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THE DESIGN AND PERFORMANCE OF NON-INITIATING SHAPED CHARGES WITH GRANULAR JETS AGAINST ERA

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Add-on Explosive Reactive Armour (ERA) may be neutralized with a leading shaped charge that punches a hole through the ERA without initiating the explosive layer, a main shaped charge jet then attacking the main armour through the hole. Such a leading charge with a plastic liner was designed by simulation with a hydrocode. The liner was ultimately modeled with SPH, which turned out to be fortuitous, since the jet was observed to be a coherent beam of very fine particles. The agreement between simulated and real jet characteristics was quite good, with fine features of the jet visible in both simulation and radiograph. The charge performed well against ERA on its own, and in conjunction with a main charge and ERA.

INTRODUCTION

For the defeat of Explosive Reactive Armour (ERA) that has been added externally to the body of an armoured vehicle, the usual approach is to activate the ERA by a smaller leading shaped charge whose jet (typically from a copper liner) initiates the explosive in the ERA. The main shaped charge is then detonated after a delay that is sufficient for the ERA plates to have been accelerated out of the path of the main charge jet. In the case of smaller calibre weapons, with smaller (non-scaled) stand-off distances of the main charge, the choice of the optimum delay time is beset with problems if all attack angles are to be considered, and there are always some attack angles for which the main jet will be hindered in its passage to the main armour.

This problem may be overcome by using a leading charge that produces a projectile whose impact onto the ERA is below the initiation threshold of the explosive in the ERA (see [1] for recent work on thresholds), but is still able to punch a hole through the ERA plates through which the main charge jet would pass. This approach was first studied by [2], who used shock impedance matching to arrive at threshold levels for initiation of ERA when impacted by jets from various materials. Good results were achieved with plastic and powdered alloy jets. The performance of various configurations of a wide-angle non-initiating shaped charge with a metallic liner giving low-velocity jets is reported in [3].

The initiation threshold I for a given explosive attacked by a shaped charge jet with a velocity V and a diameter d is given by $I = f(\rho)V^2d$, with $f(\rho)$ a slowly-varying function of the jet density ρ [1,4,5]. This relationship was used by [1] as the basis for preferring a dense metal for the liner. However, with a technology investigation into a non-initiating leading charge, one may tailor the jet characteristics to the problem. In addition, one need not necessarily be restricted to metal liners [2]. This study reports on the design of a non-initiating leading charge using thermoplastic liners, and the results achieved. It should be admitted that there was initially no distinct rationale behind the choice of liner material, except for an anticipation of large hole diameters.

Some degradation of main armour penetration relative to the case where the main shaped charge directly attacks the armour in the absence of ERA may be expected with both the initiating and non-initiating approaches [3].

THE DESIGN

The aim was to design for a tip velocity in the region of 7 km/s using a liner with a density of 1,2 g/cc, and with a quadratic increase in jet mass towards the tail. The low density of a plastic liner would lead to a thick liner, and jetting phenomena may present peculiarities. One of these is that a significant portion of the front of the jet would be formed by collapsing material that still is in the expansion phase of the first shock reverberation. This phenomenon is termed 'free-surface jetting', and can be observed in Figure 1, where the rear of the liner has a lower velocity for most of the liner length.

The simulations were performed with Autodyn 2D™. An explosive diameter of 36 mm was chosen. The liner material description was based on the standard POLYCARB from the Autodyn library, with a shock EoS and a density of 1,2 g/cc. The explosive (LX-11) and the liner were modeled as Lagrange grids to start with.

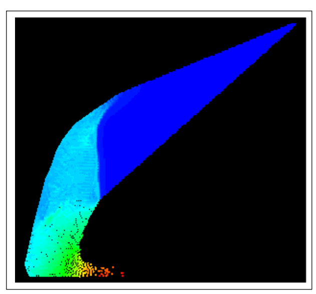

Figure 1: Velocities in the collapsing liner.

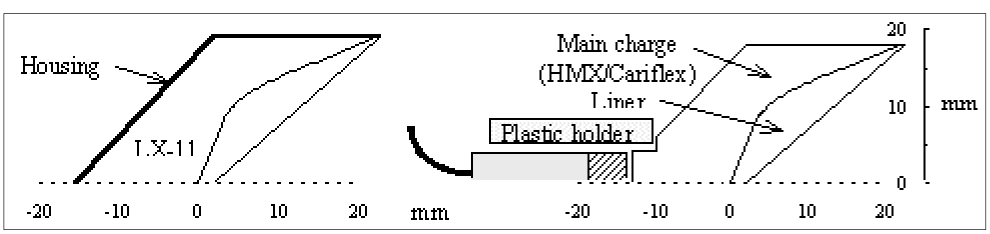

Figure 2: (a) The simulated charge, and
(b) the charge as manufactured, with booster and detonator.

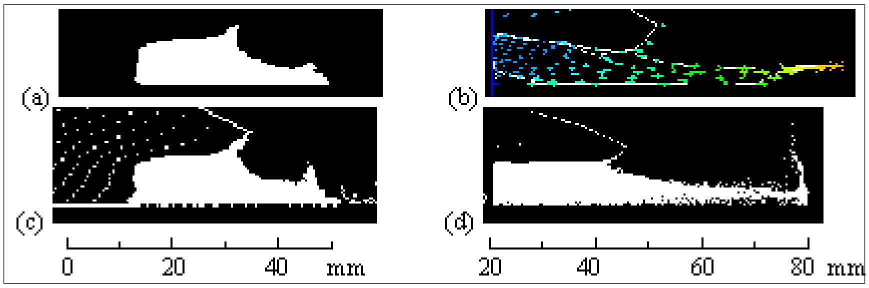

Figure 3: (a and b) Lagrange grid simulation of jet formation at 10 and 15 µs.
(c and d) SPH simulation at the same times. Figure 3b displays velocity vectors.

A large number of runs culminated in a design that best met the requirements (Figure 2a). Snapshots of the Lagrange simulation at different times appear in the top row of Figure 3. The liner was also modeled with the SPH (Smooth Particle Hydrodynamics) approach, where the volume is filled with a large number of interpolation points with associated masses. A point is strongly associated with its neighbours in terms of the material descriptors, with the coupling decreasing rapidly with distance. This approach has the advantage that grid distortion is absent, but the disadvantage that there is numerical fracture into small independent clumps when there is strong divergence, as in a shaped charge jet. It was found that one could use a strengthless description for the liner. At 10 µs after initiation there were still appreciable non-linearities, with faster material overtaking slower material at the tip. At 20 µs the fast and slow material had started to coalesce. The ensuing redistribution only ended at about 25 µs. The further evolution was a pure stretching of the jet. The major difference between the Lagrange and the SPH approach is in the detail of the tip morphology, where the Lagrange simulation has a thin high velocity off-axis overshoot, while the SPH simulation predicts a thumbtack shape that has the same cause (a region with a somewhat higher collapse velocity half-way up the liner) as the overshoot in Lagrange. There are void regions in the vicinity of the axis in the SPH jet (Figure 3d).

EXPERIMENTAL: THE SHAPE OF THE JET

The results using Teflon (PTFE) liners with a density of 2,15 g/cc are presented here. The liners were machined from bar stock. The components and assembly were tightly toleranced. A number of charges were fired in a soft flash X-ray set-up. Penumbra and motion blur was reduced to a minimum with an object-to-film distance of only 25 mm.

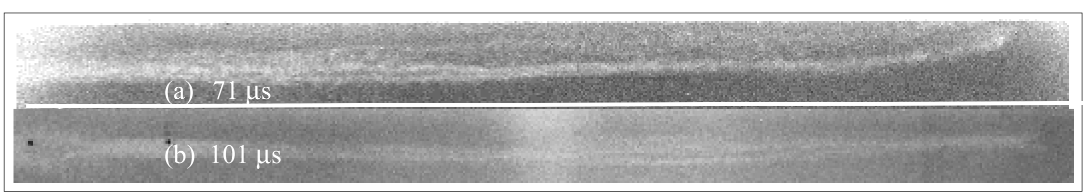

Figure 4: Radiographs of two jets from Teflon liners, with flash delays.
(a) Tip to 3 km/s, and (b) tip to rear of the jet.

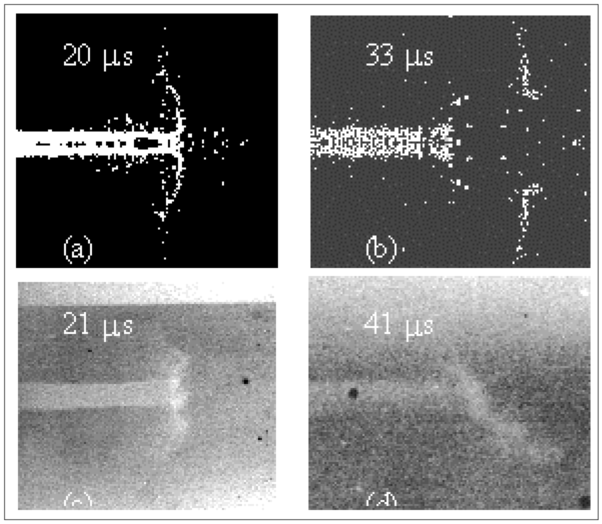

Figure 5: SPH simulations (top row) and FX radiographs at the indicated times.
Figure 5d is a radiograph of the jet tip from another plastic liner material.

The measured tip velocity of 5,3 km/s is comparable with the 5,4 km/s predicted by the code with the density increased to 2,15 g/cc. The jet appears to consist of very fine particles, and longitudinal striations are distinctly visible in the jets, for which there is no explanation at hand (Figure 4). The bends in the jets are ascribed to non-centric initiation playing a large role in such a small charge. The fact that the Teflon jet material consists of a very large number of very fine grains may be associated with the existence of spherulites in the liner material.

The resemblance between the SPH simulation of the tip region and the radiographed shape of the jet tip at 21 µs is uncanny (left column of Figure 5). One should also note that the optical density of the jet body at 21 µs seems to increase in the radial direction (Figure 5c), from which it is inferred that the particle density increases radially. This is supported by the SPH simulation, where a hollow core is also visible. The thumbtack shape of the tip cannot be ascribed to the effect of the passage of the jet through air prior to the radiograph - there is no sign of such a tip at later stages (Figure 4) in spite of nearly identical tip velocities. It is assumed that the tip head had been dispersed by air in the time between the radiographs of Figures 5 and 4. The lagging of the jet tip behind the off-axis mass in the simulation at 33 µs (Figure 5b) was caused by the interaction between the slower material at the jet tip and faster material behind it, in the time span 15 to 25µs.

EXPERIMENTAL: PERFORMANCE AGAINST ERA

A number of shots were fired against ERA stacks in different configurations, the purpose being to get an idea of the terminal configurations that would be on the threshold of initiation of the ERA. It was found that one would need to remove the flat head of the jet prior to impact onto ERA, to prevent initiation. Otherwise, the performance was satisfactory, especially in terms of the size of the holes in the SX. The results of a shot are given in Figure 7. The target assembly (Figure 6) consisted of a 3 mm mild steel plate representing a cover plate, followed by two ERA packages, each consisting of 4 mm sheet explosive (SX) sandwiched between 3 mm mild steel plates. The holes in the SX were determined from a reconstruction of the recovered pieces.

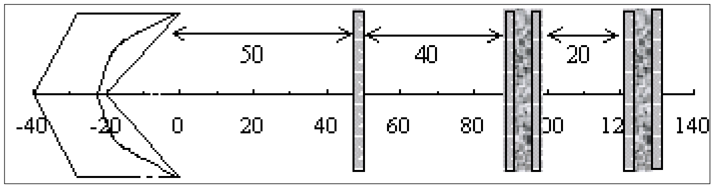

Figure 6: The test set-up, with distances between the plate stacks.

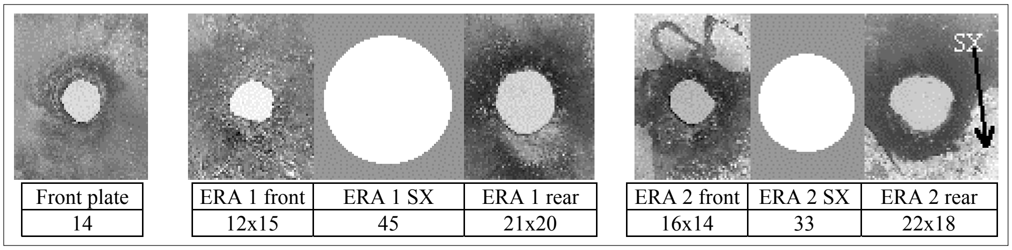

Figure 7: Photographs of the plates with a HDPE liner, to scale,
with hole dimensions in mm, and with sketches of the holes in the ERA.

Shots against inclined (60° NATO) ERA stacks were all successful, with no reaction in the explosive, provided that the flat head of the jet was removed by a steel plate simulating a cover plate. In some of these shots the first plate of a second ERA stack was not perforated, and yet holes with diameters in excess of 10 mm were punched into the SX.

A RESULT IN A TANDEM CONFIGURATION

The leading charge was tested in a full tandem configuration. The target consisted of an inclined (60° NATO) ERA package followed by an armour steel stack to measure residual penetration. The flat head of the jet was removed prior to impact on the ERA. A smallish caliber main charge was detonated after a delay. A flash X-ray radiograph was obtained with the main jet tip nearly at the position of the ERA (Figure 8). There were two holes in the second ERA plate, as sketched. It is clear from Figure 8 that the lower hole was caused by the leading charge jet, and that the main charge jet tip caused the lower portion of the upper hole. The keyhole cut in the upper hole would have been caused by a further impact by a lower velocity section of the main jet. This undesirable movement of the rear plate is caused by the shock into the SX, and is exacerbated by the fact that the SX has a low yield strength [6]. The essence of the effect is the same as that described by [7], where an inert substance was used between the plates. The penetration into the target stack was well within the range that could be expected from a similar configuration using an *initiating* leading charge.

Figure 8: FX radiograph showing the main jet and the bulging rear plate.
The holes in the rear plate were as sketched.

SOME REMARKS

A prime advantage of the non-initiating approach is that the designer of the warhead system does not need to be constrained by the time taken for ERA plates to move out of the path of the main jet. The main charge may be initiated as soon as the hole in the ERA explosive is large enough.

It is thought at this stage that there are two benefits in using *granular* jets for the non-initiating defeat of ERA. The initial shock into the explosive will be lower due to the granular nature, and the interaction time between the jet and the explosive will be longer, due to the much lower jet density of a granular jet, with its decreased penetration velocity relative to a solid jet of the same material. This will result in a larger hole in the explosive. This parameter is of prime importance in the design of non-initiating charges. These aspects are explored further in [6].

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