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COMPUTER SIMULATION OF EXPLOSIVELY FORMED PROJECTILES (EFP)

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The numerical simulation of the EFP projectiles is presented. This research had three objectives: the influence of the liner geometry is studied, the effects of the explosive (TNT, Octol and PBX – 9407) is investigated and the effect of the liner material (Copper, Iron, Tungsten, MONEL Alloy 400, INCONEL Alloy 600, INCONEL Alloy 625, INCO Alloy HX, INCOLOY Alloy 800 HT, Nickel 200 and Hadfield steel) is considered.

INTRODUCTION

The evaluation of the explosively formed projectile (EFP) is a very complex process which is dwell described e.g. in [1]. There are several basic parameters in the warhead configuration that affect the projectile shape and performance. These can broadly be classified as geometrical factors and material factors. Various investigators have studied the effects of different factors, and their efforts have resulted in much improved warheads over the years – see e.g. [1] for a review. The EFP system, however, is far from understood completely and there remain many issues that need to be investigated further.

The solution of these problems can be made experimentally and/or by modelling respectivelly. The high cost of experiments and the rapid advancements in computer technologies is driving more and more researchers to carry out simulations using hydrocodes in order to design and improve the performance of the EFPs and, of course, many other materials, materials issues and materials systems. Computational simulations are increasingly being used to design and control experiments, optimize geometries, estimate loading aid in the interpretation of results, even for investigations aimed at improving constitutive descriptions [2].

The present paper contains preliminary results on the numerical simulation of the EFP development. The influence of the liner shape, explosive and liner materil is studied in details**.**

PROBLEM STATEMENT.

Numerical simulation has been performed for the different geometry of the liner, for different types of the explosives and for liners made from different materials.

The liner gemetry is shown in Fig.1. The liners I and II differ in the angle α (α=90°- liner I, α=150°- liner II).The thickness of the liners was 3 mm with the exception of the liner made from Ta (thickness 1.5 mm).

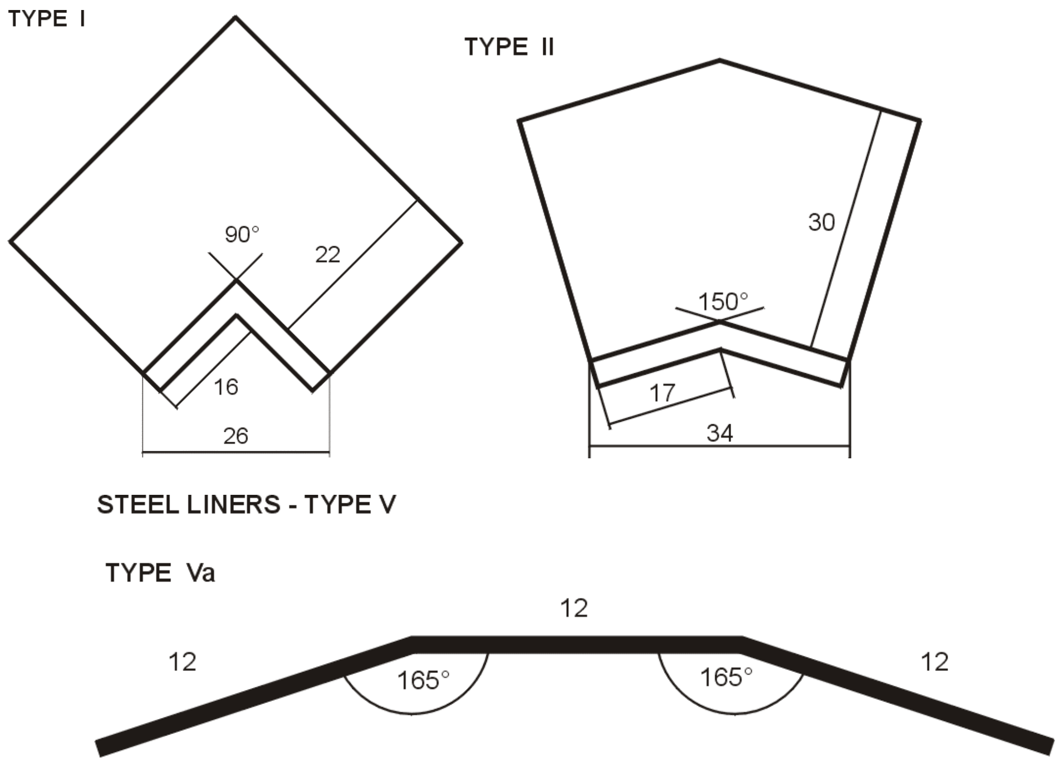

Figure 1. Geometry of the liner (in mm).

The behavior of the used explosives, has been described in terms of the Jones - Wilkins - Lee (JWL) equation of state, together with the programmed burn model. The JWL equation has the form :

$$p = A\left[1-\frac{\omega}{R_1 V}\right]\exp\left(-RV_1\right)+B\left[1-\frac{\omega}{R_2 V}\right]\exp\left(-R_2 V\right)+\frac{\omega E}{V}$$

Where p is the detonation pressure, V is the relative volume and E is the internal energy density. The parameters are given in Table 1.

Table 1. Parameters of the JWL Equation. (ρ is the explosive density, D is the detonation velocity)

Explosive	A3	TNT	Oktol	PBX - 9407
ρ (kg/m^3)	1840	1630	1783	1600
D (m/s)	8820	6930	8730	7910
A (GPa)	852.4	272.7	943.3	573.2
B(GPa)	18	18	8.805	14.64
R_1	4.6	3.231	4.7	4.6
R_2	1.3	0.95	0.9	1.4
ω	0.38	0.30	0.35	0.32
E_o (GPa)	10.2	10.2	10.2	8.6

The following materials of the liner have been considered : Copper, Iron, Aluminium, Tungsten, Tantalum, Nickel , Hadfield steel, Monel Alloy 400, Inconel Alloy 600 and 625 and INCO Alloy 800 HT. The details on chemical composition of these materials together with their properties can be found in [3].

The elastic properties are described by the Young modulus and Poisson ratio.

Johnson – Cook (J-C), Zerilli-Armstrong (S-G) and Steinberg-Guinan (S-G) constitutive equations have been used for the description of the plastic deformation of the considered materials

NUMERICAL RESULTS

Numerical simulation has been performed using of the finite element code LS DYNA 3D. Numerical model of the problem is shown in the Fig.2. The example of the projectile development are shown in the Figs.3 and 4. From the results the velocities of the projectile in y direction have been evaluated.

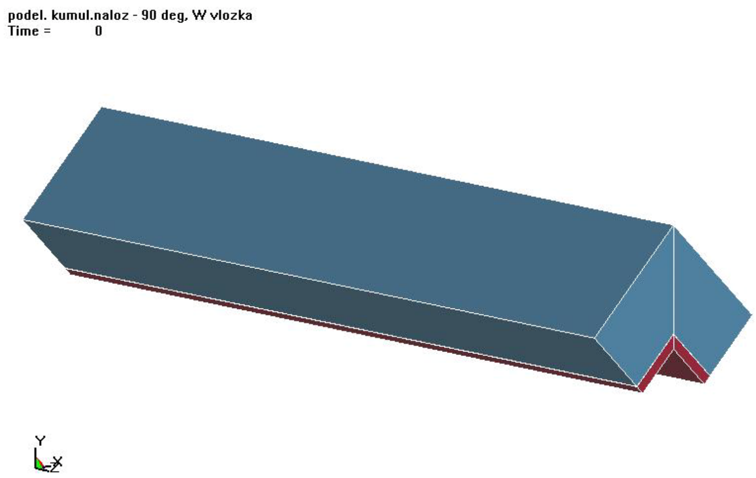

Fig.2. Schematic of the numerical model. (liner I made from the Tungsten).

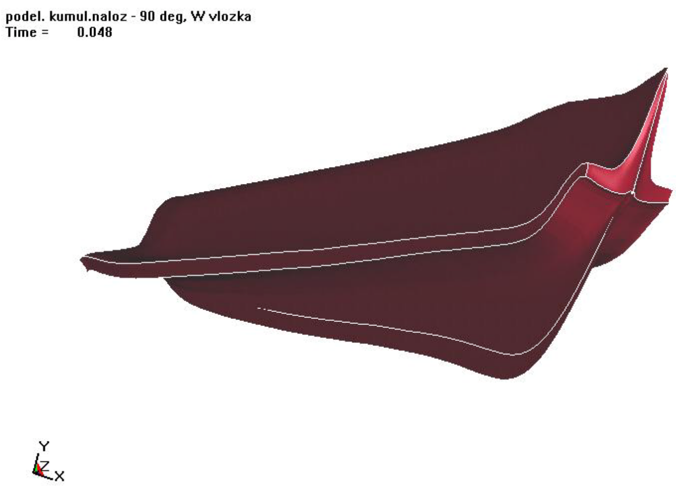

Fig.3. Liner collaps (time is in ms).

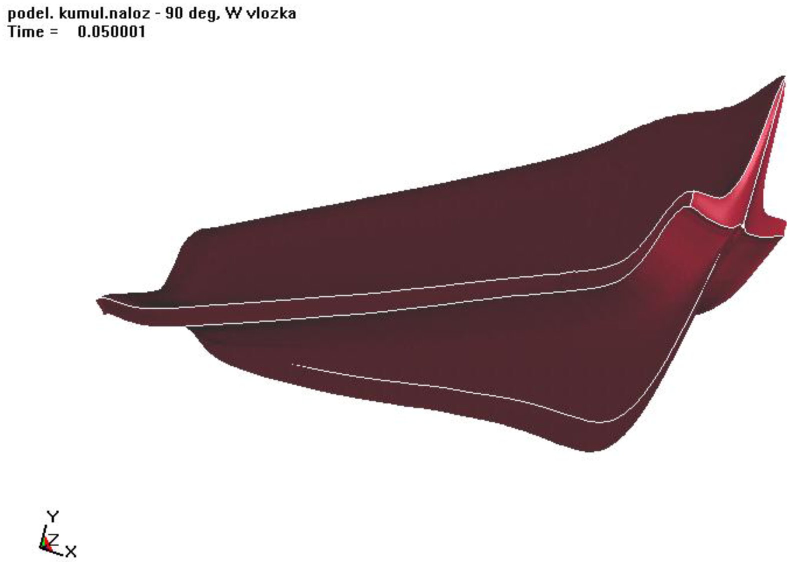

Fig.4. Liner collaps (time is in ms).

The velocities have been evaluated along the projectile (z direction) in the following nodes .

Node 1 z = 0.000 mm
Node 321 z = 5000 mm
Node 371 z = 100.0 mm
Node 421 z = 150.0 mm
Node 471 z = 200.0 mm
Node 262 z = 250.0 mm

Example of the velocities distribution is shown in Figs.5 and 6.

The same qulitative features of the velocity distribution have been found for the all tested materials. In the next considerations the average of the velocities along the projectile have been used. The values of this velocities are summarized in Tables 2 -6.

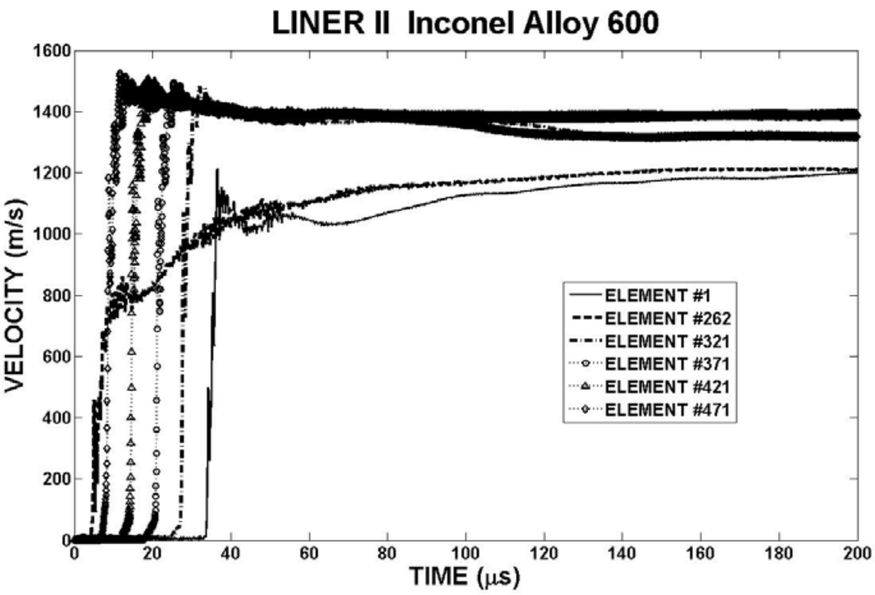

Fig.5. The distribution of the velocities of the liner.

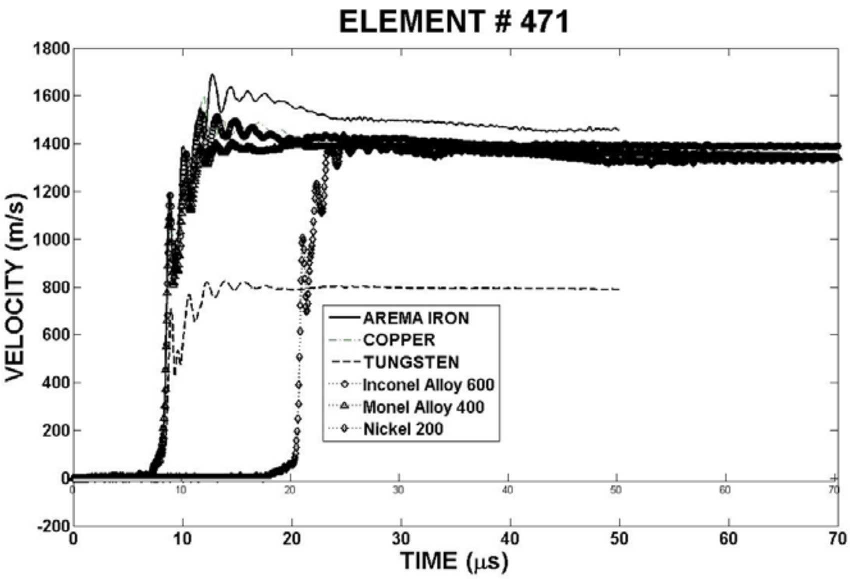

Fig.6. The influence of the liner material on the projectile velocities.

Table 2. Average velocities of the projectiles formed from the liner II.

	A3	TNT	Oktol	PBX - 9407
Inconel Alloy 600	1330m/s	1255 m/s	1300 m/s	1206 m/s
Monel Alloy 400	1280m/s	1232 m/s	1247 m/s	1186 m/s
Nickel 200	1280 m/s	1235 m/s	1244 m/s	1207 m/s
Tantalum	1310 – 1330 m/s	1240-1250 m/s	1290 - 1305 m/s	1180 – 1200 m/s
COPPER	1800 m/s	1620 m/s	1750 m/s	1600 m/s
IRON	2850 m/s	2630 m/s	2740 m/s	2580 m/s
TUNGSTEN	830 m/s	815 m/s	852 m/s	800 m/s
INCO Alloy HX	1145 m/s	1020 m/s	1130 m/s	1010 m/s
INCOLOY Alloy 800 HT	1120 m/s	1010 m/s	1100 m/s	950 m/s
Hadfield steell	1260 m/s	1130 m/s	1110 m/s	1040 m/s

Table 3. Average velocities of the projectiles formed from the liner Va

	A3	TNT	Oktol	PBX - 9407
Inconel Alloy 600	1370m/s	1290 m/s	1325 m/s	1240 m/s
Monel Alloy 400	1320 m/s	1265 m/s	1280 m/s	1215 m/s
Nickel 200	1320 m/s	1270 m/s	1275 m/s	1210 m/s
Tantalum	1330 m/s	1250 m/s	1300 m/s	1210 m/s
COPPER	1630 m/s	1580 m/s	171 m/s	1540 m/s
IRON	1410 m/s	1350 m/s	1385 m/s	1310 m/s
TUNGSTEN	840 m/s	825 m/s	860 m/s	810 m/s
INCO Alloy HX	1160 m/s	1040 m/s	1140 m/s	1030 m/s
INCOLOY Alloy 800 HT	1140 m/s	1300 m/s	1120 m/s	970 m/s
Hadfield steel	1280 m/s	1120 m/s	1100 m/s	1080 m/s

Table 4. Average velocities of the projectiles formed from the liner I, Johnson – Cook equation.

LINER	Explosive			
	A3	TNT	Oktol	PBX - 9407
COPPER	2431	2120	2230	2080
IRON	3700	3630	3720	3510
TUNGSTEN	1222	1210	1235	1175

Table 5. Average velocities of the projectiles formed from the liner I, Zerrilli – Armstrong equation.

LINER	Explosive			
	A3	TNT	Oktol	PBX - 9407
COPPER	2360	2130	2225	2063
IRON	3840	3620	3730	3540
TUNGSTEN	1268	1180	1165	1083

Table 6. Average velocities of the projectiles formed from the liner I, Steinberg - Guinan equation.

LINER	Explosive			
	A3	TNT	Oktol	PBX - 9407
COPPER	2370	2120	2230	2080
IRON	3850	3630	3720	3510
TUNGSTEN	1280	1265	1293	1210

CONCLUSION

The following conclusions can be deduced from the obtained results :

- The highest velocities of the projectiles were reported for the liners with the geometry I (see Fig.2).
- The difference between efficiency of the liners II and Va is nearly negligible.
- The highest velocity exhibits projectiles formed from the liner made from the pure iron. The minimal velocity was observed for the tungsten liner. The remaing materials exhibit nearly the same velocities..
- The use of the different projectiles forms of the constitutive equations leads to the same velocities of the projectiles.

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