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CURRENT TRENDS IN DEVELOPMENT OF MILITARY EXPLOSIVES

Marcin NITA*, Radosław WARCHOŁ*

* *Military Armament Technical Institute*
e-mail: nitam@witu.mil.pl
e-mail: warcholr@witu.mil.pl

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Abstract:

The paper includes and presents available information on the modern explosives tendencies, including insensitive explosives of very good detonation, low-melting, and thermobaric parameters. It presents information on newly created explosive substances with selected characteristics, as well as these already well-tested and introduced to the use.

Keywords:

explosive compositions, detonation parameters, insensitive secondary explosives

INTRODUCTION

The first explosive, well described by the literature, was black powder. Despite its low detonation energy, it had revolutionized and changed the face of the battlefield ever since [1]. The black powder was used to fill the bomb and grenade shells, was the propellant charge for throwing metal and stone bullets, was the propellant for the first rockets. Since its inception in 13th century in Europe, its composition has not changed significantly, and is still often used. Despite above mentioned detonation characteristic [7], it is currently used to produce pyrotechnic materials, fuses or fire impulse conductors.

One of the milestones in the history of explosive development was invention of nitroglycerine by Ascanio Sobrero, and creation of the ignition fuse in 1867 by Alfred Nobel

[14]. Mastering the methods of production of high energy explosives and the development of effective method of ignition, have increased the utility of the high energy solutions on the battlefield. A continuation of the search for new explosives, brought the invention of additional powerful secondary explosives, such as: picric acid, TNT and hexogen.

Relentless search for new explosive substances of more and more favorable detonation parameters and increased stability, remain until today. Currently developed secondary explosives should have meet the following standards: detonation velocity higher than 8500 m/s, not detonating during heating process inside of metallic encasing with opening of diameter equal or larger than 8 mm, thermal resistance to heating up at least to the temperature of 200°C, chemically stable (i.e. ability to be stored for at least 15 years), and compatibility with binding agents and plasticisers, non-water soluble or minimal water soluble, and not significant sensitivity to friction (> 120 N) and shock (> 7 J). Additionally, products of modern explosives decomposition should be environment-friendly, and their synthesis should be highly efficient brining a clean final product [13]. Meeting so many requirements at the time is not easy, thus currently, there are conducted researches focused on creation of explosive solutions characterized by selected properties, demanded from respective weapons. Researchers are interested, among others, in explosives of reduced susceptibility to incidental initiations (so-called insensitive explosives), explosives of very good detonation parameters, of increased blast capability (thermobaric explosives), and these able to melt without decomposition in the temperature of approximately 100°C, and pour into metal containers of weapons when melted [1, 6, 15, 17].

This paper undertaking the attempt to present the current tendencies in military secondary explosives. Hence, in order to accomplish this task, the authors collected and presented information regarding this issue that are available in the literature. Moreover, it presents also examples of solutions and mixtures, proposed and I introduced to use throughout recent decades.

1. INSENSITIVE HIGH EXPLOSIVES

The sensitiveness of explosives is the ability to spontaneous and exoenergetic decomposition affected by the external factor called a initiating stimulus. Friction, piercing, flame, shock, cumulative stream, electric spark etc. are the stimuli needed to initiate the transformation of explosives [14]. A number of research centers undertook an effort to develop an independent explosives that characterizes itself with low sensitivity to the incidental initialization [15]. The results of these researches – the Insensitive High Explosives (IHE) pose less threat during stockpiling and transportation, while simultaneously are of very good detonation parameters. Thanks to that, they are used to a elaboration of the Insensitive Munitions (IM). A degree of “insensitiveness” of such munition is evaluated in accordance with the methods described by the STANAG 4439, such as an observation of its behavior during an intensive heating process, piercing with cumulative stream, fragment and 12.7 mm caliber projectile [16].

Throughout decades the role of the universal secondary explosives of limited sensitivity material group had played TNT (2,4,6-trinitrotoluen). Its great popularity was a result of relative low production cost an low melting temperature, which allowed an elaboration by pouring. Currently however, this material does not meet the requirements described for modern explosives such as IHE-type, both in insensitiveness and detonation parameters [1, 14, 15].

The mixtures of powerful high explosives, such as hexogen (RDX, 1,3,5-trinitro-1,3,5-triazacykloheksan), octogen (HMX, 1,3,5,7-tetranitro-1,3,5,7-tetraazacyklooktan), and CL-20 (HNIW, 2,4,6,8,10,12-hexanitro-2,4,6,8,10,12-heksaazaizowurcytan) with synthetic polymers are characterized often by better parameters than TNT, especially the detonation pressure, while at the same time maintaining low sensitivity to the mechanical stimuli. Such compositions are marked with the PBX name (Polymer Bonded Explosives) (Fig.1).

Fig. 1. PBX explosive type

Source: Own elaboration

The systems that consist of large amount of elastomer have the quality to dump the vibrations, are less sensitive to shock, e.g. they do not detonate being shot through with rifle bullet. The charges that consist of synthetic polymers of greater hardness are easier modeled by machining processing, not creating any more danger of incidental detonation. The mixtures consisting of non-structured resin and high explosives may be combined with hardener just before an elaboration, and therefore, still in liquid form, poured into the shell of the projectile. A hardening of the composition takes from few to several hours, and an effect of shrinking of the explosive is much smaller than those created with the pouring method of melted TNT [1, 19].

The IHE PBX type explosives, that are in practical use, include the ROWANEX 1100 and its aluminized equivalent – the ROWANEX 1400 (Great Britain). They are compositions that the high-energy material is RDX in amounts of 88 and 66% respectively, whereas the binding agent is HTPB (polibutadien with terminal hydroxylol groups). The research conducted in accordance with procedures of the STANAG, ISO, QinetiQ/FST, EMTAP proved that ROWANEX 1100 retains very good mechanical parameters even after aging procedures in increased and decreased temperatures. Charges, cooled down to the temperature of -46°C and placed inside of shell encasing, dropped twice on the steel surface from the height of 2.1 meter, did not revealed any cracks or damages. There is a suggestion to use the ROWANEX 3601 for production of modern detonators. It is a PBX type explosives (it consists of 35% of hexogen, 60% of TATB (2,4,6-triamino-1,3,5-trinitrobenzen) and 5% of Viton A (fluoroelastomer) able to detonate with the velocity 8050 m/s. In Germany was developed an explosives marked DPX 1340 consisting of 96% of octagon an 4% of polymer. Thanks to the small amount of large-particle matter, it can detonate with the velocity of 8620 m/s. It is produced in the process of a desensitization of octagon crystals, not larger than 600 µm [4, 10, 20, 21]. A reduction of sensitivity to the dynamic stimuli of already known explosives could be also achieved by decreasing sizes and shapes of their crystals. It is due to the fact that the smaller the grain, the less there is discontinuations (e.g. crystallographic defects), and thus less number of hot-spots. The explosives of relatively small crystals of close to round shape, and therefore low sensitivity, are designated by the prefix RS (Reduced Sensitivity), for example RS-RDX. A production of such explosives are easier due to the fact that it bases on already known substances. There is only required additional production phase of crystals size and shape change, which usually is achieved through the recrystallization process [1, 20, 21].

The mixture of RDX crystals of size of 200 and 20 µm, were already in use at the end of 1970s and at the beginning of 1980s in the United States for production of new insensitive explosive PBXW-115. This material consists of hexogen, aluminum, ammonium perchlorate, and polyurethane binding agent. Thanks to the low amount RDX (30%) in the mixture, it behaves as the Extremely Insensitive Detonating Substance (EIDS). The contemporary equivalents of PBXW-115 are, among others, FPX7 and FOXIT, which due to the use in their production of explosive substances' crystals of carefully selected shapes, demonstrate even lower susceptibility to an incidental initiation [2, 20].

Next method of insensitive explosives production is a synthesis of totally new explosive compounds that are characterized by required parameters. Good example of such substance is TEX (4,10-dinitro-2,6,8,12-tetraoksa-4,10-diazatetracyklo $[5.5.0^{5,9}0^{3,11}]$ dodekan) [18]. It is an explosive substance of a cage structure, and thus high density. Experimentally measured density of TEX monocrystal is 1.99 g/cm^3. The compound, despite of its negative oxygen balance, detonates with theoretical velocity of 8665 m/s. It is a product of two-phased synthesis conducted in similar conditions to the synthesis of other popular explosive substances. Another explosive material, known before TEX, of extremely low sensitivity to mechanical stimuli is TATB. It is more powerful than TNT and has higher density of its monocrystals (1.93 g/cm^3), and after pressing to the density of 1.8 g/cm^3, it detonates with the velocity of 7350 m/s. Thanks to its unique characteristics, it is often used in nuclear weapons [1, 5].

2. EXPLOSIVES OF VERY GOOD DETONATION PARAMETERS

An intensive research are also conducted in order to a development of explosive compounds of very good detonation parameters (mostly in regard to the pressure and detonation velocity) exceeding those of the hexogen. This group potentially includes the compounds of cage structure of high monocrystal density and the high-nitrate compounds [13, 15].

The main, relevant, representative of the cage-structured compounds group is CL-20. This substance is produced in five crystal forms. The epsilon (ε) form characterizes itself with high monocrystallic density of 2.09 g/cm^3, detonation velocity of 9400 m/s, and decomposes after reaching temperature of 228ºC. All mentioned parameters suggest that this explosive substance will be more in use as a component of PBX type composition, rocket fuel and plastic high explosives. Currently, due to expensive multiphase production process, the vast use of CL-20 is not possible. Some inconvenience poses also high sensitivity of HINW to the mechanical stimuli, which in turn precludes its use in non-desensitized form. The recent publications indicate a possibility to eliminate this fault in the process of co-crystallization of CL-20 with other explosive substances, such as HMX. As the result, the co-crystals are safer to handle, and indicate a satisfactory detonation parameters [1, 5, 6, 15, 17].

The high-nitrate compounds are perspective and largely researched group of explosive substances. They are of interest because of:

- They produce high amount of gas products as a result of a decomposition process,
- Nitrate is the main detonation product,
- According to mathematical analyses, the high-nitrate compounds can have very good detonation parameters, unattainable for classic explosive substances groups,
- Very good detonation parameters of this class of compounds are the results of their positive creation enthalpy.

A comparison of detonation parameters of currently used explosives with theoretical parameters of the high-nitrate compounds are presented in Table 1 below.

Table 1. Detonation parameters of classic and high-nitrate explosives

Explosives	Density, g/cm^3	Detonation pressure GPa	Detonation velocity, m/s
TNT	1.65	18.9	6950
RDX	1.82	34.3	8700
N_4	1.75	77.0	13240

Explosives	Density, g/cm^3	Detonation pressure GPa	Detonation velocity, m/s
N_8	2.15	108.4	14860
N_{10}	2,21	58.0	12080
N_{60}	2.67	196.0	17310

Source: Own elaboration

Unfortunately, the creation of high-energy substances made of exclusively of nitrate, and characterized themselves with appropriate stability, permanence and low sensitivity to the mechanical stimuli, was not successful yet.

The explosive compounds that consist of approximately 80% of nitrate, and might be practically used, are the derivatives of tetrazole. This group includes, among others, HBT (1,2-ditetrazololhydrazine) and G_2ZT (5,5′-azotetrazolate bis(3,4,5-triamino-1,2,4-triazolium)). They are characterized by infinitesimal sensitivity to initiation with mechanical stimuli (respectively >30 J and >108 N, and >30 J and >360 N), and, at the same time, practically insensitive to the electrostatic discharges.

Due to the composition of after-detonation products, mainly nitrate, the HBT and G_2ZT are proposed as environment friendly and insensitive modern explosives [6, 13, 15, 17].

3. LOW-MELTING EXPLOSIVES

The substance that is able to being shaped into the charges by pouring method is called the low-melting explosives. However, the process of melting of the used compounds should be conducted in the temperature range of 80÷100 ºC. The melting procedure should not cause a decomposition of melted compound and should be conducted in relatively lower temperature than its thermal decomposition.

The low-melting explosives enjoy popularity due to their ability to be used to create charges of complicated shapes and big dimensions, as well as to be poured into encasings of small inlet. Finding of appropriate substances is possible among chemical individuals or compositions (mixtures) consisting of, among others, low-melting phase to provide the mixture with appropriate liquidity.

The professional literature often presents information on the low-melting mixtures that could replace the most popular explosive substance used for production of charges with pouring method, meaning the TNT. Pure 2,4,6-trinitrotoluene melts in the temperature of 80,8ºC, and, at the same time, is insensitive to the mechanical stimuli [1, 14, 15].

One of the prospective replacements of TNT offered for practical implementation is the TNAZ 1,3,3-trinitroazetidine). It is a solid body with the melting temperature of approximately 101ºC and low sensitivity to the mechanical stimuli. The detonation pressure of TNAZ is 34.25 GPa, its detonation velocity is 8680 m/s, and density 1.76 g/cm^3.

Its main disadvantage, that precludes it from large scale practical use, is a multi-phase and expensive method of production]1, 15]. A development of new, more efficient ways of the 1,3,3-trinitroazetidine's synthesis would surely increase its popularity.

According to the authors of the patent No. US 2012/0108838 [3], another individual explosive substance, which melts in relatively low temperature and might be used practically, is tetranitrate 2,3-bis(hydroxymethyl)-2,3-dinitro-1,4-butanediol. This compound is a crystalline solid body melting in the temperature of approximately 85÷86ºC. its assumed detonation velocity is 9100 m/s, and detonation pressure 40 GPa. The biggest disadvantage of this newly invented substance is high sensitivity to friction and shock, which is comparable to this of crystalline penthrite (pentaerythriol tetranitrate).

The example of explosive composition that is introduced to common use as the replacement of the Composition B, and consisting only one low-melting component, is IMX-104. This substance is a mixture of 2,4-dinitroanisole (DNAN), 3-nitro-1,2,4-triazal-5-one (NTO) and RDX, and detonates with the velocity of 7400 m/s, and its density is 1.74 g/cm^3. Despite that it indicates an infinitesimal susceptibility to an incidental initiation, it shows one crucial disadvantage, namely it reacts with metals. Therefore, because the majority of munitions have steel shells, before the elaboration of IMX-104 type explosives it is necessary to prepare appropriate coating layers of shell interiors.

A similar case concerns other modern low-melting explosives, such as IMX-101 (replacement of TNT in munitions of 155 and 105 mm caliber), PAX-48, OSX-12 (explosive substance of increased blast power, because of addition of aluminum to its content) [11].

A comparison of TNT parameters with characteristics of modern low-melting, and insensitive, explosive substances is presented in Table 2 below.

Table 2. Results of tests on low-melting and less-sensitive explosives

Explosive substance type	Fast heating	Slow heating	Shot through with projectile	Shot through with fragment	Inition with close detonation of round	Piercing with cumulative stream
TNT*	Detonation	Detonation	Deflagration	Deflagration	Detonation	Detonation
PAX-48**	Ignition or lack of reaction	Ignition or lack of reaction	Ignition or lack of reaction	Lack of data	Ignition or lack of reaction	Ignition or lack of reaction
IMX-104***	Lack of data	Ignition or lack of reaction	Deflagration	Ignition or lack of reaction	Ignition or lack of reaction	Lack of data

Explosive substance type	Fast heating	Slow heating	Shot through with projectile	Shot through with fragment	Initition with close detonation of round	Piercing with cumulative stream
IMX-101****	Ignition or lack of reaction	Ignition or lack of reaction	Deflagration	Ignition or lack of reaction	Completly lack of reaction	Ignition or lack of reaction

Tested in munition: * - M795 155 mm, ** - M934A1 120 mm, *** - M821A 81 mm, **** - M795 155 mm

Source: Own elaboration

4. HERMOBARIC EXPLOSIVES

Thermobaric explosives are characterized by ability to generate a long-lasting high-pressure wave, several times longer than during detonation of classic explosive. Practically this thermobaric effect is achieved usually in two ways:

- By employment of structures consisting of core made of classic secondary explosive, around which is placed a mixture of fuel with oxidant or only fuel, e.g. metallic powder;
- By detonation of specific explosive mixtures of a fixed composition within their entire quantity, e.g. liquid nitrate compounds with metallic powders.

One of the first thermobaric explosive mixtures described by the literature was a composition of mainly magnesium powder and isopropyl nitrate. In order to prevent a sedimentation of powder, there was implementation of various types of thickeners. During preparation of next generation of the mixtures, there were attempts to supersede part of nitrate-compound (nitroester) with crystals of high-energy explosives, e.g. octogen or hexogen. The result of it is a composition consisting of 30% of powdered aluminum, 30% of nitromethane and 40% HMX. Despite its very good detonation parameters, due to the liquid component, this composition was not widely used. Currently manufactured high-energy substances able to generate a long-lasting high-pressure impulses base on solid explosive components. Compositions of such mixtures, offered for use in the British Army, are presented in the Table 3 below.

Table 3. Composition of modern thermobaric explosives

Explosive substance	Composition	Density, g/cm^3
PBXIH-18	HMX/Al/Hytemp/DOA	1.92
HAS-4	HMX/Al/HTPB	1.65
HAS-4 EB	HMX/Al/PCP-TMETN	1.73
PBXIII-135	HMX/Al/HTPB	1.68

Source: Authors' own

As it is shown, all compositions are based on the same explosive substance – octogen. Aluminum is responsible for initialization of a desired explosive substance effect. The change there concerns only the type and amount of phlegmatized/binding agent.

In the work of Nancy Johnson et al, „Evaluation of explosive candidates for a thermobaric M72 law shoulder launched weapon" [9], are presented results of tests of substances both mentioned above, and other, assessing their abilities to generate prolonged high-pressure wave in the close compartments. The published results of research indicate that PBXIH-18 possesses satisfactory characteristics. This substance consists of mixture of fuel (aluminum) with octagon, prepared in advance with the use of Solvent-Lacquering method. The preparation procedure of this explosive substance rely on that a polymer was deposited on the surface of its crystals. A suspension of octagon, in appropriately selected liquid, was used for this purpose, and then a large-particle substance solution was added. Both solvents were not to dissolute the explosive substance crystals or mix with each other. Covering external surfaces of explosives' crystals with phlegmatized agent resulted in decrease of its sensitivity to mechanical stimuli and improved an ability to permanently adhere fuel to the explosives' crystals. Final detonation parameters prepared in this way PBXIH-18, largely depend on the care with which the HMX crystals were coated with polymer and fuel layer. It is vividly visible during a detonation heat measurement of two different samples from various manufacturers (Table 4).

Table 4. Various detonation heats of the same explosive material

Producer	Detonation heat PBXIH-18, cal/g
Holston	-1826
NSWC	-1774

Source: Authors' own

The PBXIH-18 composition indicates number of advantages comparing to the other thermobaric explosives. In particular during detonation in closed compartment of the approximate dimensions of 3.6 x 4.6 x 2.1 meters, it indicates the highest value of the first and second pressure peaks. The high pressure of the following 50 ms is also higher than during detonation of HAS-4 type explosives and charges of secondary explosives coated with aluminum powder or aluminum and magnesium [8, 9].

CONCLUSIONS

The results of available literature analysis show that the tendencies in military secondary explosive development is still in progress, and is more visible in relations to certain narrow groups of explosive substances. It is a result of current demand for specialized explosives that characterize themselves with specific parameters. Therefore, we could observe a dynamic development of secondary explosives, which are employed in very popular insensitive munition (insensitive high explosives). The intensive researches concerned with cumulative phenomenon, reverse cumulative effect and vehicle active protection systems are the reasons behind the search for new explosive substances (explosives of very good detonation parameters). Next optimizations of munition elaboration processes require researching new explosive substances melting in the temperature of approximately 80-100°C (low-melting explosives). An intensive progress in researches on weapons dedicated to engage enemy personnel hidden inside the buildings, is in turn the reason behind researching new thermobaric explosives.

It is important to mention that the process of manufacture of explosives characterized by very good detonation parameters is mainly connected with necessity to design and create totally new chemical individuals. In case of insensitive, low-melting and thermobaric explosives, the situation is different, because they might be manufactured in the process of mixing of classic explosives with appropriate substances.

Analyzing data available in the literature, it can be noticed that there is common tendency regarding all mentioned groups of explosives. It is a strive to create new explosive substances, more powerful than currently in use equivalents, and thus more effective.

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BIOGRAPHICAL NOTES

Marcin NITA, DSc. – is a graduate of the Faculty of New Technology and Chemistry of the Military University of Technology, Warsaw. Since 2012, he has worked in the Military Armament Technical Institute in Zielonka. Currently he is an assistant professor in the Department of Munition Research. He conducts researches on development of insensitive explosive substances. He is co-author of number of Polish and international publications in magazines and post-conference proceedings.

Maj. Radosław WARCHOŁ, MSc. – in 2003, he graduated from the Faculty of Armament and Aviation of the Military University of Technology, Warsaw. He was a director of Department of Munition Elaboration in Stawy. Currently, he is a director of the Department of Munition Research of the Military Armament Technical Institute in Zielonka. He is the author and co-author of number of publications on development and maintenance of munition.

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