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Collaboration on Pressable Explosives for Shaped Charges – A European Success Story

WEAG Technical Area 25, CTP 25.2 Working Group

(comprising of representatives from Government and Industry from UK, Netherlands, Norway, Spain and Portugal)

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Zusammenarbeit bei preßfähigen Explosivstoffen für Hohlladungen – Ein europäischer Erfolgsbericht

Das Gemeinschafts-Programm 2 der WEAG (IEPG) Technical Area 25 (CTP 25.2) wurde 1989 aufgestellt zur Untersuchung preßfähiger Explosivstoffe und der damit verbundenen Fülltechnologie für gepreßte Hohlladungen. Die teilnehmenden Nationen waren England, die Niederlande, Norwegen, Spanien und Portugal. Es hat sich als ein sehr erfolgreiches Programm erwiesen, das eine wirkliche europäische Zusammenarbeit verkörperte und nicht nur einen Informationsaustausch. Das Programm umfaßte die Formulierung, Herstellung und Charakterisierung von preßfähigen Explosivstoffen und gipfelte in einem umfassenden Hohlladungs-Abschußprogramm. Alle Nationen konnten voneinander lernen und haben Nutzen gezogen aus einem weit umfassenderen Arbeitsprogramm als dies von einer einzigen Nation hätte finanziert werden können.

Coopération en matière d'explosifs comprimables pour charges creuses – l'histoire d'un succès européen

Le programme de coopération 2 du WEAG (IEPG) technical Area 25 (CTP 25.2) a été établi en 1989 en vue d'étudier les explosifs comprimables et les technologies de remplissage associées pour charges creuses comprimées. Les nations participantes étaient l'Angleterre, les Pays-Bas, la Norvège, l'Espagne et le Portugal. Il s'est avéré que c'était un programme réussi qui représentait une véritable coopération européenne et pas seulement un échange d'informations. Le programme englobait la formulation, la synthése et la caractérisation d'explosifs comprimables et arrivait à son apogée avec un vaste programme final sur les charges creuses. Toutes les nations ont appris les unes des autres et ont profité d'un programme de travail beaucoup plus vaste que s'il avait été uniquement financé par une seule nation.

Summary

Collaborative Technical Programme 2 of WEAG (IEPG) Technical Area 25 (CTP 25.2) was set up in 1989 to investigate pressable explosives and their associated filling technology for "Pressed Shaped Charges". The participating Nations were the United Kingdom, Netherlands, Norway, Spain and Portugal. It has proved to be a highly successful programme, representing true European collaboration, rather than just an information exchange. The programme dealt with the formulation, processing and characterisation of pressable explosives and culminated in a comprehensive shaped charge firing programme. All Nations were able to learn from each other and have benefited from a far more comprehensive programme of work than could have been financed by one Nation alone.

1. Introduction

Designers of directed energy warheads continually need to improve system performance to defeat new or perceived future targets. Inevitably, this has led to the requirement for increased performance explosive formulations. One route by which these high detonation pressure explosives can be achieved is the design of formulations with very high solids loadings (approximately 95% explosive filler by weight) and relatively low inert binder contents. This results in a natural progression to the use of pressing as the filling method. The traditional alternative route to castable high detonation pressure formulations has been to use lower energetic solids contents (up to 75% by weight) but with TNT as the energetic binder. Factors other than performance and safety, such as the poor mechanical properties of TNT and potential exudation problems, have also prompted a desire to move away from the service use of TNT based formulations. Where such explosives would have been used in small or medium sized munitions, and where appropriate, interest has developed in the use of pressable formulations.

Pressed compositions have already been utilised in conventional munitions in service world-wide, employed in a diversity of roles such as fillings for shaped charges, large and medium calibre shell, cratering munitions, small bomblets/grenades and as booster pellets. Such compositions have been selected for their applications on the basis of general suitability and reduced production costs through the use of automation. There has also been experience in the use of pressable compositions in high quality precision shaped charges but early pressable formulations such as LX-14 are viewed by some nations as not fully meeting modern safety and processing requirements.

A number of European nations recognised the benefits of pressing technology and that the potential drawbacks of materials like LX-14 were not inherent and could be solved by well directed research. The lack of direct European experience in high performance, pressable explosives for precision warheads was also recognised and it was identified, within the Western European Armament Group, that a

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collaborative research programme promised the greatest chance of success, whilst minimising research costs. Based on the experience of successful collaboration in polymer bonded explosive (PBX) technology, Collaborative Technical Programme 2 of WEAG (IEPG) Technical Area 25 (CTP 25.2) was set up by the United Kingdom, Norway, the Netherlands, Spain and Portugal to address research into pressable explosives for shaped charges.

CTP 25.2 was set up in 1989 to investigate pressable explosive formulations and their associated filling technology for "Pressed Shaped Charges". The joint research activity in this programme was aimed at exploiting the performance and processing benefits of pressable explosives for shaped charges whilst selecting suitable grades of HMX and choice of binders to produce formulations with acceptable safety and hazard characteristics. The activity was not limited to formulation work alone. Pressing techniques and pressing parameters were assessed and optimised to produce high quality, high density, homogeneous fillings capable of delivering superior performance to Octol compositions. A critical element of the programme, conducted in the final Phase, was the assessment of performance in a generic shaped charge. It was recognised at an early stage of the programme that it was not adequate to merely show improved performance in terms of increased detonation pressure but that it was necessary to demonstrate the performance benefits by filling representative warheads and conducting realistic plate penetration firing trials.

2. Work Programme

2.1 Background Research

The first phase of the programme covered the background research, division of work between the nations, the planning of the later phases and the choice of a generic test vehicle for the assessment firings. A full literature survey was undertaken into the background technology and, in particular, the variety of materials available to act as binders. A shortlist of binders was drawn up for investigation in the later experimental work. Although present in only a small percentage, typically 5% by weight, the choice of binder was seen to be important in determining the final safety, pressing and other characteristics of the explosive formulation. The experimental work later confirmed that this was the case and the binder did have a significant effect on these properties. The types of binders investigated more fully in the later phases of the programme are given in Table 1.

Table 1. Binders Investigated in Phase 3

Netherlands	Impranil DLH, Desmoflex VPPU, Cariflex
Spain	Cariflex TR1101, TR1107, Kraton G1650
Norway	Hycar 4054, Binder 14, Estane, Cariflex TR1 Octastit VIII binder
United Kingdom	Hostaflon PFA6900, Kraton G1650, Cariflex TR1107, Alcotex 72.5, Wax 10
Portugal	Cariflex, Kel-F, SFE 1503

The agreed choice of filler was HMX, although some of the nations chose to use RDX in early small scale formulation and binder studies in order to minimise costs. HMX from Royal Ordnance in the UK and Dyno Industries in Norway were used throughout the programme.

2.2 Choice of the Test Vehicle

A programme of firings was drawn up to evaluate both the explosive formulations and the respective pressing techniques. For this purpose, a parametric study was undertaken in order to select a shaped charge design suitable for evaluating the merits of the various pressed fillings rather than one optimised for ultimate performance. The charge was also designed so that it was suitable for press filling and allowed a variety of pressing techniques to be explored. Many research or standard charges already existed within the participant nations but were mainly designed for castable explosives and did not have the flexibility required. A simple retaining ring arrangement for holding the liner in place meant that the liner could be assembled into the charge either before or after filling. Single point rather than multipoint initiation was also selected to reduce the number of complicating variables.

The test vehicle was a 75 mm diameter shaped charge with a 50° cone angle, flow formed copper cone in an aluminium case. One batch of liners, provided by the Netherlands, was used throughout the programme. The parametric study, design and drawings were conducted by UK, Norway and the Netherlands. The design was subsequently used in a Technical Area 9 (CTP 9.2) programme aimed at evaluating the effect of asymmetries in shaped charge performance. A common design and the same batch of copper liners was thus shared between two programmes, thereby minimising costs and maximising the amount of data available to both teams.

2.3 Formulations

The characterisation of binders and fillers was shared between the nations and each nation undertook its own formulation studies, aided by a full sharing of data and information between participants. Characterisation of the various different grades of HMX included assessment of particle size, particle size distribution, particle shape, surface area and packing density. Binder characterisation included assessments of properties such as density, thermal and mechanical properties and compatibility. Each nation investigated at least one formulation based on a thermoplastic elastomer (TPE) to provide a common point of reference, particularly in the pressing studies. Commercially available Kraton or Cariflex TPEs were selected. Suitable plasticisers were also evaluated. Plasticisation was found to be essential in a number of instances to produce the necessary safety and processing characteristics.

Packing fraction studies were carried out in order to determine the best combination of HMX grades. Most nations selected a bimodal HMX distribution for its candidate formulations in order to maximise the final pressed density. Coating methods and coating efficiency were assessed in order to establish the best conditions for the production of moulding powders. The need to address environmental considerations was recognised by the participants and several methods of solventless processing were developed, including the use of aqueous dispersions and compounding methods. All of the moulding powders were subjected to small scale safety tests, such as thermal stability, sensitiveness to impact and friction. There were some initial problems with the impact sensitiveness of some Cariflex compositions but these were solved by improvements in the coating technique.

In the early stages of the programme the pressing characteristics of the moulding powders were assessed by the pressing of simple small scale cylindrical pellets. The effect of pressure, dwell time, temperature and vacuum on the final density were assessed. Where necessary, lubricants, processing aids and release agents were used and evaluated. A range of other parameters, including performance predictions, were used to select a shortlist of candidate formulations for more comprehensive evaluation.

The final formulations typically contained 95% HMX by weight although contents as high as 97% or as low as 92% were assessed. Binders included plasticised TPEs, waxes and a curable polyurethane system. The binder was found to influence the detonation velocity and pressure through its effect on the formulation density. Here it might have been expected that high density fluoropolymers which lead to formulations with high theoretical maximum densities would lead to pressed fillings with high detonation pressures. In practice, the dense binder systems were more difficult to press and the actual density achieved was not significantly higher than that for a formulation based on a lower density binder. Thus, higher density binders did not lead to significantly higher detonation pressure formulations. This is illustrated by two of the UK candidate compositions, RF 42, based on a plasticised Kraton binder system and, RF 44, based on an aqueous dispersion high density fluoropolymer, Hostaflon. Both contained 95% by weight of a bimodal HMX. The respective densities, both theoretical and actual are shown in Table 2, together with the effect on detonation pressure.

Table 2. Comparison of Two 95 wt % HMX Formulations RF 42 and RF 44

	RF 42	RF 44
Binder	Kraton TPE	Hostaflon Fluoropolymer
TMD ($Mg \cdot m^{-3}$)	1.823	1.912
Best Pressed Density	1.812	1.871
% TMD	99.4	97.9
Detonation Pressure (GPa)*	34.0	36.7
LSGT median gap (mm)	51.2/1.95 GPa	60.5/1.39 GPa

* Calculated

The influence of the binder on final hazard characteristics is also illustrated by these two formulations. The denser Hostaflon is shown to be less efficient at desensitising HMX than the TPE, with the resultant formulation being much more shock sensitive, as measured by the large scale gap test, again shown in Table 2.

In general, the pressable formulations were found to be more shock sensitive than castable Octols but their explosiveness, or violence of response, was lower especially to thermal stimuli such as fuel fire.

2.4 Pressing Studies

This was, perhaps, the critical phase of the programme in which an understanding of the formulations was developed to a point where they could be pressed under optimum conditions for filling into the generic test vehicle for final assessment. It was identified at an early stage in the programme that there were several options for filling the test vehicles – some of which could be discounted but others of which held certain advantages counterbalanced by potential drawbacks. It was generally agreed that it would not be wise to adopt one universal filling technique but that each nation should investigate and report on its own preferred and agreed technique so that a comprehensive understanding of the various options could be obtained. These options were:

- Single end pressing from the liner end.
- Single end pressing from the initiation end.
- Double end pressing.
- Isostatic pressing.

Further variants were to press billets of explosive and then assemble into the warhead or to press directly into the case and then assemble the liner to the case. In the later circumstances, case distortion was found to be problem although the Netherlands Desmoflex based candidate containing 97% HMX was pressed in this way and did give the best performance results.

2.5 Assessment

It was agreed to fire reference charges with a typical melt cast 75/25 Octol formulation for comparison purposes. Norway, Spain and Portugal conducted the firing trials on their own candidates and UK performed the firings on behalf of itself and the Netherlands. The reference charges were also provided and assessed by the UK. Plate penetration trials used mild steel targets for economy and were backed up by flash radiography during the trials and by separate Extended Jet Analysis. Penetration stand-off curves were constructed by firings at 4, 6, 8, 10 and 15 CD. In all, full penetration stand-off assessment of 9 candidates was undertaken with over 400 firings being undertaken, including an assessment of the reference charges. There were also a significant number of preliminary firings at 6 CD to screen out other candidates.

A considerable amount of data analysis was undertaken collectively at this stage to enable the group to draw overall conclusions on behalf of all five nations. This co-operative assessment allowed considerable insight into the relationship between performance, pressing methods and pressing parameters highlighting the true value of the programme to all the participant nations. The UK TPE candidate, RF 42, is typical of what might be expected of a 95% HMX loaded composition under acceptable conditions of pressing and assembly. Performance in the shaped charge is similar or slightly better than Octols at the shorter stand-offs but significant improvement is observed at long stand-off (nearly 40% at 14 CD).

This improvement in performance at longer stand-off is most probably attributable to the homogeneity of pressed fillings, or at least their symmetry of density distribution about the shaped charge axis, which leads to lower lateral jet drift velocities than for shaped charges filled with melt cast explosives.

Analysis of the firing data also showed that the CTP 25.2 test vehicle proved to be suitable for assessing candidate formulations and comparing different pressing techniques. However, for certain candidates, unexpectedly poor penetration results were observed but it was possible to attribute these to assembly problems rather than being associated with formulation or pressing attributes. In particular, Spain's candidates produced by isostatic pressing had excellent, nearly totally homogeneous, density distributions, but gave rise to disappointing penetration results. Here, the value of flash radiography and EJA was demonstrated by giving a greater insight into the cause of these results, which is thought to be attributable to assembly problems. Such problems caused some difficulty in the final assessment but by no means negated the value of the exercise and, in fact, demonstrated that a high detonation pressure explosive and good quality filling is not all – the techniques used to integrate the explosive into the warhead are just as important.

3. Conclusions

The programme was completed successfully and clearly demonstrated the suitability of pressable explosives for modern shaped charge applications. Amongst other the other conclusions drawn the following points are worthy of comment.

It is practical to formulate high performance pressable explosives with high HMX contents which prove safe to manufacture and handle, even after aging, and which are less vulnerable than earlier formulations such as LX-14 and Octols. A range of binders have been evaluated and it has been found that the nature of the binder can have significant effect on final properties. It is noted that Thermoplastic Elastomers appear to be particularly effective at desensitising HMX if an efficient coating technique is used. A 97% by weight HMX content formulation, designed by the Netherlands, exhibited the highest performance of the candidates assessed. However, a candidate from Norway, with only a 92% HMX content by weight, gave an acceptable performance, comparable to some of the nominal 95% compositions, giving further scope to look at lower vulnerability materials.

Generally pressable explosives perform similar to or slightly better than Octols at short and medium stand-off distances but considerable improvement is gained at long stand-offs. The precise advantages depend on solids loading, choice of pressing method, suitability of integration technique and whether comparison is made with a 75/25 or 70/30 Octol.

The performance firings clearly demonstrated that pressable formulations can give rise to shaped charge jets of superior quality to those derived from melt cast Octols. Higher jet tip velocities are not unexpected, given the slight increase in detonation pressure, but other improved characteristics have been noted such as the effect on jet particulation and break up times. Perhaps one of the greatest improvements is derived from the pressing process itself which leads to high quality fillings with a density distribution symmetrical about the charge axis and free of the types of micro defects normally associated with melt cast fillings. This leads to very low lateral drift velocities which are probably responsible for the good penetration at long stand off distances.

Perhaps one of the most significant successes of the programme has been that it has clearly demonstrated the ability of five European nations to work together in a highly effective programme of research on energetic materials. The programme, through collective working and assessment, was able to achieve more than the five nations could working in isolation, and far more than anyone nation could afford to resource on its own. In a world of diminishing research budgets, collaborative research programmes of this type show the future direction of energetic materials research in Europe.

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