Research paper

Cast PBX related technologies for IM shells and warheads

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Abstract

EURENCO France and SNPE Matériaux Energétiques have been developing IM technologies for warheads for 35 years. These technologies are covering the synthesis of new molecules, the design of new cast PBX formulations or explosive charge architectures, as well as comprehensive design methods and up−to−date production processes. Qualified formulations using for example HMX, I−RDX® or RDX, or NTO are used in production or development programmes related to major applications, from underwater munitions and missile warheads to artillery or mortar shells and to GP bombs or fully IM penetration warheads. Most of them are currently qualified by French or Allied forces.

Advanced concepts are currently studied to meet present and future requirements such as IMness, low collateral damage specifications and specialized performances. These advanced concepts can require the use of new formulations with new energetic molecules or additives, such as those synthesized in SNPE/CRB labs or abroad. Such formulations can be combined in advanced architectures to promote the desired effects.

The goal of this presentation is to give an overview of current IM applications, emphasizing the artillery and mortar domain, as well as advanced architectures for warheads, with focuses on design and innovative production methods promoted by EURENCO.

Keywords : Explosive, Cast plastic bonded, Process, Insensitive Munition

1. Introduction

EURENCO France and SNPE Matériaux Energétiques have been developing IM technologies for warheads for 35 years. These technologies are covering the synthesis of new molecules, the optimization of explosive formulations or advanced charge architectures, as well as comprehensive design methods and up−to−date production processes.

EURENCO France and SNPE have been building this long history in promoting the cast cured plastic bonded explosives (cast PBX) technology. Based on the legacy works conducted by scientific and industrial teams involved in solid rocket motors, that robust technological path has been adopted and continuously improved since the early beginning in the seventies, to reach the best trade−off between producibility, performances and IMness.

The first cast PBX industrial applications in France were missile or underwater warheads. These items usually come in lots of a few units to be filled in batch operations. Thereafter, progress related to the fabrication methods, formulations and explosive charge designs allowed the use of this technology for the production of general or multipurpose aircraft bombs as well as heavy penetration warheads.

More recently, a major EURENCO France's process innovation made possible the high−volume/affordable−costs production of shell fillings. The so−called "bi−component" route is a semi continuous process, developed to overcome the pot life limitation, encountered in the usual batch fabrication, with a far shorter curing time. EURENCO France has commissioned an automated industrial production line in 2006 in its Sorgues plant. This facility is now producing cast PBX fillings for artillery, mortar, tank and soon Navy shells according to this new process principle[1)2)].

Table 1 Main qualified formulations used by EURENCO France.

Name	HMX	RDX	NTO	PETN	AP	Al	IB[a]	EB[b]	Main Applications
ORA86 B	x						x		Missile WH – Shaped Charges
PBXN–110	x						x		Missile WH – Shaped Charges
HBU88 B		x					x		Mortar rounds – Shells – WH
RH26–2		x					x		Artillery Shells
B2238 A		x					x		Booster – WH – Shells
B2188 A	x			x			x		Booster – SCO Safety Device
B2214 B	x		x				x		Penetrators – Missile WH
PBXN–109		x				x	x		GP bombs – Heavy penetrator
B2211 B		x			x	x	x		Underwater torpedoes/mines
B3108 B	x					x		x	Missile WH – Enhanced blast

a) IB : Inert Binder – b) EB : Energetic Binder

Along with this on–going effort in manufacturing development, EURENCO France also keeps high R&D impulse on formulations studies, aiming to provide optimized IM/performance/costs trade–offs and continues to explore advanced charge designs.

2. Formulations

2.1 Qualified Explosives

Most of the cast cured PBX used by EURENCO France consist of an inert binder and explosive fillers. The binder is generally based on hydroxyl terminated polybutadiene (HTPB) and isophoron diisocyanate with different additives (plasticizer, bonding agent, anti oxidant). The explosive fillers are chosen among I–RDX®, RDX, HMX and/or NTO[3] depending on the applications and their required performances. Additives such as aluminium or ammonium perchlorate can be used to improve blast performances.

Table 1 gives a list of formulations, fully qualified according to STANAG 4170 and AOP–7. The main explosives produced to date by EURENCO France for mortars, artillery or tank shells are HBU88B and RH26–2. Both take advantage of I–RDX® and its low shock sensitivity. They exhibit performances equivalent to Comp B with very good IM signatures in applications such as 120 mm M 934A2mortar[4] or 155 mm RH40 projectiles[5].

B2214B is probably one of the most shock insensitive explosive ever formulated. That last cast PBX is EIDS and is used in CBEMS 125 and 250 multiple effect bomb bodies and in a French Navy version of the AS30L missile. B2211 D is also a proven EIDS formulation which is mainly used in underwater warheads.

2.2 Future Formulations

EURENCO France supports a significant R&D effort on formulations studies, aiming to provide new and better IM /performance/costs trade–offs, tailored for specific applications.

As an example, the achievement of the highest IM specifications (MURAT**, STANAG 4439) is quite challenging in the case of 155 mm artillery ammunitions. Solutions available today mainly consist in special shielding/packaging device, advanced charge designs, or the use of highly insensitive explosives. EURENCO France is targeting the development of NTO cast PBX formulations specifically optimized in order to pass the sympathetic reaction test without any shielding in the shell pallets, while keeping reasonable critical diameters, performances and costs.

We have thus estimated target figures for gap tests (ISGT[a], STANAG 4488, annex B and ELSGT[b], STANAG 4488, annex C). Several candidates were formulated by varying the NTO/I–RDX® ratio. They were tested against gap tests as well as critical diameter requirements. The optimized formulations were then deduced from the preliminary results[6]. Table 2 describes these candidate formula-

Table 2 Candidate formulations for 155 mm IM projectiles.

Topic	B2267A	B2268A
– Formulation (%)		
HTPB binder	14	13
I–RDX®	22	15
NTO	64	52
Al	/	20
– Viscosity (Pa.s)		
at casting time	100	300
6hours after casting	250	600
– Density	1.65	1.76
– Mechanical properties (at 20° C)		
Max tensile stress (MPa)	0.72	0.72
Max tensile strain (%)	7.2	8.6
– Hardness (Shore A)	70	71
– Detonation velocity (m.s^{-1})		
Unconfined cylinder ϕ 50 mm	7570	/
Computed	7680	7440
– ISGT (cards)	95	<1
– ELSGT (mm PMMA)	55	40
– Critical diameter (mm)	$30 < \phi_c < 36$	$\phi_c > 50$

tions whose full scale assessment is scheduled in 2008. A "pass" validation to the sympathetic reaction test will induce further characterisations, included the EIDS[c] UN test series7, to prepare their qualification files according to STANAG 4170 and French national procedures.

Not only IM, but also high or peculiar performances or enhanced blast formulations are currently studied. Besides explosive materials described previously, other candidate explosive molecules produced by EURENCO are available for new formulations and applications. Among them, CL20, FOX−7[7] and FOX−12[8], are of the greatest interest, thanks to their unique properties, either high performances or low shock sensitivities.

3. Explosive grain designs

3.1 Liners

Ensuring safe and reliable warheads or shells requires to take into account internal boundary conditions (interface of the explosive grain with the casing or with the fuze pocket), not only for operational, but also accidental thermal and mechanical stimuli. Functional purposes, such as controlling the steel fragmentation or IM improvement characteristics can be introduced too in such an interface.

EURENCO has developed and patented a highly versatile and cost effective technology where a liner exhibiting the right shaping can be used as an embedded mould directly in the warhead. This liner principle is called PTCF as an acronym for Protection against Thermal stimuli and Control of the Fragmentation. It has been successfully applied for the CBEMS 125 and 250 multipurpose bomb units and can be promoted too for shells (Fig. 1) and missile warhead applications.

When control of the fragmentation is not desirable, EURENCO France has developed simpler but efficient liner processes for example to prevent friction or adiabatic compression during gun firing acceleration or during deep penetration in concrete targets.

3.2 Advanced Architectures

Thanks to cast PBX technology, it is easy to design and produce at affordable costs, association of formulations where the desirable characteristics are put to their right place.

For example, dual formulations are Eurenco patented routes to achieve enhanced performances and IMness[9][10]. The way a cylindrical dual formulation works is quite simple. The powerful inner formulation detonates at a higher velocity than the outer insensitive formulation. Thus the outer detonation wave is interacting on the metal casing with an angle promoting higher local pressures and thus fragments velocities. For IM consideration, the overall behaviour is mainly driven by the outer formulation characteristics (shock sensitivity for Sympathetic Reaction test and bullet or fragment impacts, combustion rates for Fast Cook Off...), provided the ratio be well designed.

Fig. 1 Example of a PTCF Liner for a 120 mm shell.

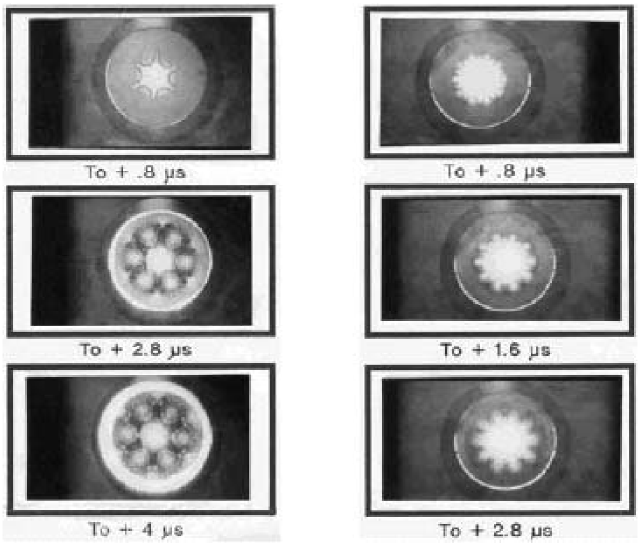

Fig. 2 Emerging detonation waves for 2 different star shaped dual formulation charges (1,250,000 frames/s).

The most advanced shapes can lead to interesting detonation waves, while promoting enhanced IM and performance characteristics, for example, a well designed star−shaped interface between the two formulations can keep a sub−critical outer layer detonating, thanks to the formation of Mach waves between the star branches and further interactions with the metal casing (Fig. 2).

3. Processes

3.1 The Classical Batch Process

The classical industrial process used to produce cast PBX explosives is a batch process (Fig. 3). A vertical mixer is used to obtain a homogeneous paste with the liquid polymer resin and the explosive filler. Then a curing agent is added in the mixer. When the preparation is finished, the available time for the filling phase is limited, due to the reaction of the curing agent with the polymer. This so−called pot life is about ten hours for optimized formulations. After casting, a curing phase at a controlled temperature (typically 60°C) is mandatory to achieve the desired level of mechanical properties. 3 to 7 days are classically required. The curing time could be reduced by adjusting the formulation of the binder, but the consequence would be a reduced pot life, undesirable and unacceptable for the manufacturer to achieve a reliable fabrication process.

The first applications of cast cured explosives were warheads missiles, underwater mines, torpedoes and multipurpose bombs. These kinds of munitions contain up to 450 kilograms of explosives and the batch process is perfectly

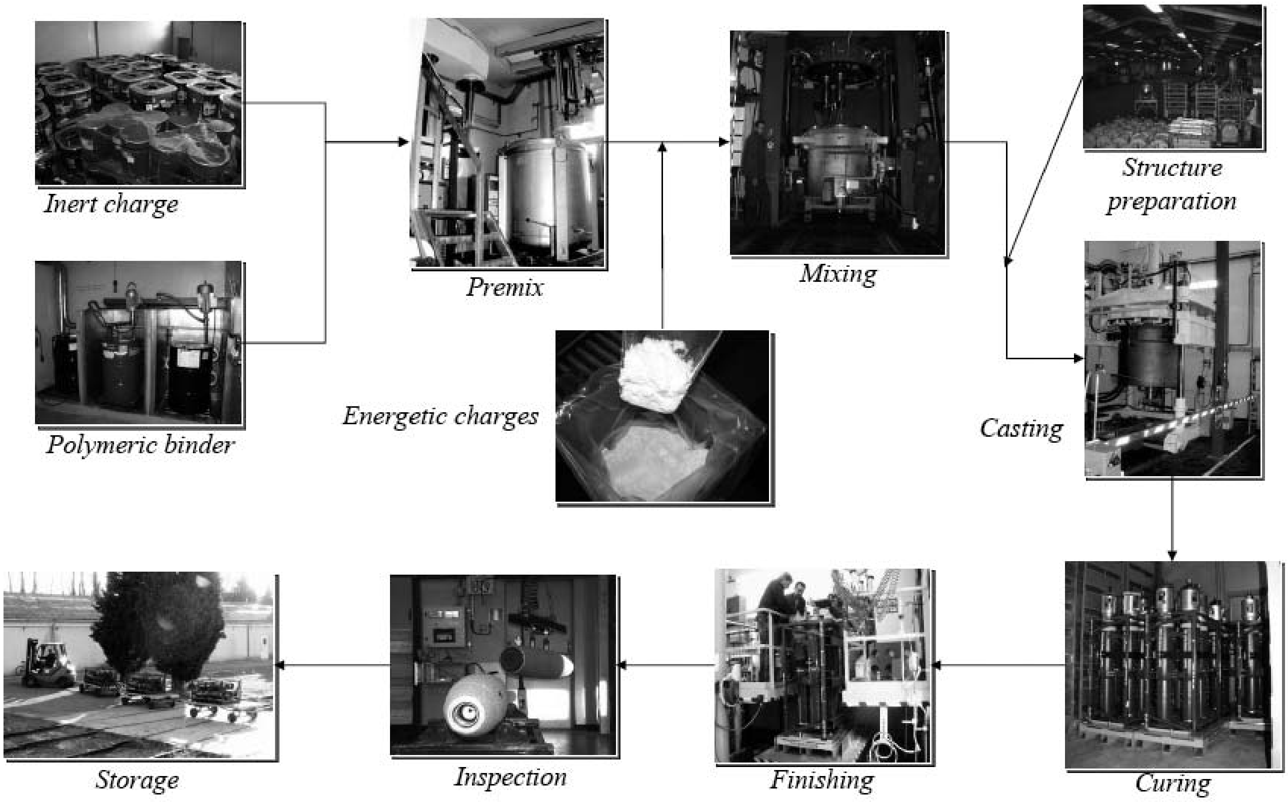

Fig. 3 Batch process synopsis for cast PBX production.

adapted for their mass production.

Besides numerous missile warheads (Exocet MM40, MICA, AS30L...) and underwater mines and torpedoes, EURENCO France has filled with this batch process during the past decade more than 12.000 bomb items, either with PBXN−109 for Mk80s series and BLU−111 or BLU−109, or with B2214B for CBEMS 125 and 250.

3.2 The bi component Process

One of the first cast PBX applications in artillery shells is about 35 year old when SNPE (EURENCO's mother company) was awarded a contract in 1972 to demonstrate the feasibility of 155 mm shells filled with a cast PBX charge. The French MoD/DGA services were responsible for the shell body and total system. SNPE was responsible for the definition and production of the cast PBX fillings, able to withstand up to 20,000 g. Successful arena tests and live gun tests were performed to validate the principle. A full scale development was completed in 1977. This technically successful program was stopped for budgetary reasons.

A strong revival of using cast cured explosives for filling artillery or mortar shells clearly occurred in the nineties. It quickly became obvious that the classical batch process was not adapted to mass produce, at the industrial scale with moderate cost, such munitions which are containing less than 10 kilograms of explosive. The main limitations come from the pot life and the curing time.

EURENCO France has developed and patented worldwide an innovative process (Japanese patent number : JP 2004035390) which overcomes these difficulties. The explosive formulation is split in two components which are prepared on a batch basis. The first component contains the polymer, the additives and the explosive fillers. The second component contains the curing agent and part of the plasticizer. These two components can be stored during several days before use. A specific installation is fed with both components which are mixed to the exact ratio through a static mixer, just before filling the shell bodies.

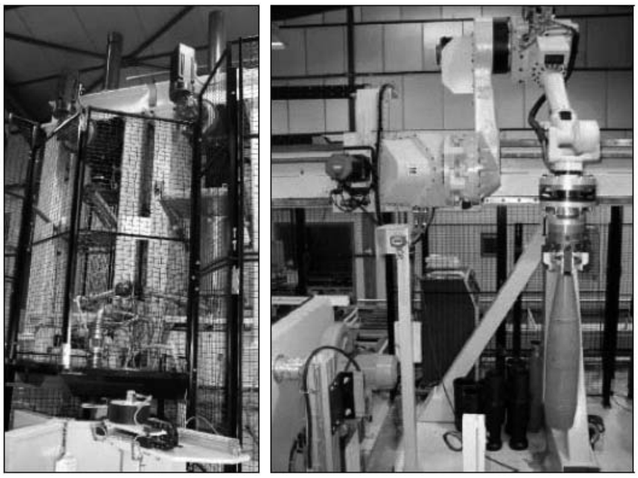

Fig. 4 Filling bi component machine (left) and handling robot (right).

With this process, it is possible to organize a continuous filling production phase and to significantly reduce the curing time by increasing the percentage of catalyst in the formulation. The complete polymerisation can be achieved in less than 24 hours at 60°C, to be compared to the "3 to 7 days" curing time in the classical batch process.

The first studies were conducted with a prototype machine installed at the EURENCO Sorgues plant at the end of nineties. This equipment has permitted to complete comprehensive studies to adapt precisely the formulations, to finalize the static mixer design and to tune the main process parameters (temperatures, pressures, vacuum levels, flow rates...). It has also been used to produce hundreds of items for evaluation and prequalification of 120 mm mortars, 155 mm and 120 mm artillery and tank shells.

EURENCO France has invested in a full scale production line in order to get an industrial facility to fill shells and mortars, from 60 to 155 mm. This highly automated plant (Fig. 4), called the POGS workshop (production plant of cast PBX charges for I.M. shells), was commissioned in 2006. It is an integrated workshop, including X−ray controls operated in line. Up to 50,000 155 mm or 100,000120 mm shells can be filled per year.

The first 155 mm shell production began in summer 2006. Thousands of 155 mm projectiles and 120 mm tank shells have been satisfactorily filled and delivered to date.

4. Conclusions

EURENCO France is developing continuously new technologies which are helpful to IM shells and warheads. Besides new molecules research and production, we are optimizing new cast PBX formulations for specific applications such as IM 155 mm or IM enhanced blast explosive charges and advanced explosive architectures where IMness is not reduced by the high performance levels.

Moreover, we are promoting cast PBX not only for its historically classical applications (missiles warheads, underwater munitions, bombs and penetration warheads) but also for shells and mortars, thanks to abreakthrough proprietary innovation which is now allowing the mass production of shell fillings at a very economical rate.

The so−called bi component process is a semi continuous process developed to overcome the pot life limitation encountered in the classical batch method, making possible a very short curing period. An automated industrial production has been commissioned in 2006 in our Sorgues plant and is now producing cast PBX fillings for artillery, mortar, tank and Navy shells according to this new process.

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[a] ISGT stands for Intermediate Scale Gap Test : a confined F40 mm−L200 mm substance acceptor is stimulated by a F40−L 40 mm RDX/Wax (95/5,1.6 indensity) donor. The number of acetate cards (0.19 mm in thickness) under which no detonation is obtained, is the measure of the shock sensitivity of the acceptor substance.

[b] ELSGT stands for Expanded Large Scale Gap Test : a confined F73.2 mm−L279 mm substance acceptor is stimulated by a F95.3−L47.6 mm RDX/Wax (95/5,1.6 indensity) donor. The thickness of the PMMA barrier under which no detonation is obtained, is the measure of the shock sensitivity of the acceptor substance.

[c] EIDS stands for Extremely Insensitive Detonating Substance