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EXPERIMENTAL AND NUMERICAL STUDIES OF ANNULAR PROJECTILE CHARGES

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For the 4 liner materials Iron, Aluminum, Tantalum and Lead charges were designed that form stable ring-shaped projectiles in the hydrocode simulation. These charges were tested against a specifically designed steel target. The results presented include the hole geometry in the target and flash X-ray picture sequences of the formation process. The influence of the charge caliber is assessed and the simulation compared with the experiment.

1. Introduction

For certain military applications it is desirable to punch large holes into relatively thin targets. As an example in a follow-through warhead the precursor charge should open up a hole of at least the diameter of the follow-on blast charge.

Conventional charges, whether they are of the shaped or the projectile type, do not produce such large holes as the energy needed to perforate is proportional to the hole volume.

In analogy to core-drilling in the construction business, large holes can be punched with annular projectiles, cutting out a central circular disc. The required hole volume is thus reduced to a narrow circular gap, so that the energy to produce such a cut is in the range of typical kinetic energies of self-forging projectiles.

Similar charges that form a kind of annular projectile have been proposed by [1] and were further investigated by [2].

The aim of the task presented in the following is however to design a charge which forms an annular projectile that should be geometrically stable in a range from 2 to 6 CD (charge diameters) stand-off – as required for a precursor in a follow-through warhead – and in diameter being equal to the charge.

In this paper several designs are presented and some hydrocode simulations thereof compared with the results of live firing tests.

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2. Projectile formation

Several designs of charges to achieve such projectiles were evaluated. In all of them a liner with an intricate shape is deformed into a tube-shaped projectile by differential acceleration in such a way that its relative axial and radial velocities eventually cancel by the plastic work done on the liner material. Hereby the liner elements do not perform a collapse on the axis of symmetry, which adds to the difficulties to control the deformation.

Basically there are two types of such deformation processes. Fig. 1 shows both of them as picture sequences from hydrocode simulations. In the first, the center of the liner forms the leading edge of the ring-projectile, whereas the rim of the liner transforms into the trailing edge. In the second type B it is the opposite with the rim of the liner leading and the center trailing behind it.

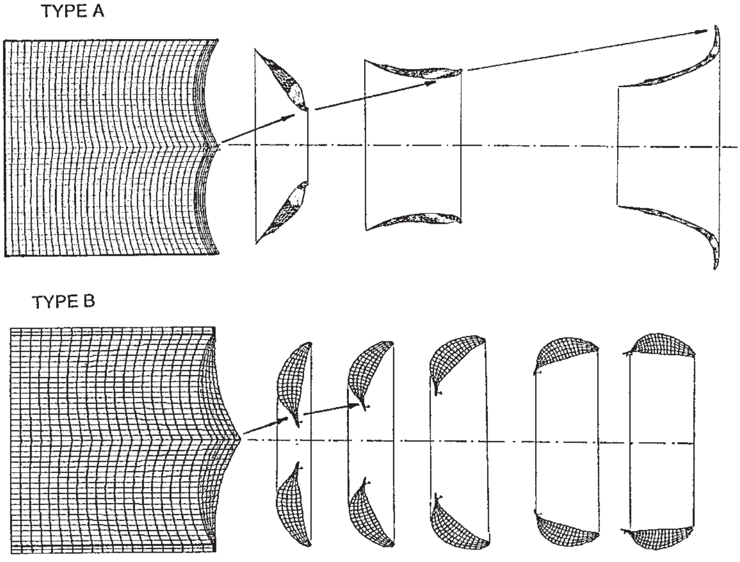

Figure 1. Simulation sequences of the 2 basic types of annular projectile charges evaluated.

For maximum penetration the ring should be as long as feasible, which translates into a large velocity difference between the front and back of the projectile. However this may not allow the material to smooth out all velocity differences and to freeze the projectile shape. Therefore for the optimal stable design some trade-offs must be accepted. In Fig. 2 the velocity histories of several Lagrangian target points on the liner during the projectile formation process are given. The large velocity differences at the beginning of the formation have to be reduced to small values so that a stable projectile results. The deviation of the curves after 60 μs shows that for the given geometry this is not yet fully accomplished.

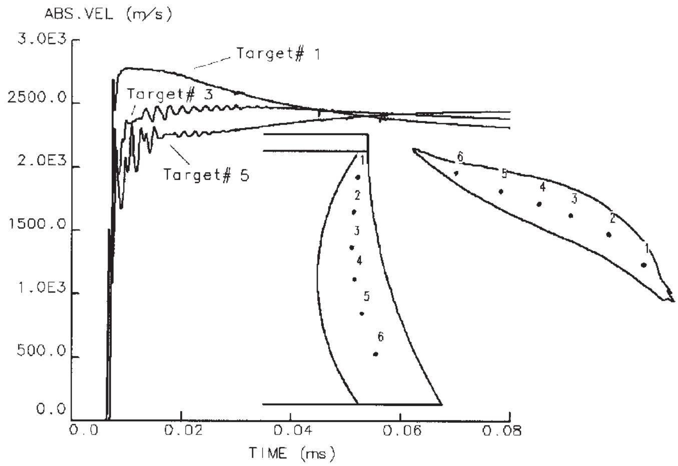

Figure 2. History of the absolute velocity of different target points on the liner during the formation of the projectile up to 80 μs after initiation. Initial and final shape of the projectile are shown.

3. Charge layout

The formation process of the projectile heavily depends on the material properties of the liner – e.g. the dynamic ductility and the ability to absorb deformation energy – so that different liner materials require different liner shapes. This makes the optimization of the liner geometry a painstaking procedure and a typical task for a hydrocode.

The basic design was of type B (Fig. 1). Further investigation of the type A charge was dropped, as the projectile of this variant necessarily develops a ragged leading edge, which is aerodynamically unstable and difficult to control.

Isostatically pressed LX-14 was used as high explosive. The charge was initiated by a precision coupler (PIC).

4. Tests performed

The charges were tested statically against a special target of steel plates at 2.5 CD stand-off.

The following charge parameters were evaluated:

- Liner material: Iron (Armco), Aluminum, Lead and Tantalum
- Charge caliber: 60, 120 and 240 mm

Measured were: Penetration, hole and disc diameter. (The “disc” is the cylindrical piece punched out of the target plate by the annular projectile). The results are summarized in Table 1.

Acceleration of the liner and formation of the projectile were observed by multiple flash X-ray.

5. Results

5.1. Stability of the projectile

The X-ray picture sequences of the 4 liner materials A1, Ta, Pb and Fe are given in Fig. 3 and 4. To compare the different liner materials, the test charges contained liners, whose shape had proven optimal in our early hydrocode modeling to form a stable ring-shaped projectile. As the modeling differs from reality to some extent, a perfectly stable projectile has not been obtained yet in practice with any of the materials.

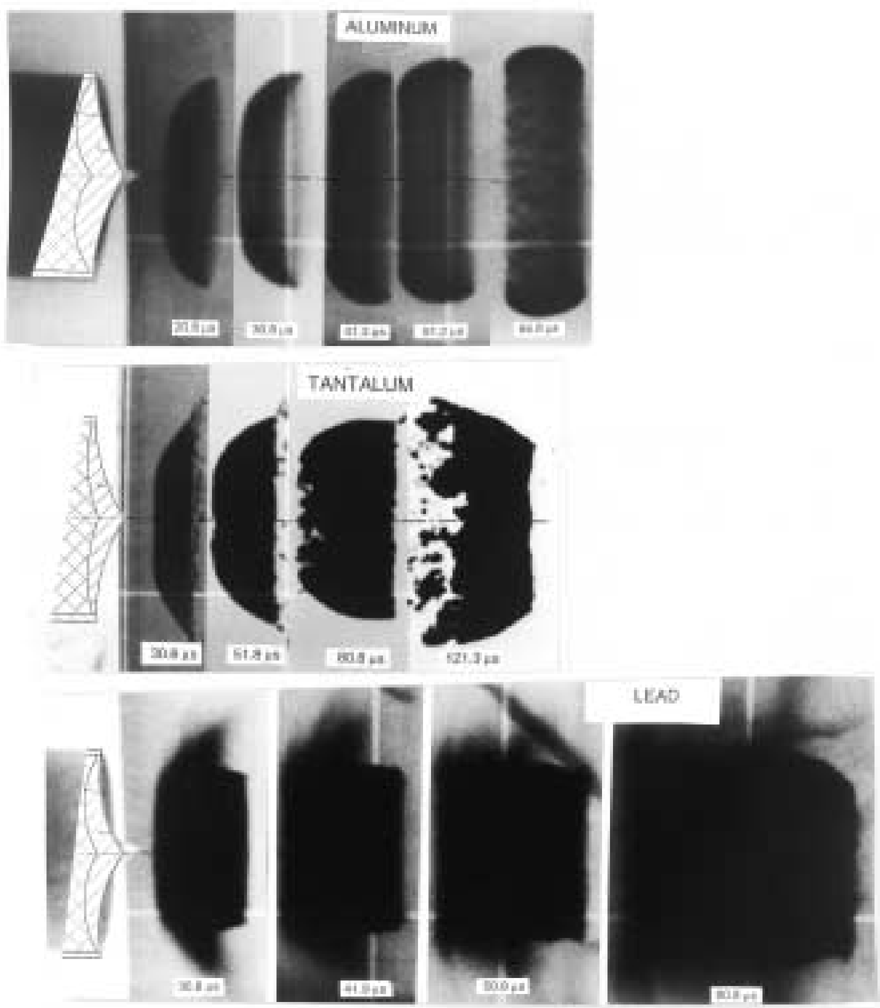

Figure 3. X-ray picture sequences of the 3 liner materials Aluminium, Tantalum and Lead. For Iron see Figure 4. Time zero ist the initiation of the PIC, the grid spacing is 50 mm. As the pictures of the Lead-projectile would overlap, they are displaced on the x-axis in order to show their full length. The back end ist obscured by either liquid or vaporized Lead.

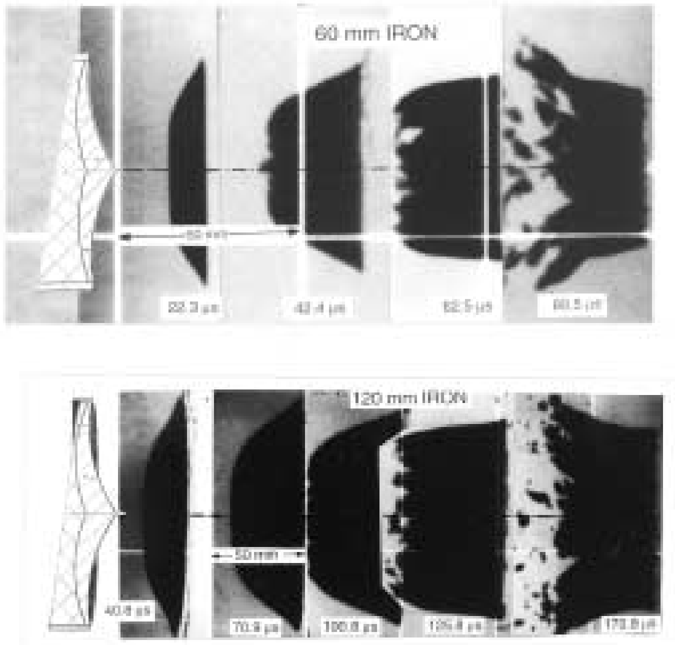

Figure 4. X-ray picture sequence of a 60 (top) and 120 mm (bottom) charge with Fe-liner. To be visually comparable, the pictures of the 120 mm variant were reduced by a factor of 2 in space. Time zero ist the initiation of the PIC, the grid spacing is 50 mm.

Liner material	Charge diameter [mm]	Stand-off [mm]	Velocity of the leading edge [mm/µs]	Hole depth [mm]	Hole diameter [mm]	Disc diameter [mm]
Fe	60	150	2.06	23	76	30
Al	60	150	2.63	27	105	65
Ta	60	150	1.08	11	77	48
Pb	60	150	2.49	30	82	59
Fe	120	300	1.91	46	130	62
Fe	240	600	-	103	285	110

Table 1. Test details and penetration results for different charge designs.

Unfortunately the inner contour of the ring is not visible on the X-ray pictures – with the exception of Aluminum – because of the massive X-ray absorption of the other materials. The “diameter of the disc” in Table 1 however gives an estimate of the internal diameter of the annulus.

Figure 5 (bottom) shows an X-ray picture sequence of a ring projectile that is radially stable but still stretching axially, whereas the A1 projectile in Fig. 3 is axially stable but radially expanding. With a slight adjustment of the liner shape a ring can be obtained that is both radially and axially stable – at least for a large range of practical stand-off distances.

5.2. Target penetration

The depth and diameters of the cut punched in the target plate are given in Table 1. The diameter of the hole is the clear opening or the diameter of a circular object that could pass. For Fe and Ta, where parts of the ragged trailing edge of the ring are sweeping radially out, a flower shaped hole is created where the petals extend to a considerably larger diameter. These "petals" however are neglected. In some cases the gap that was perforated (the difference of the hole and the disc diameter) seems to be unnecessarily large. The angle of impact was either not optimal or the projectile was too thick. However, a certain minimal thickness may be required to prevent the projectile from tumbling beyond the optimal ring shape.

The penetration depths of the 60 mm charges vary from 11 mm for Tantalum to 30 mm for Lead. We have to consider that the shapes of the projectiles for the different metals are not identical. It is therefore unsuitable to construct a mass-dependence on the basis of these results. However it is interesting to note that the Lead-projectile, which is partly liquid or even vaporized, shows the best penetration of the metals investigated, and Aluminum with its low density performs surprisingly well. Contrary to that, Tantalum with its high density only penetrates disappointing 11 mm, which may be explained by the low velocity of the massive projectile.

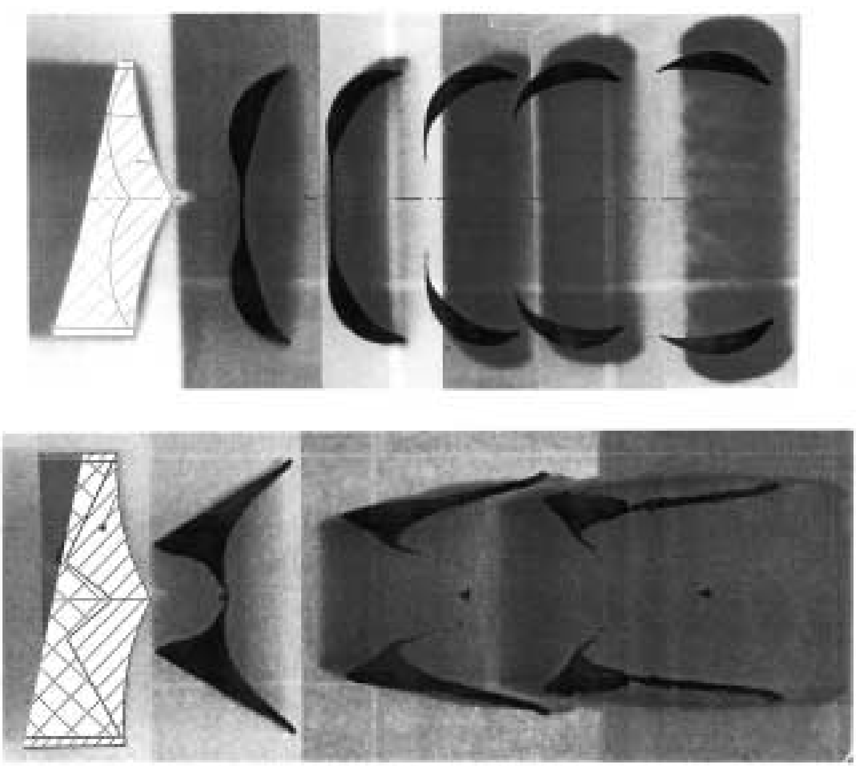

Figure 5. Superposition of the simulation sequence on the corresponding X-ray picture sequence for two Al-liner geometries. Simulations: Lagrange (top), Euler (bottom).

5.3. Scalability

To assess the influence of charge caliber, the original 60 mm charge with an Fe liner was enlarged by a factor of 2 and 4, which means to a caliber of 120 and 240 mm. In Figure 4 the X-ray picture sequences of the 60 and 120 mm charges are compared (the 240 mm charge was too large to X-ray). The visual comparison shows that the formation processes and shapes are identical if compared on a normalized basis. The picture at 62.5 µs (top) and 125.8 µs (bottom) can be compared directly as they are practically synchronous on this normalized scale. Penetration and hole geometry also follow the scaling laws reasonably close, as Table 1 shows, considering that these numbers can only be determined with lower precision.

5.4. Fidelity of the simulation

In Fig. 5 the simulation sequence of two very different liner geometries is superimposed on their experimental X-ray picture sequence to assess the fidelity of the modeling. It clearly shows that the simulation differs to some extent from reality – more in geometry and less in velocity. However no effort was made to use other than the standard parameters and material models at hand. The obvious underestimation of the radial expansion of the ring in the top of Fig. 5 is thus basically because no failure criteria was used in the hydrocode. This would account for the rupturing of the radially (and axially) expanding annulus that can be observed in the X-ray pictures. This loss of hoop stress leads also to a transfer of elastic into kinetic energy, which further accelerates the ring radially. In the second case the projectile loses some of its form at later times due to the mass transport mechanism through the Eulerian grid.

6. Conclusions

All of the liner materials tested have created holes with at least 1 CD in diameter and the disc punched out in the center is between 0.5 and 1 CD. The depth of the cut is between 0.2 and 0.5 CD. Stability of the projectiles has not yet been fully achieved at this stage. By optimizing the liner geometry, stable shapes should be realized with somewhat improved penetration. This process can be supported by simulation, which models the effects of differential changes in design quite well. This annular charge concept has shown to be feasible in caliber up to 240 mm where the scaling laws are valid.

References

1. M.C. Chick, T.J. Bussell, C.P. Lam and D. McQueen, "Development of a Cookie-Cutter Explosively Formed Projectile", *17th International Symposium on Ballistics*, Midrand, South Africa, March 1998.
2. P.J. König and F.J. Mostert, "The Design and Performance of Annular EPF's", *South African Ballistics Symposium*, Durban, South Africa, June 2000