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DESIGN AND TESTING OF AN UNGUIDED ROCKET WITH THERMOBARIC WARHEAD FOR MULTIPLE LAUNCHER SYSTEM

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Abstract: *This paper presents the development, testing and evaluation of a new unguided rocket equipped with a thermobaric warhead. The aim of the research was to design the ammunition to be integrated with an existing multiple launch rocket system. This condition introduced limitations of dimensions, mass and mass distribution. The experimental work consisted also in optimisation of the thermobaric composition and configuration. The resulting ammunition was tested for determination of effective range and precision. The destructive effect was evaluated by live firing against non-armoured vehicles and masonry light structures.*

Keywords: thermobaric, munitions, blast, energetic materials

1. Introduction

Thermobaric munitions are explosive devices that contain an oxygen consuming substance, disseminated and initiated by a classical condensed explosive. The explosive reaction takes place in two stages, a dissemination phase, when the thermobaric composition is compressed, overheated and disseminated into surrounding air by a conventional explosive and a second phase, characterised by a multi-point deflagration phenomenon in the combustible cloud[1]. The main particularities of this explosive transformation are the following[2,4,5]:

- Multiple stage explosive transformation: anaerobic detonation by redox reactions between molecular species, anaerobic deflagration of carburant species followed by an aerobic deflagration/combustion of unburned species with the surrounding oxygen containing air. This effect causes a high impetus, long duration overpressure wave accompanied by a high thermal output. The use of surrounding oxygen helps in optimising the energetic density of the explosive material, which results in a very high heat of explosion (if purged with oxygen). The second effect of this fuel-air-explosive system is the vacuum effect. The use of oxygen in the explosive transformation causes a negative pressure wave after the overpressure wave causing an overall enhanced destructive effect.
- Formation of explosive cloud: The dissemination of explosive material in a volume of air induces a very large volume of explosion, in the interval of 4000 to 8000 times larger than the volume of the explosive configuration[1,2,3]. This causes a scaled effect and also o reduced shockwave attenuation with distance.
- Heterogeneous explosive mixture: The explosive mixture is a composite material comprising, in most of formulations a powdered high energy fuel, an organic matrix (energetic or non-energetic) and, in some formulations, some oxidizing species.

The most important particular aspect of thermobaric explosives is the enhanced effect inside confined spaces[3,4].

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The disseminated detonable cloud fills the space inside a building/cave/vehicle and when explodes creates a tremendous destructive effectbased on pressure, reflection waves, temperature and vacuum effect.

The scope of the research was to design a thermobaric ammunition to be used with a portable launcher. It is destined for urban warfare, capable of destroying non-armoured vehicles, brickworks buildings and light fortifications.

In the research, we focused on the following aspects:

- Determination of the optimal chemical composition of the thermobaric mixture;
- Determination of the optimal internal configuration;
- Determination of the exterior ballistics, the stability and the precision of the ammunition;
- Verification of the desired destructive effect.

2. Determination of the optimal composition

For the thermobaric mixture we experimented on using a mixture of high energy powders and an organic monopropellant type fuel. We choose to use Isopropyl nitrate as fuel and a mixture of Mg and Al powders for the energy input.Cooper was also evaluated for its explosive performance and polytetrafluoroethylene(PTFE) powder was evaluated as a potential oxidant species.

The Magnesium powder is used in the mixture for the low ignition temperature, being a initiation catalyst for the other powders while the Aluminium powder was chosen because it has the highest energetic density for a relatively accessible material.

The powder dimension and its distribution was chosen in order to obtain high pressure detonation wave but also late aerobic afterburning of the large size particles.

Isopropyl nitrate was chosen as fluid monopropellant based on its moderate volatility, viscosity and acceptable density for an organic liquid. The nitro group from the fuel enriches the oxygen balance of the thermobaric mixture. The density of the obtained material was 1.58-1.6g/cm^3, which was evaluated as satisfactory, being close to pressed TNT.

The fuel powders were analysed by SEM-EDX microscopy in order to determine the purity of the material and particle size distribution. Also, the oxidation of the outer layers of the particles was analysed in order to determine if the oxide layer of Magnesium and Aluminium is thick enough to block the ignition of the particle by its very high melting temperature. Both powders showed a superficial oxide layer which cannot block the ignition reaction, while chemical mapping showed some contamination of the Magnesium powder with particles of Aluminium and Silicon. The contamination cannot be considered in detriment of combustion, the contaminants being combustible powders with high energy content. Figure 1 shows the composition of the Magnesium powder while figure 2 shows the composition of the Aluminium powder. In figure 3, a 1.6g/cm^3 thermobaric mixture is shown. When formulating the composition, the organic fuel was added in order to obtain a low viscosity mixture, that can be easily loaded into the ammunition and also we aimed to obtain a mixture with enough low combustion temperature fuel that can initiate the fuel powder.

The experimental composition were loaded in experimental configurations and tested by using a dissemination condensed explosive. The maximum pressure and impetus was obtained for a mixture of Aluminium-Magnesium- Isopropyl nitrate in a ratio of 2:1:1. The test device consisted of 500g of thermobaric mixture disseminated with 125g of B composition pressed to 1.65g/cm^3

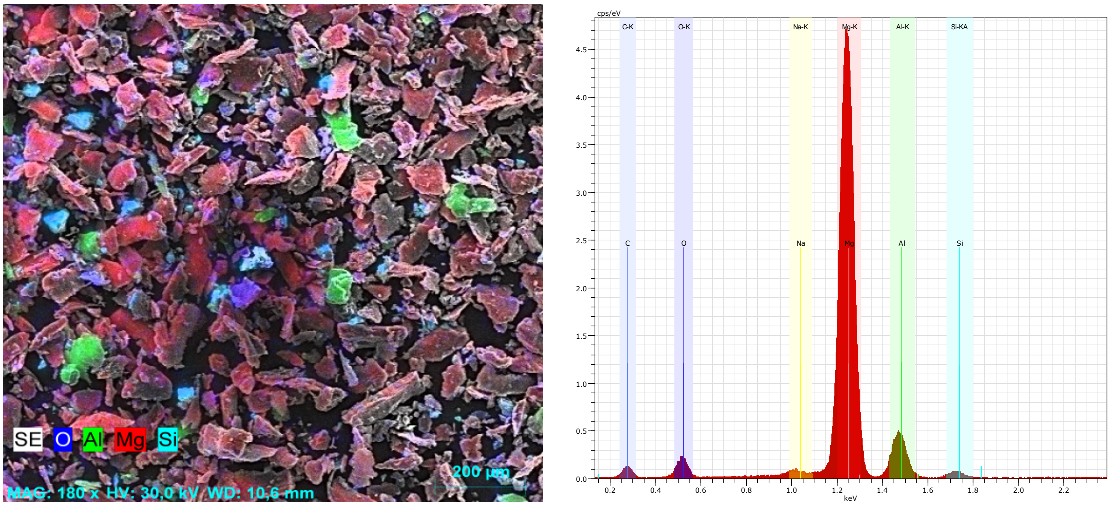

Figure 1: The structure and chemical composition of the Magnesium powder

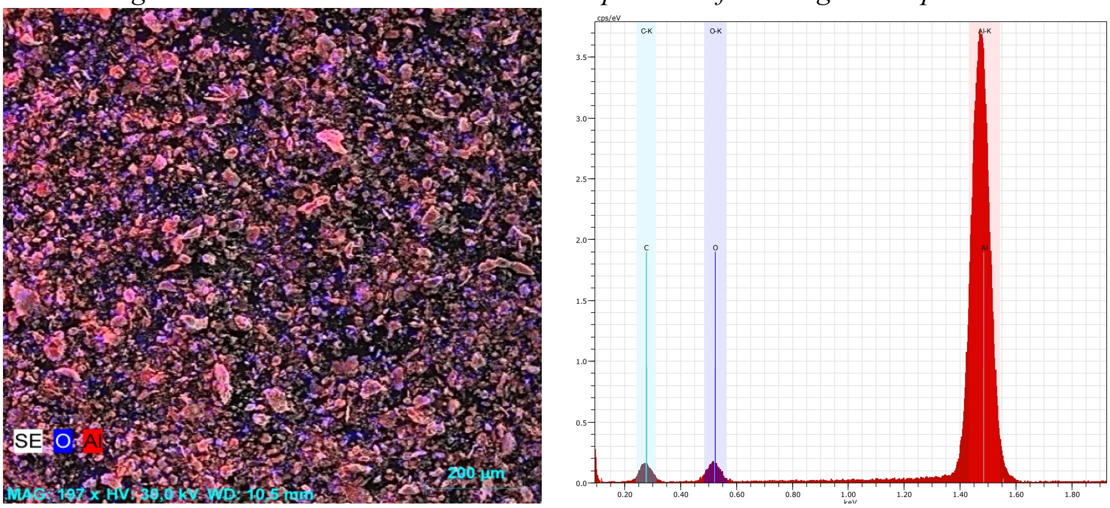

Figure 2: The structure and chemical composition of the Aluminium powder

Table 1 Explosive performance of different thermobaric compositions

Type of composition	Number of devices tested	Maximum overpressure and duration
Al-Mg-IPN 1:1:1	2	Pmax (1,2m) =9.3bar, duration: 46ms
Al-Mg-IPN 2:1:1	3	Pmax(1,2m)=12.1 bar, duration 64ms
Al-Mg-IPN 5:1:2	3	Pmax=7.1 bar, duration 41ms, incomplete combustion
Al-IPN 3:1	3	Pmax=4.6bar, duration 52ms, incomplete combustion
Al-Mg-Cu-IPN 1:1:1:1	2	Pmax (1,2m) =7.3bar, duration: 60ms, higher temperature (Hispeed camera evaluation)
Al-PTFE-IPN 1:1:1	2	Pmax= 11,6bar, duration 71ms, lower temperature (Hispeed camera evaluation)

Figure 3: The aspect of the thermobaric mixture (IPN ratio to low-left, optimal composition- right)

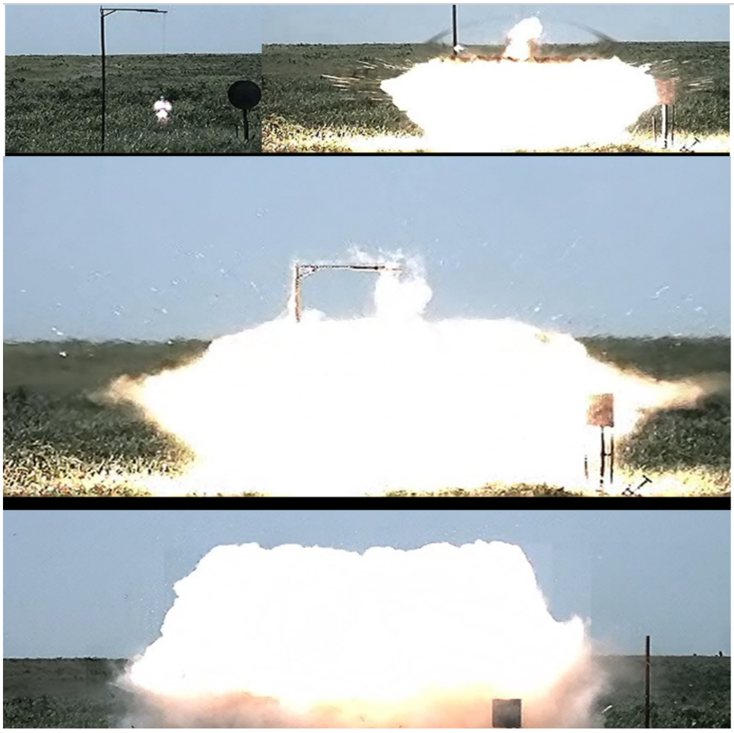

Figure 4: Thermobaric explosion stages: initiation; dissemination-detonation; anaerobic combustion, aerobic afterburning

3. Determination of the optimal configuration

In order to determine the optimal configuration of the warhead, it was important to determine the ratio between the dissemination explosive core and the overall calibre of the warhead. Also, the thickness and the material of the walls has an important contribution to the explosive performance. A test configuration was made, consisting of 500g thermobaric mixture, like shown in figure 5. The wall thickness was chosen to be 2mm, in order to minimise the material resistance but with enough resistance to withstand the launching speeds when used in ammunition. For the test configuration, the external diameter was 60.5mm and the dissemination explosive core varied from 10mm to 16mm and 23mm respectively.

The hight of the cylinder was in all cases 150mm. The dissemination explosive was composition B60 pressed to 1.65g/cm^3. For initiation, a booster of HMX of 22g was initiated with a electric blasting cap. The aluminium walls were of Al SV-EN 6060material. The obtained results are shown in table 2.

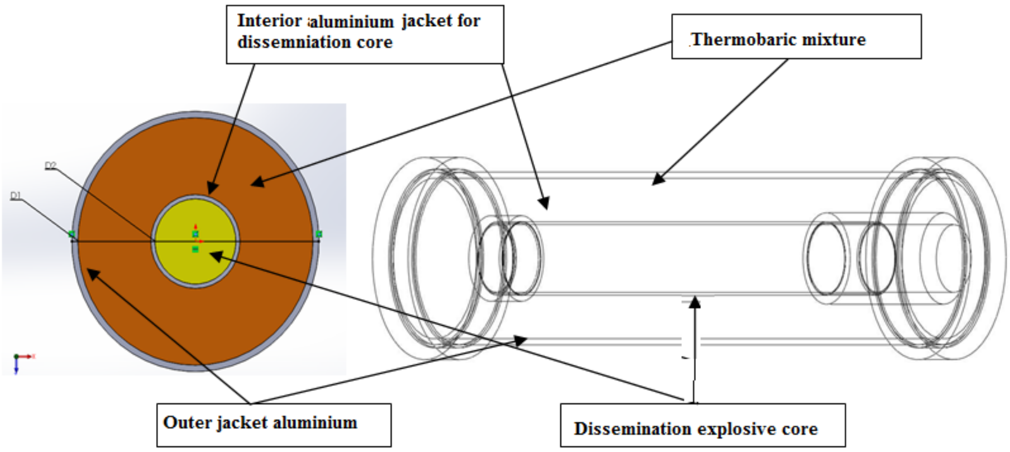

Figure 5: Experimental test configuration for the determination of optimal configuration

Table 2Performance of the experimental test configurations

Test device	Composition	Explosive core thickness	Max pressure (bar)		
			1m	2m	4m
A	Mg-IPN 2:1	23mm	7.97	0.75	0.28
B	Mg-IPN 2:1	23mm	7.512	1.58	0.32
C	Al-Mg-IPN 1:1:1	23mm	9.704	1.71	0.44
D	Al-Mg-IPN 1:1:1	16mm	4.57	0.98	0.29
E	Mg-IPN 2:1	16mm	3.45	0.8	0.22
F	Mg-IPN 2:1	16mm	2.801	0.72	0.21
G	Al-Mg-IPN 1:1:1	10mm	4.47	1.06	0.25
H	Mg-IPN 2:1	10mm	3.73	0.98	0.31
I	Mg-IPN 2:1	10mm	Sensor fault	0.97	0.32

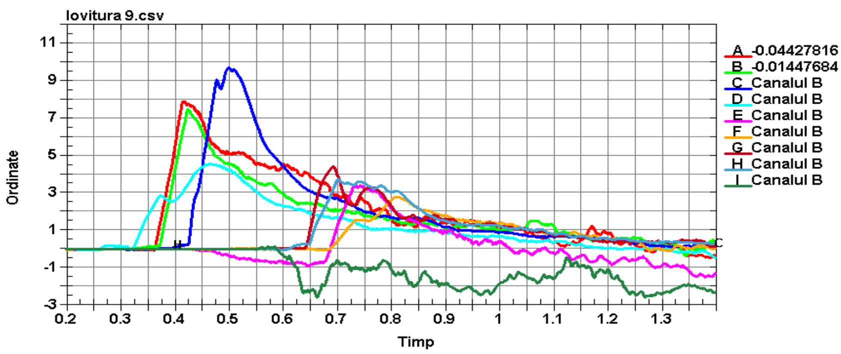

Figure 6: Pressure recording at 1m distance from the explosion epicentre

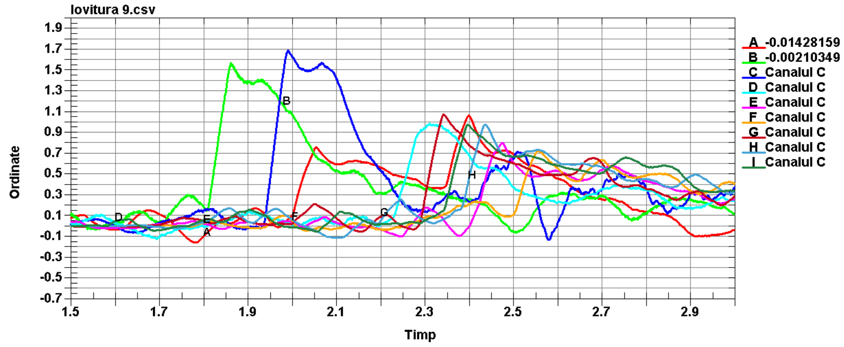

Figure 7: Pressure recording at 2m distance from the explosion epicentre

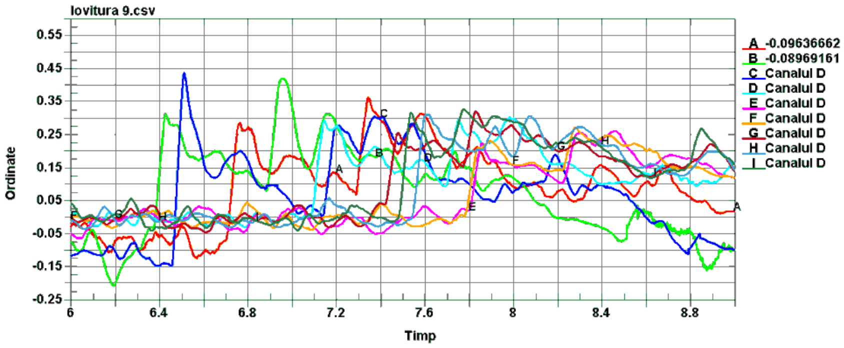

Figure 8: Pressure recording at 4m distance from the explosion epicentre

4. Ammunition design and testing

The design process consisted in choosing an existing armament system and designing the compatible thermobaric ammunition. We chose to use the Romanian Incendiary Grenade Launcher AGI 3x40mm. It is an electrically ignited triple bore 40mm shoulder mounted rocket launcher.

The calibre of the new ammunition was chosen to be 72mm, like the similar PG-2 HEAT projectile. The propulsion system and stabilizer fins and body were inherited from the incendiary ZG-2R ammunition. The electric ignition system was also adopted, in order to have the desired compatibility

Figure 9: Thermobaric rocket TBI loaded in AGI 3x40mm system left and the original PG-2 grenade (right) used as reference in design

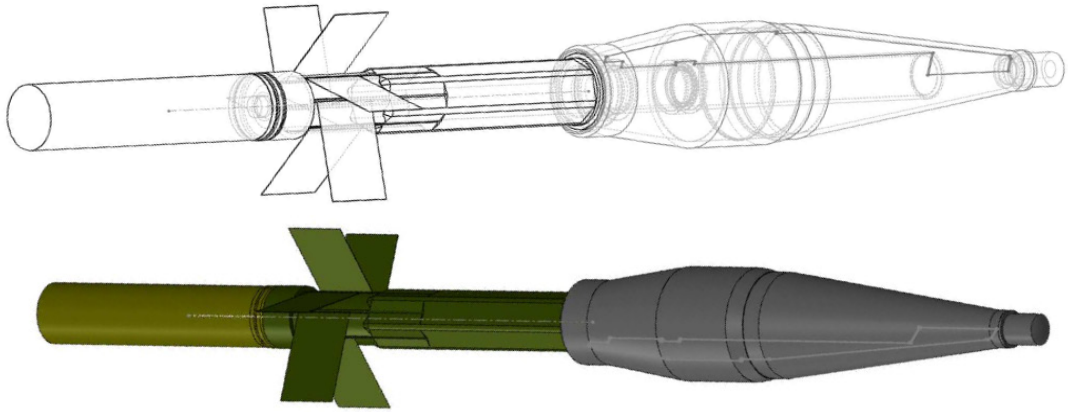

Figure 10: The new design thermobaric grenade for Incendiary Rocket Launcher AGI 3x40mm

Table 3Comparative representation of the dimensional and functional parameters of the thermobaric ammunition and the original ammunition used in AGI 3x40mm

Parameter	Original ammunition	Thermobaric ammunition
Ammunition total mass	1620g	2200-2220g
Mass of the warhead with fuse	1000g	1570-1600g
Stabilizer mass	400g	400g
Propellant cartridge mass	220g	220g
Caliber	72mm	72mm
Total length	360mm	360mm
Ammunition length without propellant cartrige	603mm	603mm
Initial velocity	90-95m/s	70-75m/s
The position of the center of mass from the bottom of the ammunition	30,2cm	33cm
Maximum pressure in barrel at temperature t=50ºC	535kgf/cm^2	650kgf/cm^2

4.1Determination of the initial velocity and acceleration

In order to determine the initial velocity and the acceleration, a Doppler radar was used mounted behind the barrel. The data was necessary both for theoretical calculation of the maximum range and to evaluate if it is possible to use the same fuse as the original ammunition. Some variations can be seen, as a result of propellant charge nature, made of black powder. The acceleration and initial velocity was also recorded using a hi-speed video camera, recording at 2,000 fps. The movement of the grenade was calibrated by marking the distance from the barrel on a concrete wall. The camera was mounted perpendicular on the launcher, at 10 meters away from the wall and 8 m away from the launcher. The mean initial velocity was 72m/s with acceleration of 1500G.

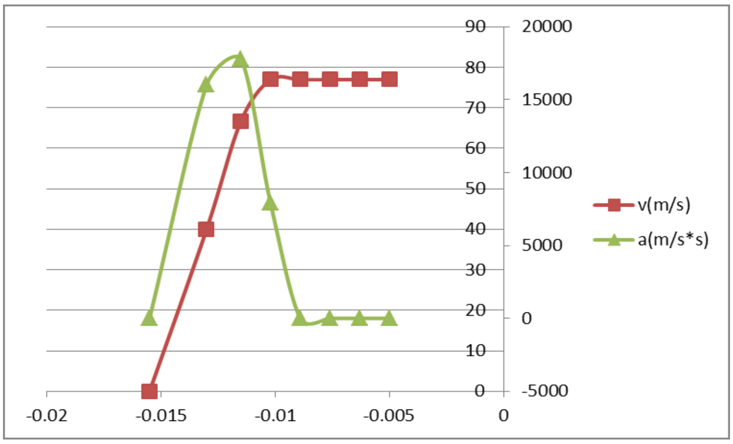

Figure 11: The typical velocity-acceleration curve for the new design acquired with Doppler radar

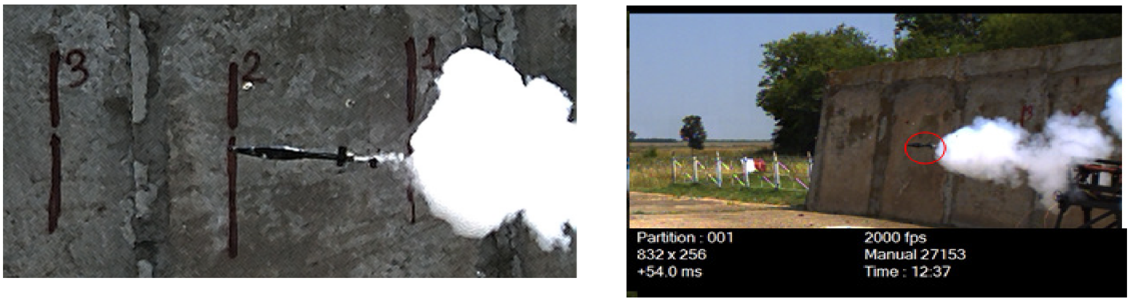

Figure 12: Determination of movement with hi-speed video camera

4.2Determination of the effective range and the precision at the respective distance

The ammunition is destined to be used in urban warfare when engaging targets covered in buildings, vehicles or other structures. In the design we considered 200m the effective range of the weapon system with thermobaric grenade. The precision at this distance has to be good enough to enable the shooter to send the round inside the building/vehicle by aiming the windows.

To determine the precision of the armament system, real shootings were made in field conditions. The ammunition was with thermobaric warhead, but the fuse was a inert equal mass dummy. Shootings were made at 100m and 200m, using textile panels of 3x3m. The precision was made using a limited number of grenades. Also, the precision of the incendiary grenades was evaluated for reference. In wind conditions the precision is still good for a relatively low velocity projectile with a mass of 2 kg. Testing were made in conditions of 28m/s frontal wind. The maximum range of the weapon system is limited to 400m because the trajectory time exceed the self destruction duration of the impact fuse.

Table 4. Precision of the weapon system when using incendiary and thermobaric rounds

Series	No of grenades	Shooting conditions	Precision
Series 1- Incendiary	5	100m <10m/s wind Barrel elevation 90/1500 Crosshair height 1,5m	$R_{distance}$: 0,7m $R_{direction}$: 0,4m
Series 2-Thermobaric	4	100m <10m/s wind Barrel elevation 90/1500 Crosshair height 1,5m	$R_{distance}$: 0,93m $R_{direction}$: 0,05m
Series 3-Thermobaric	2	100m <10m/s wind Barrel elevation 75/1500 Crosshair height 1,5m	$R_{distance}$: 0,35m $R_{direction}$: 0,15m
Series 4-Thermobaric	4	200m <10m/s wind Barrel elevation 185/1500 Crosshair height 1,5m	$R_{distance}$: 0,5m $R_{direction}$: 0,25m

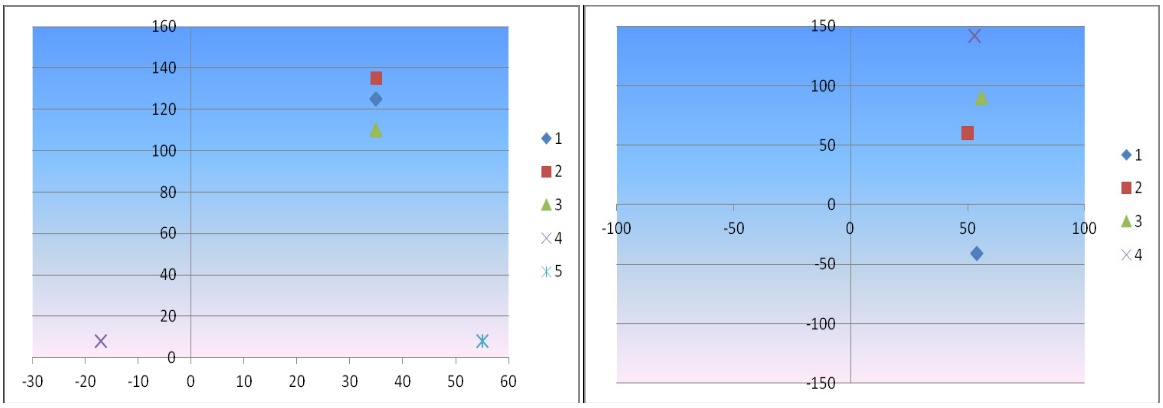

Figure 13. The precision chart of incendary and thermobaric grenades at 100m

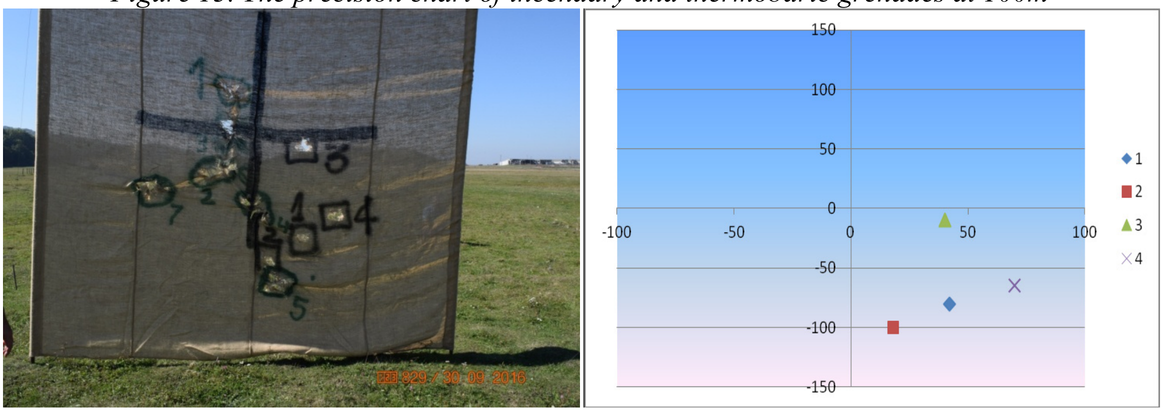

Figure 14. The precision chart of thermobaric grenades at 200m

4.2 Determination of the destructive effect

One of the most important field test necessary for evaluation of the performances of the ammunition was to evaluate the terminal effect and the correct initiation of the fuse, dissemination in dynamic condition and pressure build-up in

confined spaces.
For this reason, some targets were placed at 100m away from the launcher system. The first target consisted of a brick building with the dimensions of 3x3x3m. The second target consisted of a medium size van for passenger transport. The terminal effect was recorded using a Photron SA-3 High speed video camera and an objective with high optical zoom. The expected effect was obtained, both targets being totally destroyed.

Figure 15. Destructive effect on a brickwork house

5 Conclusions

This paper presents the efforts done to design and validate by testing a new ammunition for the AGI 3x40mm incendiary rocket launcher.

The chemical composition of the thermobaric mixture is, in optimal parameters a mixture of powdered Magnesium Aluminium and Isopropyl nitrate in a 1:2:1 ratio. The quantity of the IPN derives from the particle size and distribution of the powdered fuels. The density of the material is in the interval 1.58-1.6g/cm^3, which can be considered satisfactory.

The internal configuration of the warhead is, for optimal performance, at a ratio of 2.6 between the external diameter and the central explosive core.

For the new ammunition the propellant, stabilizer and impact fuse from the incendiary grenade was chosen. The initial velocity of the thermobaric grenade is between 70-75m/s at an propelling acceleration of 1500-2000G. For that reason, the original impact fuse can be used.

The stability of the ammunition is satisfactory, considering the precision recorded at distances of 100m and 200m.

The destructive effect of the thermobaric grenade is effective on the designated targets and in conjunction with the high precision of the rocket, we can conclude that the ammunition can be rendered a valuable weapon system for urban warfare, especially for neutralising snipers and shape charge RPG shooters sheltered or hidden in building, vehicles or behind walls.

Figure 16. Destructive effect on a non-armored vehicle

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