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IM Melt Cast Compositions based on NTO

by

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1-**Introduction**

Since the last decade, there is a more and more requested need for safer ammunition, that is why the drive towards Insensitive Munitions (IM) is an increasing priority at least within NATO countries, who do have IM policies and IM regulations enforced by law.

The purpose of IM is to reduce the risks of response to accident or attack.

In order to fulfil requirements for IM as defined by STANAG 4439, there is a need to define insensitive compositions as replacement products for conventional ones.

Filling of ammunitions is based on three main processing technologies:

-melt cast,
-pressed,
-cast cured,

and the choice of the technology is according to the available processing technologies and Industrial means.

Cast cured compositions have been proved to be a privileged solution, because of:

- intrinsic reduced sensitivity,
- ease of access to complex geometries
- good mechanical properties
- wide usable thermal operational range

and they have been proved to be the route to less sensitive compositions as attainable with conventional explosives like RDX and HMX, and with even better if Insensitive Nitramine (like I-RDX) is used as exemplified with PBX N 109 or with less sensitive explosives like NTO .

For this family of explosive compositions, equivalent (in term of performance) to conventional ones are available (from TNT equivalent to almost PBX N 5 equivalents [1]).

The two other technologies may also lead to insensitive compositions and melt cast compositions remain a major field of work because of widely available industrial means around the world, and established technology. Even if there are already known solutions, there is still a need for development work especially to lower the cost gap between standard and IM compositions.

2- Strategy to reduce the sensitivity

In the course to Insensitive Munitions, IM'ness is to be considered as a whole, and it is necessary to take into account (work on or modify):

-the energetic material,
-the explosive composition
-the ammunitions
-the packaging
-the ammunition depot or storage,

Determination of the insensitive character at the ammunition level is based on the response to the followings tests according to STANAG 4439

Test	Fast heating	Slow heating	Bullet Impact	Fragment Impact	Sympathetic detonation	Shape Charge jet Impact
Method	Stanag 4240	Stanag 4382	Stanag 4241	Stanag 4496	Stanag 4396	Stanag 4528

Response*	V	V	V	V	III	III

*with the following meaning:
I = detonation
II = partial detonation
III = Explosion
IV = Deflagration
V = Combustion

In the overall design of an insensitive ammunition, it is of major interest to consider low sensitive energetic materials and compositions, as this will allow the largest impact on the IM properties.

The insensitive character of the composition itself may be measured through the following tests (classification as EIDS according to AOP 39), and access to 1.6 transport classification needs to pass all the tests:

Cap	GAP	Susan	Friability	Bullet impact	External fire	Slow cook off
No detonation	No go at 82 mm	Pressure <27kPa	dP/dt <15MPa/ms	No explosion	No violent reaction	No fragment throw

Conventional Melt cast compositions are mostly TNT or composition B, with Aluminium added when a blast effect is needed (Tritonal, H6…), and we may consider three main levels of performance:

-TNT
-Composition B (TNT/RDX 60/40)
-Octol (TNT/HMX 70/30 to 75/25)

In the course of replacement product of conventional compositions, as listed above, there is a need of adapted solutions depending the ammunition to be filled.

The solution is to be adapted to the level of required IM'ness (IM signature according to STANAG 4439) and to the level of required performance (TNT, Composition B, Octol… level).

To reach this objective work is to be done on the explosive itself or its formulation.

If interest of less sensitive Nitramines has been demonstrated in the case of cast cured compositions, it is of no use in the case of melt cast compositions either based on TNT [2,3] or even DNAN [4].

Use of less sensitive explosive is the other alternative. A large number of Insensitive explosive molecules have been under consideration for insensitive munitions purposes during the last decades, and have been recently reviewed [5]

Amongst these products, some like TATB, NTO, FOX 7 or FOX 12 are of particular interest and are produced by EURENCO.

Formulation are usually based on TNT, even if recent developments are based on Dinitro Anisol (DNAN), which is less sensitive than TNT but has some drawbacks like lower density and lower detonation velocity. Compared to Composition B, the replacement of TNT by DNAN leads to experimental VoD decrease of about 500m (7360m/s vs 7860m/s) [4]. For this product there are also some issues with irreversible growth of DNAN up to 15% after repeated thermal cycling [5]. Search for insensitive replacement products for TNT is still very active as exemplified for example by work on novel insensitive melt cast materials 1-Methyltrinitroethyl Tetrazole and 2-Methyltrinitroethyl Tetrazole [6].

In order to be able to tailor the composition according to the need, the main parameters that are considered to be taken into account, in this approach, are:

-the presentation of the composition:

We will consider here only melt cast compositions

-the performance level required, which may be estimated for the composition through:
-density
-detonation velocity
-and the deduced detonation pressure (Pcj)

-the functional requirements, depending the ammunition calibre, what appears as meaningful is:
-critical diameter

-the level of expected sensitivity which may be estimated through simplified sensitivity characterization tests such as:
-shock sensitivity (small scale water gap test, or BICT when critical diameter compatible)
-thermal thread (Audibert Köenen test).

Even if other insensitive Explosives have been evaluated in melt cast compositions such as GUDN [7], and found promising, we will focus on NTO based melt cast compositions, as EURENCO has been for long a producer of NTO and has already developed compositions based on NTO such as Cast cured B2214 or more recently B 2267A or B 2268A [8], and as most of the known development have been based on this Explosive.

3-Development work

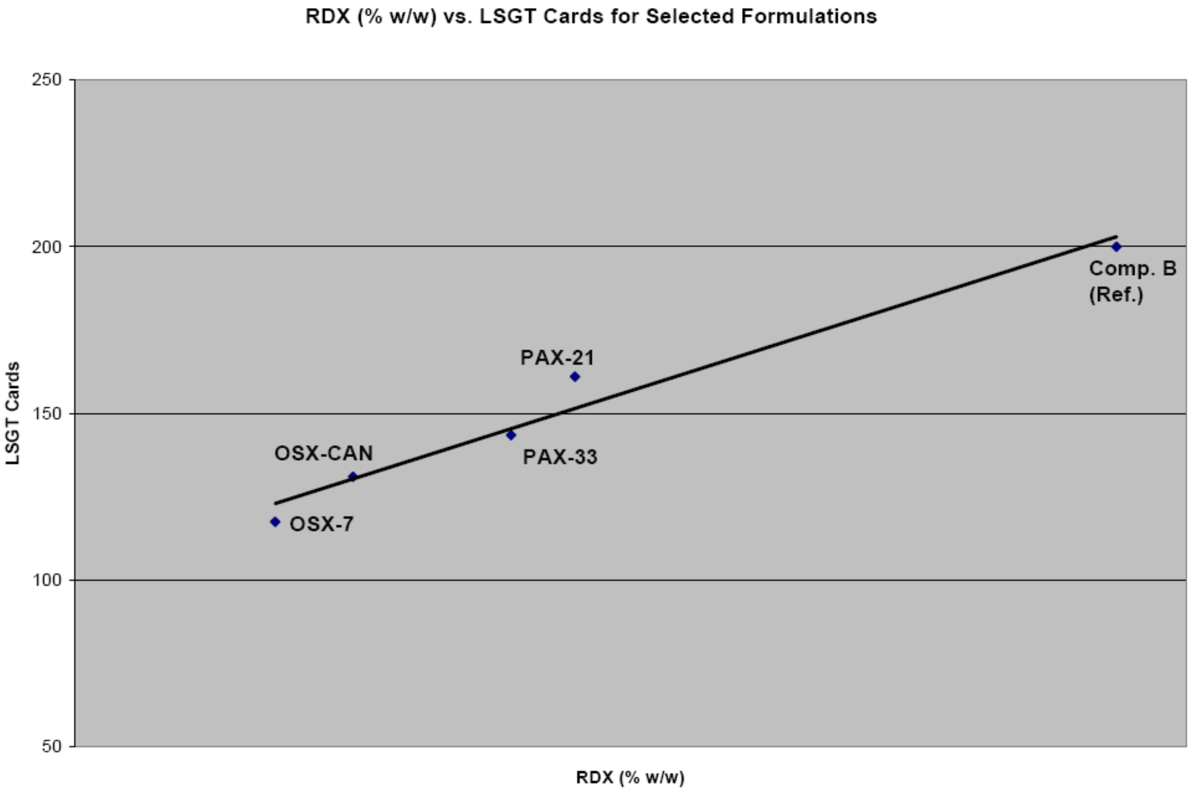
In the course of replacement of standard explosive compositions like TNT, composition B or Tritonal by “insensitive” compositions, and with the aim to be able to tailor according to the need in term of performance, functional requirements and level of insensitiveness, development work has been based on ONTALITES (compositions based on NTO and TNT) and aluminized ONTALITES (compositions based on NTO, TNT and Aluminium), with addition of RDX as additional tailoring factor.

We know that sensitivity is driven by RDX content as exemplified on melt cast compositions based on NTO, (table 1), or on pressed composition RDX/NTO/Wax/graphite 58.5/38/3.5/0.5, for which the result for shot gun test is 51 MPa/ms [10], and more especially shock sensitivity as shown by A. WILSON [9] on different compositions compared to composition B (figure 1).

Table 1

Composition	RDX/TNT 60/40	RDX/NTO/TNT 30/30/40	NTO/TNT 60/40
Shot gun	45	25	3.2
External fire 7e	detonation	explosion	No explosion
Bullet impact	detonation	deflagration	Pneumatic

Figure 1



3.1-NTO improvement

High NTO loadings need high bulk density; this point has been emphasized during AFX developments. Adjustment of coarse and fine fractions has been found a way to access to high loadings (65% NTO) [11]; Recent work on the morphology of NTO crystal has shown that up to 70% loading may be achievable [12]

EURENCO NTO standard production lead to two grades of crystallized (coarse) material (Class 1 and Class 2, ~450 and 350 µm mean diameter); two grades of fine material are obtained (Class 3 and Class 4, ~50 and 12 µm mean diameter) by air milling. These qualities are suitable for low NTO content ONTALITES, either based on one grade (coarse) or on a mix of coarse and fine grains in appropriate proportions.
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As high bulk density has been given as a key parameter to lower the viscosity of the composition, a dedicated NTO quality has been developed for melt cast applications.
As illustrated, replacement of standard class 2 NTO by NTO for melt cast application, lead to better viscosity of the slurry as measured by Efflux Viscosity (table 2)

Table 2

Ontalite		NTO (% weight)			Ontalite pouring	
NTO (%)	TNT (%)	NTO Cl. 2	NTO *	NTO Cl. 3	T° (°C)	viscosity (s.)
65	35		65	35	95	9
		65		35	95	20
60	40	50		50	95	5

*Bulk density 925 kg/m^3

3.2-Process work

Explosive composition for melt cast application may be prepared either by the belt process or by granulation under water.

Because of the solubility of NTO in water, the standard water slurry process, as used for example for the preparation of Composition B is not applicable.

For NTO based compositions (ONTALITES or Aluminized ONTALITES), the belt process is one solution for their production. Another solution is to load directly the separated ingredients in the melting vessel just before loading the ammunitions.

a process is under development to be able to offer granulated ready for use compositions. This granulated presentation may - in particular - be of use in the case of pressed application.

Granulation conditions have been found, and illustration of material (ONTALITE) prepared is shown (figures 2 and 3).

Figures 2 (left) and 3 (right)

3.3-ONTALITES

ONTALITES name refers to compositions containing NTO and TNT mostly; but they may also contain additional materials like wax, or other explosives like RDX in order to tailor the composition to the forecast application.

Main known compositions are ONTALITE 50/50 and 65/35, even if other compositions like NTO/TNT 40/60 [13] or 60/40 are also known and more or less characterized.

We will focus on NTO/TNT 50/50 and 65/35.

Main characteristics of those two compositions are reported in table 3.

Table 3

Composition	density	VoD	Critical diameter	PCj	
NTO/TNT 50/50	1.71	7370	22.5-25.5	22.6	[14]
NTO/TNT 65/35	1.80	7810	17.8-20	25.9	[11]

In order to measure the impact of addition of RDX (in order to tailor performance, critical diameter and sensitiveness), computation using CHEETAH version 2 have been performed, and results are reported in table 4 for the three compositions based on ONTALITE 65/35 with replacement of NTO by RDX to 5 and 10% extend. CHEETAH V 2.0

utilises traditional Chapman-Jouguet thermodynamic detonation theory to predict performance of new explosive compositions.

By comparison CHEETAH calculated figures for pure TNT, Composition B and NTO/TNT are also reported in table 4.

All the results reported are on the basis of the TMD (theoretical maximum density).

Table 4

Composition	density	VoD	PCj	Energy at infinite Eo	Energy at V/V0=2	Energy at V/V0=7
TNT	1.654	6886	19.57	0.0803	0.0414	0.0555
Composition B	1.727	7942	27.13	0.0956	0.0556	0.0725
NTO/TNT 50/50	1.773	7630	24.7	0.0815	0.0477	0.0616
NTO/TNT 65/35	1.812	7885	26.49	0.0824	0.0498	0.0636
NTO/TNT/RDX 60/35/5	1.807	7908	26.70	0.0829	0.0505	0.0646
NTO/TNT/RDX 55/35/10	1.802	7930	26.90	0.0841	0.0512	0.0655

From the results, NTO/TNT 50/50, may be a solution to replace TNT, the composition NTO/TNT/RDX 55/35/10 is at a level of energy close to that one of composition B.

The different compositions have been prepared for the determination of their critical diameter.

The method used for the critical diameter estimation to a first approximation is the classical stepped cylindrical charge. The compositions have been casted in home made moulds prepared via a 3D printer. The system builds three–dimensional parts by extruding a bead of ABS plastic through a computer-controlled extrusion head, producing high quality, strong and durable parts that are ready to use immediately after completion (figure 4 for illustration).

Then compositions have been poured at 95°C under atmospheric pressure.

Figure 4

The results obtained are given in table 5.

Table 5

Composition	Step Diameters (mm)	Critical diameter (mm)
NTO/TNT 65/35	40,35,30,25,20	20-25
NTO/TNT/RDX 60/35/5	35,30,25,20,15	10-15
NTO/TNT/RDX 55/35/10	25,20,15,10,5	10-15

Result for NTO/TNT 65/35 is close to that one (17.8-20mm) of the literature [11].

Additional measurements are required to distinguish the difference of critical diameter in between compositions with 5 and 10% RDX added. Nevertheless, and as expected, addition of RDX allows a reduction of critical diameter, and a slight increase of the performances of the composition.

Further characterization of these compositions is ongoing - especially regarding sensitivity level (gap test, etc..), and corresponding available results will be presented.

3.4-Aluminized ONTALITES

Aluminized ONTALITES name refers to compositions containing NTO, Aluminium and TNT mostly; but they may also contain additional materials like wax, or other explosives like RDX in order to tailor the composition to the forecast application.

Main known compositions are those developed by US Air Force like AFX 644 and 645 [15], even if other compositions like XF 13333 [16] are also known. Main characteristics are given in table 6, in comparison with Tritonal.

Table 6

Composition	density	VoD	Critical diameter(mm)	PCj	
Tritonal	1.793	6520 (d=1.69)	18.3	18.0	
40/30/20/10*	1.71	6820	51-63	20.4 (calc.)	[15]
48/32/12/8	1.63	6830	57.5	19.0 (calc.)	
48/31/13.5/7.5	1.754	7150	<60	22.4	[16]

*AFX 644 improved vacuum mix, ambient cast

In order to measure the impact of addition of RDX (in order to tailor performance, critical diameter and sensitiveness), computations using CHEETAH version 2 have been performed, and results are reported in table 7 for the three compositions based on Aluminized ONTALITE NTO/TNT/Aluminium/Wax 40/30/20/10 with replacement of NTO by RDX to 6 and 12% extend.

By comparison CHEETAH calculated figures for Tritonal is also reported in table 7.

All the results reported are on the basis of the TMD (theoretical maximum density).

Table 7

Composition	density	VoD	PCj	Energy at infinite Eo	Energy at V/V0=2	Energy at V/V0=7
Tritonal TNT/Al 80/20	1.793	6296	18.11	0.1308	0.0556	0.0725
NTO/TNT/Al/Wax 40/30/20/10	1.744	6606	17.37	0.1108	0.0429	0.0609
NTO/TNT/Al/Wax/RDX 34/30/20/10/6	1.738	6637	17.57	0.1122	0.0436	0.0620
NTO/TNT/Al/Wax/RDX 28/30/20/10/12	1.733	6667	17.78	0.1135	0.0444	0.0631

From the results, replacement of part of the NTO by RDX improves slightly the performance of the composition to a level close to that one of Tritonal, for the composition with 12% of RDX.

The different compositions have been prepared for the determination of their critical diameter. Results are given in table 8.

Table 8

Composition	Step Diameters	Critical diameter
NTO/TNT/Al/Wax 40/30/20/10	/	51-63 (at d=1.71) [13]
NTO/TNT/Al/Wax/RDX 34/30/20/10/6	50,45,40,35	45-50
NTO/TNT/Al/Wax/RDX 28/30/20/10/12	45,40,35,30	40-45

As expected the critical diameter is reduced by replacement of part of the NTO by RDX.

Further characterization of these compositions is ongoing, - especially regarding sensitivity level (gap test, etc..) and corresponding available results will be presented.

4-Way forward

In the course of replacement of standard compositions by Insensitive ones to cover IM needs, alternative melt cast solutions based on NTO as explosive have been studied.

Two types of compositions: ONTALITES (NTO/TNT based compositions) and Aluminized ONTALITES (NTO/TNT/Aluminium based compositions) have been considered.

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As crystal size distribution and crystal habits are important parameters to access high NTO content, an improved quality of crystallized NTO has been prepared.

Because NTO is soluble in water, standard granulation process is not possible and a dedicated granulation process has been developed.

In order to tailor the composition to the planned application, one parameter is the NTO content, and as shown 65% NTO leads to a more powerful composition than 50% NTO.

The other parameter studied is the replacement of part of NTO by a nitramine.

Based on results obtained so far, and as already shown for pressed compositions [17], tailoring of the energy, and reduction of the critical diameter by replacement of part of the NTO by RDX has been shown to be effective.

RDX has been chosen for cost issues, but if more energy is requested, RDX may be replaced by HMX.

Further characterization of evaluated compositions is ongoing, and of major interest will be to check if insensitivity is not affected too much by replacement of part of the NTO by RDX, and the best answer will be with the evaluation at ammunition level.

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