

PENETRATION OF EXPLOSIVELY FORMED PROJECTILES

C.A. WEICKERT and P.J. GALLAGHER

Defence Research Establishment Suffield
Box 4000, Medicine Hat, Alberta, Canada, T1A 8K6

ABSTRACT

Results of an experimental and computational investigation on the effects of the shape of an explosively formed projectile on the penetration into various targets are presented. Seven different shapes of Armco iron EFPs with a velocity range of 1666 - 1862 m/s were fired into stacked targets consisting of mild steel, RHA, aluminum armour, and OFHC copper plates. Numerical simulations were performed with the Zeus two-dimensional hydro-code. It was found that a range of projectile profiles and velocities produced differing levels of penetration into the various targets.

INTRODUCTION

The design of explosively formed projectile (EFP) warheads involves many parameters which effect the projectile shape. Physical properties and responses of the explosive, liner and casing materials represent some of these parameters. Other parameters are geometric, such as liner contours, casing dimensions, charge diameter, etc.. Successful EFP design will arrive at parameters which lead to an EFP able to defeat a specific target.

Presented in this paper are comparisons of experimental results of 19 firings (sectioned target profiles) and two-dimensional finite element calculations of EFP penetration. Correlations between the EFP profiles and velocities and the penetration depths were established.

EXPERIMENTAL SET-UP

The EFP charge design is described previously (Weickert and Gallagher, 1992). Through variation of the charge confinement parameters, seven EFP shapes were produced from a single liner/case design. Characterization of the EFPs was derived from flash X-radiographs of the projectiles in flight and through examination of soft-recovered projectiles.

A series of targets, made up of stacked thicknesses of plate, were assembled and fired against with an array of the seven iron EFP shapes generated (shown in Fig. 1.); 1-7 against mild steel, and 1, 3, 5, and 7 against each of RHA, Al, and Cu. Each target was composed as described in Table I below.

Targets were shot at close range (~1.4 m), but at a sufficient distance to allow the EFPs to form completely. Flash X-radiographs were taken for each EFP prior to impact to establish velocity and profile.

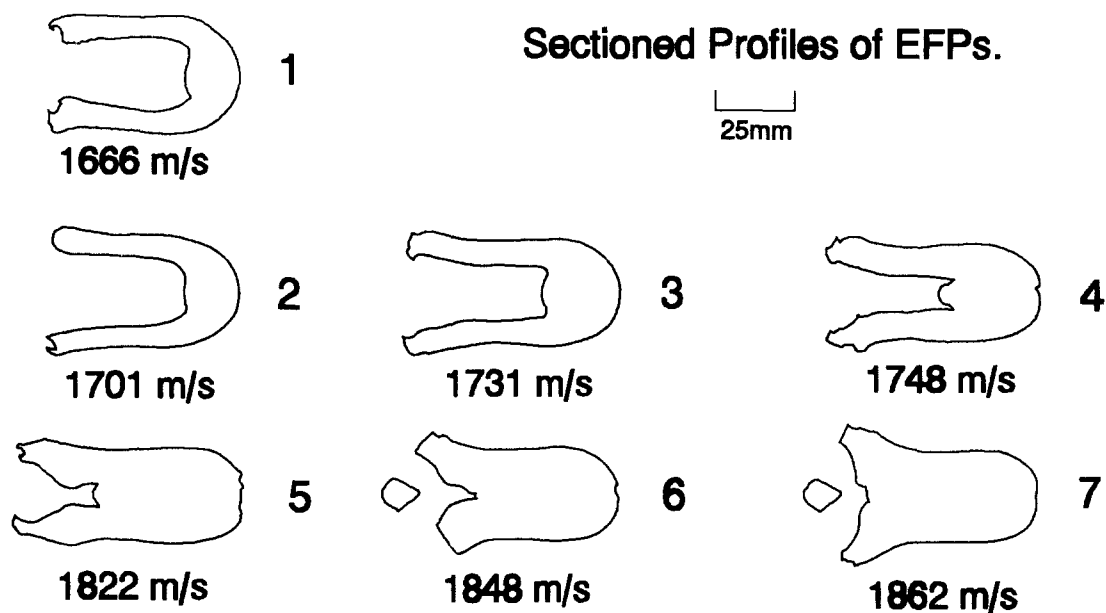


Fig. 1 Experimental EFP profiles.

Table I. Target material description.

T1	2 - 300 mm squares of 50.8 mm thick mild steel plate.
T2	2 - 300 mm squares of 50.8 mm thick RHA steel plate.
T3	4 - 300 mm squares of 38.1 mm thick 7039 aluminum armour plate.
T4	4 - 250 mm squares of 25.4 mm thick OFHC copper plate.

*All backed with 4 - 300 mm squares of 25.4 mm thick mild steel and a 600 mm square of 100 mm thick armour plate.

NUMERICAL SET-UP

Numerical simulations of the EFPs impacting and penetrating the various targets were run on an 80486 based micro computer using ZeuS (Zukas and Segletes, 1987) a two-dimensional, Lagrangian hydro-code. The penetrator and target properties used for the code's material models, are shown in Table II. This was the latest release of the ZeuS code, and there is not yet an extensive library of material properties. Furthermore, the failure and erosion criteria, in the code have been re-worked. Thus parameters controlling these events have not been developed fully for the materials studied here. They are also code dependent numerical parameters and not completely linked to a physical property. Also, strain rate and temperature dependent properties were not used, since the specific materials used here have not yet been characterized to this extent.

RESULTS

The purpose of the present study was to determine the effect of an EFP profile on the penetration into a variety of target materials.

In Fig. 1 are shown the seven EFP profiles produced, P1 through P7, and their velocities (Weickert and Gallagher, 1992). A timed sequence ($\Delta t = 25 \mu s$) of an EFP, P5, going into a target (T1) is shown in Fig. 2. The final ($t=150\mu s$) frame and experimental profile are shown in Fig. 7.

The full sequence of penetrator shapes (P1-P7) were fired against mild steel targets (T1). The computed and experimental profiles of this series are shown in Figs. 3-9.

For the RHA, Al, and Cu targets (T2, T3, T4), only penetrators P1, P3, P5, and P7 were used. The simulations and experiments for these targets are shown in Figs. 10-13 (RHA), Figs. 14-17 (Al), and Figs. 18-21 (Cu).

Reasonable agreement can be seen between the predicted and experimental penetrations, especially considering the range covered by the series. The EFP profiles were characterized by: velocity, projectile length, solid length over projectile length ratio, and percent solid volume (Table III). Plots of penetration depth versus each of these parameters are shown in Figs. 22-25. There is a knee in most of the plots indicating minimal penetration performance enhancement above a limit. Although, penetration depth is only one parameter, and closer examination of the post-impact target profiles, reveals changes to the hole size, shape and deformation of non-penetrated plates with each shot.

Table II. Model material properties.

	σ_{yield} (MPa)	σ_{uts} (MPa)	ϵ_{uts}	P_{min} (MPa)
Armco Iron (EFP)	400	500	0.20	1230
Mild Steel (Target 1)	820	820	0.0001	1230
RHA steel (Target 2)	900	1100	0.20	3030
7039 Al (Target 3)	400	500	0.20	1000
OFHC Cu (Target 4)	450	450	0.20	5000

Table III. Projectile characterization data.

Projectile	Velocity (m/s)	Length (mm)	Solid Length/ Length	%Solid Volume
P1	1666	59.7	0.29	75.2
P2	1701	60.7	0.29	68.3
P3	1731	69.7	0.36	76.8
P4	1748	67.3	0.48	86.5
P5	1822	70.9	0.67	90.6
P6	1848	65.3	0.71	91.3
P7	1862	62.1	0.86	93.4

CONCLUSION

The shape of an EFP significantly effects the depth and profile of the penetration into a target materials. Each EFP profile carried a specific set of velocity, length, and degree of solidness (wrt length and volume), and as such no single parameter could be singled out.

More work is required in properly characterizing the materials to bring the simulation into closer agreement with the experiments. The ZeuS code allows for externally defined material models, which could, in time, generate an improved matching to the experimental results. With better agreement established, then single parameter variation, computational studies could be carried out, relatively inexpensively, to further optimize EFPs.

REFERENCES

Weickert, C.A. and Gallagher, P.J. (1992). Parametric Study of the Effect of a Confinement Ring on the Shape of an Explosively Formed Projectile, *13th International Symposium on Ballistics*, Sweden, vol.2 413-420.

Zukas, J. and Segletes, S. (1987). *ZeuS, Technical Description and Users Manual*, Computational Mechanics Consultants, Towson, MD.

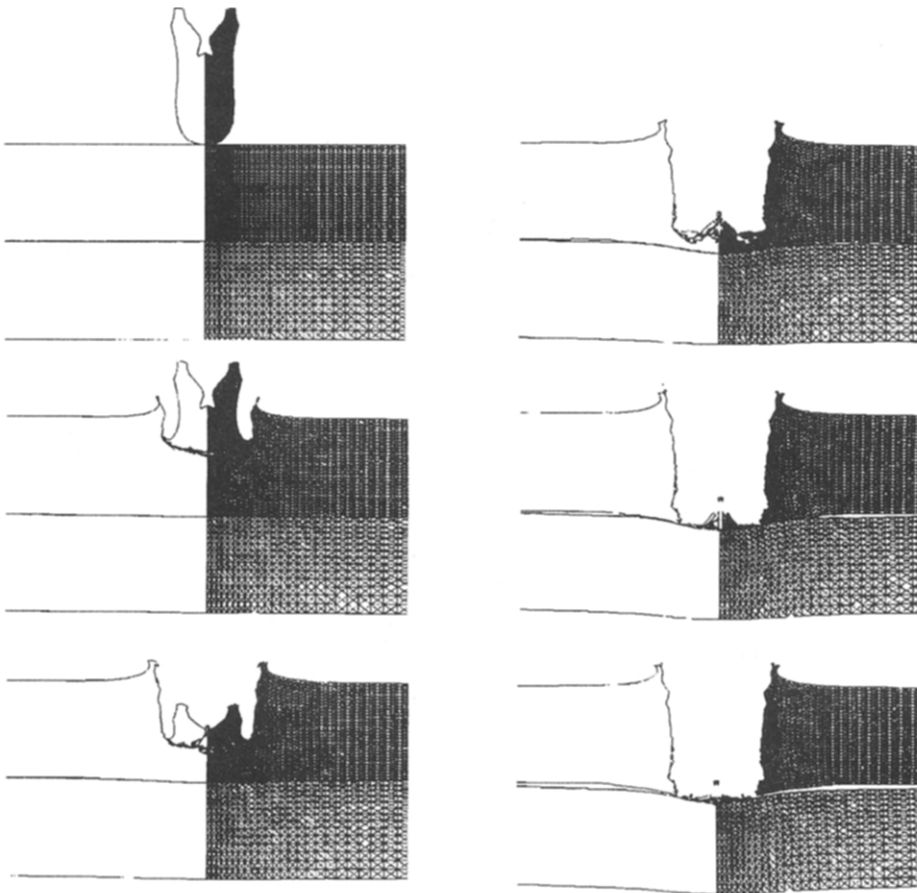


Fig. 2 Computational sequence of an EFP (P5) entering a target (T1), $\Delta t = 25 \mu s$, times 0 to 125 μs .

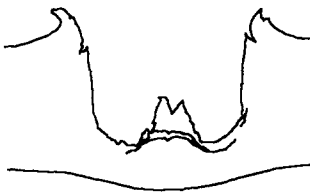
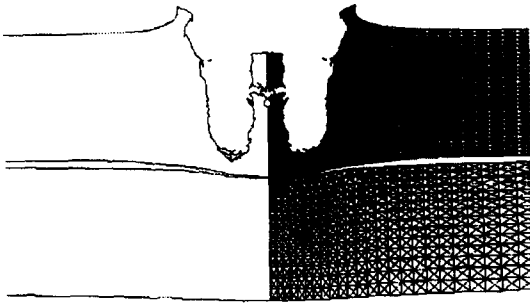


Fig. 3 Projectile (P1) into Target (T1), simulation @ 150 μ s (top) and experiment.

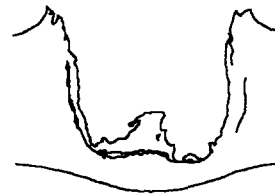
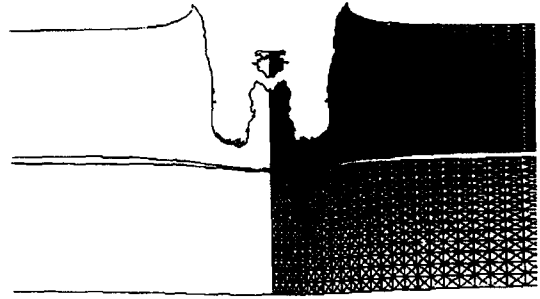


Fig. 4 Projectile (P2) into target (T1), simulation @ 150 μ s (top) and experiment.

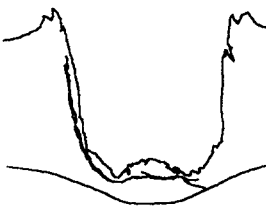
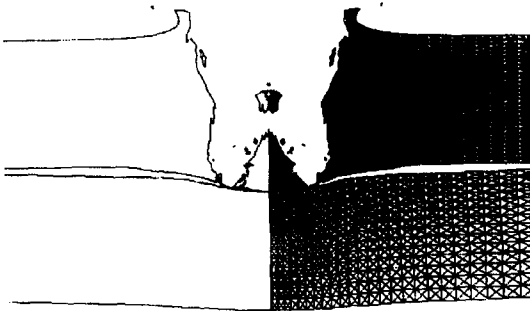


Fig. 5 Projectile (P3) into Target (T1), simulation @ 150 μ s (top) and experiment.

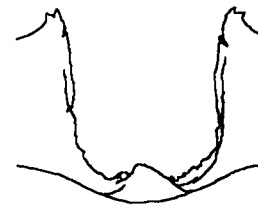
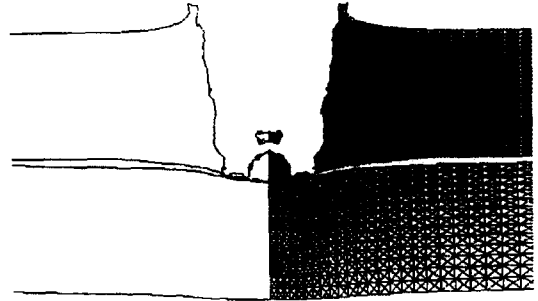


Fig. 6 Projectile (P4) into target (T1), simulation @ 150 μ s (top) and experiment.

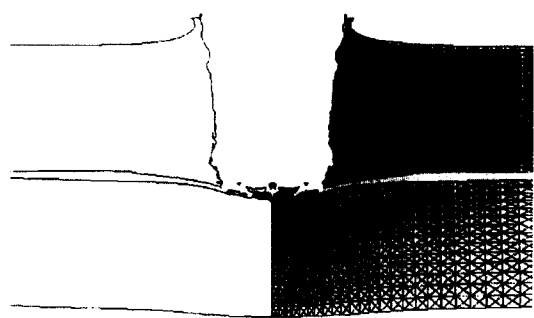


Fig. 7 Projectile (P5) into target (T1), simulation @ 150 μ s (top) and experiment.

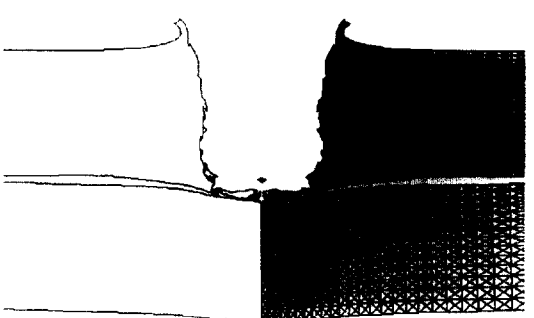


Fig. 8 Projectile (P6) into target (T1), simulation @ 150 μ s (top) and experiment.

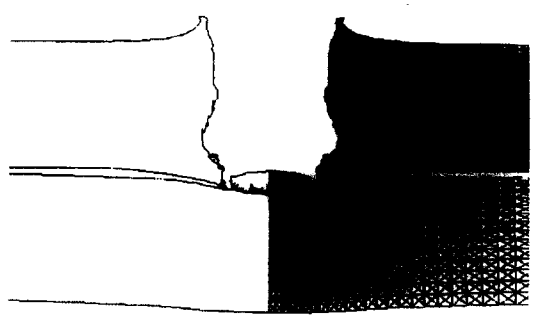


Fig. 9 Projectile (P7) into target (T1), simulation @ 150 μ s (top) and experiment.

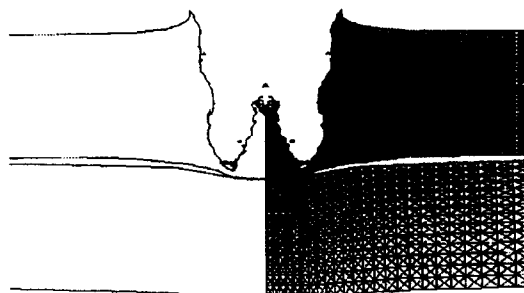
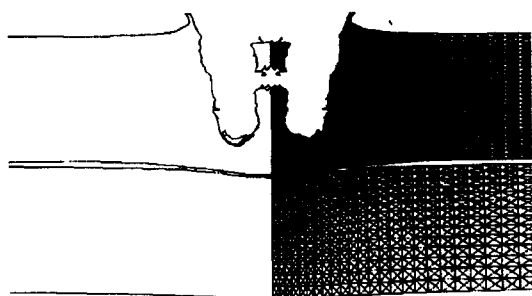


Fig. 10 Projectile (P1) into Target (T2), simulation @ 150 μ s (top) and experiment.

Fig. 11 Projectile (P3) into target (T2), simulation @ 150 μ s (top) and experiment.

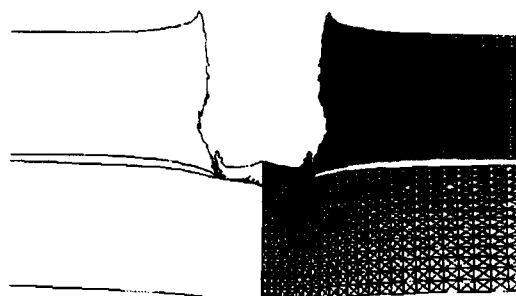
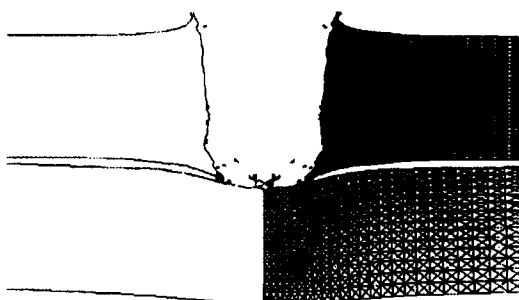


Fig. 12 Projectile (P5) into Target (T2), simulation @ 150 μ s (top) and experiment.

Fig. 13 Projectile (P7) into target (T2), simulation @ 150 μ s (top) and experiment.

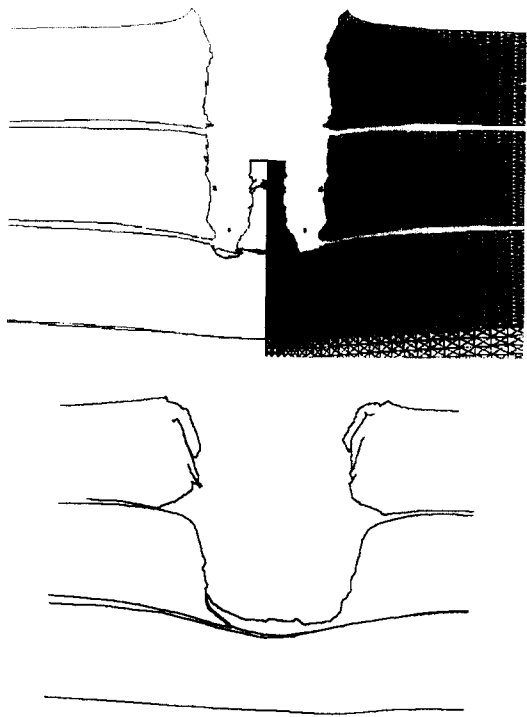


Fig. 14 Projectile (P1) into Target (T3), simulation @ 150 μ s (top) and experiment.

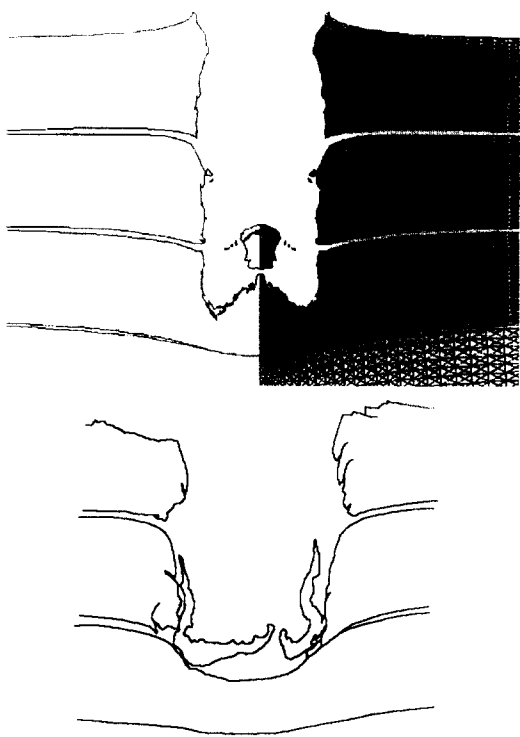


Fig. 15 Projectile (P3) into target (T3), simulation @ 150 μ s (top) and experiment.

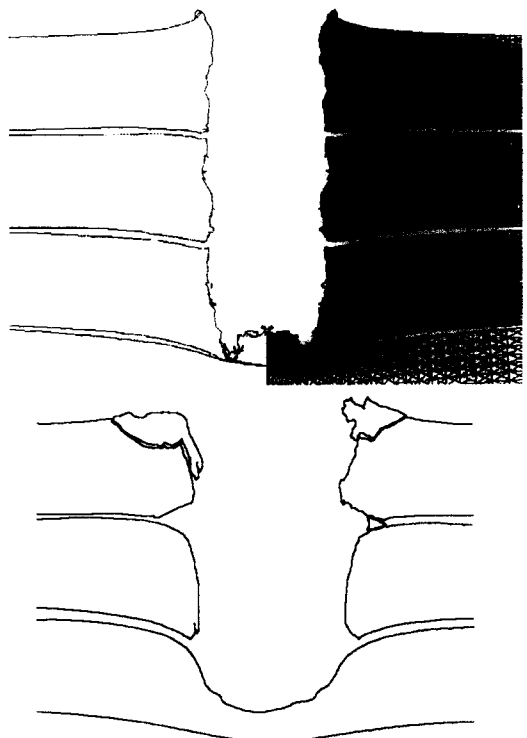


Fig. 16 Projectile (P5) into Target (T3), simulation @ 150 μ s (top) and experiment.

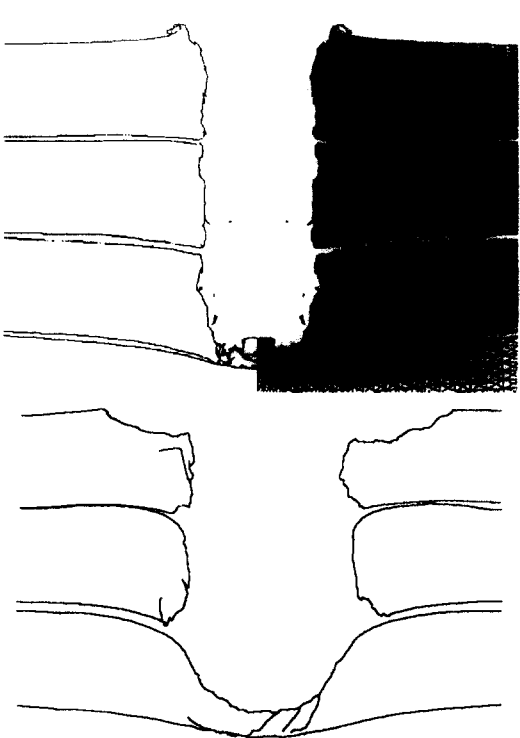


Fig. 17 Projectile (P7) into target (T3), simulation @ 150 μ s (top) and experiment.

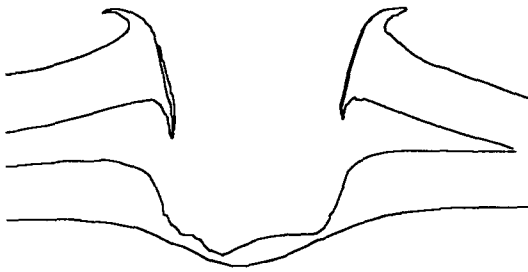
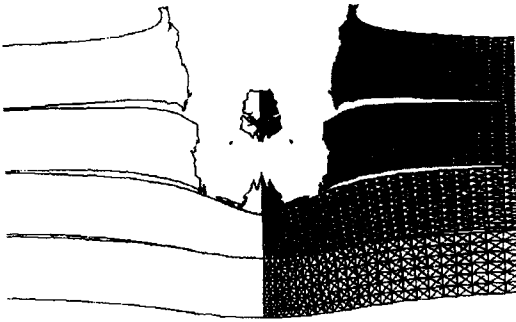


Fig. 18 Projectile (P1) into Target (T4), simulation @ 150 μ s (top) and experiment.

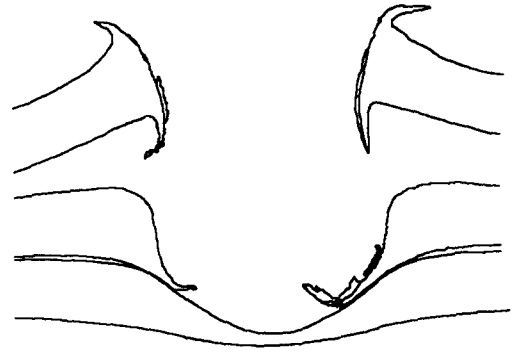
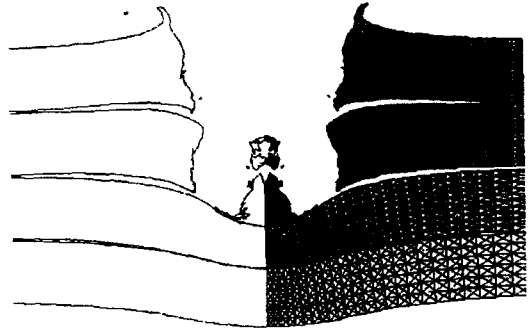


Fig. 19 Projectile (P3) into target (T4), simulation @ 150 μ s (top) and experiment.

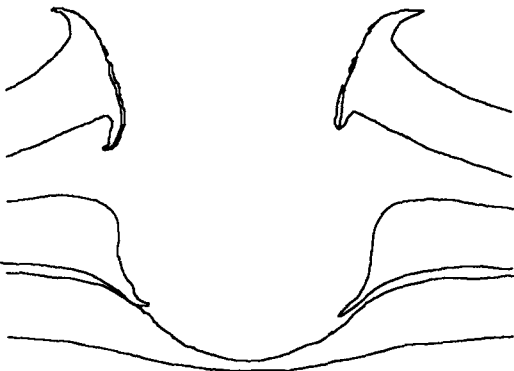
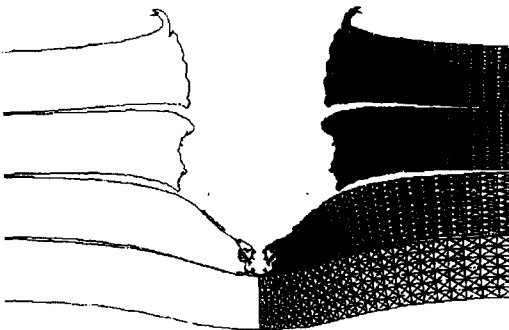


Fig. 20 Projectile (P5) into Target (T4), simulation @ 150 μ s (top) and experiment.

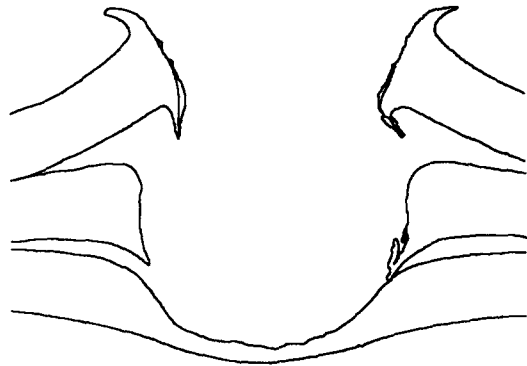
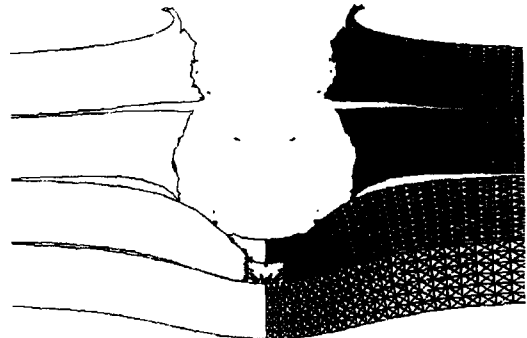


Fig. 21 Projectile (P7) into target (T4), simulation @ 150 μ s (top) and experiment.

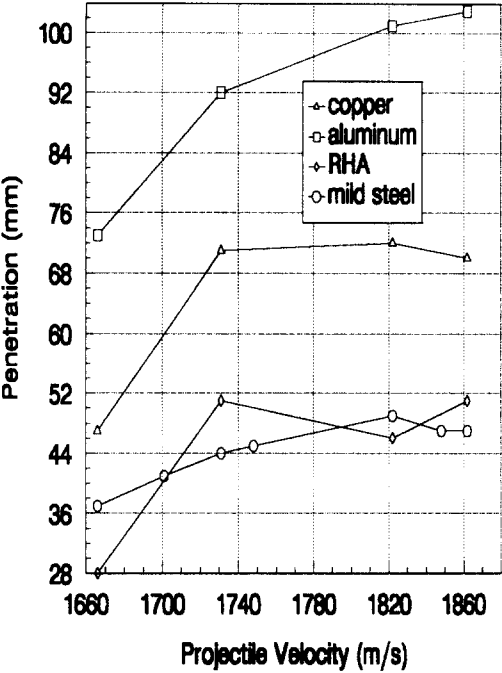


Fig. 22. Penetration vs EFP Velocity.

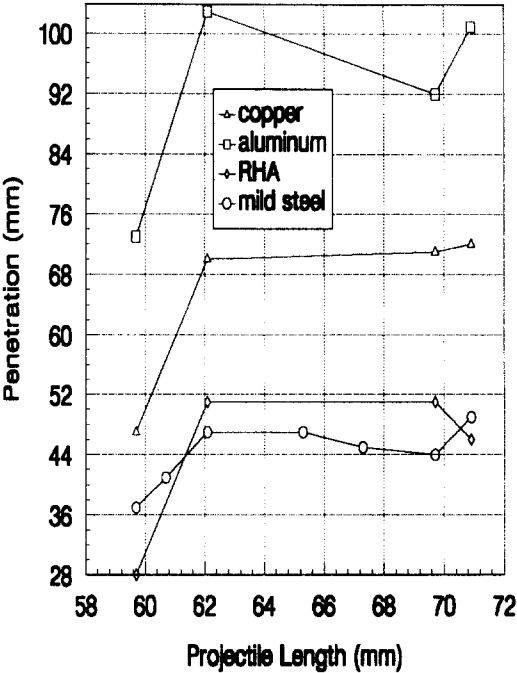


Fig. 23. Penetration vs EFP Length.

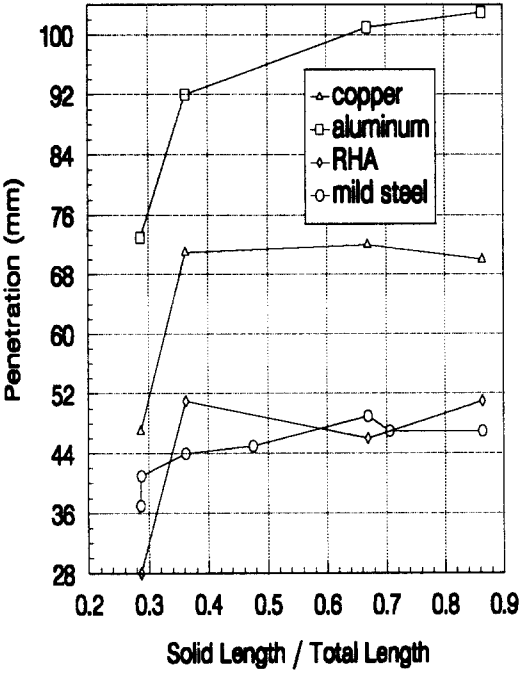


Fig. 24. Penetration vs Solid Length/EFP Length.

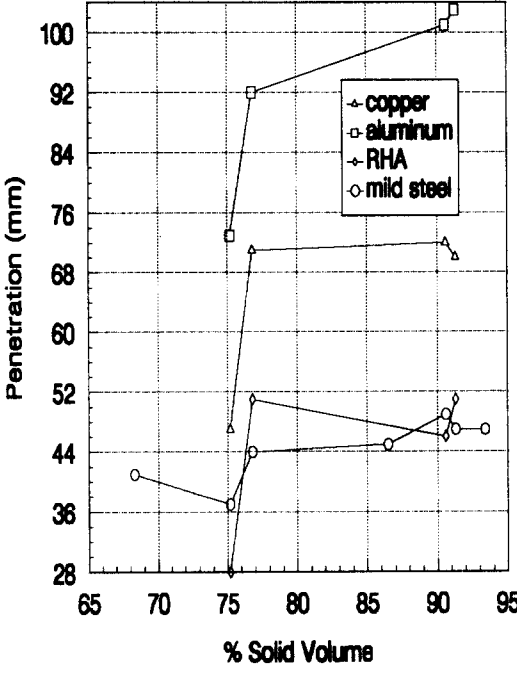


Fig. 25. Penetration vs EFP %Solid.