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EXPERIMENTAL STUDY ON ALUMINUM FOILS USE IN BLAST ENHANCEMENT APPLICATION

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Abstract. The present study aims to address, by experimental meaning for a previous defined and published particular configuration, the issue of optimum RDX/Al-foil mass ratio in blast enhancement applications. Using thin aluminum foils as case envelope, the explosive charge was wrapped up prior detonation in open field by employing 20, 60, 110 and 200 grams of aluminum. The experimental data in terms of overpressure, impulse and fireball dimension and duration are discussed. The measurements clearly indicate for the explosive-aluminum foil case a blast enhancement compared with the bare explosive case. Aluminum wrap up methodology influence in terms of overpressure and impulse for the 20 grams aluminum case was also looked into.

Keywords: blast enhancement, aluminum foil, overpressure, impulse.

1. INTRODUCTION

Conventional explosives have limited efficiency when used against targets deeply covered inside caves or fortified structures due to their overpressure vs. distance rapidly decrease characteristics [1]. One way to overcome this issue can be the use of so called TBXs (thermobaric explosives) or EBXs (enhanced blast explosives).

Although the first attempts to develop such explosives can be traced back in the WWII, major developments were made only starting with 1980's [2,3]. Basically, TBXs or EBXs are designed to use an aerobic or anaerobic secondary combustion in order to sustain a long-lasting overpressure and additional thermal loadings [4,5,6,7].

An effective way to achieve a thermobaric effect or to enhance a blast wave is to use a reactive metal as secondary fuel. Aluminum seems to be the most widely used metal fuel for such purpose [8]. Thus, a widely used TBX configuration has an annular design that assumes a HE (high explosive) core and a metal fuel rich layer [5]. Due to this particular configuration, in the following moments of HE detonation event, gas products temperature is enhanced as the aluminum burn process evolves resulting also in blast wave strengthening [3,5].

Although, based exclusively on above mentioned aspects, the use of aluminum in TBX formula could seem within reach, an efficient burn process is hard to be achieved [9,10,11]. The main issues with aluminum use are related to its high ignition temperature and particles agglomeration susceptibility [9]. In fact, the aluminum high ignition temperature is directly related with the aluminum air oxidation. Practically, by this reaction aluminum is coated with a layer of aluminum oxide (Al2O3) characterized by a 2030 °C melting temperature [4,8,12]. In other words, aluminum burn became possible only after Al2O3 layer is melt/removed or aluminum particle or layer is fractured, exposing a new fresh aluminum surface to high temperature gas products.

An alternative approach to achieve a basic blast enhancement configuration is to use active cases which will account for an energy addition during or after the HE detonation. Yet, the performance will be strongly related to case fragmentation process. Namely, if most of the resulting fragments are sub-millimeters sized, significant blast enhancement is possible [13,14].

In order to attempt to avoid the above mentioned difficulties that aluminum use raises, a special design for blast enhancement can be considered as detailed in [15]. Basically, by this novel design, the use of aluminum particles is avoided, and the bulk case is replaced by aluminum foil layers which allow a more convenient fragmentation.

For the current study, several charge-aluminum foil mass ratio are investigated for blast enhancement in open field detonation measurements. The recorded parameters refer to blast wave overpressure and fireball dimensions and durations. Also, impulse evaluation was considered. As a final step, all the data referring to blast enhancement cases were compared against bear explosive charge measured results.

2. MATERIALS AND EXPERIMENTAL APPROACH

2.1. Materials and test configuration

The tests were performed in an open space test facility as presented in Fig. 1. For pressure measurements three PCB piezoelectric transducer were used and placed at 1, 2 and respectively 3 m away from the charge and at the same height. For pressure data record a side-on configuration was adopted. All charges used a 110 g RDX based explosive (HITEX plastic explosive containing 91% RDX) with a 1.62 g/cm^3 density. The explosive was shaped as cylinder charge (37 mm diameter × 65 mm height).

Fig. 1 – Experiment set-up.

The blast enhancement study was carried out for four quantities of aluminum foil: 20, 60, 110 and 200 grams. Aluminum foil thickness was bellow 100 μm. For each test case six trials were performed. For the 20 grams aluminum foil case two approaches were considered. The first referred to a layer over layer wrap up around explosive charge while the second considered an initial fold of aluminum sheet before wrapping up around explosive core. A schematic of the above mentioned configurations is depicted in Fig. 2.

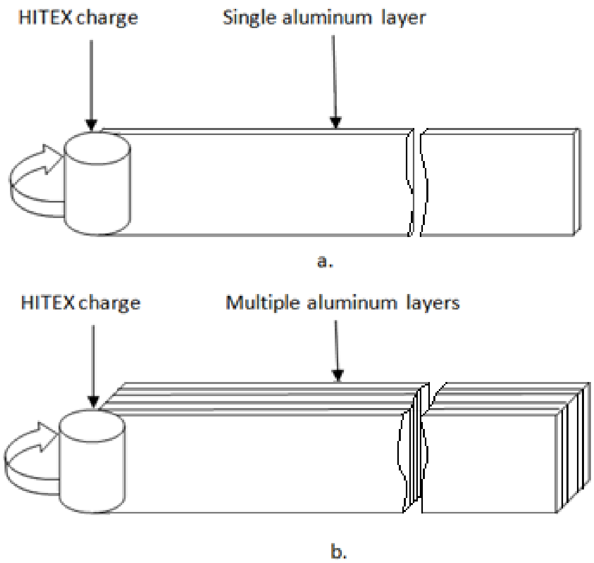

Fig. 2 – Test configuration – schematic.

Each charge was initiated from the top with the use of an electrical blast cap.

In order to evaluate fire ball dimensions and duration a high speed camera (PHOTRON FASTCAM SA1.1) was employed. The frame rate acquisition was set to 20.000 fps. The methodology involved in fire ball dimensions evaluation was based on image processing.

2.2. Experimental results

Typical examples for overpressure history recorded data are depicted in Figs. 3 to 6 for all three studied configuration (bear explosive charge – HE, HITEX/Al foil multiple layer over layer wrap up case – Al_MLOLWU and HITEX/Al foil single layer over layer wrap up case – Al_SLOLWU). The results presented and used for impulse calculus refer to incident overpressure. All experimental measured and calculated data are sintetized in Table 1.

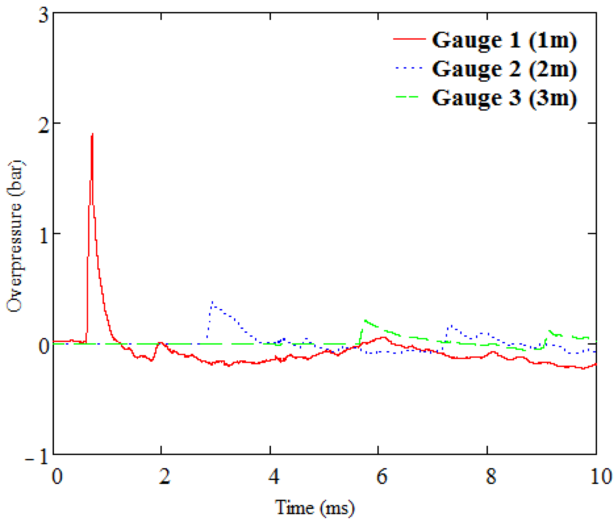

Fig. 3 – Overpressure history – bear explosive charge case.

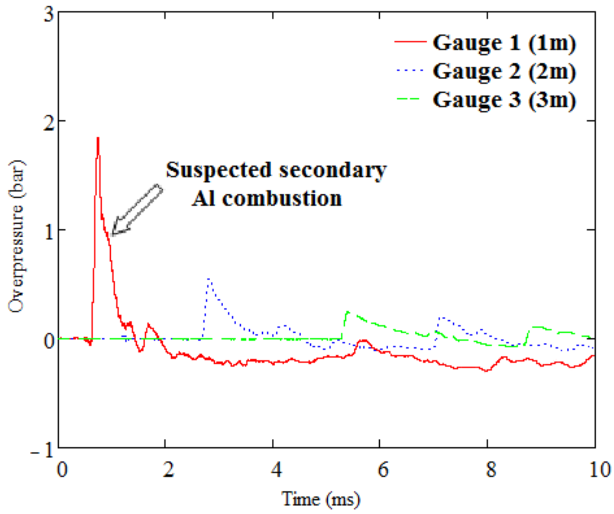

Fig. 4 – Overpressure history – 110HITEX/20Al foil multilayer case.

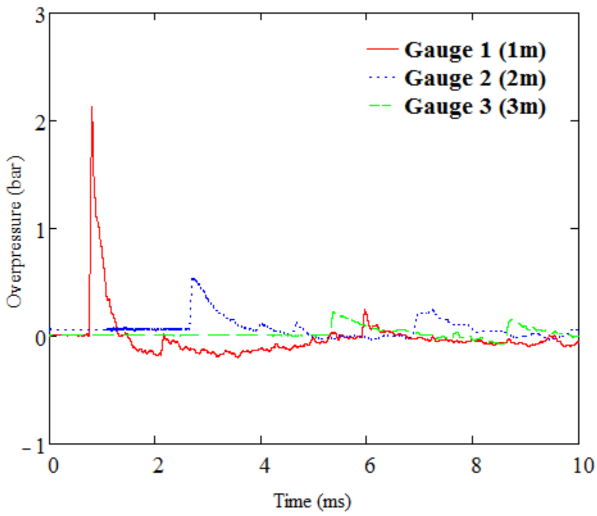

Fig. 5 – Overpressure history – 110HITEX/20Al foil single layer over layer case.

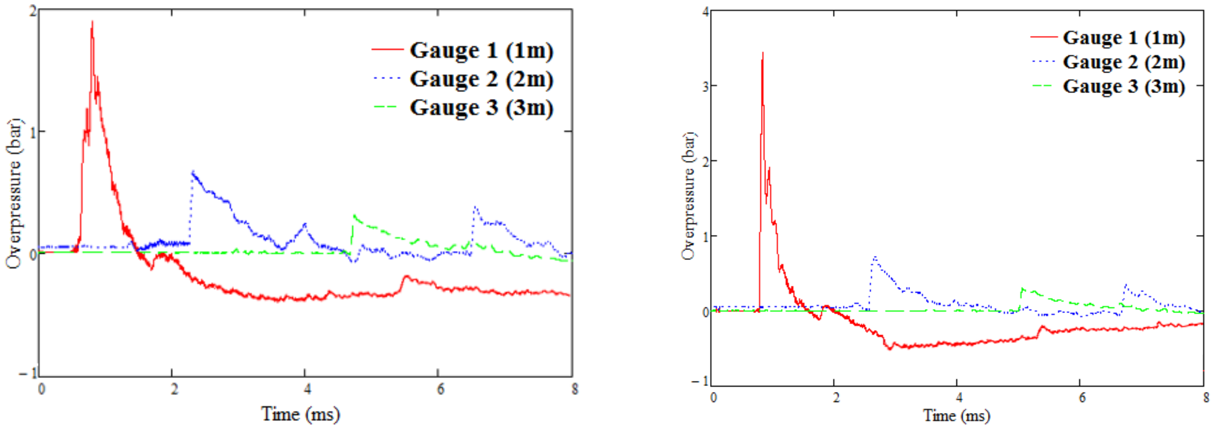

Fig. 6 – Typical overpressure records (110 g HITEX / 60 g Al foil case).

Typical images for fire ball dimensions and duration are presented in Fig. 7.

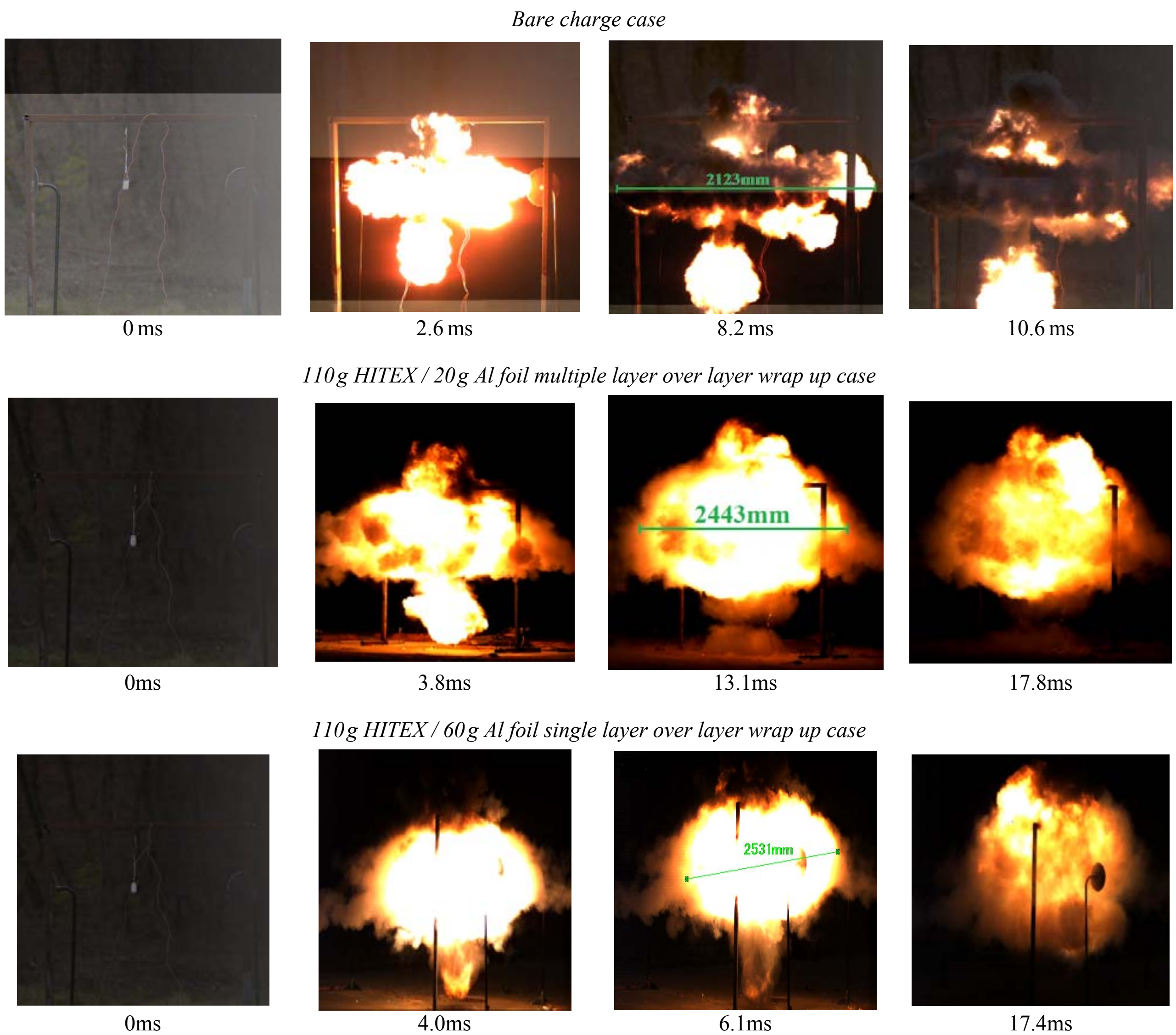

Fig. 7 – Typical fire ball image record.

Table 1

Test results

Test No.	Test configuration	Positive overpressure [bar]			Positive phase impulse [Pa × s]			Fire ball dim. [m]	Fire ball dur. [ms]
		Ch 1 (1m)	Ch 2 (2m)	Ch 3 (3m)	Ch 1 (1m)	Ch 2 (2m)	Ch 3 (3m)		
1	110 g HITEX (bare explosive charge)	1.725	0.400	0.220	43.99	19.25	14.40	1.829	10.2
2		1.818	0.414	0.221	40.92	19.09	14.52	2.123	11.8
3		1.827	0.493	0.226	38.50	18.19	14.03	1.403	10.6
4	110 g HITEX / 20 g Al foil single layer over layer wrap up	2.346	0.659	0.236	43.69	58.48	21.65	2.468	22.1
5		2.482	0.607	0.235	42.10	32.87	20.24	2.515	23.3
6		2.127	0.530	0.221	41.82	47.24	20.29	2.564	25.8
7		2.096	0.56	0.264	50.01	20.67	24.07	2.508	23.1
8		2.042	0.48	0.236	46.74	26.82	34.69	2.453	24.1
9		1.864	0.54	0.272	47.15	24.12	24.36	2.349	21.9
10	110 g HITEX / 60 g Al foil single layer over layer wrap up	2.879	0.950	0.297	59.76	47.24	23.49	2.531	20.9
11		1.885	0.672	0.316	61.56	53.96	25.16	2.767	23.2
12		3.435	0.718	0.305	62.49	47.08	24.51	2.683	21.2
13		1.342	0.561	0.336	47.14	27.94	40.07	2.611	20.8
14		1.528	0.794	0.336	48.53	32.35	37.78	2.706	21.4
15		2.070	0.531	0.336	52.54	32.50	26.38	2.814	21.9
16	110 g HITEX / 110 g Al foil single layer over layer wrap up	3.340	N/A	0.295	97.17	N/A	31.18	3.236	29.4
17		N/A	N/A	N/A	N/A	N/A	N/A	2.627	28.9
18		2.268	0.665	0.221	58.43	51.95	26.08	3.068	29.2
19		1.953	0.443	0.218	48.99	32.47	24.54	2.956	29.3
20		N/A	0.581	N/A	N/A	22.37	N/A	3.024	29.5
21		1.720	0.452	0.169	37.53	37.50	18.81	2.867	29.3
22	110 g HITEX / 200 g Al foil single layer over layer wrap up	1.972	0.524	0.219	46.41	36.74	21.35	2.519	31.9
23		N/A	N/A	N/A	N/A	N/A	N/A	2.413	30.9
24		3.569	0.976	N/A	56.32	35.56	N/A	2.611	30.8
25		1.588	0.521	0.187	24.92	27.37	24.13	2.508	30.7
26		1.682	0.417	0.172	46.58	26.86	22.32	2.524	31.1
27		N/A	0.415	N/A	N/A	22.84	N/A	2.587	32.4
28	110 g HITEX / 20 g Al foil multiple layer over layer wrap up	1.714	0.549	0.247	42.68	28.73	20.56	2.678	22.5
29		2.486	0.547	0.233	40.10	30.33	19.81	2.075	30.4
30		1.754	0.551	0.242	39.50	27.46	20.19	2.443	23.2

3. RESULTS ANALYSIS AND DISCUSSIONS

As presented in Table 1 the measured results (pressure, fireball dimension and fireball duration) are quite scattered not only between different tested configurations but also for the same configurations. In order to minimize the scattering impact on test results trend average values (the extreme values were eliminated and the average value was calculated based on the remained values) were considered for results analysis.

In terms of overpressure, due to the aluminum reactive nature, the HE/Al foil configurations exhibit different behavior as against the HE bare charge (Fig. 8). Thus, for two of the three investigated distances the HE/Al foil configurations measured data point to a higher overpressure value than the one measured in the HE bare charge case. As for similar Al_MLOLWU investigated case, slightly lower average values for overpressure and impulse criteria are observed (around 10%). Although, we can't be sure we suspect the above mentioned trend is due to a superior effectiveness interference between fragmentation and delamination of aluminum foil layers process for Al_SLOLWU case compared with the one in Al_MLOLWU case. This particular situation results in an earlier start of aluminum combustion for the AL_SLOLWU test. Circumstantial prove of the above presented hypothesis is the presence of a more distinctive discontinuity point (suspected as aluminum burn start point) on the pressure history curve of the previous mentioned cases (Fig. 4) compared against the Al_SLOLWU case.

Still, the fireball dimension and duration come in tight connection with aluminum combustion. In all studied cases, aluminum presence enhanced the previously mentioned parameters (up to 300% respectively 60% for fireball duration respectively fireball dimension).

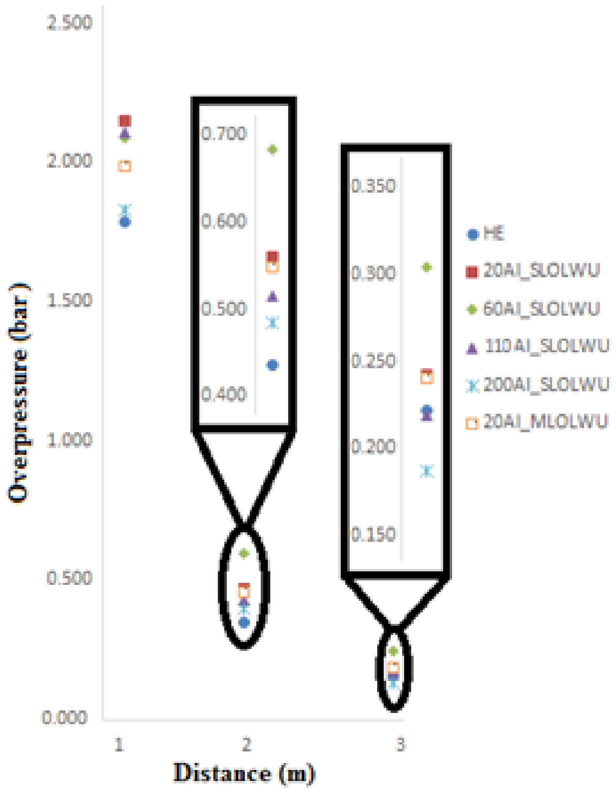

Fig. 8 – Maximum overpressure *vs* distance.

Based on the recorded overpressure history, impulse had been calculated for all studied cases (Table 1). As shown in Fig. 9, the impulse for all three investigated distances is higher when aluminum envelope is present. However, in terms of overpressure and even impulse its presence seems to be a little more efficient when SLOLWU is adopted. Those differences are expected to be more obvious with the increase of aluminum/charge mass ratio as a direct result of aluminum envelope stiffness increase.

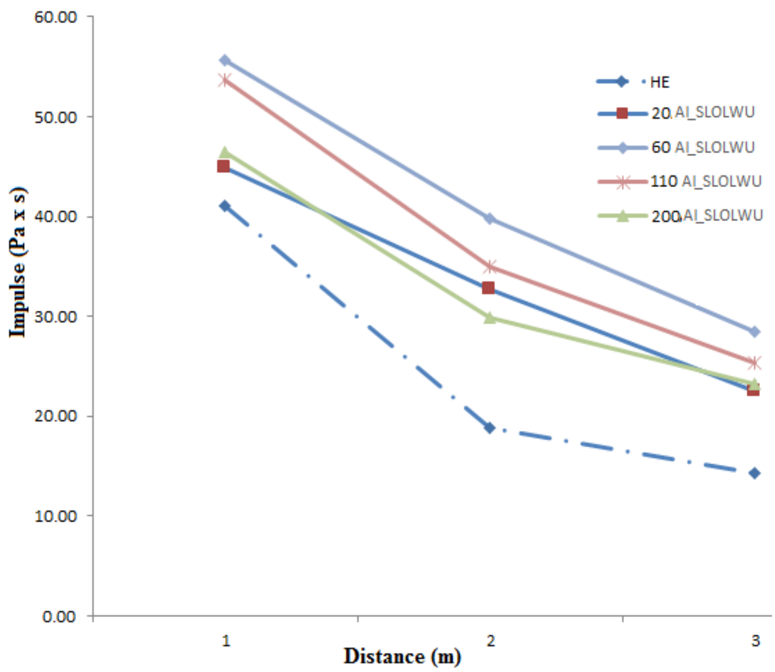

Fig. 9 – Impulse *vs* distance.

For Al_SLOLWU case an optimum ratio between aluminum case and charge mass exists being located around 0.5 ratio.

Plotting the impulse ratio (Al/HE charge impulse divided by HE charge impulse) against mass ratio (aluminum mass divided by charge mass) reveals interesting behavior for the investigated configurations (Fig. 10). In performed tests the highest impulse ratio is achieved at 2m away of the detonation point for all considered mass ratio (almost no differences are present for the 200 aluminum case). This specific data could be related with the start moment and the end moment of aluminum combustion. Thus, aluminum combustions starts before the blast wave pass the 1m gauge and ends before the 2m gauge is reached.

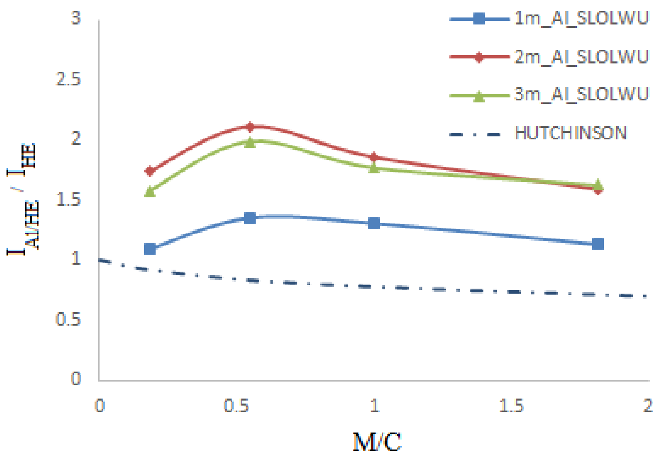

Fig. 10 – Impulse ratio *vs* mass ratio.

In order to underline the active role played by aluminum foil envelope, the impulse ratio vs mass ratio for inert casing hypothesis was plotted along with the instrumented configurations in Fig. 10. Considering Hutchinson observation regarding cased charges [16] and Shin model for impulse estimation [17], the equivalent bare charge and the impulse provided were evaluated. Thus, considering mass ratio and charge mass for tested configurations along with the aluminum inert hypothesis and 1.1 TNT equivalence factor for HITEX, the C_{EB} (equivalent bare charge or the charge mass equivalent for blast) was calculated using (1) and inputted in Shin formula (2) to estimate the corresponding impulse

$$C_{EB} = C\left[0.5/\left(0.5+\frac{M}{C}\right)\right]^{0.5} \tag{1}$$

$$\log\frac{I_s}{C_{EB}^{\ 1/3}} = C_0 + C_1(K_0 + K_1\log Z) + ... + C_n(K_0 + K_1\log Z)^n, \tag{2}$$

where: C_{EB} stands for the equivalent bare charge, C is the charge mass, M is the casing mass, I_s is the incident positive phase impulse, C_n (C_0=1.76, C_1=−0.6897, C_2=−0.3701, C_3=−0.1443, C_4=1.512, C_5=−0.7939, C_6=−1.814, C_7=1.639, C_8=−0.2572, C_9=0.4388, C_{10}=0.1685, C_{11}=−1.029, C_{12}=0.5988 and C_{13}=−0.08299), K_0=−0.5596 and K_1=1.175 constants, n order of the polynom and Z is the scaled distance.

The active role played by aluminum can also be highlighted by estimating the extra TNT equivalent mass supplied by aluminum combustion in regard to impulse data (Fig. 11). So, considering equation (2) and the recorded impulse average data for the studied configurations one can calculate the TNT equivalent mass. The TNT equivalent mass for blast can also be calculated in the aluminum inert hypothesis using equation (1). By subtracting the late results from the previously ones, the extra TNT equivalent mass are estimated. The values then can be converted in aluminum mass respectively burnt aluminum percentage (Fig. 12) considering the 4.184 kJ/g and 30.096 kJ/g values [18] for TNT respectively aluminum combustion heat respectively the aluminum mass used in each configuration.

According to Fig. 12, one can observe that along with the increase of aluminum mass, the aluminum percentage used in blast wave enhancement decreases.

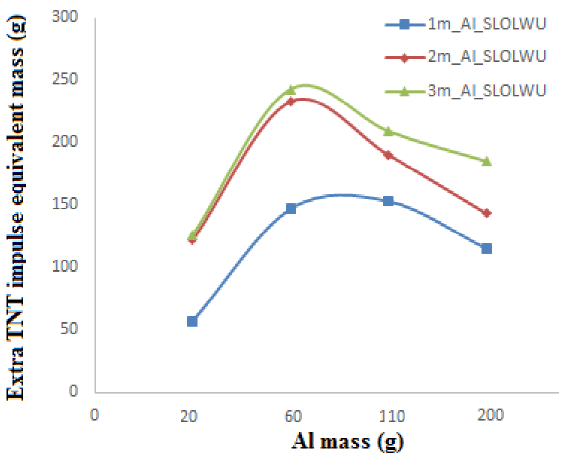

Fig. 11 – Extra TNT equivalent mass *vs* aluminum mass.

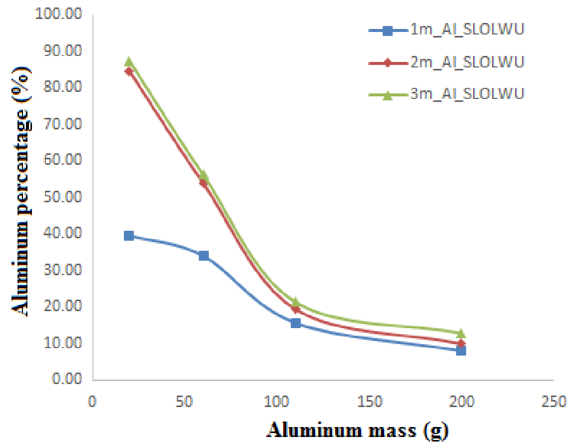

Fig. 12 – Burnt aluminum percentage *vs* aluminum mass.

4. CONCLUSIONS

The experimental tests performed aimed to investigate a possible scenario to enhance the blast wave parameters for a RDX based classical charge as well as to determine RDX/Al-foil optimum mass ratio. By correlating the experimental data for the investigated HE/Al-foil configurations and the HE bare charge, significant blast enhancement was pointed out. The presence of aluminum foils induces in open field a pseudo-thermobaric behavior for the HE charge. Single layer over layer wrap up of the HE charge is recommended since better results are obtained. Due to the charge configuration specificity (aluminum is not distributed within explosive mass), the optimum RDX/Al_foil mass ratio resulted is bound to be around 0.5. However, the use of different type of HE (with higher energy and different oxygen balance) could result in a different optimum mass ratio.

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