Performance of Distributed Bagged Stone Dust Barrier in Combating Coal-Dust Explosions

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ABSTRACT

The Kloppersbos Research Facility of the CSIR's Division of Mining Technology has developed a new method of building stone dust barriers. The new barrier makes use of a previous concept of containing stone dust in a bag, but incorporates a new method of rupturing the bag. This was achieved by adapting the closing mechanism and by balancing the stone dust content with the void in the bag.

The bagged barrier was extensively tested in the 200-m test gallery. During these tests, it became evident that these bags could be made to rupture and spread stone dust when subjected to smaller forces than those required for the most commonly used passive barrier, the polish light barrier. To validate this, as well as to gain international acceptance of this new barrier, tests were conducted in the German experimental mine, DMT Tremonia, Dortmund.

The barrier was evaluated against numerous methane-initiated coal-dust explosions. The paper describes the successful inhibition of coal-dust explosions at Kloppersbos and DMT Tremonia. The barrier has been proven successfully for static pressures of 44 to 82 kpa, dynamic pressures of 12 to 36 kpa and for flame speeds as low as 23 m/s. This barrier is now accepted by the South African government and has been implemented in numerous South African collieries.

KEYWORDS

Stone Dust, Barrier, Coal Dust, Explosions, and Bags.

INTRODUCTION

Research into reducing the methane and coal dust explosion hazard in a cost-effective manner led to the development of a new method for building stone dust barriers. The method makes use of a previous concept of containing stone dust in a bag, but incorporates a new means of rupturing the bag. The closing mechanism was adapted, and by balancing the stone dust content with the void in the bag, a new mechanism for rupturing the bags was developed. This is the first time the principle of containing stone dust in a bag has been applied effectively, despite numerous attempts world-wide.

In the development and evaluation phase, the bags were tested extensively in the 200 m test gallery at Kloppersbos. During these tests, it became evident that the bags could be made to rupture and spread stone dust even when subjected to low dynamic pressures.

This paper summarises the test work conducted in the 200-m test gallery at Kloppersbos during the development and evaluation of the distributed bagged stone dust barrier.

BACKGROUND

Various tests (more than 50) were conducted using methane explosions to create a weak dynamic pressure wave. High-speed and normal video cameras were used to record the destruction of the bags and the dispersal of the stone dust in order to evaluate the most effective closing mechanism. The findings were based on visual inspection of the actual rupture mechanism of the bags. On completion of these tests, a plastic bag with a simple closing mechanism was chosen for further tests.

Additional test work was done to determine the minimum dynamic pressure at which a unit will start to operate effectively. Effective operation is assessed as the minimum dynamic pressure at which effective stone dust distribution occurs.

Limited test work done during August 1995 at the DMT test facility (Margenburg, 1995) indicated that for the specific plastic bag tested, a minimum dynamic pressure of 6.5 kPa was required. Subsequent improvement in the quality specification of the plastic bag has resulted in a minimum dynamic pressure of approximately 3.0 kPa being required for effective operation.

Test work conducted at DMT Tremonia (Michelis, *et al.*, 1996) indicated certain limitations on the use of passive concentrated barriers. These limitations are especially valid where low-strength (<10 kPa) coal dust explosions need to be suppressed. However, they also apply to all available barrier systems, with a minimum dynamic pressure of 20 kPa being required for effective operation of the water trough barrier for large cross-sectional areas. This limitation of the water trough barrier was determined at DMT Tremonia in the large cross-sectional gallery (Michelis, *et al.,* 1992).

During such an explosion (low strength), the resistance inside the barrier results in a decrease in the dynamic pressure, which leads to partial operation of the passive barrier. The partial operation results in a large amount of stone dust or water falling to the ground before the arrival of the flame, so that there is only partial extinction of the flame.

The final recommendation from the test work done at DMT is to use a distributed barrier layout in critical areas (Michelis, *et al.,* 1996).

PERFORMANCE CRITERIA

In general, the performance of any type of barrier is measured against a pass/fail criterion, where a pass requires that a barrier should stop the propagation of a coal-dust explosion. It is suggested that the pass criterion should be defined more specifically as meaning that the propagation was -

- * stopped on the spot, or
- * stopped.

It is accepted that an explosion could be considered to have been "stopped on the spot" if the flame did not exceed a distance of 25 m beyond the end position of the barrier. The barrier could be considered to have "stopped" an explosion if the flame propagation (i.e. flame distance) was less than it would have been without the barrier. It is in terms of these criteria that the dispersed barrier was tested at the CSIR's Kloppersbos Research Facility.

The explosions against which the barrier was evaluated are briefly discussed below. The ability to prevent flame propagation was evaluated against the results of the barrier explosion (Du Plessis, *et al.,* 1995). A weak, standard barrier explosion (Du Plessis, *et al.,* 1995) (further referred to as a standard explosion) was developed for testing explosion barrier systems. It was similar to an initiating 9% methane/air mixture explosion of 36 m^3 volume with a wind pressure of approximately 25 kPa, and with flame propagation throughout the gallery from coal dust combustion, without the production of additional pressure. The mean delay time (between flame and dynamic pressure wave) for the standard explosion was 400 - 600 ms. The experimental lay-out for the standard and barrier explosions is shown in Figure 1.

The explosions are initiated by a 9% methane/air mixture of 36 m^3 volume. Coal dust is spread on the shelves for a distance of 10 m, and with the rest of the coal dust (138 kg) is distributed on the floor for a distance of 140 m.

Further explosions were developed against which to evaluate the operation of the barrier across a wider spectrum of explosion conditions. They are referred to as either strong or weak explosions. The strong explosion is similar to the standard explosion, but a larger amount of coal dust is used.

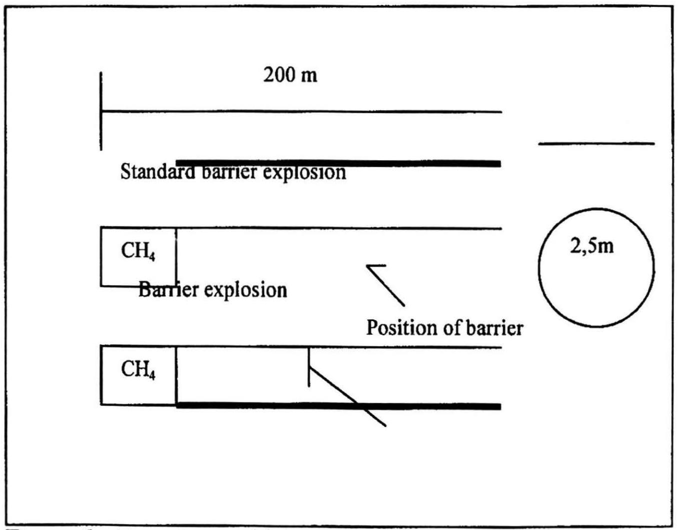

Figure 1. Experimental layout for standard and barrier explosions.

The coal-dust loading is increased by 25% (144 kg of coal dust to 192 kg of coal dust) with the same initiating methane explosion. This change results in a propagating explosion reaching a dynamic pressure of approximately 50 kPa at the tunnel mouth if unsuppressed.

The weak explosion is similar to the standard explosion, the only change being in the actual initiator used: a 200 J igniter is used to ignite the methane/air mixture.

All of these explosions will result in flame lengths of greater than 200 m.

BARRIER DESIGN SPECIFICATIONS

The layout of the distributed stone dust barrier will be discussed in greater detail here. The basis of the design is such that a greater area is safeguarded so that greater protection should be afforded against coal-dust explosion propagation in bord-and-pillar mines.

Loading

Cybulski (1975) reported success in suppressing coal-dust flame propagation through the use of a stone dust concentration of 0.25 kg/m^3. He further recommended that a concentration of 1 kg/m^3 should be used for the stone dust barrier.

Cybulski further defines three quantities that will affect the stone dust distribution on a barrier. They are:

Q_A - the quantity of stone dust on the whole barrier per square meter of the gallery's cross-section (kg/m^2); this is normally a regulatory requirement.

Q_1 - the quantity of stone dust on a single shelf per square meter of the gallery's cross-section (kg/m^2).

Q_V - the concentration of stone dust in the zone in which the barrier is situated, i.e. the quantity of stone dust on the whole barrier in relation to the volume of the working area which it occupies (kg/m^3).

The way in which Cybulski defines the Q_V value is different from that suggested for the water trough barrier (free volume between barriers). It is recommended that Cybulski's method of calculation be adopted as it ensures a greater amount of stone dust present in the barrier zone.

Cybulski (1975) also states that: "Distributed barriers are barriers in which the shelves are placed at such distances as to satisfy the following basic conditions: Q_V should not amount to less than 1 kg/m^3. The value of Q1 should not be lower than 0.5 kg/m^2. Although it has been stated that to ensure adequate effectiveness of barriers of this type it is sufficient to satisfy the condition of having Q_V not lower than 0.5 kg/m^3 or even Q_V = 0.25 kg/m^3 - yet, for the purpose of attaining an appropriate level of confidence, the above higher requirement should be complied with".

It is recommended that the following criteria be met in designing the distributed dispersed barrier:

Q_A - regulatory requirement of at least 100 kg/m^2 of roadway area

Q_V - not less than 1 kg/m^3

where the greater of the quantities must be used.

Spacing of bags

The spacing of the bags should conform to the following minimum standards:

Distance between bags in a row
- not closer than 0.4 m
- not further than 1.0 m

Distance between rows
- not closer than 1.5 m
- not further than 3.0 m

Distance to sidewall of outer bags
- not nearer than 0.5 m
- not further than 1.0 m

Distance to roof
- not nearer than 0.5 m for seam heights greater than 3.5 m

Height restrictions
The following are minimum requirements, i.e. if the mine wishes to install more levels of bags within the other specified requirements, it may do so:

- for roads with a height range of less than 3.0 m: a single level of bags suspended below the roof.
- for roads in the height range 3.0 m to 3.5 m: a single level of bags suspended at approximately 3.0 m height.
- for roads in the height range 3.5 m to 4.5 m: a double level of bags suspended at approximately 3.0 m and 4.0 m above floor level.
- for roads in the height range of more than 4.5 m but less than 6.0 m: a triple level of bags suspended at approximately 3.0 m, 4.0 m and 5.0 m.

Spacing of individual barriers

- the first sub-barrier, closest to the face, to be installed not closer than 60 m from the last through road and not further than 120 m.
- the fourth sub-barrier, furthest from the face area, to be installed not more than 120 m from the first row of bags in the first sub-barrier.
- the two intermediate sub-barriers to be placed in between.

Worked example

An example of a typical calculation for the distributed barrier in the 200-m test gallery is as follows:

a) Distance from face: Assume 50 m

b) Protection distance chosen: 100 m

c) Cross-sectional area:
Height = 2.5 m
Area = 4.91 m^2

d) Volume of protection area = 4.91 x 100
= 491 m^3

e) Amount of stone dust required:
Q_A = 4.91 m^2 x 100 kg/m^2 = 491 kg
Q_v = 491 m^3 x 1 kg/m^3 = 491 kg

f) Number of bags required:
6 kg/bag = 491/6
= 81.83 bags
Say : 82 bags

g) For four sub-barriers: 82/4 = 20.5 bags/barrier

h) Four bags suspended per row, five rows of bags per sub-barrier (one row with five bags). As the bags are spaced 2.0 m apart and the closed end of the tunnel is the zero po-sition, the sub-barriers will be located as shown in Table 1.

Table 1. Distributed barrier positions.

Distance from last through road (m)	Description
0	Begin
50 – 58	First sub-barrier
80 – 88	Second sub-barrier
110 – 118	Third sub-barrier
140 – 148	Fourth sub-barrier

CHECK: (98 m x 4,91) x 1 kg/m^3 = 481.18 kg
21 bags x 4 x 6 kg = 504 kg

RESULTS

200-m Test gallery, Kloppersbos

The distributed barrier was evaluated against the weak, standard and strong explosions, with the stone dust bags suspended in four separate individual barriers. The first barrier was placed 50 m from the closed end of the tunnel (ignition source) with five bags suspended every 2 m and the other individual barriers spaced 20 m apart. The principle of 1 kg/m^3 of the volume of the barrier was adhered to. The results of the tests conducted at Kloppersbos, with the barrier at 50 m from the end of the tunnel, are shown in Table 2. The flame speeds indicated were determined between the first and second individual barriers.

Table 2. Distributed barrier results with first barrier at 50 m.

Expl No.	Type of expl.	Static pres. (kPa)	Dynamic Pressure (kPa)	Flame Speed (m/s)	Flame length (m)
47	std.	72	N/r	39	50
48	std.	64	N/r	42	110
49	std.	68	N/r	23	90
50	std.	82	N/r	24	100
51	sem.	107	N/r	100	+200
54	sem.	94	N/r	133	+200
56	strong	63	N/r	67	90
69	std.	69	30.2	100	60
71	strong	68	31.3	45	50
73	strong	57	28.4	47	90
86	weak	67	29.6	67	70
87	weak	51	14.6	67	80

The distributed barrier proved effective in preventing flame propagation beyond the barrier positions.

In the tests conducted with coal dust spread on the shelves, ensuring the dispersal of the coal dust into the air, the barrier failed to stop the propagation of the explosion. This result can be explained by the small time delay between the flame and the pressure front, which was less than 50 ms at the second barrier position for the tests conducted. The distributed barrier had the effect of slowing down the flame speed and decreasing the static pressure, but the flame extended along the whole length of the 200-m tunnel.

The position of the first barrier was then moved to 90 m, with the rest of the barrier remaining as described previously. The results of these tests are shown in Table 3.

Table 3. Distributed barrier results with first barrier at 90 m.

Expl. No.	Type of Expl.	Static Pres. (kPa)	Dynamic pressure (kPa)	Flame speed (m/s)	Flame length (m)
81	Strong	63	30.7	100	140
99	strong	74	35.5	50	90
85	std.	63	31.2	48	110
100	std.	69	27.1	37	110
97	weak	41	11.6	42	110
98	weak	52	17.0	98	130

The barrier proved to work effectively for a dynamic pressure range from 11.6 kPa to 35.5 kPa. Ability to cope with low dynamic pressures is essential as this ensures the effective and quick operation of barriers.

20 m^2 Gallery

Tests were conducted at DMT Tremonia in the 20 m^2 explosion gallery (Margenburg and Du Plessis, 1996) (Du Plessis, 1996).

Baseline Coal Explosion

In the baseline explosion, the explosion strength increased considerably. A dynamic pressure measurement (74 m) of 21 kPa was recorded just inside the proposed first barrier position. Dynamic pressure of this magnitude should ensure good stone dust distribution and good operation of the barrier.

The key characteristics of the baseline coal explosion were:

- Length of flame: 236.0 m
- Dyn. pressure at 1st barrier:20.6 kPa
- Static pressure at 1st barrier: 120.5 kPa
- Delay time: 352.0 ms

The position of the first barrier coincides with the position of the dynamic pressure sensor. At this position, calculation of the time delay indicates the minimum time available for effective barrier operation. At the first barrier position, a time delay of 352 ms will be more than sufficient for proper dust distribution.

The test results for barrier performance with the baseline explosion are shown in Table 4:

Table 4. Test results.

	Flame length (m)	P_{dyn} (kPa)	P_{stat} (kPa)	Delay time (ms)
Test 1	136.0	21.2	57.0	388.0
Test 2	136.0	18.2	53.9	311.0
Test 3	122.0	19.6	55.5	486.0

The propagation of the coal-dust explosion shows two different reaction zones. In the baseline explosion, the maximum flame speed in the second reaction zone is 250 m/s. A comparison of the flame length and speed for the explosions is shown in Figure 2.

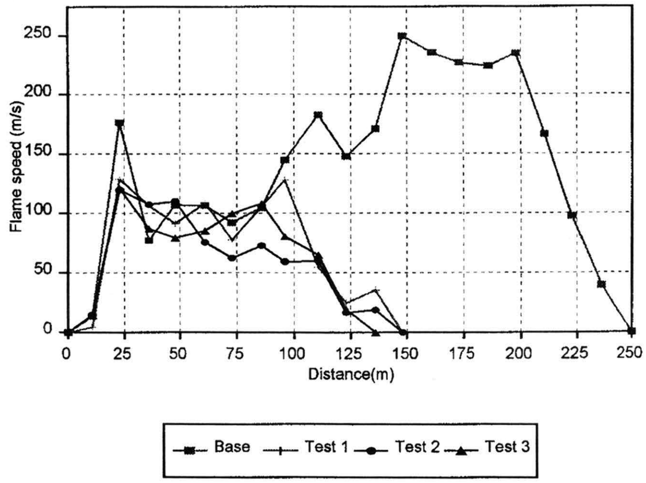

Figure 2. Comparison of flame speed and flame length for baseline and barrier tests.

The stone dust dispersed in the air results in a decrease in flame speed until full extinction of the explosion flame is observed.
The main findings of this study were:

- Flame propagation decreased by at least 100 m
- There was a large decrease in temperature
- Static pressure decreased to less than half of the original
- Dynamic pressure decreased to almost a quarter of the original at the fourth barrier position
- Barrier operated quickly (Du Plessis, 1996).

CONCLUSIONS

The conclusions drawn are based on the test results and experience gained from the 200-m test gallery and on other test results and personal communications with DMT experts.

Coal-dust explosions were effectively arrested for a dynamic pressure range from 12 to 36 kPa and flame speeds as low as 23 m/s.

The distributed barrier has proved effective in the inhibition of coal-dust explosion propagation in tests conducted at DMT, Tremonia in a 20 m^2 gallery under low dynamic pressure conditions.

The distributed bagged barrier is the best-suited barrier for use in bord-and-pillar mining layouts.

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ACKNOWLEDGEMENTS

The authors wishes to thank the staff at Kloppersbos for their participation in the project work and SIMRAC for the funding of the work.