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NUMERICAL SIMULATION OF SHAPED CHARGE JET INTERACTION WITH MULTILAYERED TARGET

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The main aim of this paper is to present the interaction of shaped charge jet with multilayered targets, containing a combination of metal, explosives and ceramic layers. The numerical calculations with a copper lined shaped charge were carried out by HEFP hydrocodes based on "free particles" method. In the next stage of our work we calculate interaction of long copper shaped charge jet with multilayered target containing explosives and coramics. The parameters of jet were taken from the simulation of shaped charge jet formation. Very important role of the parameters of different layer of target is shown. The model for ceramics is based on the modified elasto-plastic Steinberg's constitutive relations for ceramics. Finally, simulations are carried out on elasto-plastic/brittle model.

INTRODUCTION

In the paper we present the results of numerical studies on interaction of shaped charge jet with metal/ceramic and metal/explosives/ceramic targets. The numerical analysis was carried out by hydrocodes based on "free particles" method [1,2], prepared for isotropic material models (in the range of elasticity material properties). Equations of the conservation of mass, momentum, and energy have been completed with semi-empirical equation of state.

The material model for metals includes the elasto-plastic theory [3,4] and Steinberg's or Johnson-Cook's constitutive relations connected with the behaviour of the yield strength and bulk modulus as a function of plastic strain, plastic strain rate, pressure, density, and temperature [5,6,7,8]. The physical-mathematical model is completed with the model of growing and closing cracks for ductile materials [9] and relations describing influence of the cracks on dynamic behaviour of metals.

The model for explosives is based on the hydrodynamics theory of detonation products.

The model for ceramics is based on the elasto-plastic Steinberg's constitutive relations for non-damaged, ideal ceramic material [10,11,12]. It is modified for behaviour of brittle material and is completed with the model of growing cracks and relations describing the influence of the cracks on strength characteristics of brittle materials [2].

We would like to show behaviour of different light multilayered armours, containing a combination of metal/explosives/ceramic and metal/ceramic layers. The numerical simulations were carried out for several combinations of the layers. The exemplary results of our studies are shown.

PHYSICAL MODEL OF BEHAVIOUR OF MATERIALS UNDER HIGH DYNAMIC LOADING

The model describing dynamic deformations of metals (the case and liner of warhead, the shaped charge jet and the layers of the target) is based on the elastic-plastic theory [1,3,4,13]. It is supplemented with semi-empirical relations necessary for description of behaviour of the metal under high dynamical loading:

- equation of state (EOS) [1,3,4],
- the Steinberg-Guinan model describing behaviour of the yield strength [5,6,7],
- the model of cracks forming in the structure of metal [1,9,14],
- the model of the influence of cracks on yield strength and shear modulus [1,3,4].

The model of ceramics (the layers of the target) is based on elastic-plastic theory and includes conservative equations and constitutive relations:

$$\frac{d\rho}{dt} + \rho\nabla\cdot\vec{w}=0 \tag{1}$$

$$\rho\frac{d\vec{w}}{dt} = \nabla\cdot\hat{\sigma} \tag{2}$$

$$\rho\frac{dE}{dt} = \hat{\sigma}\cdot\nabla\vec{w} \tag{3}$$

$$\overset{\nabla}{S}_{ik} = 2\mu\cdot\left(\dot{\varepsilon}_{ik} - \frac{1}{3}\dot{\varepsilon}_{ll}\delta_{ik}\right) \tag{4}$$

Huber-van Mises yield condition:

$$S_{ik}S_{ik} \le \frac{2}{3}Y^2 \tag{5}$$

here ρ is density and E denotes the specific energy per unit mass.

The model is supplemented with the models describing elastic-plastic/brittle characteristics of ceramics: EOS, the model describing the effect of the plastic strain rate, pressure, density and temperature on the yield strength, the model of cracks forming in crashed ceramics [2].

The model of behaviour of the explosives (explosives in the warhead, and layer in the target like a part of the reactive armour) is based on the hydrodynamics theory of the detonation products with JWL equation of state.

RESULTS OF NUMERICAL STUDIES

The set of differential equations and relations describing the properties of the materials, commented in a foregoing section with the relevant initial-boundary conditions have been solved numerically by a "method of free particles". This method may be used for solving various non-stationary, two-dimensional or three-dimensional problems of the continuous media. To validate hydrocode of "free particles", including material constants, many simulations were performed and compared with experiments.

Figure 1 presents the results of free particles code calculations for shaped charge jet formation from conical liner of 60 mm diameter.

Figure 2(A) shows the example of simulation of steel reference target penetration by the jet of 4 cm length and linear velocity gradient of 2.5–4.5 km/s. Consecutive frames illustrate the process of target perforation. In Fig. 2(B) the example of simulation of steel, reference target penetration by the jet of 4 cm length with linear velocity gradient of 5.5–7.5 km/s, and deformation of both the jet together with the multilayer target are shown.

Figure 3(A) and 3(B) present the results of simulation of multilayered steel/ceramic target penetration by the jet of 4 cm length and with two linear velocity gradients – in Fig. 3(A) of 2.5–4.5 km/s, and in Fig. 3(B) of 5.5–7.5 km/s.

In Fig. 4 it is shown the example of simulation of steel/ceramic/explosives target (reactive armour) penetration by the jet of 4 cm length and with linear velocity gradient of 5.5–7.5 km/s. The comparisons of computational results of final depth of penetration between different kind of targets shown us remarkable differences. Finally the fragments driven by explosives catch the jet. The "method of free particles" was found to be useful for explaining of some interesting stages of the processes of penetration of multilayered targets containing ceramics.

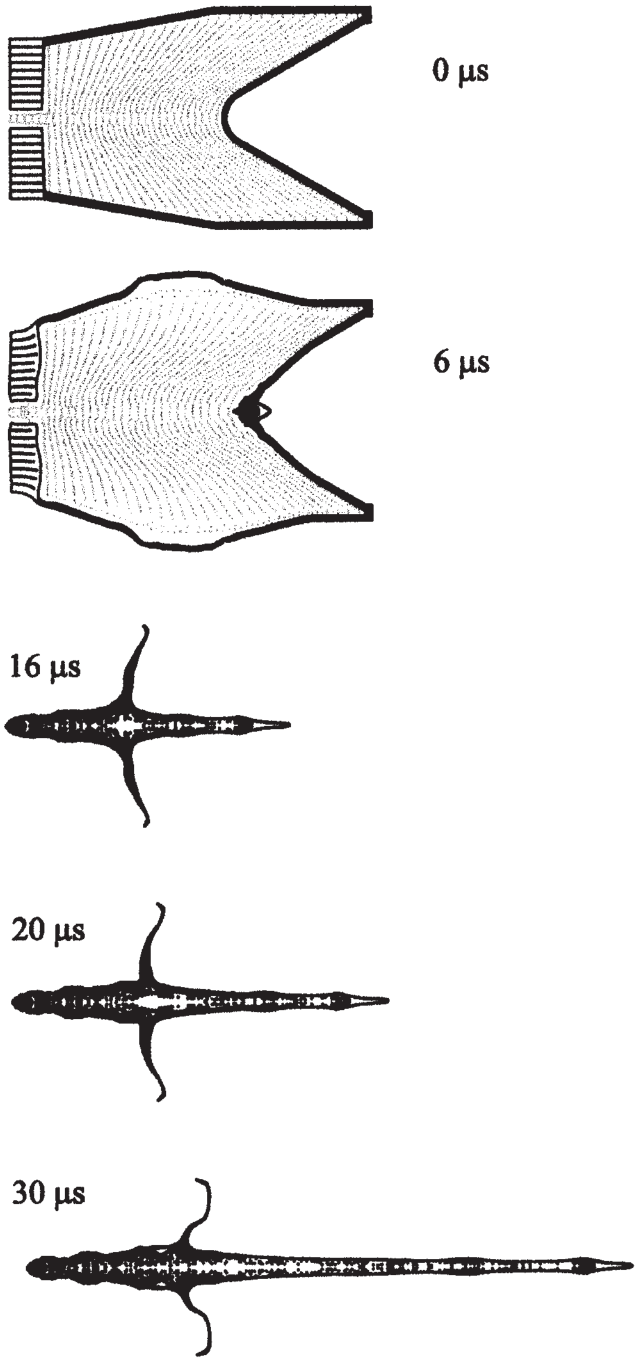

Figure 1. Free particles code calculations for shaped charge jet formation from conical liner of 60 mm diameter.

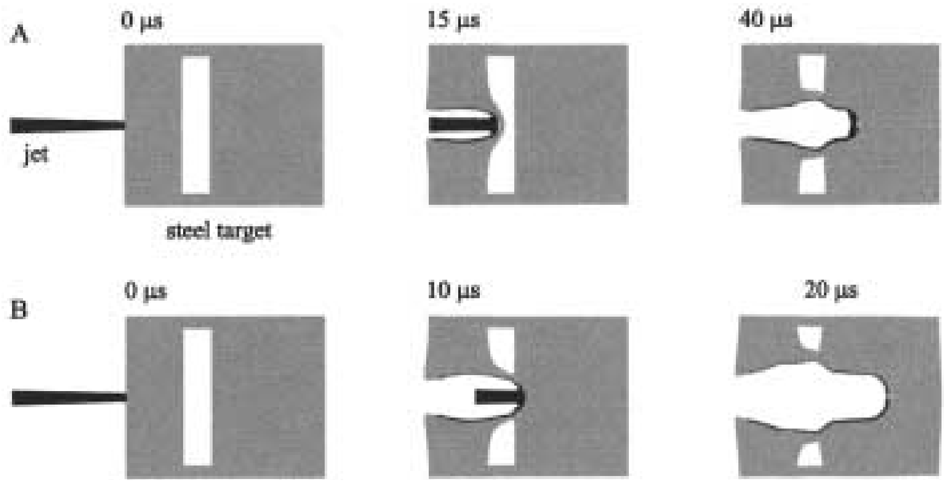

Figure 2. Simulation of steel, reference target penetration by the jet. (A) – the jet of 4 cm length and velocity of 2.5–4.5 km/s. (B) – the jet of 4 cm length and velocity of 5.5–7.5 km/s.

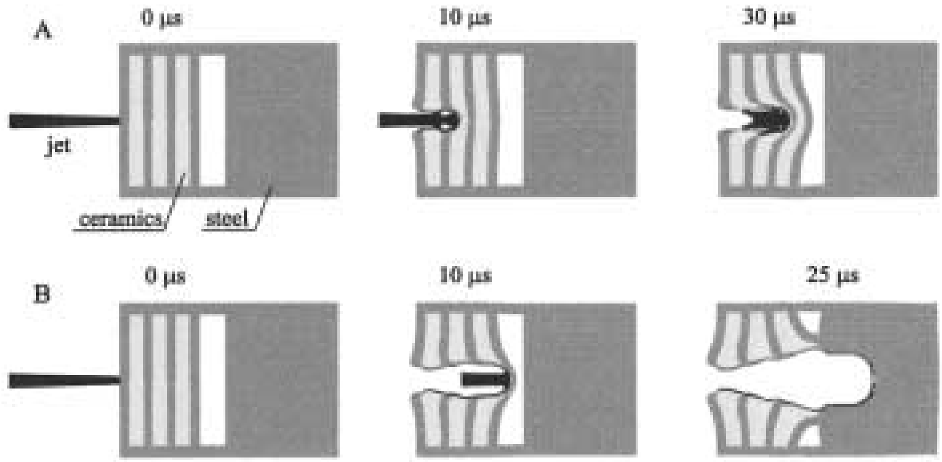

Figure 3. Simulation of steel/SiC target penetration by the jet. (A) – the jet of 4 cm length and velocity of 2.5–4.5 km/s. (B) – the jet of 4 cm length and velocity of 5.5–7.5 km/s.

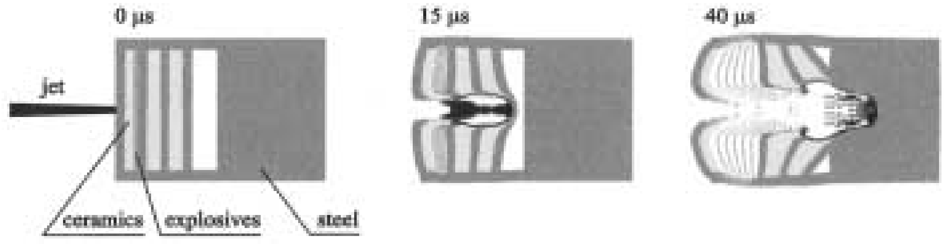

Figure 4. Simulation of penetration of steel/SiC target with reactive layer by the jet. A length of the jet is 4 cm and velocity – 5.5–7.5 km/s.

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CONCLUSIONS

The numerical studies on penetration of multilayered targets containing ceramics and reactive layers show possibilities of application of the numerical code HEFP to modelling of the processes including jet's large velocity gradients, large deformations of the affecting media, and the damages of their structure. The "method of free particles" was found to be useful for explaining some interesting stages of the processes of penetration of reactive armours by very fast parts of the jets, and it is helpful for optimization of the parameters of multilayered steel/ceramic and steel/ceramic/explosives armours.

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