# ON THE ROLE OF INTERMEDIATE LAYER LOCATION IN PREVENTION OF SYMPATHETIC DOTONATION BETWEEN REACTIVE ARMOR SANDWICHWES

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Sympathetic detonation prevention of Explosive Reactive Armor (ERA) sandwiches by the use of intermediate low density layers has been studied. A comparative experimental study of the influence of the layer location on sympathetic detonation has been preformed. Also, complementary one- and two-dimensional numerical calculations have been conducted using AUTODYN2D™. Our main result is that locating the intermediate layer adjacent to the donor sandwich is more effective in sympathetic detonation prevention then in locating it adjacent to the acceptor sandwich. The physical mechanism underlying this phenomenon is revealed via numerical simulations suggesting that it is of a geometrical nature. While attached to the donor sandwich, the intermediate layer undergoes large geometric deformation during the detonation stage, resulting in multiple impact points on the acceptor sandwich. Thus, multiple pressure waves are generated within the explosive layer of the acceptor sandwich. However, their overall magnitude is decreased leading to the eventual lower probability of sympathetic detonation.

## INTRODUCTION

Explosive Reactive Armor (ERA) plays an important role in armored vehicles protection against shape charges and kinetic energy threats. Usually, ERA boxes are built up from a row of several reactive sandwiches. Prevention of sympathetic detonation of the sandwiches adjacent to the one initiated by the threat is advantageous for the inside and surroundings of the hit vehicle. Furthermore, it would increase the multi-hit capability of the vehicle armor.

The use of intermediate layers, placed between adjacent reactive sandwiches, made of low density materials in prevention of sympathetic detonation is well known [1]. However, to our best knowledge there is no reference in the literature relating to the influence of the intermediate layer location on the sympathetic detonation mechanism, which is the subject of the current study. First, a comparative experimental study has been conducted in the aim of evaluating the effectiveness of intermediate layer in prevention of sympathetic detonation. By means of x-ray shadowgraphs it could be seen whenever the initiation of one sandwich (i.e. the donor sandwich) leads to sympathetic detonation, or no reaction of the other sandwich (i.e. the acceptor sandwich).

Complementary one- and two-dimensional numerical simulations were conducted for better physical understanding of the phenomena. The probability of sympathetic initiation probability was analyzed using a simplified analytical model of High Explosive (HE) initiation threshold based on critical energy [4]. Finally we conclude the study by making some comments regarding the importance of the intermediate layer location.

## EXPERIMENTS

Two test set-ups were used for the examination of sympathetic detonation. Both of them were built up of two reactive armor sandwiches (the donor sandwich and the acceptor sandwich) separated by an air gap L (Fig. 1). All the sandwiches consisted of mild steel plates (so called flyer plates) with C4 explosive between them. A low density intermediate layer was placed between the sandwiches. The thickness of the layer was identical to that of a steel flyer plate. In the first test set-up (Fig.1.a) the intermediate layer was attached to the donor sandwich, while in the second test set-up (Fig.1.b) the layer was attached to the acceptor sandwich.

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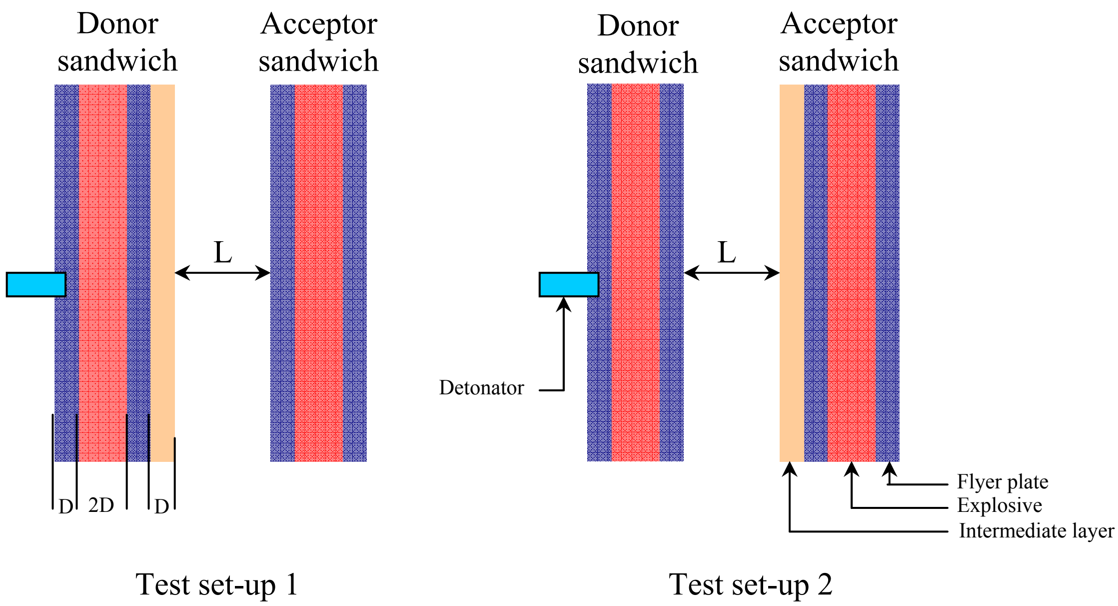


Figure 1: Test setups for the examination of sympathetic detonation:
(a) Intermediate layer attached to the donor sandwich;
(b) Intermediate layer attached to the acceptor sandwich.

In all tests, the donor sandwich was initiated by means of a detonator, resulting in the acceleration of the right flyer plate (with or without the attached intermediate layer) towards the acceptor sandwich. Upon impact of the flyer plate on the acceptor sandwich, two kinds of reactions were observed by the means of x-ray shadowgraphs (Fig.2). While in the first test set-up, no sympathetic detonation of the acceptor sandwich occurred (Fig.2.a), a clear sympathetic detonation occurred in the second test set-up (Fig.2.b). In the later, the flyer plates of the acceptor sandwich are separated and moving in opposite directions. Furthermore, an additional crater is formed in the wood block underneath the acceptor sandwich.

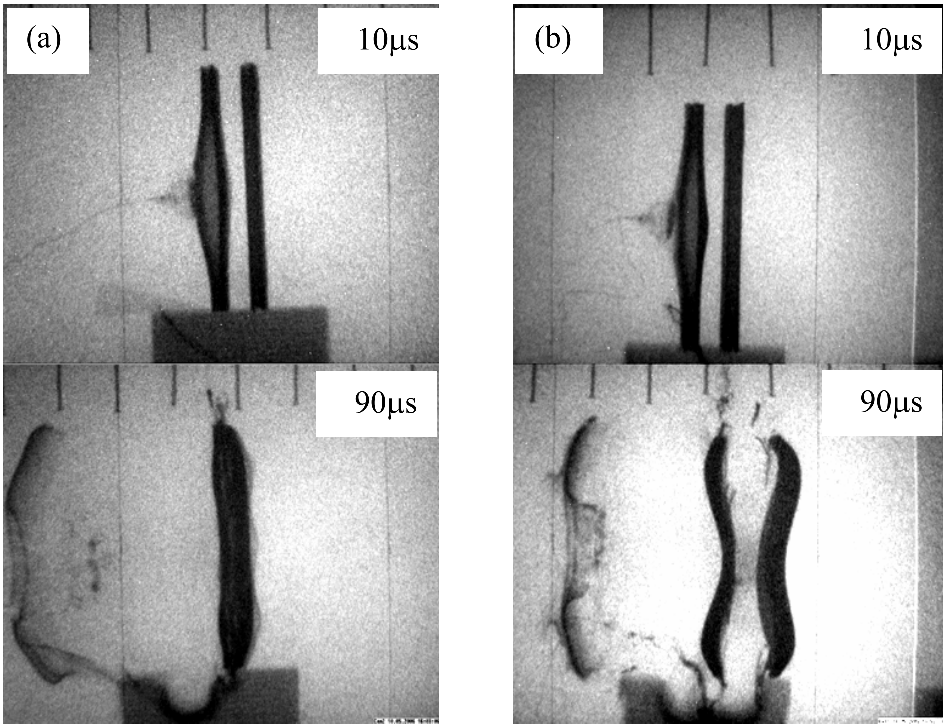


Figure 2: X-ray shadowgraphs obtained at different times relative to the moment of initiation, where:
(a) No sympathetic detonation occurred - corresponds to test set-up 1.
(b) Clear sympathetic detonation occurred - corresponds to test set-up 2.

The acceptor's sandwich flyer plates velocities in opposite directions is a clear indication of sympathetic detonation. Another indication is the occurrence of a crater in the wood block underneath the acceptor sandwich.

## NUMERICAL ANALYSIS

Numerical simulations corresponding to the above experiments were conducted using AUTODYN2D$^{TM}$ finite difference hydro-code [3]. The calculations were done into two steps. The first step simulated the donor sandwich explosion, employing a Lagrange solver for the flyer plates and an Euler solver for the explosive. The second step simulated the interaction between the flyer plates and an 'inert' acceptor sandwich where the Lagrangian solver was employed for all parts. A shock equation of state and a Von-Mises strength model were applied to all parts except the explosive layer of the donor sandwich which was described by JWL equation of state with no strength. Both, one- and two-dimensional simulations have been preformed in order to gain more physical insight of the phenomena.

### One-dimensional simulations

As a first step, one-dimensional numerical simulations of the donor sandwich explosion were preformed. The simulation results, in terms of the right flyer plate velocity are depicted in Figure 3 in comparison with the Gurney model [2] predictions. According to this model, the right metal flyer plate will gain velocities of 1290 m/s and 1610 m/s with and without an attached intermediate layer, respectively.

The second step included the simulation of the interaction between the right flyer plate and the acceptor sandwich. Pressure-time history measurements in the explosive layer of the acceptor sandwich were made for both test set-ups. However, no distinct conclusion could be drawn from these one-dimensional simulations.

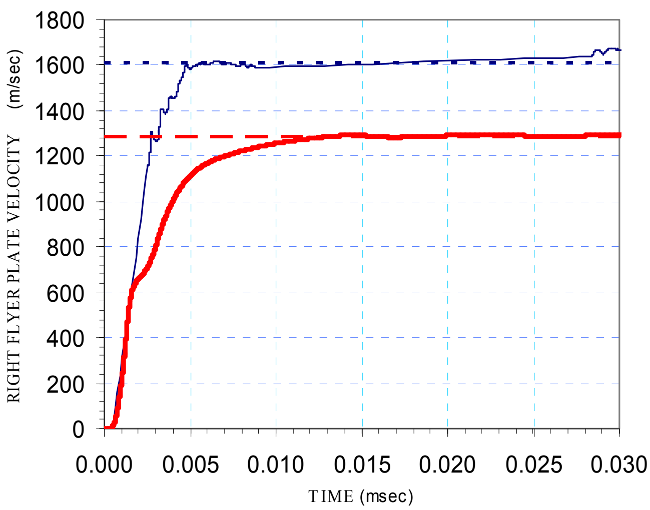


Figure 3: Comparison of the right flying plate velocities obtained via numerical simulations and Gurney model

## Two-dimensional simulations

Since the one-dimensional simulations could provide no explanation for the experimental results, we hypothesized the phenomena to be of a two-dimensional origin. Even though the real test set-up was of a three-dimensional nature, we chose, for simplicity reason, to approximate it by two-dimensional axis-symmetric simulations. From the simulations (Fig. 4.a,b) it can be seen that the existence of the intermediate layer has no effect on the resulting shape of the metal flyer plate, but only on its final velocity. From Figure 4b it can be seen that the intermediate layer detaches from the flyer plate in several locations. This effect was also obtained experimentally as can be seen in Fig. 4.c. These complex geometrical features are in marked contrast to the one-dimensional case, wherein all plates are assumed to be always planar.

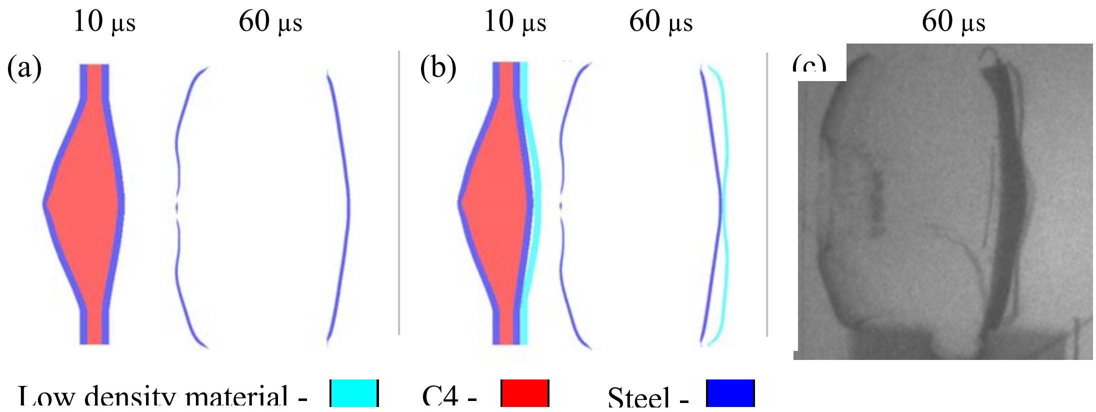


Figure 4: Donor sandwich explosion:
(a) Simulation - no intermediate layer attached to the donor sandwich.
(b) Simulation - with intermediate layer attached to the donor sandwich.
(c) X-ray photography – with intermediate layer attached.

The geometrical shape of the flyer plate has a significant effect on the pressure wave transmission mechanism into the acceptor sandwich, which this in turn effects the sympathetic detonation probability. Upon the impact of the flyer plate on the acceptor sandwich, a pressure wave is transmitted to the explosive layer within the acceptor sandwich (Fig. 5). In the case when no intermediate layer was attached to the donor sandwich, a single pressure wave propagated within the explosive layer from the central point of impact towards its outer edges (Fig. 5a). By contrast, in the case when the intermediate layer was attached to the donor sandwich, multiple points of impact on the acceptor sandwich are obtained (Fig.5.b), resulting in a simultaneous propagation of several pressure waves into the explosive layer.

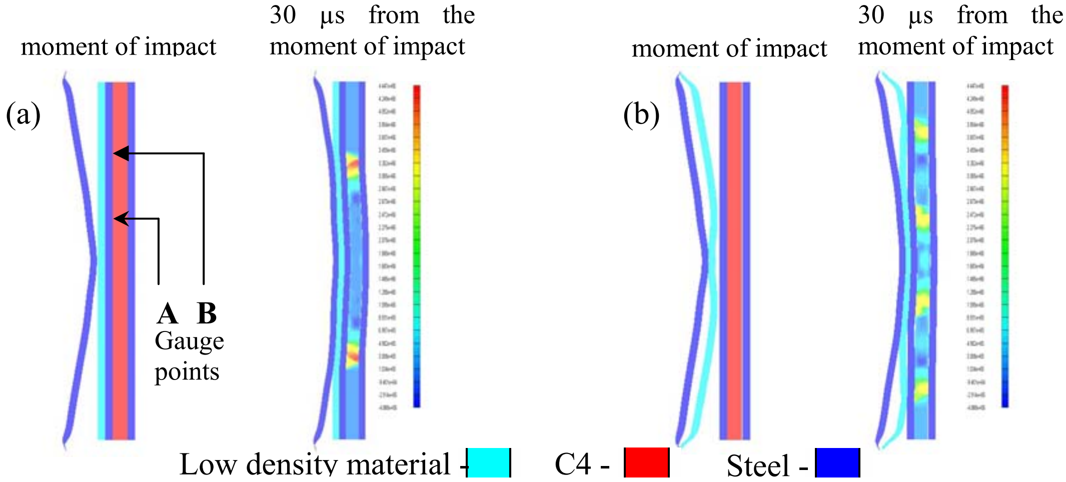


Figure 5: Simulation of the interaction between the donator flying plate and the acceptor sandwich;
(a) The intermediate layer is attached to the acceptor sandwich; left – material plot; right – pressure plot.
(b) The intermediate layer is attached to the donor sandwich; left – material plot; right – pressure plot.

Pressure-time history measurements for different locations A and B (Fig. 5a) within the explosive layer of the acceptor sandwich are presented in Figure 6. It can be clearly seen that in the case of a layer attached to the acceptor sandwich, a single pressure wave resulted as indicated by a single pressure peak. By contrast, in the case of a layer attached to the donor sandwich, multiple pressure waves resulted as indicated by the several pressure peaks. However, the magnitude of the single pressure wave is significantly larger then the magnitude of each of the multiple pressure waves.

The above simulation results were compared, in terms of their initiation probabilities, based on the analytic model [4] for the critical energy required to cause an ignition of the High-Explosive (HE) material. In its original form [4], the energy transmitted by a large diameter plate to the HE is given by:

(1) $$E_C = P^2 \cdot \tau$$

Where $P$ is the impact pressure and $\tau$ is the positive pulse duration. From the above simulation results, a higher value of $E_c$ was obtained in the case when the intermediate layer was attached to the acceptor sandwich then in the case when it was attached to the donor sandwich, and in a respective way also the probably of sympathetic detonation. This is in agreement with the experimental results.

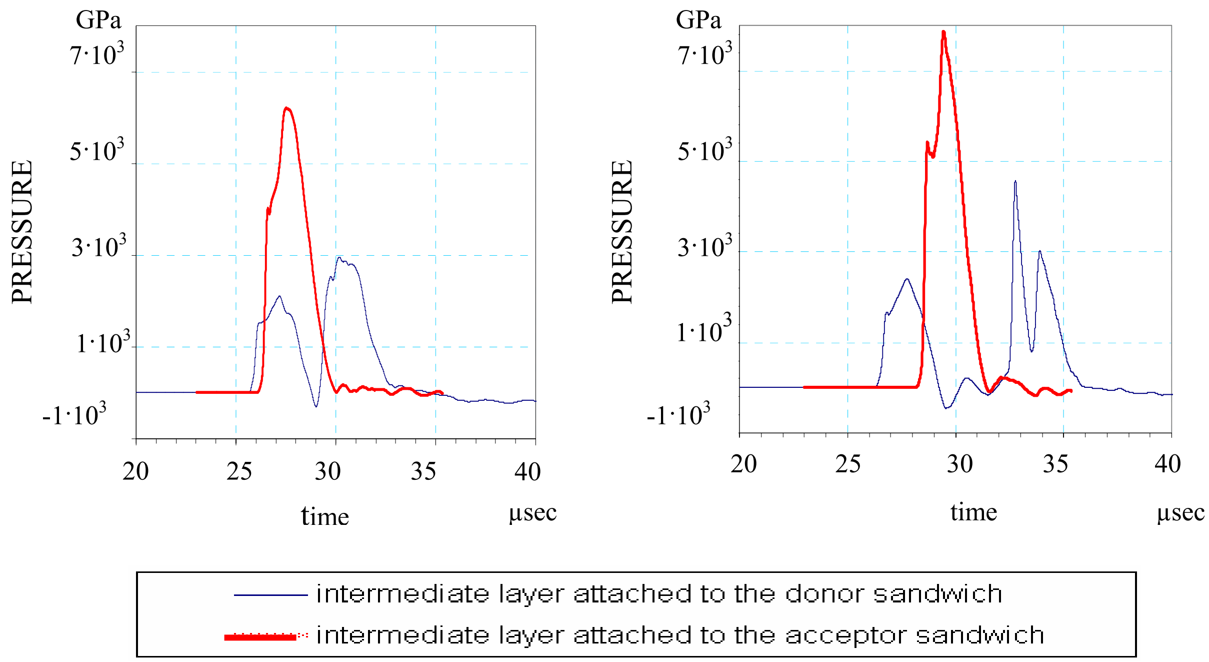


Figure 6: Pressure-time history profiles within the explosive layer of the acceptor sandwich. Left – gauge point A, right – gauge point B.

In addition, we studied via numerical simulations the effect of the intermediate layer thickness on the sympathetic detonation of the acceptor sandwich. The calculations showed that for a sufficient thick intermediate layer, no effect can be seen because of the fact that the thick layer deforms similarly to the metal flyer plate. On the other hand a very thin layer is not effective because of the low momentum value it has comparative to the flyer metal plate. Hence, there is an optimum thickness for the intermediate layer intended to prevent sympathetic detonation.

## SUMMARY AND CONCLUSIONS

Based on the above numerical and experimental results we concluded that:

- The use of low density intermediate layer has a great deal of importance for sympathetic detonation prevention of the reactive boxes.
- The probability of sympathetic detonation strongly depends on intermediate layer location.

- The most effective location of the intermediate layer is on the donor sandwich. This is due to the geometric deformations that the intermediate layer undergoes during the explosion of the donor sandwich. Those deformations create multiple interaction points between the donor and the acceptor sandwiches and effectively lower the pressure peak in the acceptor's explosive layer.
- Future work may include the study of the effect of the intermediate layer material properties and its optimum thickness. .

## REFERENCES

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