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Study of high-speed interaction processes between fluoropolymer projectiles and aluminum-based targets

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Abstract

The experimental results and numerical modeling of penetration process of fluoropolymer projectiles in aluminum-based targets are presented. Analysis of mathematical models for interaction of elastoplastic projectile and target without taking additional energy released during interaction of fluoropolymer and aluminum into consideration is carried out. Energy fraction which is spent effectively on the increase in cavity volume is determined. The experimental and calculated results of penetration by combined and inert projectiles are compared.

Keywords: Reactive materials; Fluoropolymer; High speed strain; Interaction; Aluminum; Titanium alloy; Numerical modeling

1. Introduction

A promising direction in arms development is an application of "reactive materials" instead of inert ones in its design. One of the first works in this direction was the experiments carried out in Ural Federal University during 1984 and 1988 [1,2]. In the USA, the first works on reactive materials were published in the late 1990s and the early 2000s. Beside USA, UK and China are also involved in research and testing of new principles of damage increase for kinetic, shaped charge and fragmentation projectiles, including the reactive materials in their design. Application of reactive materials could allow to solve a wide range of tasks in the future – from increasing the damage and effectiveness of the projectiles to enhancing their safety and reliability.

One of the components of modern mixture reactive materials is fluoropolymer (TFE). Fluoropolymer has the ability to develop chemical reactions with energy released under certain conditions, not only under static loads and heating [1–3], but also under high-speed deformation together with targets containing aluminum [4–6]. The goal of the investigation is to determine the behavior of fluoropolymer under the condition of dynamic high-speed loading during its interaction with titanium alloy, and also to determine the behavior of target material.

2. Experimental results

Additional energy, which is released in the exothermic chemical reactions of fluoropolymer, is transferred into a mechanical work on cavity expansion in target; the amount of effective work increases with the impact velocity. In order to

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check this effect, the experimental data of dynamic interaction of textolite and monolith metal projectiles containing fluoropolymer and inert filler with semi-infinite targets from aluminum alloys AlMn1 and D16-AT was comparatively analyzed.

Projectiles with $d_0 = 0.013$ m and elongation $\lambda = L_0/d_0 = 2.4$, where L_0 *is* projectile length, were used in the experiments. The experimental results are presented in Tables 1 and 2. After the experiments, the cavity parameters in targets were measured (Fig. 1). The depth h_{cav}, diameter d_{cav}, and volume W_{cav} of cavity were determined.

The cavity in the semi-infinite target is formed by the kinetic energy of the projectile and partially by the energy released from thermochemical reaction of fluoropolymer with aluminum-based target. The energy balance equation can be written as

$$E_0 + E_{ch} = E_{ep} + E_{cav} \quad (1)$$

where E_0 is kinetic energy of the projectile; E_{ch} is energy released during chemical reaction and spent on cavity formation; E_{ep} is energy spent on elastic and plastic deformation of the projectile; and E_{cav} is energy spent on cavity formation.

The amount of energy spent on cavity formation for undeformable projectile can be determined by the amount of specific displacement work A_{sp} of target material.

$$A_{sp} = \frac{E_0}{W_{cav}} = \frac{\int_0^{h_f} F_r \mathrm{d}h}{\int_0^{W_{cav}} \mathrm{d}W} \quad (2)$$

where h, h_f are current and final penetration depth, respectively; F, E_0 are target resistance force and kinetic energy of the impact, respectively; W_{cav} is cavity volume.

Table 1
Cavity parameters from fluoropolymer projectile impact ($d_0 = 0.013$ m, $\lambda = 2.4$) on a AlMn1 target.

V_0/mps	$h_{cav}*10^{-3}$/m	$d_{cav}*10^{-3}$/m	$W_{cav}*10^{-6}$/m^3
507	0.0046	0.0207	1.20
514	0.0077	0.0229	2.05
564	0.0036	0.0187	0.52
624	0.0049	0.0215	0.95
625	0.0049	0.0205	0.87
629	0.0050	0.0210	0.93
685	0.0056	0.0225	1.45
722	0.0070	0.0238	1.74
744	0.0080	0.0240	2.08
879	0.0111	0.0250	3.25
930	0.0140	0.0253	4.00
962	0.0127	0.0255	4.05
1104	0.0170	0.0269	6.40
1108	0.0171	0.0270	6.50
1165	0.0190	0.0273	7.00
1250	0.0200	0.0285	8.25
1256	0.0200	0.0280	7.60
1406	0.0195	0.0342	11.50

Table 2
Cavity parameters from fluoropolymer projectile impact ($d_0 = 0.013$ m, $\lambda = 2.4$) on a D16-AT aluminum alloy target.

V_0/mps	h_c*10^{-3}/m	d_c*10^{-3}/m	$W_{ex}*10^{-6}$/m^3
322	0.00070	0.012	0.08
430	0.00125	0.012	0.15
439	0.00100	0.012	0.11
477	0.00075	0.012	0.10
505	0.00160	0.012	0.20
525	0.00180	0.013	0.25
542	0.00210	0.014	0.30
625	0.00330	0.016	0.60
778	0.00520	0.022	2.40
791	0.00620	0.018	2.30
803	0.00820	0.023	4.00
866	0.00860	0.025	3.90
889	0.00940	0.024	4.20
1025	0.01110	0.029	6.40
1010	0.01060	0.027	6.20

Fig. 2 shows the results for the experimental determination of the specific displacement work A_{sp} for fluoropolymer, textolite and steel projectiles. The analysis of the results shows that the specific displacement work necessary for the formation of the cavity with same volume in the fluoropolymer strikers is less than that in the steel strikers.

A_{sp} was determined based on the method of continuous acceleration registration during reverse ballistic experiments.

In order to determine the specific displacement work of material targets, the experiments on penetration of undeformable projectile ($d_0 = 0.005$ m and elongation $\lambda = 10$) were carried out. The nose part of projectile was a cone with $\alpha = 60°$. The targets AlMn1 and D16-AT were 80 mm in thickness with Brinnell hardness of 30 MPa and 43.5 MPa, respectively. The obtained results are presented in the form of functional relations

$$A_{sp}/HB = f(V_0/V_{cr}) \text{ and } A_{sp}/HB = f(\bar{h}) \quad (3)$$

The critical velocity [7] is expressed as

$$V_{cr} = \sqrt{\frac{HB}{\kappa \rho_0}} \quad (4)$$

The value of critical velocity was determined from the hardness of the projectiles, which is equal to 663 mps for AlMn1 and 788 mps for D16-AT alloy. The functional dependencies for both alloys in the ascending branch of the

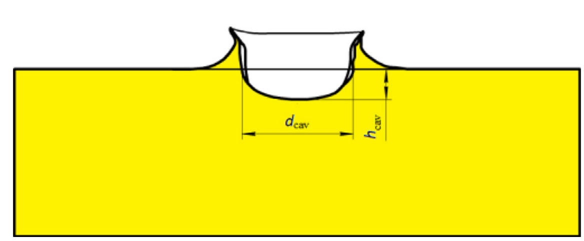

Fig. 1. Measured parameters h_{cav} and d_{cav} of semi-infinite target.