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Different Types of Ventilation Systems of Munitions

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Abstract. In the article it is presented the guideline and requirements for construction and technology designing of munition, that allows mitigation and decreasing after effects of stimuli impacting the Insensitive Munition (IM), used in military equipment, i.e. in case of pressure and temperature increase during fire, fast and slow heating, sympathetic detonation, perforation of the munition by a projectile, a fragment or a shaped charge jet. The construction of the IM munition is specified with the use of barriers, ventilation/deaeration of the munition case and double-purpose technology. The features of the active and passive/inert ventilation systems of the IM munition are presented, examples of absorbing energy materials and structure of covers/barriers of a „sandwich" type. Depending on the IM classes of threats and different representative standards and one metric of munition response and technology maturity, there are different consequences of detonation, explosion, deflagration/propulsion, burn, not sustained reaction, etc. observed. Some examples are presented with the use of the shaped-memory alloys or polymers in the Insensitive Munition.
Keywords: ventilation system, insensitive munition, shape-memory alloy

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1. INTRODUCTION

The introduction of new technology to enable munitions and weapon systems to reduce their vulnerability to safety-related hazards and hostile threats requires a means to ensure the suitability and effectiveness of this technology.

Blast, overpressure, fragment spray and heat produced by the munitions as a consequence of stimuli generated by a threat or combination of threats, are considered as the insensitive munition (IM) response. Under some conditions, a very rapid release of chemical energy, for example in projectiles, can cause deflagration, thermal explosion or detonation of the munitions.

The tests are described as follows [1-4]: Fast Heating (Fast Cook-Off) – fast heating is represented by fires with temperatures exceeding 800°C (lasting up to 20 minutes); Slow Heating (Slow Cook-Off) – constant heating rate of 3.3°C/h until the munition reacts and assessment of bullet/fragment impact – reaction of a munition to the bullet/fragment impact stimuli are represented by the 12.7 mm AP bullet and normalized steel fragment impact.

Tests and passing reactions (type III and V) and different reactions (type I-VI) for different threats types are shown in Table 1.

The most effective method leading to the successful IM design is the use of three key elements [1, 2]:

1. The choice of the energetic materials (EMs);
2. The mitigation technologies and design trade-offs integrated in the design of the case and more generally in the inert parts of the munition;
3. The mitigation technologies and design trade-offs integrated in the design of the packaging.

Table 1. Threats, tests and passing reaction, and reaction of insensitive ammunition

<table>
<tr><td>IM classes of threats are relevant</td><td>Threats</td><td>Fuel Fire Such as a truck or an aircraft on a flight deck</td><td>Nearby heat Such as fire in adjacent maga-zine, store or vehicle</td><td>Bullets Such as small arms from terrorists or combat</td><td>Frag-ments Such as from bombs, artillery or IEDs</td><td>Sympa-thetic reaction Such as detona-tion of adjacent stores</td><td>Shaped charge jet RPG, bomblets, ATGMs: combat or terrorists</td></tr>
<tr><td rowspan="3">Standards are representative and one metric of munition response & technology maturity</td><td rowspan="3">Tests & passing reactions</td><td>Fast Cook-Off</td><td>Slow Cook-Off</td><td>Bullet impact</td><td>Frag-ment impact</td><td>Sympa-thetic reaction</td><td>Shaped charge jet</td></tr>
<tr><td>FCO</td><td>SCO</td><td>BI</td><td>FI</td><td>SD</td><td>SCJ</td></tr>
<tr><td>Type V Burn</td><td>Type V Burn</td><td>Type V Burn</td><td>Type V Burn</td><td>Type III Explo-sion</td><td>Type III Explo-sion</td></tr>
<tr><td rowspan="2">Reaction conseq-uence. Affects investment strategy for munition incremental improv-ements & IM science & technology</td><td rowspan="2">Reaction</td><td>Detonation / partial detonation</td><td>Explo-sion</td><td>Defla-gration/ Propul-sion</td><td>Burn</td><td colspan="2">No sustained reaction</td></tr>
<tr><td>Type I/III</td><td>Type III</td><td>Type IV</td><td>Type V</td><td colspan="2">Type VI</td></tr>
</table>

2. THE ENERGETIC MATERIAL SELECTION AND TESTING

Selection of energetic material as insensitive material should take into account [1-4]:

1. cost;
2. performance;
3. ability to being produced (infrastructure availability, supply decisions and off-sets for ingredients);
4. technology maturity (development status, existence of specifications, whether qualified or not);
5. health & safety (environmental considerations, toxicity, etc.);
6. sensitiveness to shock, heat and impact;
7. ageing.

One of the very important safety assessment of the IM munition is conducting the full-scale tests, that:

1. provide a measure of the munition's response to each hazard or threat and enable an assessment to be made of the likely collateral damage from the munition's reaction, which can be used to evaluate the risk posed by the response of the munition;
2. make possible to evaluate or determine the need for appropriate mitigation and risk reduction measures, based on the test results.

The benefits of the IM will accrue in both peace and war: in peace, the lower risk of adverse events occurring and the reduced accident damage will lead to economies in logistics; and during combat, through improved overall effectiveness by improving safety and survivability of weapon systems. The use of IM is very important for the survivability of soldiers, for open battlefield munitions and embedded munitions on platforms (tanks, ships, and aircrafts) [2-13].

The IM testing differs from all other ordnance and munitions safety testing in that the pass criterion for each test most often involves a violent response [3]:

1. For all other safety testing, the pass criterion is no explosive response and the munition is expected to remain safe, either for use or for disposal.
2. For the IM testing, the reaction of the tested munition may range from full detonation to no reaction, but also may include responses with varying degrees of severity between these extremes.
3. The results of the IM assessment process define the IM signature for a munition.

With an out of line system the detonator – the first element in the explosive train – is separated from the next element by a physical barrier until the fuse is armed. Provided that the AOP 20 test D1 is successfully completed it is only necessary to consider the energetic material which is below the barrier. To be an acceptable solution the initiation system has to function under all the required environments and through the full life of the munition, or at least only fail safely and within the required reliability targets. However, to achieve the requirements for the IM the fuse explosive train must be as insensitive to shock as possible and thermal aggression must not result in munition response higher than burning. The key point is that the used explosive has to be suitable to be either ignited or shocked and then to transfer to detonation, while at the same time not being susceptible to accidental initiation from threat environment such as fuel fire, slow heating or handling shocks.

3. MATERIAL SELECTION AND DESIGN PROCESS OF THE IM

The possibilities of developing the mitigation technology of munition can be divided into three types:

1. Barrier technologies aiming at preventing or/and mitigating the effects of the IM stimuli.
2. Venting/de-confining technologies aiming at releasing/preventing the catastrophic build-up of pressure due to the reaction of the energetic material if reaction occurs. The critical parameters for designing a suitable venting system are the rate of pressurization and the rate of pressure release through venting. The venting can be achieved either through the natural disruption of the case (this is for example the case for lightly confined systems that are usually able to break open once the explosive ignites) or the utilization of mitigation techniques (this is for example required for heavily confined casing).
3. Natural venting. Trade-offs need to be made between performance and IM reaction level for the considered case thickness and strength.

The Insensitive Munition related to the advantages and disadvantages of various natural venting technical solutions are presented in Table 2.

Table 2. Comparison of natural venting technological solutions

Type of case	Advantages	Disadvantages
Thick or thin case	Higher shock attenuation Higher protection against impact Lower temperature increase vs. time	Smaller venting after perforation Higher pressure build up Lower critical diameter Higher weight
High strength or low strength case	Higher performance Lower pressure build up (if brittle)	Higher weight
Metallic or non-metallic case	Higher protection against impact Lower cost	Higher pressure build up

Mitigation technologies with the use of venting systems are divided into two types (Table 3):

1. Active systems that rely on the initiation of an energetic device to cut open the case or create sufficient weakness to allow a relatively benign separation at a certain pressure. In these ventilation systems, the high energetic material (or other) is initiated and within milliseconds, at high speed, makes the elements closing vents open. This results from

weakening or movement of the closure elements vents, which makes the case of the projectile, rocket motor, missile shells unseal or open.

2. Passive systems that rely on chemical or physical changes within specific materials to allow the creation of vent holes or the soft expulsion of end plates/closures. In these cases, the opening or creating vents occurs as a result of chemical reactions in solids. Physical reaction resulting in the force which makes the vents open can also occur in special materials, like the shaped memory materials (shaped memory alloys – SMA or shape memory polymers – SMP).

Sometimes the above mentioned technologies can both act as a barrier and a venting system. The IM technology is especially very important in the fusing systems in which the fuse expulsion, fusible plugs, stress risers, frangible joints, SMAs [4, 14-32], venting systems and booster venting holes [1] may be used.

The NiTi alloys – Nitinol, FeNiAl, CuAl, CuZnAl, CuAlNi, CuNiAlZnMn are capable to memorize their initial size and shape, and they may be applied in the munition. The shape memory alloys are commonly used in the housing industry, automobile, aircraft and space industries, biomedicine, etc.

The technology of the shaped memory alloys allows to prevent pressure built-up, with benefits of low/medium cost, medium/high reliability, however with ageing disadvantages.

The ventilation systems (executive systems) can be divided into the following ones:

1. vents in the explosive of a projectile or a booster, in a propellant of a rocket motor, in a powder contained in the cartridge, etc.;
2. elements offloading completely or only reducing stress (e.g. in a detonator/fuse, in a shell of the projectile, etc.);
3. fragile metal or plastic connections (in a detonator/fuse, in a shell of the projectile, etc., in a rocket motor);
4. closures and/or mechanical sealing or resulting from melting of a special easy-fusible material;
5. elements causing displacement of a primer, detonator/fuse, etc.;
6. shape memory materials.

Table 3. Mitigation technologies mechanisms and applications

Techno-logy type	**Mitigation technology**	**Mechanism**	**Applications/ locations**
Barrier	Intumescent paint	Increases the reaction time to thermal stimuli	External casing surface
	Bore mitigant foam	Reduces impact loads from propellant debris	Rocket motor conduit
Venting	Fusible devices (plastics, metals)	Melts at temperatures well below the ignition temperature providing a vent path	Within end closures / caps
	Forward/aft venting plates	Allows pressure release through a large vent	
	Mechanical release	Releases a confining end closure at a pre-determined pressure or temperature	
	Stress riser groove	Allows the case to break open when pressure builds up	External casing surface
	Preferential insulation	Allows the case to fail along an uninsulated or less insulated area	
	Case cutters	Cut through the munition casing at a pre-determined pressure or temperature	
	Bonded structures	Lose mechanical strength at a temperature well below EM ignition temperature during thermal exposure. Under impact loads, perforation of the case creates a large entry and exit hole for subsequent venting. Reduces number of possible hazardous fragments	Casing
	Combustible cartridge case	Allows the case to fail through a thermal decomposition of the casing	
	Pre-emptive ignition devices	Ignites the EM prior to its auto-ignition temperature	Internal
	Vented booster	Prevents pressure build up following the booster ignition	Junction booster / casing
Dual-Purpose	Internal liner	Attenuates shock and bullet impacts and provides a vent path when thermally decomposed	Between energetic material and casing

4. THE EXAMPLE OF THE USE OF SHAPE MEMORY MATERIALS IN THE MUNITION

The examples of the use of the shape memory materials in munition are presented in Figs. 1-3 [18-32].

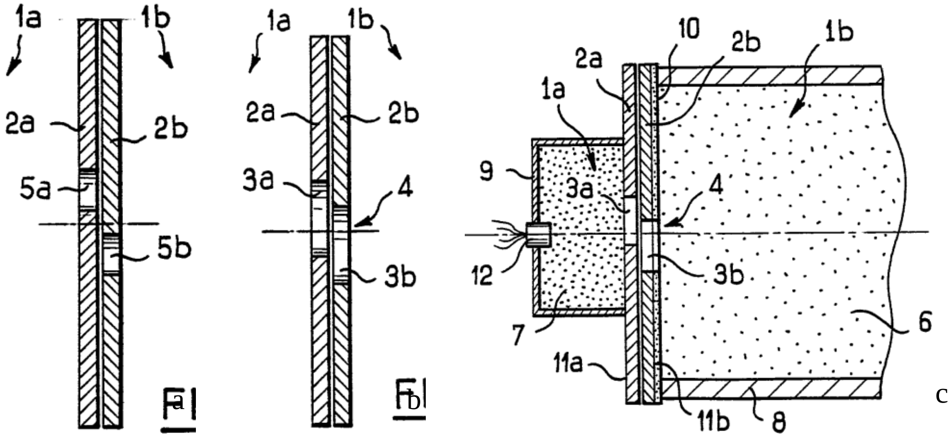

Fig. 1. Temperature-actuated separator for munition – comprises shape memory alloy plates (Cu-Zn-Al; Cu-Al-Ni; or Ni-Ti) with overlapping apertures: a – closed plates, b – opened plates, c – munition [23]

A device for separating two spaces, when a temperature increase above a threshold temperature occurs, has two or more parallel adjacent plates (2a, b) which have openings (3a, b) and which separate the two spaces, at least one of the plates being made of a shape memory alloy Cu-Zn-Al; Cu-Al-Ni; or Ni-Ti) which changes shape at about the threshold temperature (Fig. 1) [23]. When the device is below the threshold temperature, the openings (3a, b) have an overlapping zone (4) and, when the device is above the threshold temperature, the opening in the shape memory alloy plate contracts to eliminate the overlapping zone. In a munition having a main explosive charge (6) in a first space (1b) and a detonator charge (7) in a second space (1a), the novelty comprises provision of the device (A) between the two spaces.

The advantage of this device is used especially as a pyrotechnic safety separator in munitions. It is simple, inexpensive and compact and functions reliably when abnormally high temperatures occur.

The disarming assembly for a cap (5) fitting over an orifice (2) in the body of the munition and held in place by a locking element (8) incorporates at least one retaining member (9) made from a material with a shape memory effect (Fig. 2).

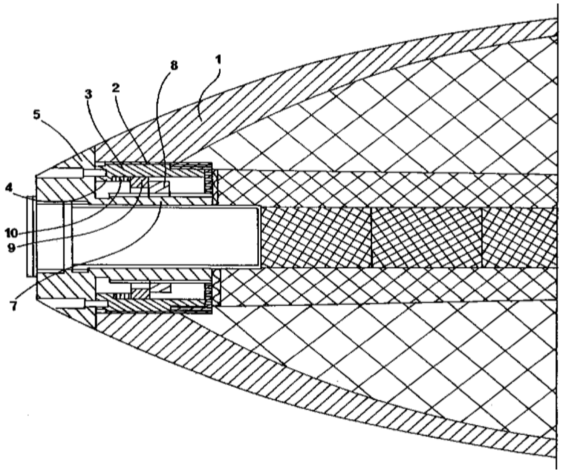

Fig. 2. Munition disarming assembly [24]

The retaining member is made from a nickel-titanium alloy and is actuated by an excessive temperature, e.g. in the event of a fire, releasing the lock, so that the cap is ejected. The locking element (8) is in the form of a nut screwed onto a threaded portion of the cap, and the retaining member is in the shape of a ring between the nut and the body of the munition. The assembly can include an additional ring (10) with a shape memory effect between the main ring and the body.

Behaviour of device which unconfines a charge containing an explosive by employing a deformable element made of shape-memory material is presented at three phases: before, during, and after temperature increase (Fig. 3).

The invention relates to a device which unconfines a charge containing an explosive in the case 5, of the type comprising a sealing plug and a means of fastening this plug, characterised in that the means of fastening the plug comprises a deformable element made of shape-memory material which can successively occupy a blocking position at ambient temperature and an unblocking position when the ambient temperature is greater than a predefined critical value (Fig. 3). According to a preferred embodiment, the sealing plug 3 includes, at its periphery, a deformable clamping ring 1, a guide disc 6 is fixed on to the upper part of the plug 3 and the plug 3 and the guide disc 6 are held by a clamping device 2. An O-ring 4 is used to reinforce the seal.

Different types of Insensitive Munitions with the SMA and SMP are being manufactured, among others, in Picatiny Arsenal Dover [26].

The use of IM (grenades, projectiles, rockets, bombs, reactive armours, etc.) with ventilation systems is very applicative in case of fire on the battlefield, in magazines or during transport for protection against explosion.

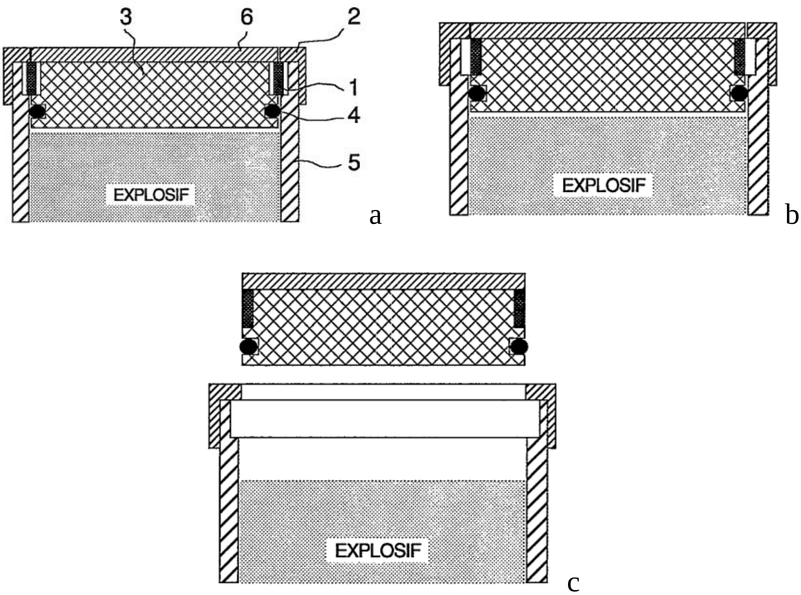

Fig. 3. Device which unconfines a charge containing an explosive by employing a deformable element made of shape-memory material: a – closed device, b – device during temperature increasing, c – opened device [25]

These types of munition are less endangered by its ignition or explosion when a vehicle (train) collides with an obstacle, catches fire and it covers the transported cargo, or in the case of terrorist attack (firing, improvised explosive devices – IEDs).

5. CONCLUSIONS

The use of the described above insensitive munition with ventilation can be summarized as follows:

1. The Insensitive Munition may be precisely assessed with the application of Slow Cook-Off, Fast Cook-Off and bullet/fragment impact (according to STANAG 4297) tests.
2. The ventilation system based on the shape memory materials is very useful for application in the Insensitive Munition as a means of protection against initiation while its burning, impact of fragments and penetration with a shaped charge jet.

3. The special construction of casing filled with propellant or high explosive (with pyrotechnic devices), combined with the shape memory alloys or shape memory polymers may be used in the Insensitive Munition, i.e. shells or projectiles (guns, mortars), rocket motors, bombs, torpedoes, missiles, explosive reactive armours, etc.
4. The SMAs or SMPs used as a ring or a wire intended to shrink on heating, having memory of stretching, may be implemented in the rocket motors, bombs, torpedoes, missiles, and other invented arms.

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Różne typy systemów wentylacyjnych amunicji

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Streszczenie. W artykule zaprezentowano wytyczne i wymagania dotyczące projektowania konstrukcji i technologii amunicji, które pozwalają złagodzić i zmniejszyć efekt bodźca uderzenia w amunicję małowrażliwą (IM) stosowaną w sprzęcie wojskowym, tj. w przypadku wzrostu ciśnienia i temperatury w czasie palenia, szybkiego i powolnego ogrzewania, przenoszenia detonacji, przebicia amunicji przez pocisk, odłamek lub strumień pocisku kumulacyjnego. W konstrukcji amunicji małowrażliwej (IM) pokazano użycie barier, wentylacji/odpowietrzenia obudowy amunicji i technologii o podwójnym zastosowaniu. Zaprezentowano cechy aktywnych i pasywnych systemów wentylacji bezwładnościowej amunicji małowrażliwej, przykłady materiałów absorbujących energię i strukturę pokryć/barier typu „kanapka”.
W zależności od klasy zagrożeń amunicji małowrażliwej (IM) i różnych odpowiednich standardów dla amunicji o długości jednego metra, zaawansowania technologii, obserwuje się różne rezultaty detonacji, wybuchu, deflagracji/napędzania, palenia, niepodtrzymywania reakcji itp. Zaprezentowano przykłady użycia stopów lub polimerów z pamięcią kształtu w amunicji małowrażliwej.
Słowa kluczowe: system wentylacyjny, amunicja o małowrażliwa, stopy z pamięcią kształtu