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GUNTONAL- an Insensitive Melt Cast for Underwater Warheads

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Summary and conclusion

GUNTOL is a family of new high explosive compositions for melt cast with TNT as the melting ingredient and the relatively new explosive FOX-12 as a crystalline filler. Extensive water gap testing clearly shows that these compositions are amongst the most insensitive towards shock when compared to other alternatives discussed in connection with Insensitive Munitions. This is due to the presence of FOX-12. FOX-12 is one of the most insensitive explosive described in the open literature that at the same time has a detonating pressure matching military explosives.

The raft at Muskö from where the underwater performance for a GUNTONAL filled torpedo charge was tested for the first time

The performance in GURNEY tests for GUNTOL was presented at previous NDIA meeting 2008 in Tucson and was found to match or be better then alternative IM fills. This paper will present underwater test of a torpedo warhead filled with a composition based on GUNTONAL (GUNTOL with Aluminum). A warhead filled with conventional melt cast composition HBX-1 was used as a comparison. The test clearly shows that the shock wave from the collapse of the bubble where significantly larger for GUNTONAL.

The new formulations described here offers at the same time a performance and a sensitivity which may match standard PBX’s and conventional explosive compositions. This is valid for fragmentation as well as for underwater applications.

GUNTOL and GUNTONAL

Compositions with TNT as the melting ingredient in the casting process, is still the most widely used explosive fill in large calibre gun shells, bombs, mines and torpedoes, due to existing of widely spread of infra structure for melt cast. The compositions could be TNT itself. When enhanced performance is needed PETN, RDX or HMX is added as solid fillers. One disadvantage with these compositions is the sensitivity which will not meet the requirements for Insensitive Munitions (IM).

Dinitroanisol (DNAN) has recently been proposed as a less sensitive substitute for TNT. However, even if the sensitivity is low for DNAN its poor performance is a limiting factor for most application. It is also a more expensive alternative, since TNT is very inexpensive.

GUNTOL is the name of melt-cast compositions with the principal ingredients FOX 12 (Guarnylureadinitramide) and TNT. TNT is the component that is melted in the casting process and forms a matrix when solidified with FOX-12 as crystalline filler. Other detonating ingredients in GUNTOL could be HMX or RDX when extra performance is preferred. By adding wax or other inert components the already low sensitivity towards shock can be further reduced. GUNTOL can also contain HNS to improve the crystal structure of the TNT. HNS will drastically reduce the risks for cracks by making the macrostructure more amorphous. Also additives to reduce the exudation from the TNT are preferred. The additives to improve the TNT cast have a long record in conventional compositions from Eurenco Bofors.

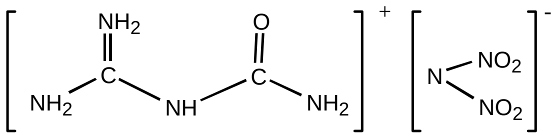
GUNTONAL is a GUNTOL where Aluminum has been added to increase the heat and the duration of the shock which is a desired property for a charge used in a torpedo or a underwater mine.

The naming GUNTOL and GUNTONAL is an analogy with the conventional melt cast compositions HEXOTOL (composition B), OCTOL or HEXOTONAL (HBX, Torpex). It signals the important fact that they can be used in the same filling stations without any extra investments in the melt cast plants that exist today. This is also valid for demilitarization where the new composition can be melted out from the war heads with the existing plants.

All GUNTOL and GUNTONAL compositions are castable with a viscosity in the same order as conventional melt cast compositions. Also the same quality criteria for mechanical integrity can be applied.

FOX 12

General



FOX 12 is the principal component in GUNTOL. FOX 12 is also named GUDN and has the formula $C_2H_6N_7O_5$ and the CAS number 217464-38-5. The molecule dissociates as a salt in water solution and is represented as a salt. However, the solubility is limited to 2 % at room temperature. The low dissociation in water is reflected in its stability to humidity and the fact that it is non-hygroscopic in contrast as other dinitramide salts such as ammonium dinitramide (ADN) or salts or nitrate such as ammonium nitrate (AN). It has also been shown to have a thermal stability making it suitable in any military application. The chemically compatibility with the other ingredients used in the compositions described in this study has rigorously been tested and in all cases established. Physico-chemical properties that we know today are listed below.

Mol weight: 209.12
Decomposition gases: 3½ N_2, 3½ H_2O, 1½ CO, ½ C
Gas moles produced: 40.63 moles per kg
Density: 1.74
Enthalpy of formulation: -85 kcal/mol
Melting point: Decomposes
Decomposition temperature: 212-215°C (DSC)
pKa: 11– 12 (for guanylurea)
Heat of explosion: 1300 – 1400 J / g (DSC)
Caloric value: ~ 835 cal/g
Burn rate: r = 1,52 p0,69(r is burn rate in mm/s and p is pressure measured in MPa)
Burn rate exponent does not change with particle size within 5-50 microns
Water solubility: ~ 5 g/l 20°C ~30 g/l 60°C
Hygroscopicity: None
Friction sensitivity: >353 N (BAM)
Impact sensitivity: >180 cm / 5 kg = 88 J (ERL)
Electric spark discharge: > 3125 mJ (BAM)
Spark test: No ignition
Ignition temperature: 200 – 225°C
Detonation velocity: 7870 m/s(@1.66 g/cm^3
Koenen test: 2mm
Detonation pressure: 26GPa (Calculated from steel tube test and valid at theoretical density, 1.74 g/cc)

Sensitivity for FOX 12

FOX 12 does not respond with explosion in any of the standard methods. The highest energy produced with the fall hammer (ERL) is 90 J (2m, 5kg) but still there is no explosive response. This could be compared with for example RDX which has a threshold for reaction at around 4J. This shows that GUDN is a very mechanically insensitive explosive, compared to those reported in the open literature, and with a performance that matches military needs.

Explosive properties for FOX 12

Even though FOX 12 is extremely insensitive it is an explosive that can be detonated if confined and boosted with a large charge. 300gram Plastic Explosive detonated the pressed FOX 12 It did not detonate when a 60gram booster was applied which, as the fall hammer result, also reflects the unique insensitivity towards shock. The detonation velocity was measured to 7870 m/s (pressed density of 1.66 g/cm^3) in a Steel Tube Test with the inner diameter of 60 mm. From the high speed pictures taken in the Steel Tube Test the detonation pressure was calculated to 26 GPa (1.74 g/cm^3). This is between the values for TNT and RDX.

Experimental results

Gurney

What is the performance of an explosive? This question has a different answer depending on the application. The energy of detonation is of course a parameter of relevance. It is thermodynamically and experimentally well defined. The problem is that only a fraction of the detonation energy is adequate for the performance of a warhead. In fragment munitions it is the fragmentation and the kinetic energy for the fragments that is of interest. Only a part of the total energy will be used for this. A significant part of the total energy will instead be released as heat. How the total detonation energy is dissipated into different forms is difficult to predict without doing tests specially designed for different applications.

The straight forward way would of course be to perform live tests with the explosive in the munitions in question. This would be tremendously expensive and time consuming for optimizing an explosive composition involving 4 or 5 components as we have in GUNTOL. A more rational method is to use the GURNEY test. In this test a charge is detonated inside a Cupper tube. The vertical acceleration of the Cupper is calculated from the images taken with a high speed camera. This acceleration correlates with the detonation pressure. It is also a valid assumption that it correlates with the performance in a Burst Yard Test where the number and kinetic energy of the fragments are studied for a specific warhead. This test is relevant for warheads with fragmentation or shaped charges.

Four tubes where filled with GUNTOL by melt casting by NAMMO in Sweden and sent to WIWEB for the GURNEY test.

The results are listed in the table below. Sample 14-16 are the tubes filled with GUNTOL and 17 filled with GUNTONAL. The samples 1-13 where tested earlier at WIWEB and are listed as a comparison.

Sample	Composition	RDX %	HMX %	TNT %	Al %	FOX-12 %	Binder %	Gurney
1	PBXN 109	65	0	0	15	0	20	1.88
2	PBXN9		92				8	2.4
3	RDX/Binder	92					8	2.22
4	RDX/Binder	86					14	2.33
5	RDX/Binder	88					12	2.38
6	RDX/Al/Binder	67			18		15	2.03
7	PBXN5		95				5	2.43
8	PBXW11		96				4	2.46
9	RDX/Binder	96					4	2.4
11	HMX/Al/Binder		55		33		12	1.9
12	RDX/Binder	88					12	2.42
13	RDX/Al/Binder	70			20		10	2.18
14	GUNTOL			55		45		2.07
15	GUNTOL w RDX	25		40		35		2.31
16	GUNTOL w HMX		25	40		35		2.44
17	GUNTONAL w RDX	15		35	15	35		2.23

PBXW11 and PBXN5 with the highest loading of HMX (96 and 95%) also have the highest Gurney velocities of 2.46 and 2.43. GUNTOL with RDX and HMX has a higher Gurney value than GUNTOL without nitramines. Adding HMX results in a higher value than adding RDX do. In the GUNTONAL, when RDX is substituted for Aluminium, the value decrease. All results are expected from general experience from the ingredients and confirm the validity of the test itself.

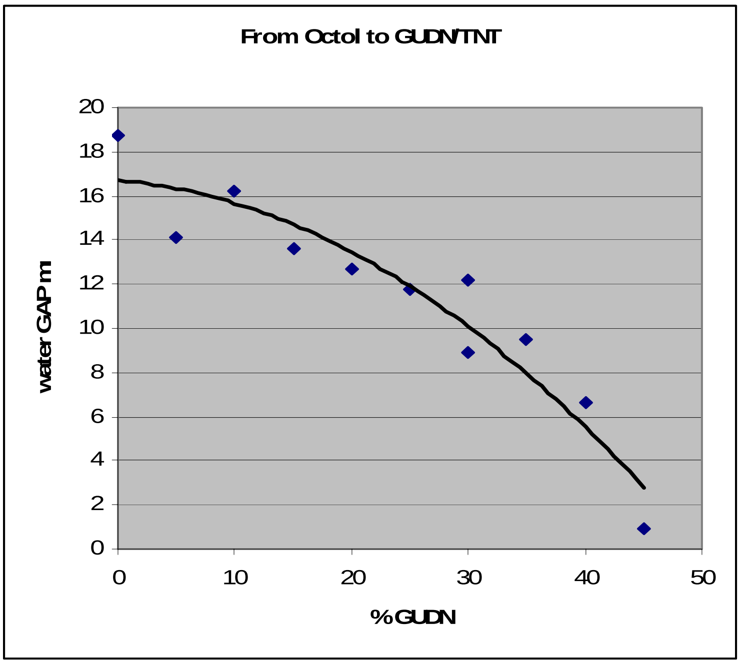
It is a fact that the Gurney values for the GUNTOL compositions can be compared to the values for standard PBX compositions. When RDX, and even more so HMX is added the values are in parity for the values for HMX based pressed PBX compositions such as PBXN-9 which contains as much as 92% HMX. The aluminium containing GUNTONAL (17) has a significantly higher value then PBXN 109 (1). This is an interesting comparison since both compositions are aimed for torpedoes or underwater mines It should also be noted that there exist improved PBX formulations such as B2211D and B2258 from Eurenco for torpedoes.

Water Gap Test

The water gap test is well defined in STANAG 4488 method A. In this test the threshold distance for transfer of a detonation from a donor charge thru a gap of water is determined. The donor is a pressed charge of wax-flegmatized RDX. The test results are listed in the table below (some of these results where published at the previous NDIA meeting in Tucson, 2008). The last six samples where tested at WIWEB. All other tests have been performed at then Ballistic Laboratory at EURENCO Bofors. The threshold pressures for detonation which are listed in the right column are interpolated from the table of water gap versus pressure published in the STANAG 4480. However, the pressure is only published for gap values larger than 7mm. Some gap values in this study are lower than this. Instead we then obtained the pressure by using a Large Scale GAP result on sample 10 done earlier at WIWEB. In this test the gap was determined to 31mm corresponding to a pressure of 59 kbar according to STANAG 4488.

Sample	Composition	FOX 12	TNT	HMX	Inert	Al	Gap mm	P kbar
1	Octol	0	30	70			18.7	19.9
2	GUNTOL	5	34	61			14.1	28.1
3	GUNTOL	10	38	52			16.2	24.1
4	GUNTOL	15	41	44			13.6	29.2
5	GUNTOL	20	43	37			12.7	31.9
6	GUNTOL	25	46	29			11.8	33.5
7	GUNTOL	30	48	22			8.9	42.5
8	GUNTOL	35	51	14			9.5	44
9	GUNTOL	40	53	7			6.6	50.0
10	GUNTOL	45	55	0			0.9	59
11	GUNTOL	30	40	30			12.2	32.6
12	GUNTOL	35	35	15		15	4.4	52
13	GUNTOL	45	35	10	10		0	70
14	GUNTOL	45	45	5	5		0	70
15	GUNTONAL	45	35	5		15	3.4	54
16	GUNTONAL	35	35	15	7.5	7,5	3.5-5.7	53.7
17 (W)	GUNTOL	40	35	25			11	35.5
18 (W)	KS32 (PBX)			84	16		10	39
19 (W)	PBXN110			85	15		10.2	40

The first 16 tests where performed at EURENCO Bofors and test 17-19 at WIWEB.



To the left is a graph of the GAP result versus the content of FOX 12 going from Octol to composition 10 which is GUNTOL without HMX.
As can be seen in the diagram to the left there is an unambiguous relation between the content of FOX 12 and the water gap. A polynom with quadratic terms had a fit with a standard deviation of 0.9.

Since both laboratories rigorously followed the test set up described in the STANAG we can compare our results for GUNTOL and GUNTONAL with gap values obtained on other types of compositions determined by WIWEB. This assumption is reassured by the fact that sample 17, tested at WIWEB, has a value that could be expected by interpolating between the values obtained at Eurenco Bofors.
Test 18 and 19 where earlier made at WIWEB on two PBX:s with insensitive HMX from Eurenco Bofors. The gap values of 10mm are good for a PBX with such a high loading of HMX. It compares to a GUNTOL with 25 % HMX. The GURNEY value for this GUNTOL is 2.44 which in turns compares to PBXN-9 that has the

GURNEY value 2.4. The HMX content in PBXN-9 is as high as 92%. It is therefore reasonable to assume that a GUNTOL with the same sensitivity has a higher performance than a HMX based PBX.

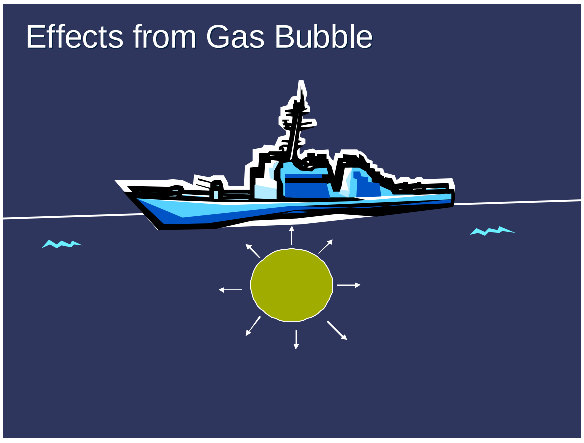
Underwater test of GUNTONAL

In an underwater detonation the effect of the fragments from the warhead has a very limited or none tactical value. The GURNEY values measured above are therefore not relevant for prediction on how an explosive composition would perform for example in a warhead of a torpedo.

In a detonation under water part of the total energy is released as mechanical work when the gas from the detonation forms a bubble under the water. This energy is called the Bubble Energy (EB) and can be viewed as the product between the water pressure (P_w) and the maximal volume of the bubble (V_b):

$$BE=P_w*V_b$$

In a well designed charge for underwater detonation BE is a significant part of the total detonation energy. Since water is incompressible the bubble pushes a radial wave of water. This wave of water can cause significant structural damage on nearby ships. This is often the most important tactical effect for a torpedo or an underwater mine.



P_w is only dependent on the depth for the detonation. Hence, highest BE is obtained by maximizing the volume of the gases. This can be done by increasing the number of moles gases or the temperature of the gases. The common way is to increase the temperature by adding Aluminium powder to the composition since a tremendous amount of heat is released when Al_2O_3 is formed. Underwater charges are traditionally made by adding Aluminium into melt cast compositions. Hexotonal is a family where Aluminium has been added to TNT and RDX. One of them is HBX-1, defined in MIL-E-22267. It is widely used in torpedoes. A torpedo or sea mine filled with HBX-1 will most likely fail in most of the IM tests. On bases of what we have learned above from FOX-12 based compositions it is more likely that the same torpedo filled with GUNTONAL would pass an IM qualification, of coarse more trials are necessarily to prove if this is the case.

The purpose with the test was to find out if the FOX-12 containing GUNTONAL could match the BE released from a charge of HBX-1. FOX-12 has a better oxygen balance than the RDX in HBX-1 which is a good circumstance. On the other hand FOX-12 creates detonation gases of lower temperatures than RDX that might be a disadvantage since Aluminium needs a high temperature to start burning.

A full scale test, involving live warheads for a torpedo[1] was performed at FOI:s Underwater Test Range at Muskö outside Stockholm in Sweden. The water depth in the test reservoir is 40m which is a necessary depth for this size of charges. Theoretically the reservoir allows a

[1] The size of the charge is confidential

bubble with the diameter of 40m as the charge is placed at mid depth. The booster charge where 250gram of plastic explosive composition, Composition O4, containing 86% HMX.

This test is expensive since they involve many people at the testing range. Therefore only one composition of GUNTONAL was tested. The two warheads, including the reference with HBX-1, where filled at NAMMO Sweden melt cast plant.

The composition of the two charges is shown in the table below. The Aluminium used in the GUNTONAL was H-10 obtained from Valimet with a medium particle size of 12.5 micron.

Composition	FOX 12	TNT	HMX	RDX	Al	Wax lecithin	Bubble Energy MJ/dm^3
HBX-1		40.4		37.8	17.1	4.7	4.64
GUNTOLAL	30	40	10		20	0	5.57

As can be read from the table the Bubble energy per volume unit is 20% higher for GUNTONAL than HBX-1. This is a significant difference.

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