—cartridge wrapper removed	No ignition

* Completely encased in a tightly wound spiral

TABLE II
EVALUATION OF FUME BY PERMITTED EXPLOSIVES FROM LABORATORY MEASUREMENTS

Test no.	Explosive	Diameter mm × mass, g	Cartridging materials	CO l/kg	NOx l/kg
1	Ajax	29 × 200	Post-waxed paper	32,8	2,2
2*	Ajax	29 × 200	Post-waxed paper	31,4	1,1
3†	Ajax	29 × 200	Post-waxed paper	23,3	1,7
4†	Ajax	29 × 200	Post-waxed paper plus coarse coal	27,1	1,7
5†	Ajax	29 × 200	Post-waxed paper plus fine coal	32,4	1,4
6	Ajax	29 × 200	Pre-waxed paper	10,2	2,5
7	Coalex 1	32 × 200	Post-waxed paper	22,9	2,3
8	Coalex 1	29 × 160	Post-waxed paper	30,2	2,2

Notes:
* The average of 3 measurements
† On cartridges from a single batch. The free space around the cartridge in the cannon borehole was filled with coal dust as indicated

(Coalex 1) could be ignited was examined in a series of tests that were conducted on a single, unconfined cartridge of explosive. The ignition source was an incendiary cord (Slow Ignitercord). These simple tests, which are summarized in Table I, showed that, under atmospheric pressure, Coalex is difficult to ignite, even with a fierce heat source. More sophisticated tests are being examined for use in the further study of this behaviour.

Allied to ease of ignition, partial misfire of a column of explosive is a necessary cause of deflagration. Tests to identify causes of misfires fall into the broad class of tests on the quality of detonation, and are dealt with below. The conclusions about which methods give the most reliable detonation are similar to those reached elsewhere[1].

Fume Testing

All explosives produce a small amount of noxious fume on being detonated. The major species are carbon monoxide (CO) and oxides of nitrogen (NOx). The commonest international test for fumes from explosives involves the Bichel Gauge, which is a small chamber in which a single stick of explosive is fired unconfined. The heavy, sealed apparatus completely contains all the gases produced by the detonation, which are then analysed.

The experimental set-up in the AECI laboratory is similar to the 'Large Chamber' operated by the United States Bureau of Mines[3]. It consists of a steel mortar situated in a 17 m^3 slightly vented cubicle (Fig. 1). The shot is fired in the confinement of the mortar, and the product gases fill the cubicle. Excess pressure after the shot is allowed to vent, the remaining gases are allowed to mix, and samples are withdrawn for analysis. The readings are reduced to litres of gas per kilogram of explosive, selections of which are shown in Table II.

For comparison, a series of tests was conducted in a bord-and-pillar coal mine, where measurements of the CO and NOx concentrations were taken at intervals after production blasts of 1, 2, or 3 ends at a time. The results are given in Table III.

A comparison between laboratory and fume measurements shows the following:

(a) the laboratory tests correlate well with the real situation,
(b) the amount of fume generated does not increase in proportion to the mass of explosive used,
(c) even with the best explosive, good ventilation is essential to create hygienic working conditions after blasting,
(d) significant quantities of fume are trapped in the broken coal and released during loading,
(e) elimination of post-waxing of Ajax cartridges significantly reduces the amount of carbon monoxide liberated, and
(f) Energex 140 produced the lowest concentration of fume.

Most of these findings are confirmed by more extensive studies done elsewhere[4].

As a result of this work, the post-waxing of commercial Ajax and Coalex 1 has been discontinued.

Impact and Friction Sensitivity

The standard tests for impact and friction sensitivity conducted in the AECI laboratory are the traditional 5 kg fall-hammer and torpedo-friction tests[5]. A sketch of the latter is given in Fig. 2. These tests are valuable during the formulation of explosive compositions. For example, they can show whether a change in formulation has made

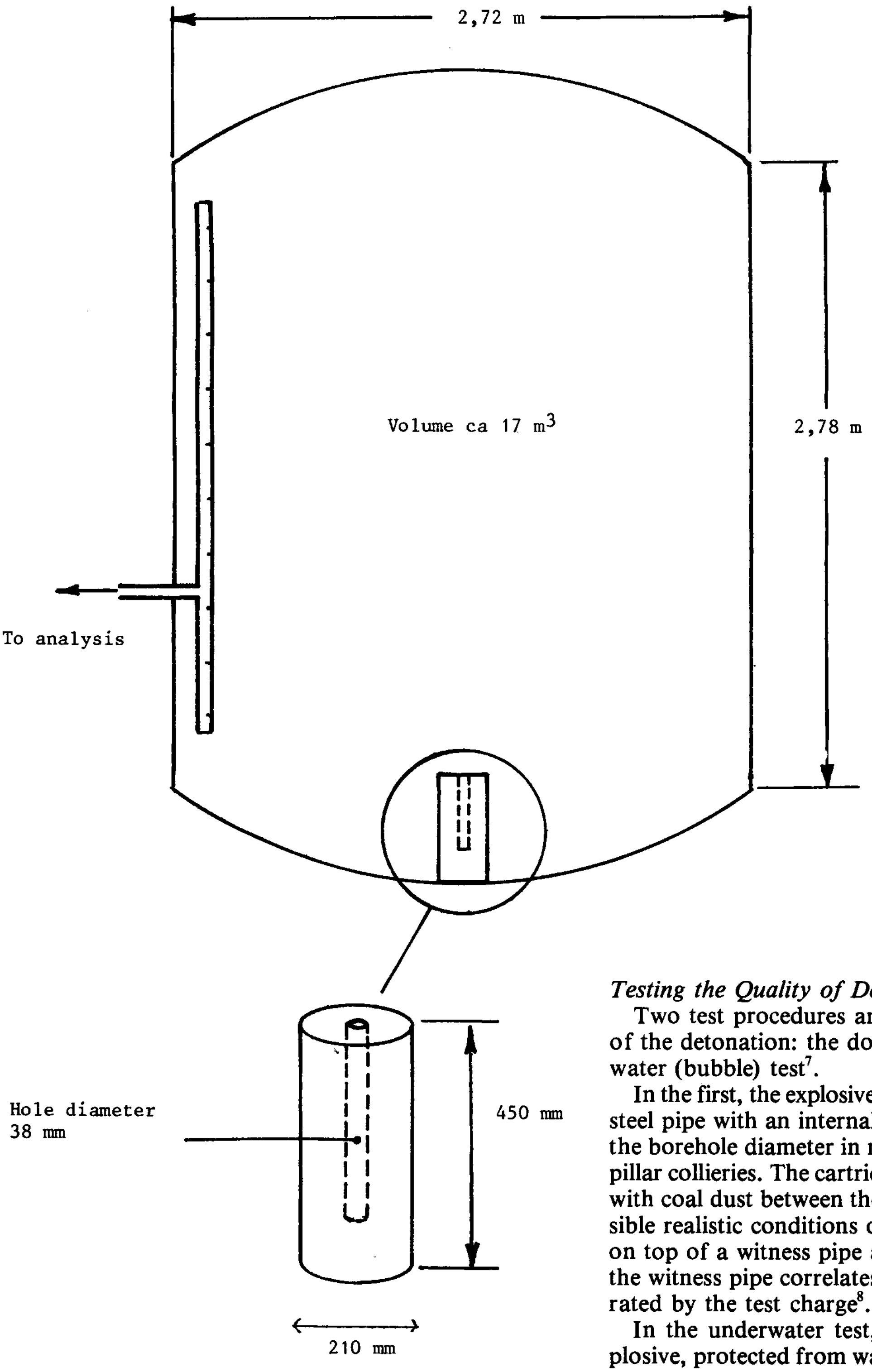


Fig. 1—Chamber and mortar for the testing of fume

the composition more or less sensitive, how a new composition ranks against older ones of well-known sensitivity, and whether factors like the particle sizes of solid ingredients or the presence of grit adversely affect the sensitivity.

The rating of explosive compositions by fall hammer or torpedo friction does not have a direct bearing on their safety in use. In general, nitroglycerin-based explosives react more readily in these tests than water-based explosives. The latter are very dependent upon the special conditions of the test, e.g. the kind of grit present.

Testing the Quality of Detonation

Two test procedures are used to indicate the quality of the detonation: the double-pipe test[6] and the underwater (bubble) test[7].

In the first, the explosive cartridges are placed in a mild-steel pipe with an internal diameter of 40 mm, which is the borehole diameter in most South African bord-and-pillar collieries. The cartridges are arranged, for example with coal dust between them, to represent as far as possible realistic conditions of use. The test pipe is placed on top of a witness pipe at firing; the depth of dent in the witness pipe correlates with the peak pressure generated by the test charge[8].

In the underwater test, the charge of permitted explosive, protected from water penetration, is fired under 6 m of water. The bubble energy of the explosive[7] is derived from the resulting oscillation of the bubble of product gas. A second charge (of Pentolite) can conveniently be used to generate precursor shocks in the water to show the effect of precompression on the energy yield of the test charge.

Pressure Desensitization Tests

Two major forms of pressure desensitization affect the performance of cartridged explosives, including permitted explosives: the channel effect[5], and dynamic desensitization from a preceding adjacent shot.

TABLE III

MEASUREMENTS BY DRÄGER TUBE OF FUME IN A BORD-AND-PILLAR COLLIERY

Blast no.	Explosive*	Mass kg	Distance in from last through road m	Air velocity in last through road m/s	CO, ppm after			NOx, ppm after			Remarks
					2 min	15 min	30 min	2 min	15 min	30 min	
1	Ajax	16	13	0,75	300	250	150	90	10	–	
2	Ajax	16	12	0,6	160	100	220	50	Tr	–	3rd reading during loading
3	Ajax	16	13,5	0,6	310	200	200	100	20	–	
14	Ajax	16	16	0,86	350	170	100	60	20	–	
10	Ajax	16	19,5	1,0	500	190	100	100	30	–	
11	Ajax	16	11	1,0	280	160	100	70	Tr	–	
12	Ajax	16	12	1,0	290	90	90	60	6	–	
13	Ajax	32	15	0,86	300	230	120	90	20	–	2 faces
4	Ajax	48	16,5	1,0	300	130	280	110	20	–	3rd reading during loading
31	Mod. Ajax	16	15	0,5	280	100	50	100	5	Tr	
32	Mod. Ajax	18	13	0,8	220	50	20	80	Tr	Tr	Stone bands
33	Mod. Ajax	17	10	0,8	240	40	40	70	Tr	–	Stone bands
34	Mod. Ajax	16	12	0,8	200	80	60	80	Tr	–	
35	Mod. Ajax	16	10	1,0	100	40	20	40	Tr	–	
29	Mod. Ajax	16	18	1,0	80	20	Tr	60	Tr	–	
30	Mod. Ajax	44	18	1,65	500	200	200	300	20	Tr	3rd reading during loading
8	Sinex 905	16	20	1,0	120	110	50	90	Tr	–	
9	Sinex 905	16	20	1,0	100	10	–	50	Tr	–	Face holed through
5	Sinex 905	16	15	0,86	120	40	30	80	Tr	–	
6	Sinex 905	16	15	0,86	100	50	10	80	Tr	–	
16	Sinex 905	16	20	1,2	160	80	10	70	10	–	
17	Sinex 905	16	19	1,2	150	60	10	60	10	–	
18	Sinex 905	16	14	1,2	110	70	10	60	Tr	–	
15	Sinex 905	32	17	1,2	90	20	Tr	60	Tr	–	2 faces
7	Sinex 905	48	18	1,0	160	90	10	80	20	–	3 faces
21	Energex 140	16	18	1,0	200	15	Tr	50	Tr	–	
19	Energex 140	16	16	1,0	80	30	Tr	50	10	–	
22	Energex 140	16	20	1,2	60	10	Tr	30	Tr	–	
23	Energex 140	16	16	1,2	120	30	Tr	40	Tr	–	
24	Energex 140	16	14	1,2	100	10	Tr	30	Tr	–	
25	Energex 140	16	11	1,8	100	60	20	40	Tr	–	
26	Energex 140	16,8	8	1,0	80	20	Tr	30	Tr	–	Stone bands
27	Energex 140	16	20	1,0	20	Tr	6	20	10	–	
28	Energex 140	32	18	1,0	100	60	10	40	Tr	–	
20	Energex 140	32	17	1,0	210	180	50	80	20	–	2 faces

* Mod. Ajax = Ajax without post waxing

Tr = Trace

The channel effect occurs when a column of explosive cartridges of smaller diameter than the borehole is not pressed home to fill the cross-section of the hole. The space between the explosive and the borehole wall forms a channel in which an air shock is created during detonation. The air shock runs ahead of the detonation in the charge, pre-compressing the explosive and altering its mode of detonation. Results of channel-effect tests using the double-pipe technique are shown in Figs. 3 to 6.

All the permitted explosives tested suffer from the channel effect. The peak borehole pressure (as measured by the depth of dent) declines along the length of the charge as the precursor air shock becomes established. Not surprisingly, the magnitude of the channel effect is erratic, but the phenomenon is none the less real. The dent profiles of Figs. 7 and 8 show that consolidation of the test charge in the pipe eliminates the channel effect. (Even relatively mild consolidation of cartridges, so as to buckle rather than squash them, has been found to effectively eliminate the channel effect.)

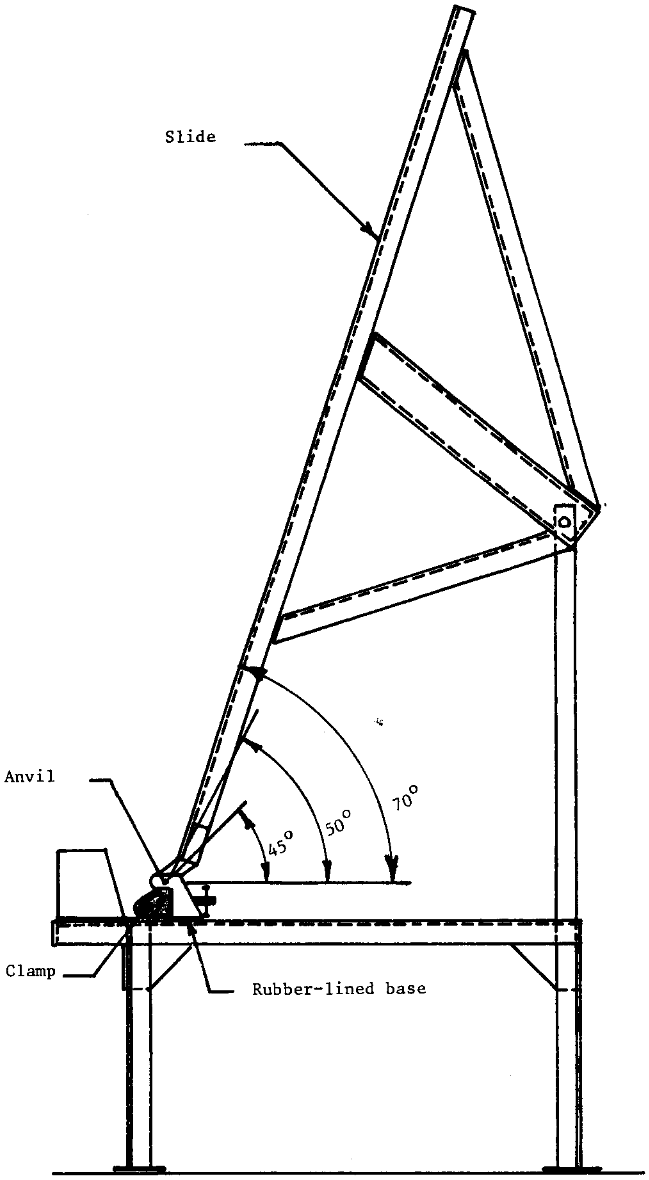


Fig. 2—Torpedo-friction apparatus used in testing the friction sensitivity of explosives

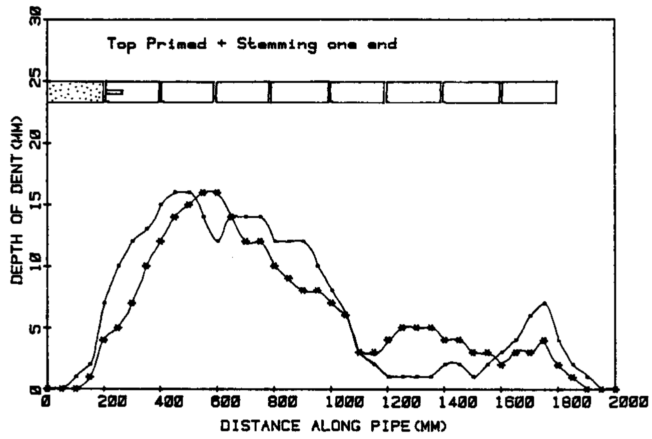


Fig. 3—The results of channel-effect tests on Coalex 32 × 200 with top priming and stemming one end

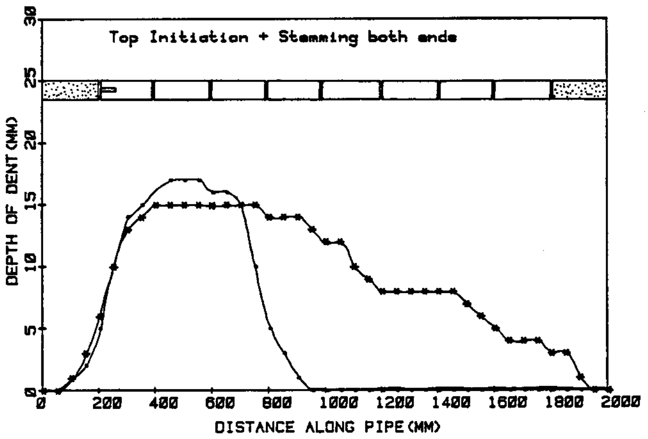


Fig. 4—The results of channel-effect tests on Coalex 32 × 200 with top initiation and stemming both ends

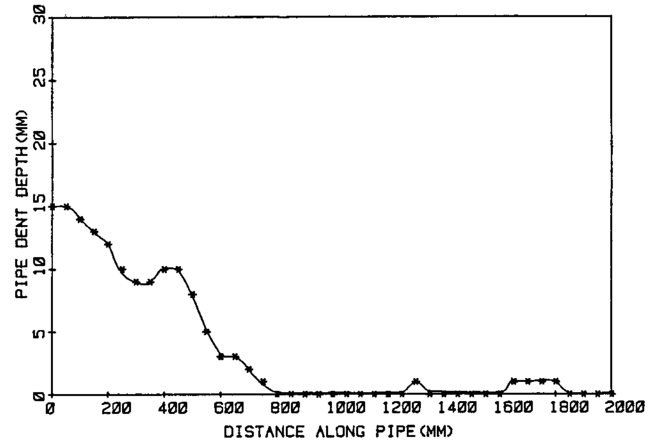


Fig. 5—The results of channel-effect tests on Ajax 29 × 200

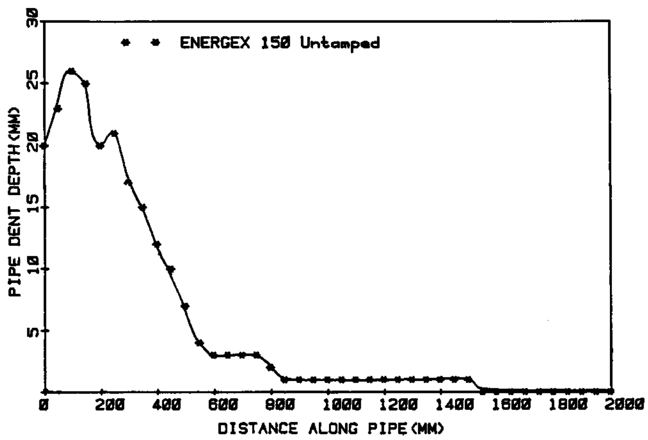


Fig. 6—The results of channel-effect tests on Energex 150 32 × 200

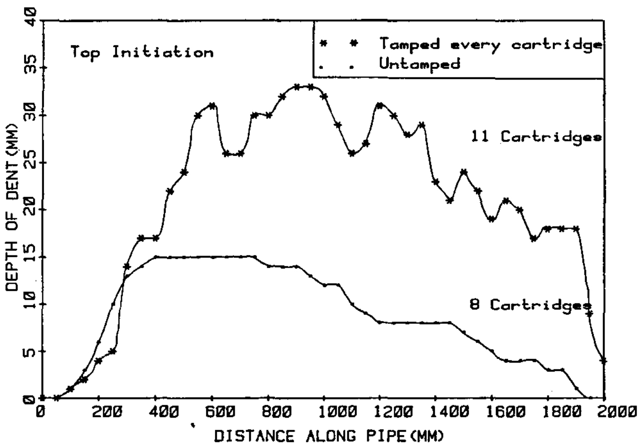


Fig. 7—Dent profiles for Coalex 32 × 200 with top initiation

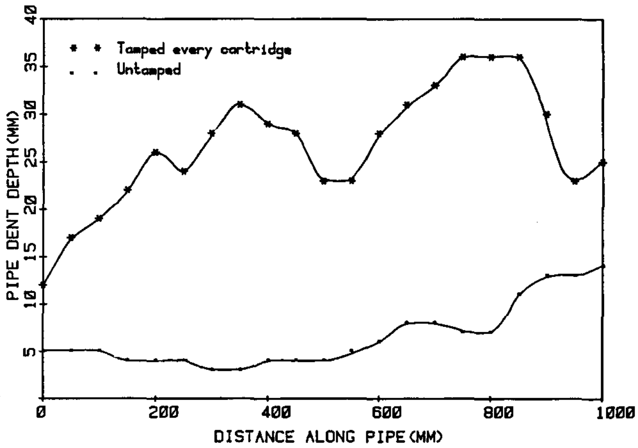


Fig. 8—Dent profiles for Ajax 29 × 200

These tests show that, if permitted explosives are not consolidated in a borehole, the performance is poor and erratic, with potential failure of part of the explosive column away from the point of initiation. Similar behaviour is exhibited by non-permitted explosives[6].

The maximum peak pressure occurs when the explosive cartridges are well consolidated in the borehole. Depths of dent in the double-pipe test corresponding to this situation are shown in Table VI. The significance of these data is discussed below under 'Performance Parameters'.

In the same way that the detonation of an explosive charge can be affected by a precursor shock in its own borehole, adjacent charges in a multiple-hole blast can affect the quality of the detonation by sending precursor shocks through the medium being blasted. The sensitivity of Ajax to this phenomenon was examined in the underwater bubble test. A shock donor charge of 150 g of Pentolite is fired in the water at various distances from the test charge and at various time delays before the test charge. For the results shown in Fig. 9, the delay between the firing of the donor and the test charges was 30 ms. These results indicate that progressively stronger precursor shocking of the test explosive causes progressively lower bubble energies. Such behaviour is evidence of incomplete reaction during the detonation of the explosive or, in general, a poor quality of detonation.

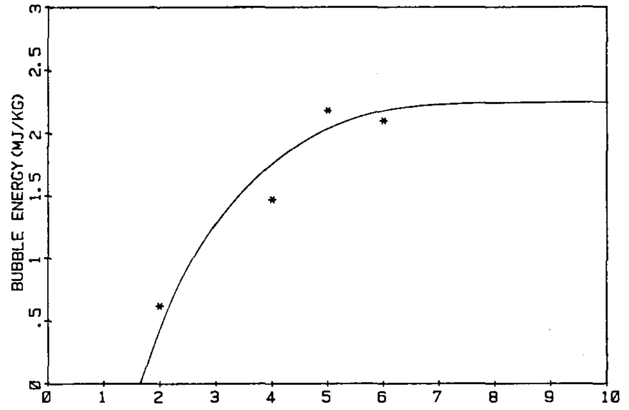


Fig. 9—Dynamic desensitization of Ajax measured in the underwater test facility

The double-pipe test reflects the pressure generated during the early part of the explosive reaction. The bubble test reflects the energy available when chemical reactions in the explosive are essentially complete. Taken together, the results discussed above show that precompression of permitted (and many other) explosives can cause a severely limited release of energy over the whole of the work-doing cycle of the explosive. In general, these problems can be eliminated in practice if

(a) the charge is pressed home in the borehole, and
(b) no two holes firing one after the other are too close together (Nenquin and Delemenne[9] recommend a minimum burden of 400 mm in coal blasting).

Gaps in an Explosive Column

Poor charging practice can lead to gaps between cartridges in an explosive column. These gaps may be empty (air gaps) or filled with coal dust. Since gaps filled with coal dust are more likely, and more serious as a potential interrupter of detonation, they were studied by the use of double-pipe tests.

For convenience, cartridges of coal dust of the same diameter as the test pipe were prepared. As a thorough test of whether the detonation can jump a chosen gap, the gap was repeated between each cartridge and the next in the column. Finally, it was known that the ability of a detonation to jump a gap would be affected by the run-up distance from the point of initiation to the first obstacle encountered. A copper electric detonator was therefore placed in a cartridge in the middle of the explosive column, so that the detonations running forwards and backwards from the detonator could be observed. The details and results of these tests are shown in Figs. 10 to 12.

The critical size of coal-dust gaps for the explosives studied is summarized in Table IV. All the explosives were able to detonate across fairly substantial gaps of coal dust. Careless practice in the loading of boreholes is nevertheless a potential cause of problems. In addition, the practice of mid-priming, which requires the detonation to run both ways from the initiator, places the greatest demands on the explosive for reliable performance.

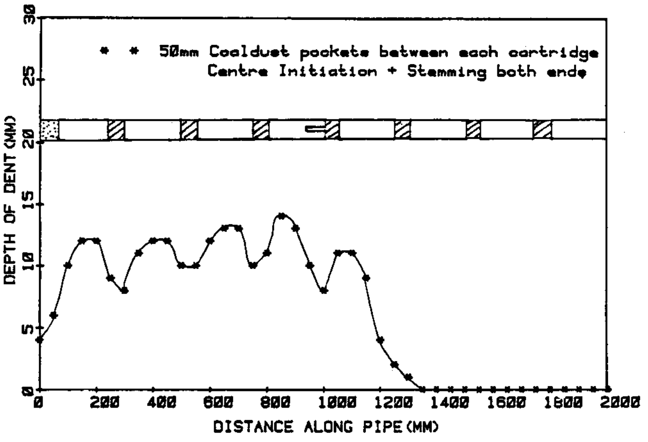


Fig. 10—Effects of coal-dust gaps on Coalex 32 × 200

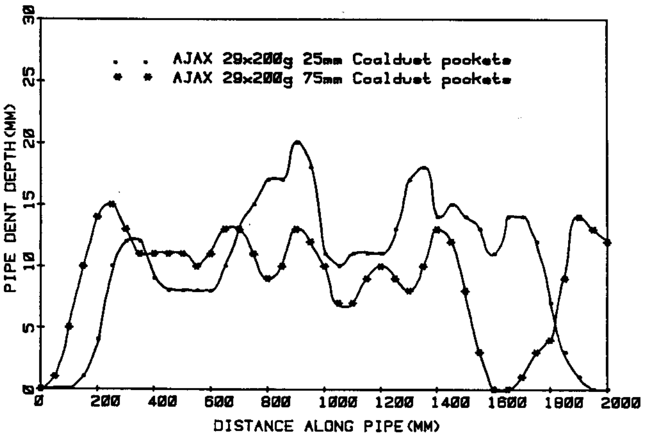


Fig. 11—Effects of coal-dust gaps on Ajax 29 × 200

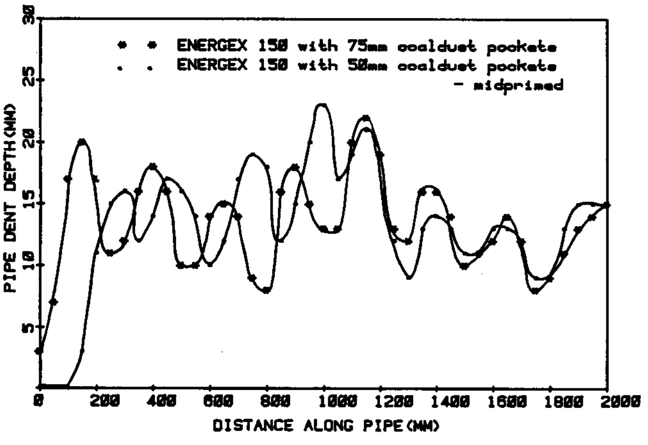


Fig. 12—Effects of coal-dust gaps on Energex 150 32 × 200

TABLE IV

CRITICAL SIZE OF COAL-DUST GAPS

Explosive	Size of gap mm
Ajax	> 75
Coalex	50 to 75
Energex 150	> 75

Performance Parameters

Blasting in bord-and-pillar mining is assessed largely in terms of advance per round, but fragmentation is often important as well. For explosives to 'pull the round drilled', the coal must be fractured and then removed from the face for easy loading. The authors regard the effective field performance index of permitted explosives as a combination of a fragmentation index and a heave index. Good fragmentation without adequate heave or displacement of the broken coal is not much use, and *vice versa*.

No single laboratory parameter of explosive performance adequately reflects this requirement. The measures of performance that are applied in the AECI laboratory and their meaning are summarized in Table V, and five permitted explosives are rated in Table VI. The data in this table illustrate the complexity of the situation: the ranking of the explosives depends on which test is used. One method of using the available data is in some way to combine the various parameters of performance yielded by the different tests to give an empirical field performance index (FPI) that conforms to practical blasting experience.

The derivation of reliable empirical methods of rating the blasting potential of permitted and other explosives is a challenge for the future. In addition, AECI and associated laboratories are working on ways of calculating the energy delivered from non-ideal, small-diameter explosives.

Conclusions

The testing procedures discussed represent a comprehensive set of techniques aimed at optimizing the performance of permitted explosives in terms of safety, quality of detonation, and blasting potential. They are used in the AECI laboratory more or less routinely in the formulation of guidelines and in the derivation of recommendations for the best methods of use of the explosives. This approach is empirical and practical, but gives useful insight into how permitted explosives behave in field use, and which features of these explosives are important in controlling their performance.

Among the tests applied to permitted explosives, the gallery test has been extremely valuable in ensuring a range of explosives with a very good safety record in fiery mines. The double-pipe test is a more recent introduction, but it has given valuable depth to our understanding of the complex manner of explosive behaviour under realistic conditions.

Further application of the tests described should lead to continued improvements in the safety and efficiency of permitted explosives in South Africa.

TABLE V
MEASURES OF PERFORMANCE OF EXPLOSIVES

Performance measure	Property of explosive reflected	General relevance to blasting
Absolute strength value (ASV)	Theoretical (calculated) maximum amount of energy an explosive can deliver to its surroundings	The ASV indicates the idealized potential of the explosive, all else being equal. In practice, many different factors intrude, particularly non-ideal quality of detonation of explosives, so that ASV is not a useful measure of blasting performance
Maximum dent depth, double-pipe test	Effective peak borehole pressure	Indicates broadly the fragmentation ability of the explosive. The peak pressure gives no indication of how well fractured material will be displaced or heaved
Underwater bubble energy	Residual energy in explosion product gases after the explosive has created and released a shock wave in the water	The timescale of energy release in the under-water test is similar to that of the early (fragmentation) stage in blasting. This parameter shows whether potential energy, shown by the ASV, can be released quickly enough in practice
Ballistic mortar energy	Amount of energy the explosion product gases can deliver to a projectile in the low-pressure regime	Gives no indication of peak pressures. This parameter correlates most closely with the heave potential of the explosives

TABLE VI
PERFORMANCE PARAMETERS OF PERMITTED EXPLOSIVES

Explosive	Calculated ASV MJ/kg	Bubble energy MJ/kg	Ballistic mortar value % BG†	Maximum* dent depth mm
Ajax	3,11	1,90	59	8
Coalex 1	3,34	1,98	66	6
Sinex 905	3,32	1,96	66	15
Energex 140	2,75	1,92	58	15
Energex 150	3,37	1,98	73	15

* See Fig. 13
† BG = Blasting gelatin

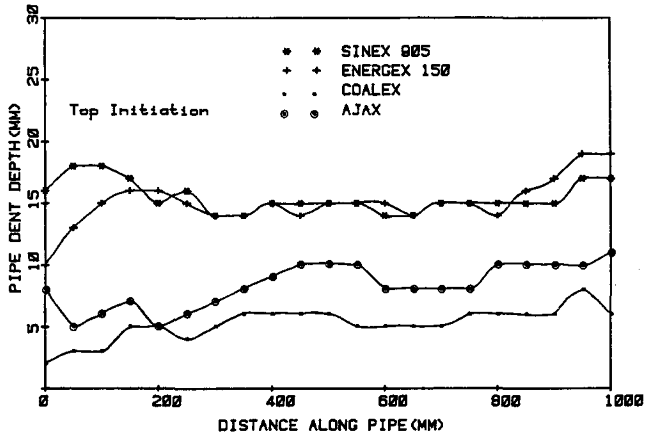


Fig. 13—Peak borehole pressures when all the charges are fully coupled by tamping (the witness pipes used in these double-pipe tests were thicker and stronger than those used in all the other tests reported in this paper)

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