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Response of small-scale blackpowder storage in partitioned wooden boxes to external fire

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Research Report

HSE

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Response of small-scale blackpowder storage in partitioned wooden boxes to external fire

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Research has shown that when a partitioned wooden box containing twenty five plastic bottles, each bottle containing 1 kg of blackpowder is exposed to an external wood fire, the bottles of powder do not explode en masse but ignite over a short period of time. Fire resistance times for the specified box design of no less than 8 minutes were observed before blackpowder ignitions started to occur.

Following blackpowder ignitions within the wooden box, ejection of full bottles of blackpowder may occur with bottle ejection distances of up to 5 m having been recorded.

In the event of an incident involving blackpowder stored in the box designed as described, the ejected bottles of blackpowder could pose a hazard to emergency services and consideration should be given to disseminating the information to them.

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EXECUTIVE SUMMARY

The Explosives Team of the Health and Safety Laboratory had previously developed a partitioned wooden box capable of containing up to 9 x 0.5 kg plastic bottles of blackpowder; this box design prevented mass explosion of the contents when exposed to an external wood fire. The box design was incorporated into the Approved Code of Practice (ACoP) for the Manufacture and Storage of Explosives Regulations (MSER).

Subsequently, the Explosives Inspectorate of HSE identified a need to store larger quantities of blackpowder (up to 25kg) within a similarly designed box.

The objectives of the study were to:

- establish if the current box design could be adapted to store 25 x 1 kg bottles of blackpowder whilst maintaining overall safety to response teams in an emergency situation,

- demonstrate whether mass explosion or other significant hazards occurred when the box was subjected to an external fire,

- establish the fire resistance time of the box (i.e. the time from fire engulfment of the box to ignition of the first bottle of blackpowder).

The research has demonstrated that a mass explosion of the contents of a box containing up to 25 x 1 kg bottles of blackpowder does not occur when subjected to an external fire but generally proceeds by sequential ignition of the bottles over a period of between 6 and 24 seconds. The fire resistance times for the box design are in excess of 8 minutes.

During the studies it was noted that, occasionally, full bottles of blackpowder were ejected from the box when other adjacent bottles ignited and that these full bottles were propelled up to 5 m from the box. It is considered that in the event of an incident involving a fire, ejected bottles would pose a hazard to the emergency services either by immediate interaction of the bottle and contents with other fires within the area or via cookoff if no direct flame contact occurred.

It is recommended that details of the results of this research be disseminated to the appropriate authorities.

CONTENTS PAGE

1. INTRODUCTION

As part of a previous review of explosives legislation by the Health and Safety Executive (HSE), the Explosives Team in the Major Hazards Unit (MHU) of the Health and Safety Laboratory (HSL) conducted extensive testing of the behaviour of tins and plastic bottles containing 500 g of blackpowder (BP) or smokeless powders stored within various storage vessels; these storage vessels included both wooden boxes and metal ammunition boxes.[1,2] The results from these preliminary studies led to the development of a partitioned wooden box capable of containing up to 9 x 0.5 kg plastic bottles of BP without a mass explosion of the contents occurring when exposed to an external wood fire.[3]

These previous tests also indicated that the boxes as designed resisted fire engulfment for over 15 minutes before the contents started to ignite. The data formed the basis of the guidance on the small-scale storage of BP (in lots of up to 4.5 kg) that was included in the Approved Code of Practice (ACoP) to the Manufacture and Storage of Explosives Regulations (MSER).[4]

Following the initial study, HSE raised concerns that the fire challenge assessed during these original trials might not have been sufficiently severe to accurately represent a fire in a domestic dwelling. These concerns led to doubts that the 15 minute fire resistance of the boxes would be reflected in a "real world" fire scenario. In addition, HSE identified a need to determine whether the storage method recommended in the ACoP would achieve the same objectives (ie preventing a mass explosion and offering a reasonable degree of fire resistance) when used to store up to 25 plastic containers each holding 1 kg of blackpowder.

HSE's Explosives Policy Unit commissioned HSL to perform a further series of fire engulfment tests to demonstrate the effects of the proposed changes to the box design and explosive quantity. This report describes the results of those tests.

2. IMPLICATIONS

The data indicate that, within the parameter ranges assessed in this research, the performance of the partitioned wooden box is independent of:

1) box wall thicknesses (in the range 18-24 mm),

2) the number of compartments in the box (in the range 9 to 25),

3) the mass of blackpowder in each bottle (in the range 0.5 to 1 kg),

4) the blackpowder used (FOA or Swiss No. 1).

Studies also show that the current box design can prevent the mass explosion of blackpowder stored in such a manner when subjected to external wood fire.

If adopted, this information has the potential to extend the versatility of the guidance provided by the ACoP to MSER by allowing the amount of blackpowder intended for use as shooters powder to be:

- increased from 4.5 kg to 25 kg and,
- the mass of powder in each bottle to be increased from 0.5 kg to 1.0 kg,

while ensuring that the risk to public safety arising from the mass explosion of the shooters powder are controlled.

3. METHODOLOGY

All measurements presented in this report are traceable to national standards.

Photographs are of digital format and were provided by HSL's Visual Presentations Services (VPS) who retain the master discs for them. Copies of photographs and videos are stored on CDs on the HSL investigation file (No. 031200).

3.1 WOODEN STORAGE BOXES

The boxes used for all the tests were based on the design incorporated into the ACoP to MSER[4] but the number of compartments was either nine or twenty five depending on the test being performed. The boxes were fabricated from panels made from WBP grade exterior plywood (commonly called "Marine Ply") to standards EN13986 and EN638-35 and were assembled using joints that were nailed together. The lid was held shut by a closed and barred metal hasp and staple. An intumescent strip (10 mm wide and 4 mm high) was incorporated between the lid and the top of the box to hinder the ingress of flame. The strip had 'certfire approved CF276', printed on it. Boxes with 18 mm and 24 mm wall thicknesses were used during the tests but all internal partitions were 6 mm thick and held in place with pins. Figure 1 shows an example of the nine compartment box used. A diagram of the construction of the nine compartment, 18 mm wall box is given in Appendix 1.

Figure 1: Typical design of wooden storage boxes used during trials

3.2 BLACKPOWDER SELECTION

Preliminary testing was performed on a range of different blackpowders to establish their relative burning rates. This was achieved by using the HSL flash test method detailed in the UN Manual of Tests and Criteria.[5] Within this test a small amount of material (0.5 g) was ignited within a fixed volume and the time taken for the pressure to rise over the range 690 to 2070 kPa recorded. This procedure was performed six times for each sample. Table 1 summarises the results of the various test samples.

Table 1: Rise times of a range of blackpowders

HSL sample i.d	Description	Minimum rise time (ms)	SD (ms)
2429/5/1	Swiss Blackpowder No. 1	2.14	0.47
2429/5/2	Swiss Blackpowder No. 2	2.67	0.35
2429/5/3	TS2 Gunpowder	3.25	0.71
2429/1	FOA Black Powder	4.83	0.84

The shorter the rise time the more energetic the material is considered to be. The data indicates that Swiss No 1 blackpowder had the fastest rise time suggesting that it was likely to be the most energetic in terms of mass flow per second. The standard deviations for the Time / Pressure testing of BP Swiss No. 1 and BP Swiss No. 2 make it unclear if the difference in rise time between them is significant.

FOA powder was chosen for the majority of the tests because it had been used for the majority of the previous work at the 0.5kg bottle scale.[3] BP Swiss No. 1 was also selected to represent a "worst case scenario" as it gave the fastest minimum rise time in the tests and so would be expected to burn most rapidly within the box tests.

Specifications for the two types of blackpowder used in the trials are given in Appendix 2.

3.3 TESTING

3.3.1 Bonfire trials

Blackpowder (BP) was decanted into high density polyethylene (HDPE) bottles of the appropriate size and loaded into all the compartments in the wooden box (Figure 2). The bottles used were not the same as those used to transport blackpowder in that they were not carbon loaded to combat static build-up. However, it was considered that the base polymer was similar and would approximate to the bottles normally used for transport. Tests were set up with the boxes of BP exposed to an external wood fire challenge generated as described in the method for UN series 6(c) tests.[6] As per the UN Series 6(c) procedure, a small amount of paraffin was added to the fire stack to aid ignition but this was consumed before the boxes were engulfed in flame. The box was placed on a steel mesh fitted to the top of a 1 m tall steel table and a wood stack built beneath it. The wooden lathes used for the fire extended at least 1 m beyond the outer dimensions of the box to ensure total fire engulfment.

During the tests, two normal speed video cameras were positioned to view the test at 90º to each other so that the progression of the fire through the wood stack could be observed. Once the test was complete, debris was recovered and the distance that it had been projected was recorded. Any unreacted bottles of blackpowder were also recovered and their positions noted.

Video records were examined to establish the time at which:

1) the fire stack started to burn,

2) the wooden box was engulfed in flame and

3) each blackpowder ignition was observed.

Fire resistance time was calculated from the time the box was engulfed in flame to the time at which the first blackpowder ignition was observed.

The time over which BP ignitions took place was also determined from the video record and the number of ignitions recorded; these ignitions are referred to as the number of "resolved ignitions" within Table 3. It was accepted that because only normal speed video recordings were used to observe the burning, it was possible that more than one bottle of blackpowder could ignite in the time period between frames, which would mean that, in some instances, not all ignitions could be observed separately.

Figure 2: Set-up showing plastic bottles of BP in wooden box on steel table surrounded by fire stack

In addition to the bonfire trials, 2 tests were performed to demonstrate the effect of 9 kg and 25 kg of FOA blackpowder reacting en masse in the wooden box. For these tests the external construction of the boxes was the same as that used for the bonfire trials. However, the inner partitioning was not present and the entire quantity of blackpowder was placed in the box in an antistatic plastic bag. Ignition was effected by firing a matchead fuse approximately in the centre of the bag of powder. This ignition method would be predicted to result in a more severe sample response than the bonfire trials due to the increased degree of confinement that the sample would experience compared to ignition within a partly burned box.

Table 2 details the tests that were performed.

Table 2: Test programme for BP storage in wooden boxes

Test i.d.	Wall thickness of box (mm)	Type of BP	Number of compartments	Mass BP per compartment (kg)	Total mass (kg)
1 to 3	18	FOA	9	0.5	4.5
4 to 6	24	FOA	9	0.5	4.5
7	24	FOA	1	9.0	9.0
8 to10	18	FOA	9	1.0	9.0
11 to 13	24	FOA	9	1.0	9.0
14 to 16	24	FOA	25	1.0	25.0
17	24	FOA	1	25.0	25.0
18	24	Swiss No. 1	25	1.0	25.0

4. RESULTS AND DISCUSSION

Table 3 provides data on whether the BP functioned en masse, the fire resistance, the number of full bottles of BP recovered after the trial, the number of box panels recovered and the maximum projected distance of the panels from their original position. In addition, data is given on the number of resolved ignitions observed and the time period over which they occurred. In some instance BP bottles were thrown off the fire stack and ignited well after those that remained on it due to the bottles falling into the embers of the fire or being close enough for radiant heat to effect ignition (cookoff). These results have been asterisked and removed from the calculation of the mean duration of the ignition sequence.

The data clearly show that mass explosion of all the bottles of BP in a trial did not take place and that the video recordings indicated that, in general, ignitions occurred sequentially. As has already been stated, ignition of all the bottles of BP in a test was not observed suggesting that some bottles ignited almost simultaneously but these were not resolved using the normal speed recording system. In general, the projected distance of the box panels supports sequential ignition of the bottles since most were not thrown more than 9 m whereas panels from trials 7 & 17 (ignition of 9 kg and 25 kg of BP en masse) were projected 60 m and 66 m, respectively, indicating a much more powerful event. However, the reduced distances that panels were thrown during the bonfire trials cannot be solely attributed to sequential ignition because panels recovered after the tests were significantly degraded by the bonfire resulting in them being much thinner (Figure 3). This would mean that, at the time of first ignition, the degree of confinement would be less than for the original boxes, thereby reducing the effectiveness of any BP explosion. The degree of degradation is indicated by the low numbers of panels recovered after each test since many were almost totally destroyed by the bonfire or the BP ignitions.

Figure 3: Charred panel from Test 18 showing fire degradation

The mean maximum projected distances of box panels varied substantially between tests (3-9 m). This, coupled with the small number of trials makes analysis of trends within the data uncertain.

Trials with compartmented boxes containing 25 bottles of BP (tests 14-16 and 18) were performed on boxes with 24 mm panels and 1 kg bottles of blackpowder. Fire resistance was

observed to be in the range 8.8-9.5 minutes compared to 9.8-12.8 minutes for equivalent 9 compartment box trials (trials 8-10). This may be due to weaker box joints as a result of their extra length. Further work would be needed to demonstrate this.

It was also noted that in one of the 25 compartment tests (test 15) the maximum projected distance of panels was approximately double that of any of the other trials (14 m compared to 4-9 m). This may indicate ignition of more than one bottle of BP in quick succession but the test set up did not allow corroboration of this.

In general, ignition of the bottles of BP that remained on the fire stack burned for a period of between 6 and 24 s. It was expected that the longer periods would be observed for boxes with 25 compartments since 9 of the compartments would not be in direct contact with the joints used on the outer walls of the box compared to only one compartment in the 9 compartment box. It was considered that bottles of BP in these compartments would be protected from the fire to some extent (until the bottles closer to the box joints ignited) and that this would extend the ignition period. However, no significant differences were observed between tests using the different types of box. Further work would be necessary to investigate this.

One trial was performed on a 25 compartment box using 1 kg bottles of Swiss No 1 blackpowder (trial 18). This had a higher rise time on the time-pressure test and was expected to provide a 'worst case scenario'. The data indicates that there is very little difference in the values measured for this type of blackpowder compared to the equivalent trials on the FOA powder (trials 14-16), suggesting that the packaging system provided an equal level of protection for both types of blackpowder although the higher burn rate of the Swiss No 1 test sample was reflected in a nominally shorter burn time for ignition (12 s compared to 16 s).

It is interesting to note that the panel projection distances were approximately the same (60 m & 66 m), even though Test 17 contained substantially more BP (25 kg) compared to Test 7 (9 kg). Examination of the test area and the direction that the panels were thrown shows that for Test 17 the panel thrown the furthest was found on a raised bank which would have foreshortened its travel, whereas in Test 7 the panel projected the furthest was across a relatively flat area.

Two full bottles of BP were recovered after trial 9 and had been projected up to 5 m from the fire stack. A further full bottle was ejected during trial 11 but no distance measurement was recorded. Both trial used 1 kg bottles of BP but test 9 was performed in a 9 compartment 18 mm wall thickness box whereas trial 11 was performed in a 25 compartment box with 24 mm walls. The low incidence of these events does not allow the significance of the results to be quantified but serves to demonstrate that ejection of full bottles of BP is possible and that emergency services should be made aware of this.

Table 3: Summary of results from bonfire and bag charge trials

Test i.d.	Type of BP	Description	Mass explosion (Y/N)	Fire resistance (mins)		No. resolved ignitions	Duration of BP ignition sequence (s)		Full bottles of BP remaining after test		Box panels recovered after test		
				Each test	Mean		Each test	Mean	No.	Projected distance (m)	No.	Max. projected distance (m)	Mean max projected distance (m)
1	FOA	Bonfire trial 9x0.5 kg BP 18mm wall	N	12.7	11.6	6	6	12	0	n/a	5	7	7.7
2			N	12.7		6	12		0	n/a	3	8	
3			N	9.3		6	18		0	n/a	3	8	
4	FOA	Bonfire trial 9x0.5 kg BP 24 mm wall	N	9.6	10.5	7	24	16	0	n/a	2	7	7.0
5			N	11.3		4	6		0	n/a	3	8	
6			N	10.7		6	18		0	n/a	2	6	
7	FOA	Bag charge trial 9 kg BP 24 mm wall	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	6	60	60
8	FOA	Bonfire trial 9x1.0 kg BP 18 mm wall	N	12.5	11.7	8	12	8**	0	n/a	4	5	6.3
9			N	12.8		4	6 (42*)		2	5	3	5	
10			N	9.8		5	6		0	n/a	3	9	
11	FOA	Bonfire trial 9x1.0 kg BP 24 mm wall	N	11.1	11.2	6	12	10**	1	Not recorded	5	6	4.3
12			N	13.7		9	12 (30*)		0	n/a	5	4	
13			N	8.7		5	6		0	n/a	2	3	
14	FOA	Bonfire trial 25x1.0 kg BP 24 mm wall	N	9.5	9.5	11	18 (42*)	16**	0	n/a	3	8	9.3
15			N	10.1		7	12		0	n/a	5	14	
16			N	8.9		14	18		0	n/a	2	7	
17	FOA	Bag charge trial 25 kg BP 24 mm wall	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	4	66***	66
18	Swiss No. 1	Bonfire trial 25x1.0 kg BP 24 mm wall	N	8.6	8.6	6	12 (60*)	12**	0	n/a	4	8	8

* Final ignition time but BP bottle ignited off the fire stack or embers. ** Mean calculated without bottles that ignited off the fire stack or embers.
*** Panel projection arrested by raised banking

5. CONCLUSIONS

1. The data suggest that the box wall thickness (in the range 18-24 mm), the number of internal compartments (in the range 9-25), the mass of BP in each bottle (in the range 0.5-1 kg) and the type of blackpowder used (over a time pressure rise time in the range 2.14-4.83 ms) have little effect on the performance of the partitioned wooden box against external fire and that the current design can prevent the mass explosion of blackpowder stored in such a manner within these limits

2. Wooden panels from the partitioned box can be projected up to 9 m

3. Ejection of unreacted bottles of BP can occur and ejection distances of 5 m have been observed. These could pose hazards to emergency services.

6. FURTHER WORK

While the tests have shown that the partitioned wooden boxes provide approximately 8 minutes fire resistance before ignition of the contents starts to occur, it would be beneficial to understand how the box breaks down in the fire so that improvements to the design can be made. Fire ingress is proposed to occur at the butt joints of the plywood and possibly via degradation of the intumescent strip; an improved design would attempt to minimise this flame ingress without increasing the failure pressure (ie the degree of confinement) experienced by any product within the box. Instrumented testing to better determine the box failure modes and thermal / flame transition through the wooden shell would be of benefit.

7. REFERENCES

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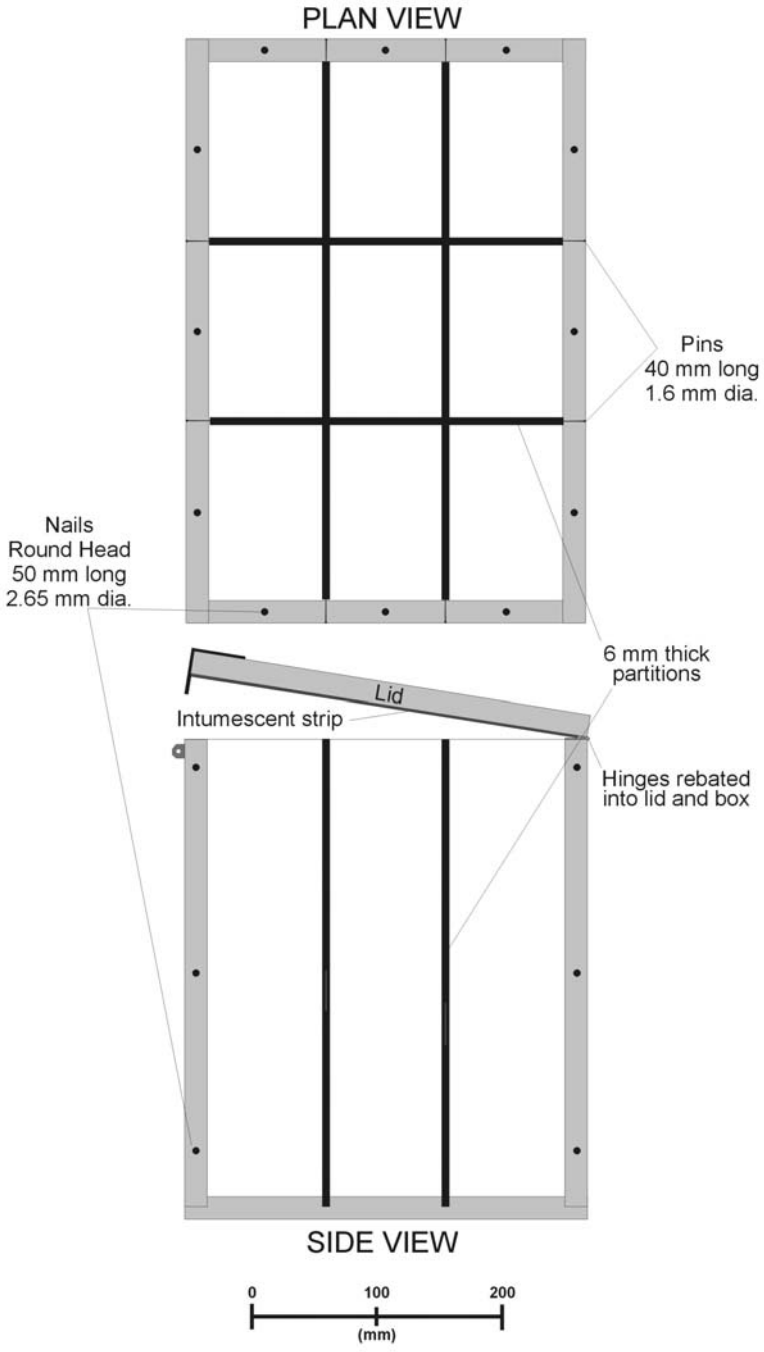
5. Recommendations on the Transport of Dangerous Goods – Manual of Tests and Criteria. Fifth revised Ed. United Nations (2009), pp443-450.

6. Recommendations on the Transport of Dangerous Goods – Manual of Tests and Criteria. Fifth revised Ed. United Nations (2009), pp 149-153.

8. APPENDICIES

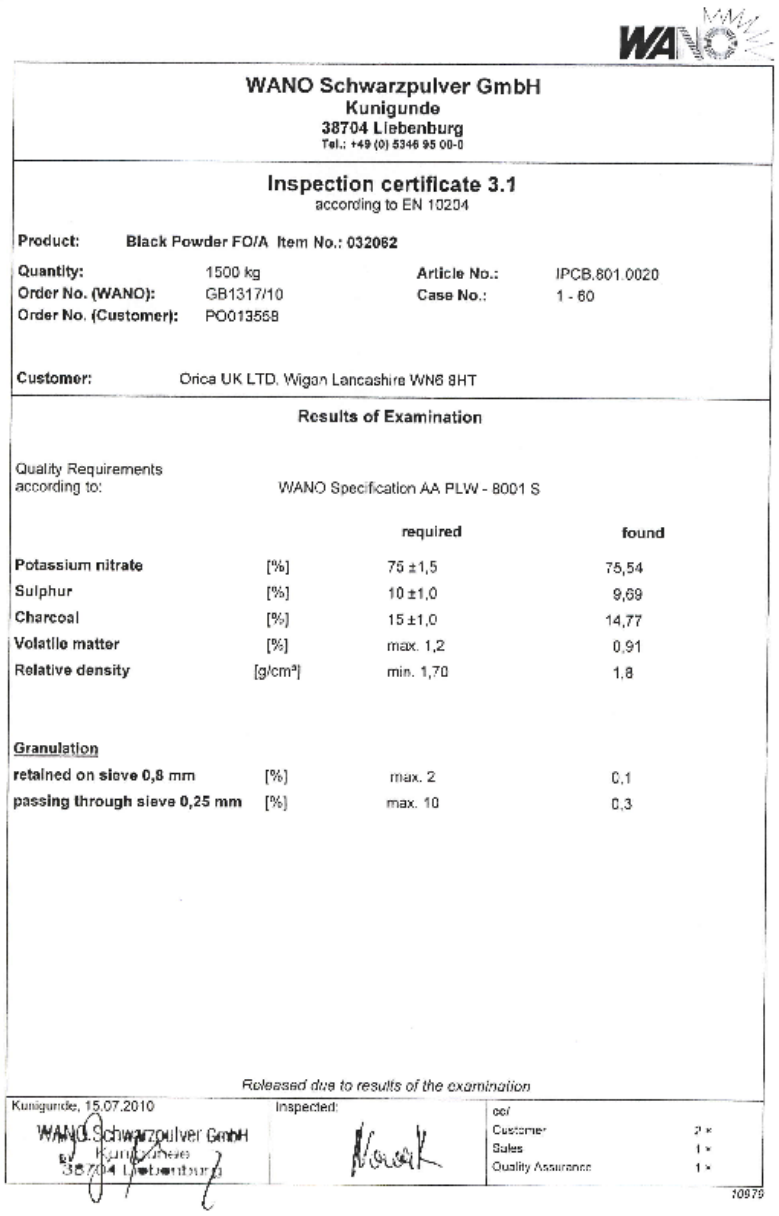
Appendix 1: Box diagram

(9 compartment box, 18mm wall thickness)



Appendix 2: Blackpowder specifications

FOA Blackpowder



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Kunigunde
38704 Liebenburg
Tel.: +49 (0) 5346 95 00-0

Inspection certificate 3.1
according to EN 10204

Product: Black Powder FO/A Item No.: 032062

Quantity:	1500 kg	**Article No.:**	IPCB.801.0020
Order No. (WANO):	GB1317/10	**Case No.:**	1 - 60
Order No. (Customer):	PO013568		

Customer: Orica UK LTD. Wigan Lancashire WN6 8HT

Results of Examination

Quality Requirements according to: WANO Specification AA PLW - 8001 S

		required	found
Potassium nitrate	[%]	75 ±1,5	75,54
Sulphur	[%]	10 ±1,0	9,69
Charcoal	[%]	15 ±1,0	14,77
Volatile matter	[%]	max. 1,2	0,91
Relative density	[g/cm³]	min. 1,70	1,8
Granulation			
retained on sieve 0,8 mm	[%]	max. 2	0,1
passing through sieve 0,25 mm	[%]	max. 10	0,3

Released due to results of the examination

Kunigunde, 15.07.2010 — WANO Schwarzpulver GmbH Kunigunde 38704 Liebenburg

Inspected:

cc/
Customer 2 ×
Sales 1 ×
Quality Assurance 1 ×

10979

Swiss No. 1 Blackpowder

Poudrerie d'Aubonne SA

POUDRERIE
D'AUBONNE S.A.

Technical Specifications

BLACK POWDER	
Type : **Shooting Powder**	**No 1 (4 Fg)**
Potassium nitrate	78,0 % +/- 1,5 %
Sulfur	10,0 % +/- 0,8 %
Charcoal	12,0 % +/- 1,0 %
Graphite	light
Humidity	max. 1 %
Ash content	1 - 4 %
Apparent density	0,930 - 1,020 g / cm3
Specific density / vol. mass (Bianchi method)	min. 1,7 g / cm^3
Specific density / vol. mass (Picnomètre method)	1,95 +/- 0,05 g / cm^3
Grains per gram	10'000 to 15'000
Grain size	265 mic. - 500 mic.
Granulometry test : max.3% retaining on a ..... microns sieve	none
Granulometry test : max 5% passing through a ..... microns sieve	none
Sensitivity	≥ 10 J.
Friction sensitivity	≥ 360 N.

Doc. No : SPT-PA-01
Version no : 2
Du : 01.07.2008
Visa : Fia.

FO 3.1.4.1 Spécifications techniques
Date d'édition : 05.12.2001/DT
Version du : 30.08.2005

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