The Development of a Pyrotechnic Torch for Mine Destruction and Capable of Local Manufacture

Funded by DFID

Undertaken by Disarmco Ltd

& Cranfield University

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DEVELOPMENT OF A PYROTECHNIC TORCH FOR MINE CLEARANCE APPLICATIONS

1. INTRODUCTION

1.1 One of the 'pillars' to the Department for International Development's (DFID) global strategy for mine action is that of technology innovation conducted under its Mine Action Research (MAR) programme.

1.2 DFID has been asked twice to import high explosives into countries where there is no existing supply for use by mine clearance organisations. In addition, it is known that some people have died trying to extract explosives from anti-tank mines to use against anti-personnel mines. Even if deaths are not involved, it is not a practice to be encouraged.

1.3 The aim of this project was to provide a cheap, readily available alternative that could be made in the country in which it was needed, wherever possible using locally procured materials and labour.

2. CONTRACTING

2.1 In 2002 Disarmco Ltd was contracted by DFID to develop a pyrotechnic torch, which could destroy all anti-personnel mines (the essential requirement) and small UXO, including anti-tank mines (a highly desirable requirement). Further to this, it was tasked to provide the design for and to test a prototype manufacturing facility that could be installed in selected developing countries.

2.2 Cranfield University was sub-contracted by Disarmco to take the lead in all technical matters and in particular to explore suitable pyrotechnic formulations. The formulation, or formulations identified, would then be developed into a suitable torch configuration and tested against anti-personnel mines. In addition those tests necessary for classification under the UK's Transport of Dangerous Goods Regulations would be completed.

3. FINDING AN EFFECTIVE AND CHEAP FORMULATION

3.1 DFID wanted a formulation that could be manufactured by local workers and filled into a suitable container to act as a pyrotechnic torch. The main reason for choosing a pyrotechnic formulation was safe manufacture by relatively unskilled workers.

3.2 The initial part of the work was to find a suitable composition that could be mixed and, very importantly, filled into tubes safely. Additionally it should have a better performance than already available products and be produced at an acceptable cost. Using these criteria there were several possibilities that could be pursued as follows:

- Thermite
- Hand stemmed compositions with minimised sensitivity
- Very insensitive water based composition.

3.3 Thermite

3.3.1 Thermite is a mixture of coarse aluminium powder and black iron oxide and is used for welding purposes since it produces molten iron at a temperature in excess of 1530^{0}C. Indeed the actual temperature is likely to be as high as 2000^{0}C so it was thought that if molten iron at this temperature could be directed onto a mine it would burn through any casing and ignite the explosive. Experimental evidence at Cranfield University has shown that it will penetrate at least 3mm of mild steel with relative ease. Furthermore, thermite is a commercial product and relatively inexpensive. Commercial igniters are available though thermite is a difficult material to ignite.

3.3.2 The thermite torch concept was tested against a plastic target and it raised several relevant issues. The most pertinent was the ease with which the molten iron ran off the plastic material and although it deformed the case due to the heat, it did not penetrate it. One further practical reason for dropping thermite was the possibility that an operator could fire a thermite torch against a mine, the mine might survive and then it would be coated in solid iron. This would then become extremely difficult to destroy thus making the job significantly more difficult.

3.3.3 None of the tests gave a penetration that justified further study and it was decided to abandon thermite as a possible solution.

3.4 Hand stemmed compositions

3.4.1 This concept required a composition that could be mixed safely and then filled into tubes in a similar manner to fireworks. This is a standard technique, using a wooden rod to tamp the mixture into a tube. The choice of ingredients had to minimise hazards such as friction sensitivity, not be complicated in formulation, and minimise toxicity. The compositions chosen for test were based on aluminium powder as the fuel and either potassium or strontium nitrate as oxidiser. The use of gunpowder as an additive was avoided due to the hazards it posed.

3.4.2 The results of these tests showed that the compositions did not ignite readily and that it would be necessary to have a first-fire layer in any torch configuration. The burning characteristics, however, appeared to be very favourable as the flames from all compositions were very hot. It was decided that compositions based on these mixtures should be taken forward for trials as pyrotechnic torches.

3.5 Very insensitive water based composition

3.5.1 Initial discussions raised the little known pyrotechnic mixture of aluminium powder as fuel with Plaster of Paris as oxidiser. The reason that Plaster of Paris can act in this way is due to the oxygen atoms held in the sulphate part of the chemical since Plaster of Paris is essentially calcium sulphate (CaS04). The composition had several significant advantages, the first being cost as this is probably the cheapest oxidiser available. However, the most important advantage is safety. Even as a dry mix it is considered to be insensitive but it would be water slurry when poured into the tubes. This wet mix would be extremely insensitive and, even better, allow a filling process that did not need pressing. The filling would use the known properties of Plaster of Paris to set to a solid thus the pyrotechnic torch would be filled by pouring the aluminium/Plaster of Paris/water mixture into a tube then simply leaving it to set.

3.5.2 Various ratios of aluminium powder to Plaster of Paris were cast into rectangular rods and the burning characteristics assessed. It was decided that the mixture to be taken forward to be trialled in a torch would be the 50/50 mixture with boric acid added to minimise any reaction of the aluminium powder with the water.

4. PYROTECHNIC TORCH TRIALS

4.1 Introduction

Disarmco already had 2 proprietary torches that were used to benchmark the testing of the concepts under development. The proprietary products are referred to later as ‘existing products’ or EP.

4.2 Aluminium/Nitrate Formulations

4.2.1 The first study of compositions in tubes was undertaken with formulations based on aluminium powder mixed with:

- potassium nitrate,
- strontium nitrate,
- barium nitrate
- a mixture of potassium and strontium nitrates.

4.2.2 A range of tests was conducted using aluminium/potassium nitrate mixes and aluminium/strontium nitrate mixtures. These were tested in different formulations both in ratios and in weight. In addition different sized tubes were used. The results of the tests seemed mixed but were comparable with the results of two existing products. There was good penetration of test targets using aluminium/barium nitrate and aluminium/strontium nitrate and it was decided that a version of these formulations would be trialled against live mines.

4.3 **Aluminium/Plaster of Paris Formulations**

4.3.1 The composition chosen for these trials was a 50/50 mixture of aluminium powder with Plaster of Paris. The first torch trial used a 103mm long tube with an internal diameter of 15mm. The nozzle was created using Plaster of Paris without any aluminium and therefore was inert. Two nozzle sizes were trialled, 12mm and 9mm and the target was 3mm plastic. The torch with the 12mm nozzle burned through the target in 3.0s and 2.9s (for 2 firings) indicating a very effective penetration. When the first of the 9mm nozzle torches was fired it exploded. Observations suggested that this was caused by a blockage of the nozzle by molten slag products, which could not clear the nozzle quickly enough. This indicated the importance of nozzle size for this type of filling.

4.3.2 The next trial used a larger tube to increase the burn time. The tube used was 150mm long with an internal diameter of 25mm. Two firings were carried out using an 11mm nozzle with 50g of composition in the torch. They burned for 8.6s and 7.0s with a burn-through time against 3mm of plastic of 5.0s and 4.0s respectively. Further firings were then undertaken with 70g of filling using a 12mm nozzle against a selection of targets.

4.3.3 The results demonstrated reasonably consistent burning characteristics averaging at just under 9s for the burn-time. The penetration performance against 6mm steel and plastic indicated limitations but for 3mm of steel and 3mm of plastic looked quite reasonable. Thus, it was considered that a greater mass burning rate might increase the performance. This could be achieved by increasing the area of the burning face by having a tube with greater diameter. Trials were then carried out using a tube 210mm long with an internal diameter of 39mm. The nozzle was 16mm to allow for the possible production of more molten slag that might block the nozzle. These torches contained 120g of filling. Two torches burned for 10.5s and 10.8s and penetrated a 3mm plastic target in 3.5s and a 3mm steel target in 2.9s.

4.3.4 Next a larger tube was acquired to contain a greater mass of filling in an attempt to increase the overall burn-time. The idea was to have a significant burn-time after penetration of any casing material to ensure destruction of the target. The tube size was 270mm long with an internal diameter of 25mm and the filling weighed 150g. Two torches burned for 15.3s and 15.0s, one against a 6mm plastic target and one against a 6mm steel target. Neither gave penetration. However, what gave serious concern was the fact that 2 torches in this type of tube exploded.

4.3.5 These explosions are likely to occur when the nozzle is blocked by a molten slag build-up. This required a rethink of the formulation used and as the slag is related to the aluminium content it was considered that a reduction in the aluminium percentage would alleviate the problem. Thus, a new mixture of Aluminium/Plaster of Paris 45/55 was trialled. Also at this time a new tube had been sourced as a possible candidate for the production of torches. This tube was 300mm in length with a 25mm internal diameter and

4mm thick wall. Tubes were filled with 150g of the 45/55 mixture and a nozzle of 12mm used. The results were excellent. The burn appeared to be extremely consistent, the burn-time increased and the penetration improved.

4.2.6 Taking all of the firings into consideration and to maintain project deadlines it was decided that the 45/55 formulation in the 150mm tube was acceptable to take to the next stage of the project; to test the torches against mines or simulated mines.

5. TRIALS OF TORCHES AGAINST SIMULATED MINES

5.1 Introduction

It had been intended to test the torches against a series of live anti-personnel mines but it became too difficult to obtain any in the UK for the project so a simulated mine was designed and manufactured. It was filled with cast TNT as this would be the most difficult explosive to ignite that is commonly found in mines.

5.2 Trial Plan

5.2.1 Pyrotechnic torches

It was decided to trial 3 types of torch: two existing products as the baseline and then the best of the aluminium/nitrate filled torches and the aluminium/Plaster of Paris filled torch. Details of the latter 2 torches are given in Table 1.

Table 1. Details of the Torches to be used in the Live Mine Trial

Composition	Filling Weight (g)	Tube Dimensions (mm)	Nozzle Diameter (mm)
Aluminium/barium nitrate (35/65) with 2% Acaroid resin	100	Length 139 Internal diameter 25 Wall thickness 7	12
Aluminium/Plaster of Paris (45/55) with boric acid	165	Length 300 Internal diameter 25 Wall thickness 4	12

5.2.2 Mine targets

Cast TNT was filled into a thin walled plastic container with snap-on lid to simulate the bulk explosive in a mine body. To simulate the typical wall materials that might be encountered, a disc of either plastic or steel was then glued to the base of the container ensuring that it completely covered the base. Thus, when the simulated mine was buried with this base facing upwards any pyrotechnic torch would have to penetrate the base to contact the explosive.

Any real anti-personnel mine will contain a detonator so this would need to be simulated. Thus, 2 types of simulated mine were produced. The first had no detonator, only cast TNT. These would be used to assess the effects of the torches on just the explosive, as ignition of the explosive was required in all cases. Also, it would be of interest to see how the explosive material reacted in its own right. The second design had a central hole from the centre of the snap-on lid to within 10mm of the container base. Into this hole would be placed a demolition detonator simulating the detonation system within the fuze of the mine. When the mine was buried base upward the detonator would be situated vertically up the centre of the explosive filling with the end 10mm from the base material being assessed. A diagram of this design when buried for a trial is given in Figure 1 and a photograph in Figure 2.

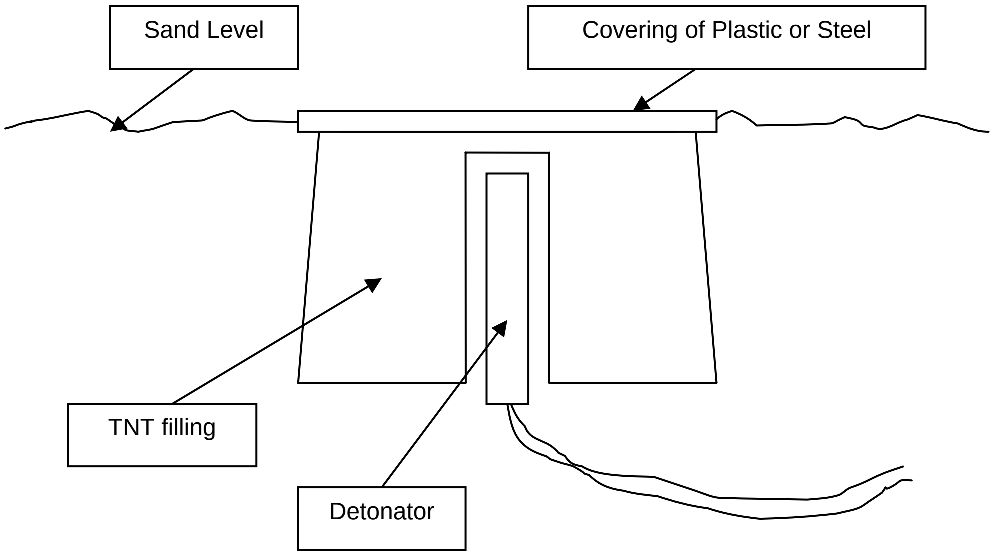

Figure 1. Design and Placement of the Simulated Mine

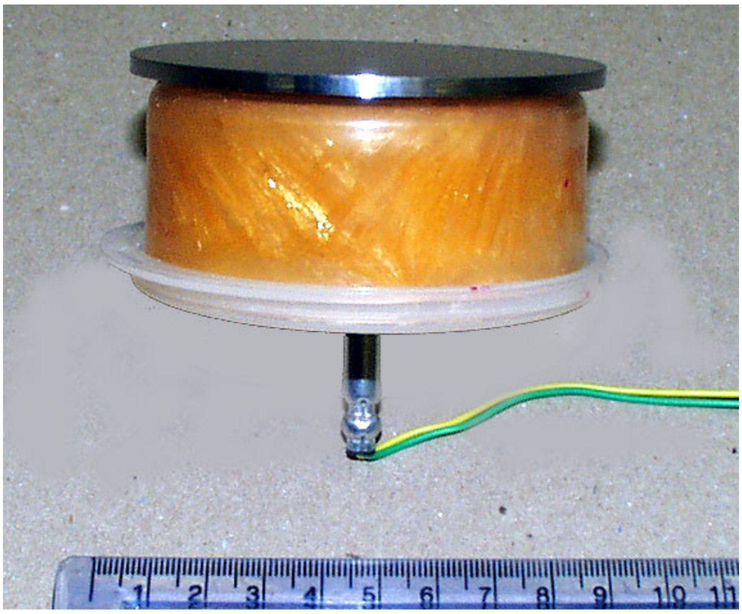

Figure 2. Photograph of the Simulated Mine

5.2.3 Conduct of the trial

Testing the pyrotechnic torches against live simulated mines was carried out at COTEC (a dedicated Cranfield University test and evaluation range with all the facilities to carry out explosive trials). Pits were dug and filled with sand in which the simulated mines were buried. It was assumed that only the top of the mine would be uncovered before disposal was carried out. Figure 3 shows a photograph of a simulated mine buried ready for the trial with a torch positioned ready for firing. A series of firings were to be undertaken against mines without detonators to assess the effects on the explosive filling. This would be followed by a series of firings with detonators inserted into the simulated mines. When detonators were present they would be connected to a firing circuit in case they did not detonate and would leave a significant hazard for disposal.

Figure 3. Photograph of a Buried Simulated Mine with Torch Positioned for Firing.

The simulated mines were placed in a series of 6 sand filled pits thus allowing up to 6 configurations to be set up before firing. Once the set-up was complete each was fired individually and the result recorded on a video system. This allowed the trial to continue without waiting for a mine that had been ignited to burn out before the next serial could be set up. The tests are shown in Table 4:

Table 4. Firing Plan for the Simulated Mine Trial

Firing Series	Torch Type			Detonator	Target
	EP	Al/ PoP	Nitrate		
1	2	2	2	No	3mm plastic
2	2	4	0	No	6mm plastic & 3mm steel
3	1	0	2	No	6mm plastic & 3mm plastic
4	3	3	0	Yes	3mm plastic
5	3	3	0	Yes	3mm steel

5.3 **Trial Results**

5.3.1 Series 1 firings compared the 3 torch types against a simulated mine with no detonator and with a 3mm plastic top. For each type of torch 2 were tested and in all 6 cases in this series the mines ignited and burned for approximately 5 to 6 minutes until they were completely burned out. A photograph of the remains following the mine burning is given in Figure 4. During this series of firings it was noted that the aluminium/barium nitrate torches both gave a violent event with one exploding after 9 seconds. However, there was still time for the torch to burn through the 3mm of plastic and ignite the TNT filling.

5.3.2 Series 2 tested the performance of the existing commercial products (EP) torches against 3mm of steel and the aluminium/Plaster of Paris against 6mm of plastic and 3mm of steel. It had already been seen that the latter torch would penetrate 6mm of plastic in 15s and that it burned for approximately 18 to 21s. This would test the ignitability of TNT if the penetration of the mine casing took some time and there was little burn-time left after penetration. The EP was known to penetrate 3mm of steel, however, if it did not, heat would be transferred readily through the metal and this might ignite the explosive. Again, in all cases the mine explosive content was ignited and the mine burned out completely.

5.3.3 Series 3 considered once again the aluminium/barium nitrate torch against 3mm of plastic covering the mine. Both attempts ignited the explosive and the mine burned out completely. However, one of these torches exploded as in Series 1 and so even though it appeared that the torch did the job required it was decided to abandon any further testing with this type of torch. Also in Series 3 an EP torch was fired against a mine covered by 6mm of plastic. It was known that this would not penetrate the plastic however it did ignite the explosive and the mine was burned out completely.

Figure 4. Example of a Burned Out Mine (No Detonator Present).

5.3.4 Series 4 comprised 6 firings against the simulated mines, this time with detonators inserted. Three were using the EP and 3 using aluminium/Plaster of Paris. The covering was 3mm of plastic and once again the EP torches all ignited the TNT filling and then after some minutes (3min 5sec, 4min 7sec and 10min +) the mines finally exploded, which was assumed to be the detonator detonating. The aluminium/Plaster of Paris torches behaved quite differently. After less than 20s the detonators exploded and in 2 cases detonated the TNT filling. In both cases the TNT filling ignited just before the detonator explodes. However, in one case, even though the detonator functioned, some TNT was seen to carry on burning until it burned out completely. It was likely that the torch burned through the 3mm of plastic and then through the explosive (which melts at ~80^0C) into the detonator channel. This would heat the detonator until it functioned.

5.3.5 Series 5 completed the trial by assessing the performance of the EP and aluminium/Plaster of Paris torches against mines with detonators and a 3mm steel covering. The EP cannot burn through the 3mm of steel but again, like the 3mm of plastic, it heated the explosive until it ignited. This burned until the detonator functioned through heating by the burning explosive. Perhaps not surprisingly, as metal is a better conductor of heat than plastic, the detonator functioned somewhat more quickly than with the plastic covering. The detonators functioned at 2min 47sec, 3min 6sec and 2min 49sec. However, with the aluminium/Plaster of Paris torch the mines detonated after 5, 8 and 18 seconds. This was to be expected, as this torch will penetrate 3mm of steel in approximately 3 seconds. This result, together with the results from the mines with plastic covering, indicated that the aluminium/Plaster of Paris torch was certainly capable of destroying mines that closely simulate anti-personnel mines.

6. <u>SENSITIVENESS OF ALUMINIUM/PLASTER OF PARIS</u>

6.1 The term ‘sensitiveness’ is used to describe the reaction of an explosive material to an unplanned stimulus such that it might cause accidental initiation. These hazard tests indicate how safe an explosive material is to give guidance on its suitability for use. The tests chosen to assess this material were the Rotter Impact Test, the Mallet Friction Test, Bickford Fuze Test and Temperature of Ignition Test.

6.2 The Rotter Impact Test takes a small sample of powder (0.03 cm^3) placed in a metal cap on a metal anvil and drops a weight on to the cap. The height for a reaction is found and compared to a standard (RDX). This gives a number called ‘the figure of insensitiveness’. A value of <30 is classed as very sensitive; 30 to 90 sensitive; and >90 relatively insensitive. If the value is >200 the result is quoted as ‘greater than 200’.

6.3 The Mallet Friction Test takes a small quantity of powder spread in a thin line on an anvil and is then struck a glancing blow with a mallet. To obtain differing levels of friction a series of anvils is used together with 3 different mallets. The combination creating the greatest friction is the steel mallet with a steel anvil. This combination was used to assess friction sensitiveness.

6.4 The Bickford Fuze Test uses a length of burning pyrotechnic fuze filled with gunpowder to produce a flash of flame that impinges on the sample held in a glass test tube. Thus, the test is for sensitiveness to a flash of flame and the result is to record the event that occurs, such as ‘ignites and burns quietly’, ‘explodes’, ‘does not ignite’, etc.

6.5 The Temperature of Ignition Test takes a small powder sample and raises its temperature at a set rate of 5^0C per minute. The temperature is then recorded when the sample is seen to react, for example a puff of smoke, flash, or flame, etc. The test is stopped at 400^0C and if no ignition seen to this temperature then the result is given as ‘>400^0C’.

6.6 The results for these tests are given in Table 5 below, indicating that the aluminium/Plaster of Paris mixture is a safe, benign material.

Table 5. Results of Sensitiveness Tests on Aluminium/Plaster of Paris

Test	Result
Rotter Impact Test	Figure of Insensitiveness 115 – relatively insensitive
Mallet Friction Test	Steel on steel – no ignitions in 20 tests
Bickford Fuze Test	Does not ignite
Temperature of Ignition Test	>400^0C

7. FACTORS AFFECTING TORCH PERFORMANCE

7.1 Sensitivity of the Torch to Temperature

7.1.1 It is known that the temperature at which they are used can affect the performance of explosive devices. To assess any temperature effects trials were carried out to measure the torch burning times and target burn through times when the torches are fired at -20^0C and $+70^0$C. These temperatures were chosen since it was extremely unlikely that de-mining operations would be undertaken at temperatures lower than -20^0C and that torches left out in the sun in hot climates may well reach $+70^0$C.

7.1.2 For the firings at $+70^0$C the torches performed at least as well as at ambient temperature, if not better. The average times for length of burn and burn-through times are compared for these temperatures and ambient in Table 6.

Several things can be noted from Table 6. The average burn-times for the high and low temperature trials gave highly consistent results and the average burn-time was quicker for the hot firings than the cold, as would be expected. The average for the ambient firings was reasonably consistent but did not match the high and low temperature results. Undoubtedly this is because the ambient average is from a number of batches and so direct comparison is not a fair one. Perhaps worthy of note, however, is the fact that the burn-times for all torches is reasonably similar and so temperature has little effect on the burn-time. As for penetrative performance, the torches fired when hot seemed to have a faster penetration of all target types than the cold and ambient firings. But once again the actual values varied relatively little for all temperatures and importantly were much shorter than the total burn time of the torch except for the 6mm plastic.

Table 6. Performance of Aluminium/Plaster of Paris Torch at Various Temperatures

Temperature	Target	Average Burn-Time (sec)	Average Burn Through Time (sec)[(4)]
Ambient	3mm steel	22.2 (±4)	2.8
	3mm plastic		5.8
	6mm plastic		15.0
+70^{0}C	3mm steel	18.1 (±1.0)	2.0
	3mm plastic		4.0
	6mm plastic		11.0
-20^{0}C	3mm steel	21.0 (±1.0)	2.5
	3mm plastic		4.5

7.2 <u>Sensitivity of the Aluminium/Plaster of Paris Torch to Impact</u>

7.2.1 The European regulations for the transport of dangerous goods require that tests be carried out on the packaging for robustness to impact caused by dropping. The test requires a drop of 1.5 metres. Thus, it was deemed appropriate to assess if the packaged torches were damaged in the drop test. This is not part of the packaging test as this only tests the packaging, however, it would provide useful information as to the robustness of the torch itself.

7.2.2 The assessment involved firing a selection of torches taken from packages that had been dropped in the packaging test. Six torches were chosen at random from the 24 in the test package. X-ray of these torches showed that they had not experienced any cracking. There was some evidence of porosity, however, this appears to be a property of manufacture and does not affect the performance of the torch. The torches then were fired and the burn-times were as expected from previous successful firings.

7.3 <u>Sensitivity of the Aluminium/Plaster of Paris Torch to Humidity</u>

7.3.1 As the torches were to be tested in Cambodia, a country with expected high humidity, it was decided to assess the effect of humidity on their performance. This was achieved by manufacturing 10 torches, 5 of which were held in normal storage conditions (ambient UK temperature and humidity) with the other 5 held for 7 days at 95% RH at 21^{0}C. Of these latter 5, 3 had the first fire composition and fuzehead present and the other 2 did not. The initiation system was inserted immediately prior to firing.

7.3.2 The results from the firings indicate that the humidity did not affect the burn times for the torches.

7.4 **Quality of the Aluminium/Plaster of Paris Ingredients**

7.4.1 As part of the project it was necessary to train some unskilled operators to manufacture the torches in the factory unit that had been built by the Contractor. A mine clearance organisation provided unskilled staff[1] to carry out the trial. They attended a 5-day course in March 2005 and manufactured torches. The training of these staff indicated that it was certainly possible to give unskilled staff the training to allow them to manufacture torches successfully.

7.4.2 However, when the torches were test fired against a 3mm steel plate they failed to penetrate, unlike previous batches produced during the torch development. Three torches that had been prepared with standard drying conditions were fired first and then it was decided to increase the drying process by drying in an oven for a further 12 hours. This additional drying did not change the performance; those 3 torches also failing to penetrate 3mm steel plate. What became very evident was the burn-time for this batch of 6 torches had increased significantly. The average burn-time was 30.66 sec (± 10%) whereas for the torches produced earlier, the average was 21.2 (± 5%).

7.4.3 It was concluded that a possible change in the source of formulation components was affecting the performance of the torches. Three changes had occurred; another batch of Plaster of Paris had been procured, as had a new batch of aluminium powder and boric acid. Thus, a series of tests was performed to see if the effect of changing any one of these could account for the reduction in penetrative performance. The results concluded that the major cause of the problem was the Plaster of Paris. Another type of Plaster of Paris was tested (Cal Sulphate) and this material appeared to perform extremely well and was of a higher specification (it is used for medical purposes).

7.4.4 A batch of torches using this new Plaster of Paris was prepared and tested. Twelve were manufactured with the original aluminium and 12 with the second batch of the same material (same source and specification). All 24 were extremely effective, all burning through the 3mm steel plate in a very short time. The fact that different samples of nominally the same aluminium powder had average burn-time/burn-through times of 21.5/1.77 sec for the original aluminium and 20.2/1.56 sec showed that the aluminium did have some effect but the major effect was caused by the Plaster of Paris.

7.4.5 The conclusions from this were that the source of Plaster of Paris is critical to the performance of the torch. Even if a material has been used and is successful in penetrating the chosen target material, if a new batch is purchased then some test samples must be prepared and tested before work continues.

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1 The use of the term 'unskilled staff' referred to their lack of knowledge of the manufacturing process.

8. **SERIES 6 BONFIRE TEST FOR UN HAZARD CLASSIFICATION**

8.1 This test is used to allow the relevant authority, in this case the Health and Safety Executive (HSE) Explosives Inspectorate, to give the torches inside their packaging a Hazard Classification Code for transportation. Being explosive in nature the torches will come under Hazardous Goods Class 1. This test ascertains the Hazard Division (1 to 6) and the Compatibility Group. Normally, a pyrotechnic device would be Compatibility Group G, however, it may be possible to allocate the Compatibility Group S.

8.2 It should be noted here that the objective was to obtain classification to move the torches such that they could be tested in the field. The torches were not assembled as this was to occur on location, the filled tube with the aluminium/Plaster of Paris was packed together with a small plastic container of first fire mixture and a plastic container of electric fuzeheads. The torch bodies were packed as 4 layers of 6 and the plastic containers placed at one end of the box. This can be seen in Figures 5-7.

Figure 5. Articles for Packing, Box and Packaging Material

Figure 6. Layers of Torch Bodies in the Package

Figure 7. Plastic Containers of First-fire and Fuzeheads at One End of the Package.

8.3 The Bonfire Test was carried out at COTEC and a report submitted to the HSE together with video evidence of the test and appropriate application forms to obtain classification. Following its assessment, the HSE granted the package of aluminium/Plaster of Paris torches (with first-fire and fuzeheads) a Hazard Classification Code of 1.4G.

9. IN-COUNTRY TRIALS

9.1 As part of this project there was a requirement to test the torches against representative anti-personnel mines. This was carried out in Lebanon, where they performed extremely well indicating that it would be very effective.

9.2 A further requirement was to test the mobile factory and the concept of local workers manufacturing the aluminium/Plaster of Paris torches. This part of the trial was carried out in Cambodia, where local workers manufactured 40 torches and 12 were fired against a 3mm steel target. The torches performed exactly as required burning through the steel in approximately 4 seconds and continuing to burn with a total time of around 20 seconds.

9.3 In Cambodia the transportation of igniters (HZ/DC Class 1.4S) proved impossible to surmount because of a Thai law that prohibits the carriage of all explosives across its airspace by airlines. This issue highlighted the increasing difficulties faced by the mine action community in moving Class 1 explosives that this MAR project was designed to overcome. A decision was made to develop an inert igniter compatible to the aluminium/Plaster of Paris torch. That was completed satisfactorily in December 2005 using a designated radio resistor to initiate the red lead and silicon mixture. Test firings were conducted in January 2006 using the locally manufactured igniters and torches with complete success. Now all of the materials required to produce the aluminium/Plaster of Paris torch, including the igniters, are non dangerous air cargo and are therefore transportable by air.

9.4 1200 torches are being produced in Cambodia and are being test fired by mine action organisations in the country against a wide range of UXO. They will be fired against anti-personnel mines and land service ammunition up to 120mm both to test effectiveness and to seek the optimum placement of the torch. Full details will be available in May 2006.

9.5 The Development Technology Workshop is manufacturing the torches with Cambodian labour trained by Disarmco Ltd. The production trial will establish the practical production capability of one team (two of the three operators are handicapped, one from mine accident). They are already producing 50 a day and will build up to between 65 and 70 torches on a normal working day. This indicates that an annual production of 12,000-14,000 is feasible from the one production facility.

10. **SUMMARY**

10.1 The project has shown that it is possible to manufacture a pyrotechnic torch that can be filled safely using a water slurry as the filling medium. Attempts to use a hand stemming method of filling with conventional nitrate type oxidisers produced torches that functioned, however, they were found to be prone to explode when burning. Also, a brief study of thermite powder indicated that it was not suitable for demining purposes.

10.2 The successful filling was a mixture of aluminium powder and Plaster of Paris. This allowed the water slurry type filling method as Plaster of Paris will set after several minutes without expanding or shrinking to any noticeable extent. Torches filled with this formulation demonstrated their ability to penetrate up to 6mm of plastic and 5-6mm of steel. When fired against simulated mines without detonators fitted the torch ignited the TNT filling, which burned out completely. If detonators were fitted to the simulated mine the mines exploded well before the torch finished burning.

10.3 Trials have been undertaken to assess the performance of the torch against a range of anti-personnel mines in Lebanon and were very successful. A trial of the mobile factory was undertaken in Cambodia. here it was demonstrated that local workers could use the facility and manufacture torches that performed as required.

11. **FUTURE USE OF THE CONCEPT**

11.1 There are two options for the future use of the concept and these are briefly explained below.

11.2 DFID has fully funded the research and development of the concept under its Mine Action Research programme. One condition of providing such funding is that DFID has full access to the intellectual property rights (IPR) and, under certain circumstances, can make it available to appropriate and approved agencies. It may agree to fund the construction of a manufacturing facility in suitable countries. Further details can be obtained from either:

Andy Willson
Project Officer

Email: a-willson@dfid.gov.uk

Alistair Craib
EOD and Demining Advisor

Email: baric@btconnect.com

11.3 The Contractor owns the IPR has given the aluminium/Plaster of Paris torch the proprietary name ‘Dragon’ and is marketing it commercially under that name. Further details of this can other products and services can be obtained from:

Christopher Le Hardy or John FitzGerald
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or on: www.disarmco.com