HIGH PERFORMANCE MELT-CAST PLASTIC-BONDED EXPLOSIVES

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ABSTRACT

DRDC Valcartier has been developing new melt-cast explosives containing nitramines, TNT and a family of energetic thermoplastic elastomers (ETPEs) based on Glycidyl Azide Polymer. It was proven that the ETPEs, added in small amounts to the TNT, modified the glassy behaviour of the compositions and created a new product that showed enough elasticity to pass mechanical Insensitive Munitions tests such as the bullet impact test. The performance of those compositions was very close to that of Composition B and it was possible to process them in typical melt-cast equipment. Using the same products, but increasing the percentage of nitramines, the work on these formulations lead to another new class of products, namely high-viscosity melt-cast explosives that can be processed in equipment usually dedicated to cast-cured plastic-bonded explosives (PBXs). The binder for these new PBXs consisted in a mix of TNT and ETPEs. Nitramines (RDX and HMX) were added to increase the performance. It was then possible to use the high density of melted TNT and the energetic part of the polymer to increase the performance while keeping the nitramines at a reasonably low level. The end product is an explosive that is still meltable at temperatures around the melting point of TNT, which should be an advantage in thermal IM tests and at the end of the life cycle for demilitarization and recycling. It is easily processed in standard PBX equipment and the limits of processability were found for fixed amounts of ETPE (7.5% and 10%). The performance of some the new explosives will be presented, along with shock sensitivity data and results from bullet impact tests performed on small cylinders. It will be shown that it is possible to obtain melt-cast PBXs with a performance superior to that of Composition B and with a lower shock sensitivity.

INTRODUCTION

In the development of explosives for Insensitive Munitions (IM) applications, three main classes of products were created: 1- Cast-cured plastic-bonded explosives; these explosives and their processing are now well-known, and while they have been used mostly for large items in IM munitions, they have now started to appear as likely candidates for smaller items such as artillery shells and mortar rounds. 2- Pressed explosives; typically they exhibited better performances, higher vulnerabilities, and were used as boosters. 3- Melt-cast explosives (also called melt-pour explosives); these formulations appeared more recently and are used typically for smaller items, as direct replacements for conventional melt-cast explosives such as TNT, Composition B, Tritonal, or Octol. A number of formulations of the latter class were developed based on DNAN [1-5], on NTO/TNT [6, 7] or simply waxes. The objectives of those studies were to use existing melt-cast processing equipment and exploit the advantages of this method for large-scale production items.

DRDC Valcartier has developed its own family of IM melt-cast products containing an energetic thermoplastic elastomer based on GAP [8-12]. The simple idea behind the development of the product was to use melted TNT as a solvent for new energetic thermoplastic elastomers (ETPEs) based on GAP and patented by DRDC Valcartier. Upon cooling, the mix of the two products creates a new explosive that has hybrid properties in terms of mechanical properties and that exhibits a lower sensitivity to impact and friction. A whole family of products was then created. This work lead to another idea for new formulations. It was decided to increase the percentage of nitramines in those mixes in order to find the limit of processability and consequently the best performance possible. The idea was not completely farfetched, since, as a binder, a mix of TNT and an ETPE would offer a good density and a good performance, and it was demonstrated that this mix also changed the friability of TNT-based products. The resulting product would then have some processing characteristics of a PBX (high viscosity), with others from melt-cast explosives (meltability, absence of a curing cycle). The next step was to find a suitable method to process those explosives and to test their IM properties. This paper presents the development of those new explosives and the results of the performance and vulnerability tests.

RESULTS AND DISCUSSION

Limit of processability

The objective was to create a high-performance material. One of the first tasks was to establish the boundaries for the formulations. The starting point was selected as the melt-cast formulations that were developed as direct replacements for Composition B (see Table I). These were formulations with rather low viscosities and that passed the bullet impact test. Since some of the parameters had to be fixed to pursue the exploration, it was decided to select two percentages of ETPE: 7.5 % and 10 %. Starting with those percentages, the proportions of other ingredients were varied (RDX and TNT or HMX and TNT).

Table I: Low-viscosity melt-cast formulations

	RDX	TNT	ETPE
XRT-10%	54 %	36 %	10 %
XRT-7.5%	60 %	32.5 %	7.5 %

Two factors influenced the viscosity of the mixture: first, the percentage of ETPE in TNT; the polymer influences not only the solid behaviour but also the liquid one. TNT is a simple liquid at temperatures above its melting point. The ETPE increases the viscosity of TNT exponentially. Figure 1 presents the viscosity of the TNT/ETPE mixture as a function of ETPE content. The second factor is the solids loading; as any highly loaded mix, there is a limit to how much solids can be added before it becomes impossible to cast.

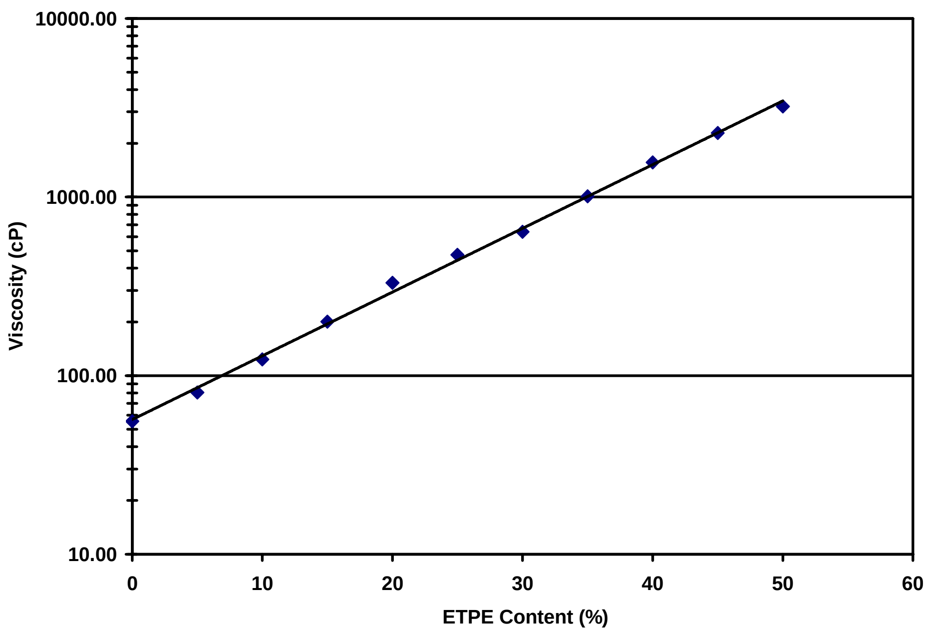

Figure 1: Viscosity of the TNT/ETPE mixture (measured at 95 °C).

A small 2CV helicone mixer (0.37-l capacity) was used to perform small mixes. This mixer is a standard equipment for PBX and rocket propellant processing at our establishment. The percentage of nitramines was increased until the limit of castability was reached (impossible to gravity cast). Four formulations were then created and are listed in Table II. The viscosity of RDX mixes was measured at each incremental step using a Brookfield DV-III+ with a T-spindle and the Rheocalc V2.3 software. This gives a graphical representation of the increase of viscosity with the solids content (see Figure 2). The mix goes from viscosities in the order of 1000-5000 cP at solids loading below 60% (Comp. B being around 1000-2000 cP) to viscosities of 700000 cP at 75% solids. This is comparable to cast-cured plastic-bonded explosive before the addition of isocyanates. At 7.5% ETPE, the maximum amount of RDX was 75%, while it was 74% at 10% ETPE. This is somewhat lower than what was expected. With HMX, the percentages were 70% and 69.5% respectively. The shape of the particles can probably explain the difference with RDX. In all mixes, class 3 and class 5 nitramines were used in a 60/40 ratio.

Table II: High-viscosity melt-cast formulations

Formulation	RDX (%)	HMX (%)	TNT (%)	ETPE (%)	TMD[1] (g/cm^3)	VoD[2] (m/s)	P_{CJ}[3] (GPa)
HV-XRT 1	75		17.5	7.5	1.73	8217	28.8
HV-XRT 2		70	22.5	7,5	1.78	8311	30.4
HV-XRT 3		69.5	20.5	10	1.77	8349	29.7
HV-XRT 4	74		16	10	1.71	8148	28.1
Comp. B	60		40		1.74	8047	28.1

1- Theoretical maximum density
2- Detonation velocity calculated using CHEETAH 2.0 from LLNL
3- Chapman-Jouguet pressure, calculated

Performance

Larger-scale mixes of the same formulations were processed using an Helicone 4CV (5 pt) mixer. Three of them were selected for evaluation: 7.5% ETPE and RDX, and 7.5% and 10% ETPE and HMX. Since the performance was our main goal, those three formulations were the best choices. The formulations were processed similarly to plastic-bonded explosives, including mixing and casting under vacuum. This produced perfect qualities of samples.

The performance was measured using plate dent tests (see Figure 3). Cylinders 25.4 cm long and 4.1 cm in diameter were cast under vacuum. The cylinders were initiated using a RP-502 detonator, a pellet of tetryl and a pellet of RDX/wax. The samples were placed on a stack of three 1018 steel plates. The depth of indentation created by the detonation is a measure of the brisance and an approximation for the detonation pressure. For each sample, the detonation velocity was determined using ionization probes. Three ionization probes were spaced at 51 mm from each other starting at 10 mm from the bottom of the cylinder. The velocity was determined through time measurements. Table III summarizes the results.

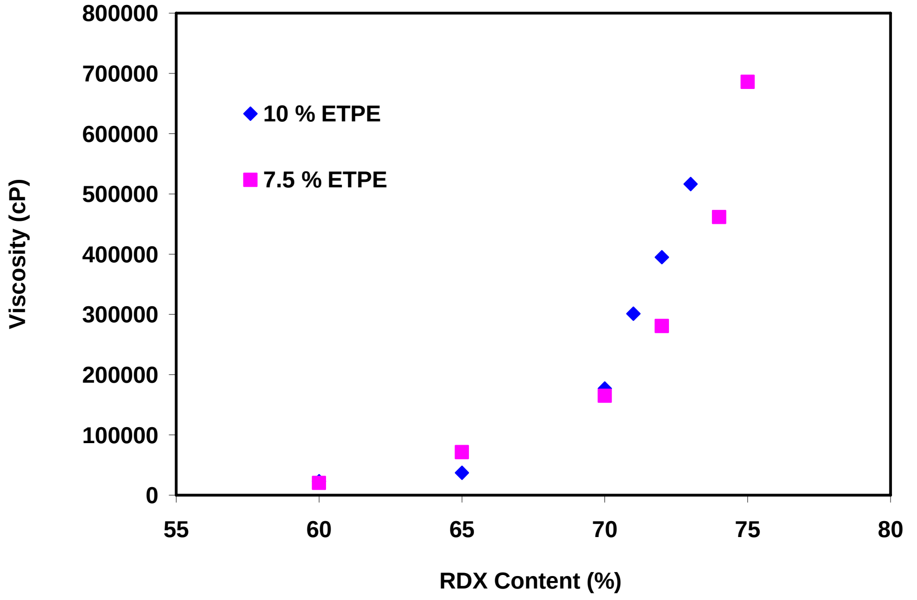

Figure 2: Viscosity as a function of RDX content in TNT/ETPE/RDX mixes.

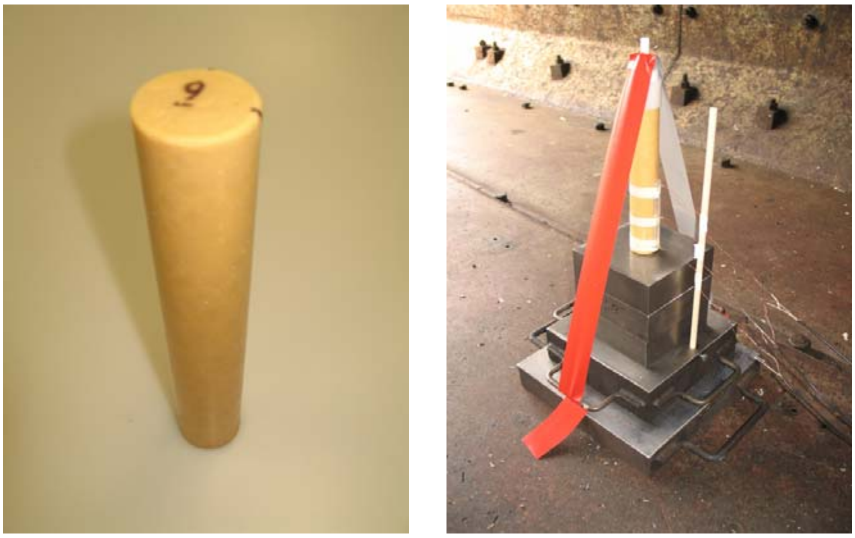

Figure 3: Left: cast cylinder of explosive for performance testing. Right: plate dent test coupled with velocity measurements.

Shock sensitivity

The shock sensitivity of the new formulations was measured using the NOL card GAP test. Table IV presents the results of the tests. Composition B was also tested and the value measured was a little higher than the value of 203 cards often reported [3]. Two formulations showed sensitivities that were low relative to their nitramine content. All of them had values lower than Composition B. With 70% of HMX, Formulation 3 had the same shock sensitivity as XRT-10, which has 54% of RDX. The higher ratio of ETPE to TNT must be the cause of this lower sensitivity. In any case, those rather low values were encouraging.

Table III: Performance results from plate dent tests

	Exp. density (g/cm^3)	VoD (measured) (m/s)	Plate dent (cm)	Relative performance (% Comp. B)
HV-XRT 1	1.70	8107	0.820	104.9
HV-XRT 2	1.76	8160	0.841	107.5
HV-XRT 3	1.73	8064	0.826	105.6
Comp. B	1.69	7885	0.782	100
XRT-10%	1.64	7689	0.714	91.3

Table IV: Card GAP tests results

Composition	Nitramine content (%)	Number of cards
HV-XRT 1	75	203-204*
HV-XRT 2	70	171-172*
HV-XRT 3	69.5	167
Composition B	60	216
XRT-10%	54	167

* Two samples missing to establish the 50% level.

Bullet impact tests

Bullet Impact tests were performed on test cylinders that were machined at our laboratory and that were filled with the new explosives. These cylinders were designed with the same thickness as a 105mm M1 projectile, and used the same metal hardness. They were built with a thread at the top to allow a good confinement of the explosive. Figure 4 shows one of the cylinders. The volume of the cylinders was such that each one contained approximately 650 g of explosives. This is significantly less than the 2.3 kg of a 105mm M1, which helps to keep the costs down and reduce the safety template for the tests. Tests were performed in the past to confirm that it is a good representation of a 105mm in the bullet impact test. Composition B, for example, reacts violently in this configuration. Three tests were performed on each composition. They were performed according to STANAG 4241, with only one bullet fired, at 850 m/s. No pressure measurements were made.

The results are presented in Table V. Even if it was clear that the formulations demonstrated a reduction in reaction violence, only one of them passed all three tests. The other two behaved in a GO - NO GO fashion, with either a violent reaction or no reaction at all. The reaction violence was difficult to evaluate since no pressure measurement was made. However, the fragments recuperated indicate a type II-III reaction (see Figure 5). In contrast, the formulation with 10% ETPE and 69.5% HMX showed all burning reactions. This demonstrated that the formulations had the potential to pass the bullet impact test in real items. The next step will be to modify slightly the formulations to improve their behaviour, and cast them in 105mm for testing later this spring.

Figure 4: Test cylinder used in the bullet impact tests.

Table V: Bullet impact test results

Composition	Reaction Level		
	Sample 1	Sample 2	Sample 3
HV-XRT 1	Type II-III	No reaction	No reaction
HV-XRT 2	No reaction	No reaction	Type II-III
HV-XRT 3	Burning	Burning	Burning
XRT-10%	No reaction	No reaction	Burning

Figure 5: Bullet impact test results on HV-XRT 2. Left: violent reaction. Right: no reaction.

CONCLUSION

A new type of melt-cast plastic-bonded explosive was created. It is based on TNT and hence keeps a melt-cast behaviour. However, since its viscosity is high, it was processed in equipment designed for plastic-bonded explosives. The limit of processability and castability was established for RDX and HMX as the solids, and with levels of 7.5% and 10% of ETPE in the mix. Its performance is better than that of Composition B, mostly because of the energetic binder, which is made of TNT and an energetic thermoplastic elastomer designed at DRDC Valcartier. The shock sensitivity of one of the formulations is as low as a formulation containing 15% less nitramines. This formulation passes the bullet impact test in cylinders that are mock-ups of 105mm shells.

ACKNOWLEDGEMENTS

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REFERENCES

1. Nicolich, S., Niles, J., Doll, D., Ray, M., Gunger, M., and Spencer, A., “Development of a Novel High Fragmentation/High Blast Melt Pour Explosive”, Proceedings of the 2003 Insensitive Munitions & Energetic Materials Symposium, Orlando, FL, USA, March 2003.
2. Ferlazzo, P., Nicolich, S, Niles, J., and Doll, D., “Insensitive Munitions Explosive Development for Melt Pour Munitions”, Proceedings of the 2003 Insensitive Munitions & Energetic Materials Symposium, Orlando, FL, USA, March 2003.

3. Niles, J., and Doll, D., "Development of a Practical Reduced Sensitivity Composition B Replacement", Proceedings of the 32nd International annual conference of ICT, Karlsruhe, Federal Republic of Germany, July 2001.
4. Niles, J., Nicolich, S., Doll, D., and Rasmussen, N., "Mitigating Shaped Charge Jet Impact on Munitions", Proceedings of the 2004 Insensitive Munitions & Energetic Materials Symposium, San Francisco, CA, USA, November 2004.
5. Wilson, A.R., Alexander, B., Kuhnle, W., and Vinh, P., "Product Improvements for the Explosive Melt Cast Formulation PAX-21", Proceedings of the 2004 Insensitive Munitions & Energetic Materials Symposium, San Francisco, CA, USA, November 2004.
6. Cliff, M., and Smith, M., "Assessment of a Melt-Castable NTO/TNT Formulation", DSTO-TR-0998, Aeronautical And Maritime Research Laboratory, Melbourne, Australia, July 2000.
7. Mesnil, R., and Aumasson, R., "Development and Assessment of Low Sensitive Melt-Cast and pressed Explosives", Proceedings of the 2004 Insensitive Munitions & Energetic Materials Symposium, San Francisco, CA, USA, November 2004.
8. Ampleman, G., Marois, A., Desilets, S., and Beaupré, F., "Synthesis of Copolyurethane Thermoplastic Elastomers for Use in Helova Gun Propellants", DREV Report 9716, Defence Research Establishment Valcartier, Canada, February 1998, UNCLASSIFIED.
9. Ampleman, G., Brousseau, P., Thiboutot, S., Diaz, E., and Dubé, P., "New Insensitive Melt-Cast Explosives Based on Energetic Thermoplastic Elastomers", Proceedings of the 2001 Insensitive Munitions & Energetic Materials Symposium, Bordeaux, France, October 2001.
10. Ampleman, G., Brousseau, P., Thiboutot, S., Diaz, E., Dubois, C., "Insensitive Melt Cast Explosive Compositions Containing Energetic Thermoplastic Elastomers"; U.S. Patent 6,562,159, May 2003.
11. Diaz, E., Brousseau, P., Ampleman, G., and Thiboutot, S., "Less Sensitive Melt-Cast Explosives Containing Energetic Thermoplastic Elastomers", DREV TR 2001-185, Defence Research Establishment Valcartier, Canada, March 2002.
12. Brousseau, P., Trudel, S., Ampleman, G., and Dubé, P., "Bullet Impact Tests on an Insensitive Melt-Cast Explosive Composition", Proceedings of the 2004 Insensitive Munitions & Energetic Materials Symposium, San Francisco, CA, USA, November 2004.