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SENSITIVITY OF ERA-BOXES INITIATED BY SHAPED CHARGE JETS

A. Koch[1] and F. Häller[2]

[1] Defence Procurement Agency, Feuerwerkerstrasse 39, 3602 Thun, Switzerland
[2] Swiss Ammunition Enterprise Corp, Allmendstrasse 74, 3602 Thun, Switzerland

We study the initiation sensitivity of ERA-boxes impacted by shaped charge jets. Our work focuses on two main topics. On the one hand, we are interested in the initiation threshold of the ERA when the impact angle of the projectile on the box is varied. On the other hand, we try to determine the variation of this threshold for different jet materials and filling explosives. We finally analyse our experimental results in the light of three models predicting the threshold dependence on the projectile density, velocity and diameter.

INTRODUCTION

Explosive reactive armors (ERA) are mounted on military vehicles to protect them against attacks with shaped charges. For people implementing this kind of explosive protections on tanks, as well as for their antagonists, it is important to have a precise knowledge of the initiation criterion of these ERA. However, for some types of explosives, it is quite difficult to find data concerning the detonation threshold under impact by fast projectiles ; moreover, even for standard explosives like C4, the initiation values found in literature may vary, due to different experimental geometries (e.g., explosive covered or not [1]), or because of difficulties in making precise measurements (e.g., determination of the shaped charge jet diameter).

So, we decided to perform a series of tests in order to get the initiation thresholds of ERA containing one of the three following explosives: C4, DPX-14 or PBXN-110. We were also interested in obtaining the threshold variation with the impact angle of the jet on the reactive armor. As a last point, we investigated the influence of the jet density on the initiation of an ERA.

After a short description of our experimental geometry, we shall present data related to the effect of the impact angle on the initiation threshold of ERA-boxes filled with PBXN-110. Then we shall describe results concerning the initiation thresholds of C4, DPX-14 and PBXN-110 by jets of materials with by different densities. Finally, these experimental observations will be compared to the predictions of three theoretical models for explosive initiation which can be found in literature [2,3,4,5,6,7].

EXPERIMENTAL TEST SETUP

The explosive reactive armor (ERA) used in the experiments described hereafter consists of a 7 mm thick explosive sheet confined between two 2 mm thick steel plates. The explosive is thus only slightly covered [1].

All experiments were performed with 50 mm / 60° shaped charges driven by PBXN-5. The charge was used without casing. The liner had a constant thickness depending on the material used: 1.4 mm for Cu, 1.6 mm for Fe, 3 mm for Al, and either 0.7 mm or 1.1 mm for Ta liners. With the exception of the 1.1 mm Ta cone and the 3 mm Al one, the liner thicknesses were chosen so as to get cones having approximately the same mass.

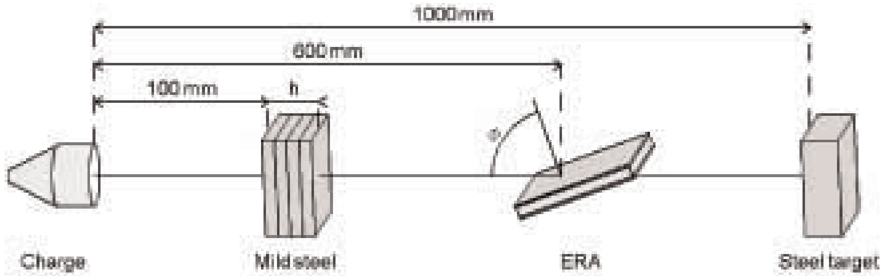

Figure 1: Experimental test setup. The shaped charge jet is slowed down by a mild steel target of variable thickness h, positioned at a stand-off equal to 100 mm. The ERA-sandwich is located at a distance of 600 mm from the liner base. The jet is X-ray flashed three times during its flight to the ERA. Behind the latter, at 1000 mm stand-off, a steel target allows the measurement of the remaining penetration capability of the jet.

Figure 1 shows the experimental setup used to study the initiation threshold of reactive armors. A shaped charge is fired and its jet slowed down by a mild steel target of variable thickness; the outcoming remaining jet then impacts the ERA-sandwich. The box is inclined so that the normal to its front surface makes an angle ϕ with the jet axis.

We studied three explosives: the well known C4, DPX-14 sheets and cast-cured PBXN-110. The last one is an insensitive explosive which resists high impact velocities up to 4 km/s without detonating. This is advantageous from an experimental point of view since the shaped charge jet has to be only slightly slowed down by the first steel target. As a consequence, one obtains a jet with a clean tip, and with well defined velocity and diameter.

EFFECT OF THE IMPACT ANGLE

In order to study the effect of the projectile impact angle ϕ on the initiation of reactive armors containing PBXN-110, a shaped charge with copper liner is used. The critical velocity is then determined for various angle ϕ by varying the impact velocity of the copper jet.

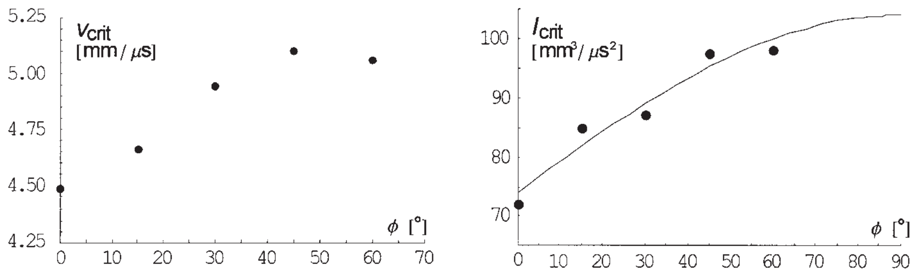

Figure 2: Experimental results for the critical jet tip velocity v_{jet} (left) leading to detonation of an ERA filled with PBXN-110 as a function of the impact angle ϕ, and the deduced value of the initiation threshold $I_{crit} = v_{jet}^2\, d$ (right). The curve corresponds to the fit (2).

Figure 2 presents experimental results for the critical jet tip velocity v_{jet} which induces detonation of the sandwich with a probability of 50%. On the same figure, we have also reported the critical value of the initiation criterion I_{crit} [1] defined by

$$I_{crit} = v_{jet}^2\, d, \tag{1}$$

where d stands for the diameter of the jet tip. It clearly appears that the angle ϕ has an important effect on the initiation of the ERA, the most sensitive case being a box placed perpendicularly ($\phi = 0°$) to the jet axis. As the angle ϕ increases from 0° to 60°, the initiation parameter I_{crit} increases from 70 mm³/µs² to 100 mm³/µs². In other words, the initiation sensitivity decreases as the angle ϕ increases. The threshold I_{crit} is reasonably well approximated by the following function

$$I_{crit}(\phi) = 74 \cdot [\, 1 + 0.4 \sin(\phi)\,]\ \mathrm{mm^3/\mu s^2}. \tag{2}$$

This form is somewhat surprising; we expected a stronger dependency of the threshold I_{crit} on the angle ϕ, like $I_{crit}(\phi) \approx I_o / \cos(\phi)$, in order to get a diverging value for I_{crit} in the limit $\phi \to 90°$ (grazing impact angle). The numerical factor 74 mm³/µs² is specific to PBXN-110. It is however likely that the coefficient 0.4 in front of the angular function is a mere geometrical factor which should remain constant for other types of explosives.

The previous data were obtained by firing charges against sandwiches filled with PBXN-110. The increase of the initiation parameter $I_{crit}(\phi)$ with the impact angle ϕ was fully confirmed by other experiments with charges fired against boxes filled with C4 (data not shown here).

INFLUENCE OF THE JET DENSITY AND OF EXPLOSIVE

This section is devoted to the presentation of results concerning initiation thresholds of explosive armors when impacted perpendicularly by shaped charge jets of diverse materials. We compare our experimental data to the predictions of the three following expressions for the initiation. The first one, characterized by equation (3), has been proposed by Mader and Pimbley [3,4,5] ; the second one, described by (4), is due to Chick et al. [6]; the last one, corresponding to equation (5), has been defined by Held [7,8].

$$I_M = (\rho / \rho_{Cu})\ v_{jet}^2\, d, \tag{3}$$
$$I_C = (\rho / \rho_{Cu})^{1/2}\ v_{jet}^2\, d, \tag{4}$$
$$I_H = \{ [1 + (\rho_{HE} / \rho_{Cu})^{1/2}] / [1 + (\rho_{HE} / \rho)^{1/2}] \}^2\ v_{jet}^2\, d. \tag{5}$$

In these expressions, ρ_{HE} stands for the high explosive density, ρ_{Cu} for the density of copper, ρ for the jet density, v_{jet} for its tip velocity and d for its diameter. Since copper is the most extensively studied element, we have scaled equations (3,4,5) in order to get in each case the usual expression $I = v_{jet}^2\, d$ when Cu is used as liner material; furthermore, with this scaling, the three expressions have the same units, namely $mm^3/\mu s^2$. For a given explosive, the value of the initiation thresholds I_M, I_C and I_H defined by (3,4,5) should be a constant, regardless of the impacting jet material.

The following tables present our experimental results for the three explosives C4, DPX-14 and PBXN-110. Investigated liner materials are aluminum, copper, iron and tantalum. The critical jet tip velocity and diameter are determined on X-ray pictures. Due to the difficulty to measure accurately the jet diameter, the values *d* listed below correspond to the average tip diameter measured on consecutive X-ray pictures.

High explosive C4 ρ = 1.57 [g/cm^3]						
Jet material	ρ [g/cm^3]	v_{jet} [mm/µs]	d [mm]	I_M [mm^3/µs^2]	I_C [mm^3/µs^2]	I_H [mm^3/µs^2]
Al	2.70	2.90	5.7	14	26	31
Fe	7.86	3.24	4.4	41	43	44
Cu	8.96	3.39	3.4	39	39	39
		Mean value of *I* :		31	36	38

High explosive DPX-14 ρ = 1.5 [g/cm^3]						
Jet material	ρ [g/cm^3]	v_{jet} [mm/µs]	d [mm]	I_M [mm^3/µs^2]	I_C [mm^3/µs^2]	I_H [mm^3/µs^2]
Al	2.70	2.55	7.0	14	25	30
Fe	7.86	2.50	5.3	29	31	32
Cu	8.96	2.83	3.7	30	30	30
		Mean value of *I* :		24	29	31

High explosive PBXN-110 ρ = 1.67 [g/cm^3]						
Jet material	ρ [g/cm^3]	v_{jet} [mm/µs]	D [mm]	I_M [mm^3/µs^2]	I_C [mm^3/µs^2]	I_H [mm^3/µs^2]
Al	2.70	4.15	4.6	24	43	51
Cu	8.96	4.49	3.5	71	71	71
Ta	16.60	4.87	3.6	158	116	101
		Mean value of *I* :		84	77	74

If the constancy of the initiation threshold for a given explosive is used as a criterion to discriminate the three proposed expressions for I, then our measures suggest that the linear dependence of Mader's I_M on the density of the jet is too strong; better results are achieved with Chick et al.'s threshold I_C or with Held's I_H. On the basis of our experimental observations, none of these two last threshold forms can be preferred to the other one. However, the data spread is slightly lower with Held's threshold I_H, and last but not least, the theoretical derivation [8] of the density dependence of I_H is very appealing.

CONCLUSION

Experimental results have been presented concerning the angular dependency of the initiation threshold of explosive reactive armors, as well as its changes with the density of the impacting jet.

As intuitively expected, the initiation threshold of an explosive sandwich increases as the impact angle ϕ increases, the most sensitive situation being therefore an impact normal ($\phi = 0°$) to the surface of the reactive box. According to our data [Eq. (2)], one should expect an increase of 40% of the threshold when ϕ goes from 0° to approximately 80°.

The influence of the impacting jet density is clearly observable in the data presented above. The experimental results are reasonably well fitted either by Chick et al.'s relation $I_C \approx \rho^{1/2} v_{jet}^2 d$ or by Held's equation $I_H \approx v_{jet}^2 d / [\, 1 + (\rho_{HE} / \rho)^{1/2} \,]^2$; for the three explosives investigated here, the best agreement is obtained with Held's expression I_H.

The initiation of explosives by fast projectiles depends among other things on its confinement [9], as well as on the existence of air gaps between the explosive and the front cover plate. This may explain the difference between our threshold for C4, I_H = 38 $mm^3/\mu s^2$, and the one given in [8], I_H = 64 $mm^3/\mu s^2$. Another difficulty which could explain such differences is linked to the measurement of the jet diameter on X-ray pictures. Let us however mention that they were consistently measured in the experiments presented above. As a consequence, if it appears that the threshold value for one of the explosives studied here should be modified by a factor λ, then the critical values of the three explosives should be scaled with the same numerical correction factor λ.

As a conclusion, let us state that the most favorable materials to defeat reactive armors without initiating them are those characterized by a high density. For a given liner mass, jets of high density materials are quite thin compared to those of lighter elements. This allows a higher tip velocity. Furthermore, such dense jets have better penetration capability in the plates which usually cover reactive armors. This tendency was observable in our experiments: at initiation threshold, the critical jet tip velocity of tantalum is about 10% higher than the one of a copper jet; the same remark is valid for copper and aluminum jets.

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