2. Предложенный метод позволяет учитывать результаты проникания фторопласта в алюминий содержащие преграды в широком диапазоне скоростей проникновения с высокой степенью точности (погрешность составляет менее 10%)
3. Результаты делают возможным применение этого метода для расчета проникания других взаимодействующих пар, таких как фторопласт-титан.
4. Анализ результатов показывает, что при таких условиях взаимодействия химическая реакция не реализуется в полной мере. Повышение количества полезно используемой химической энергии возможно при использовании смесей, полученных путем механического перемешивания алюминиевых и фторопластовых нано частиц, в качестве материала ударника. Ударник может быть получен компрессионным обжатием механо-активируемой смеси.

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NUMERICAL SIMULATION OF PROCESSES OCCURING DURING THE INTERACTION OF REACTION MATERIALS WITH BARRIERS FROM LIGHT ALLOYS

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A promising direction of development of penetrating ammunition, especially small-caliber, one is the use of "reactionary materials" (RM) in their designs instead of conventional explosives. Using the RM allows us to solve a wide range of problems - from increasing the power and effectiveness of the submunitions to increasing safety and reliability of the ammunitions.

Tetrafluoroethylene (PTFE) is RM, which is capable to develop chemical reactions with the release of energy only under certain conditions. Conditions of the chemical reaction can be implemented as at under static loading and heating [1] and during high-speed deformation of the material on the light alloy-based target, such as aluminum (Al), magnesium (Mg), titanium (Ti) [2].

Studies conducted by the authors discovered a chemical exothermic reaction [3] derived by reacting PTFE striker and aluminum-based target at impact of velocity more than 600 m/s (see figure 1).

The purpose of the study is the selection of physical-mathematical model that adequately describes the conditions of dynamic interaction between PTFE striker and target made of aluminum alloys.

The solution to the problem of calculating the kinematic and dynamic characteristics of penetration of PTFE striker in elastoplastic formulation can be carried out using a number of methods implemented in the following software products, ("Terminal ballistic" [3], "TIM-2D").

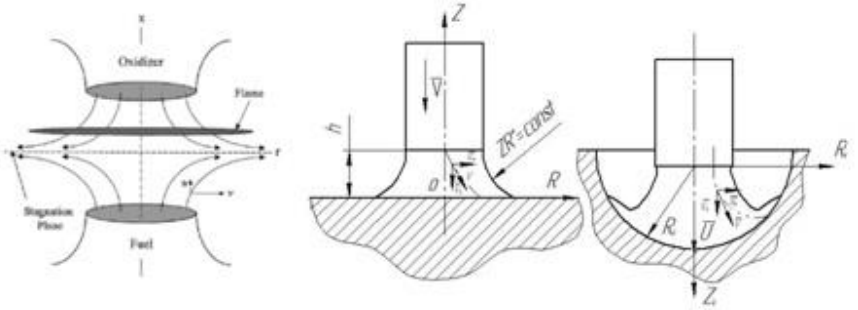

Figure 1. The scheme of penetration of PTFE striker into the aluminum-based target with the realization of the radial energy

To compare the results of calculations obtained by the above-mentioned methods, numerical experiment was made with the same input parameters to match the experiments. The calculations were made without taking into account the additional energy released by a chemical exothermic reaction. In process of calculating were chosen models describing the elastic-plastic deformation of the striker (von Mises model [2, 3]) and the target (Johnson-Cook [2, 3], von Mises, Glushak models) and various equation of state striker and target materials (Zababakhin equation of state and "barotropic dependence") to adequately describe the elastic-plastic deformation process. [3].

Table 1 sow the results of calculating and experimental results for the volume of the cavity. The dependences of the volume of the cavity on the impact velocity of the PTFE striker with the aluminum-based target are shown in Figure 2.

Table 1. Parameters of the volume of the cavity from the action of PTFE striker in the aluminum-based target (Ø13mm , m=8.6g)

Initialvelocity	Von Mises model (MLP method, equation of state: Zababakhin)	Glushak B.L. model (MLP method, equation of state: Zababakhin)	Johnson-Cook model (MLP method, equation of state: Zababakhin)	Johnson-Cook model (SPH method)	Von Mises model (MLP method, equation of state: barotropic relationship)	Experimental results
m/s	cm^3	cm^3	cm^3	cm^3	cm^3	cm^3
507	0,065	0,077	0,015	0,875	0,073	1,2
685	0,537	0,682	0,064	1,084	0,693	1,45
930	3,27	3,147	0,62	6,763	2,607	4
1108	6,055	5,827	2,276	7,872	4,049	6,5
1406	13,01	11,742	6,369	3,939	7,05	11,5

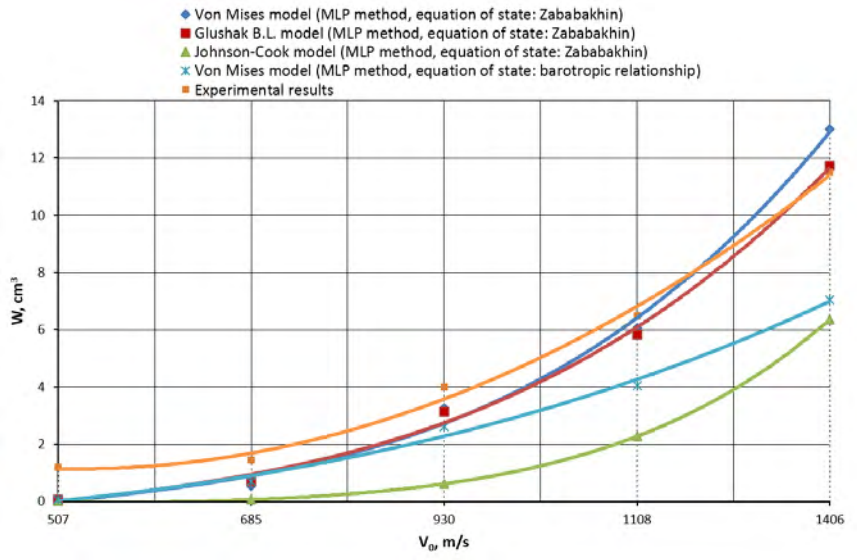

Figure 2. The dependence of the volume of the cavity on the impact velocity of PTFE striker with the aluminum-based target

The release of chemical energy occurs with some delay and therefore its influence begins to affect in the deep layers, which leads to an increase in the volume of the cavity.

The quantity of additional chemical energy is defined as:

$$E_{ch} = A_{sp}\left(\mathrm{W}_{ex} - \mathrm{W}_{calc}\right) \tag{1}$$

where W_{ex} and W_{calc} – experimental and calculated cavity volume, m^3.

The analysis of the graph show, that von Mises model and Glushak model give clearly excessive results for the volume of the cavity and don't take into account the effect of the chemical reaction in the calculation by the MLP method with Zababakhin equation of state for aluminum. From viewpoint of the Authors, the process of elastic-plastic interaction of PTFE striker and targets is described by the Johnson-Cook model with the Zababakhin equation of state and von Mises model with the equation of state in the form "barotropic dependence" in the calculations by the MLP method for aluminum most accurate. [1].

The appearance of soot on the surface of the target and the presence of aluminum fluorides suggest that intensive oxidative reaction of the target material takes place during the process of penetration.

Assuming that layers of the target material layers and those of the distorted striker move in parallel directions as suggested by figure 1. The processes of parallel oxidation were examined with various kinds of gas mixtures and formulated in the method of Counterflow Diffusion Flames (CDF), first proposed by Tsuji and Yamaoka [5].

Laminar counterflow diffusion flame is generally regarded as a pure diffusion flame. In this case, the authors chose a model counterflow diffusion flame as the counterflow diffusion flame established in the forward stagnation region of a cylindrical porous burner to simulate processes taking place during the penetration of the striker of PTFE in aluminum-based target.(seefigure. 1).

The flow velocity of the oxidizing agent (PTFE) can be calculated as the radial component of the velocity of the triggered part of the projectile (see figure 2). As experimental results show, the generator of the side surface of the projectile is well described in cylindrical coordinates ORZ (see figure 1), by the equation:

$$ZR^{n} = \mathrm{const} \tag{2}$$

where $n > 0$ is exponent, depending on the material of the projectile and the conditions of its deformation. Assuming that the equation for the velocity of streamlines for particles of the projectile material during its

deformation is also described by equation (2), we find the functional relationship between the axial and radial components of the velocity of the particles of the material:

$$\vartheta_R = -\frac{R}{nZ}\vartheta_Z \tag{3}$$

The components of the velocity must satisfy the continuity equation, which for an incompressible medium in a cylindrical coordinate system has the form:

$$\frac{\partial \vartheta_Z}{\partial Z} + \frac{\partial \vartheta_R}{\partial R} + \frac{\vartheta_R}{R} = 0 \tag{4}$$

The continuity equation taking into account (3) has the form:

$$nZ\frac{\partial \vartheta_Z}{\partial Z} - 2\vartheta_Z - R\frac{\partial \vartheta_Z}{\partial R} = 0 \tag{5}$$

The axial component of the velocity of the deformed material particles will be equal to the speed of the hard part of the projectile at the interface between the rigid and plastic areas drummer, that is, when Z = h, $\vartheta_z = -V$. From the solution of equation (5) with given boundary conditions, we find an equation for the axial components of the velocity of the deformed material particles:

$$\vartheta_Z = -V\left(\frac{Z}{h}\right)^{2/R} \tag{6}$$

where h - current height of the deformed part of the projectile.

Using (6) in (3) weobtain:

$$\vartheta_R = V\frac{R}{nh}\left(\frac{h}{Z}\right)^{\frac{n-2}{n}} \tag{7}$$

Determining the radial and axial component of the velocity from the solution of the problem of plastic deformation of PTFE projectile interacting with the target, we find the velocity of the oxidant along a generator of the cavity ϑ_R and the pressure value at the interface of the projectile with the target.

The heat-release velocity and reaction velocity of each species can be calculated by the quasi-one-dimensional energy conservation equation and species-continuity equation, respectively.

$$Q = A^{-1}\left[\rho_0 \upsilon_0 \sum_i G_i C_{pi}\frac{dT}{dy} - \frac{d}{dy}\left(A\lambda\frac{dT}{dy}\right)\right] \tag{8}$$

The net reaction velocity K_i, i.e., the net molar velocity of generation or consumption of species i per volume unit per time unit due to chemical reaction, is calculated by

$$K_i = \frac{p\upsilon}{M_i}\frac{dG_i}{dy} \tag{9}$$

In these equations, A is the stream-tube-area ratio at any point, T the gas temperature, ϱ the density of gas mixture, C_{pi} - the specific heat of species at constant pressure i, λ - thermal conductivity of the gas mixture, and M_i the molecular weight of species i. The subscript 0 denotes some reference point. G_i - the mass-flux fraction of species i, is defined by

$$G_i = \rho Y_i\left(\upsilon + \upsilon_{di}\right) \tag{10}$$

where v is the flow velocity.

The mass concentration Y_i of species iis given by

$$Y_i = \frac{X_i M_i}{\sum_i X_i M_i} \tag{11}$$

where X_i is the mole fraction of species i.

The diffusion velocity of species iis calculated by:

$$\upsilon_{di} = -\frac{D_i}{X_i}\frac{dX_i}{dy} \tag{12}$$

where $D_i$is the binary diffusion coefficient of species i.

The density of gas mixture is calculated from the measured temperature and stable-species concentrations by the equation of state:

$$p = \frac{\rho R^{\circ} T}{\sum_i X_i M_i} \tag{13}$$

where p is the pressure, and R° is the universal gas constant.

The stream-tube-area ratio A is found from the density and the measured velocity by the global continuity equation

$$\rho v A = \rho_0 v_0 \tag{14}$$

By assuming that the binary diffusion coefficients of all pairs of species are equal and that the mass concentration Y_i of species i is a function of some conserved scalar ξ (or any Shvab-Zeldovich function), the species conservation equation can be transformed into the simple form:

$$w_i = -\rho D (\vartheta_R \xi)^2 \frac{d^2 Y_i}{d\xi^2} \tag{15}$$

wherew_i is the net reaction velocity of species i (mass per volume unit per second) and D is the molecular diffusivity.

The distinctive feature of this equation is that only composition and temperature measurements are necessary to derive the chemical reaction velocity. To get the required temperature parameters we have to solve the problem of elastic-plastic its in each cell.

To account for the influence of the chemical energy on the process of penetration block of calculation of heat based on CDF in the method of large particles was introduced,it is advisable to perform calculations using the CDF method for chemical interactions between the Euler and Lagrangian stages.

An important step is the creation of a mixed cell, in which occurs a chemical reaction and the reaction products appear in the form of aluminum fluoride. The pressure that occurs at the contact surface contributes to the occurrence of this reaction. The calculation allowed estimating the resulting pressure (see Figure 3). The analyses show, that the maximum pressure is far above the limit pressure at which the chemical reaction initiated (200 MPa) [1].

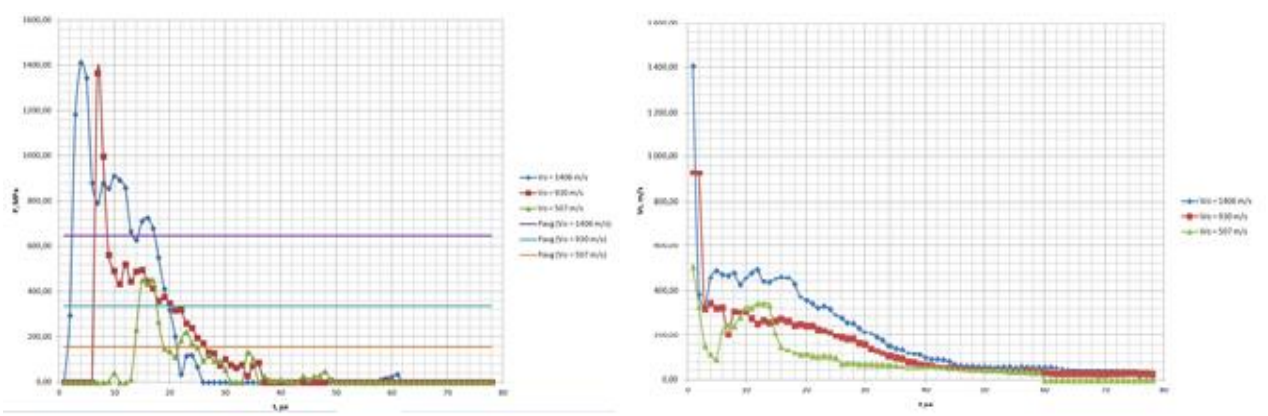

Figure 3. The pressures that occurs at the contact surface, MPa
and the radial velocities of flow tetrafluoroethilene, m/s

An analysis of the radial velocities of flow fluoroplastic (see Figure 3) was held to determine of the velocity of the chemical reaction.

The MLP-CDF method provides results that are qualitatively and quantitatively consistent with the experimental ones.

Conclusion

1. The study of the PTFE striker deformation on the aluminum-based target process in conjunction with parallel oxidation of the contact layer processes allowed the development a combined method of calculation describing this interaction processes (MLP-CDF).
2. The proposed method allows evaluate the results of the interaction of PTFE with aluminum-based target in a wide range of interaction velocity with sufficient degree of accuracy (relative error does not exceed 10%).
3. The results make it possible to apply this method for calculations of interaction results for other interacting pairs, such as PTFE-titanium.
4. Analysis of the results shows that under these interaction conditions, the chemical energy is not used in full. Increase of amount of useful used chemical energy is possible if to use mixtures derived from mechanical mixing aluminum and PTFE nanoparticles as striker material. Strikers can be obtained subsequently compressing of the mechanically activated mixture.

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ЧИСЛЕННАЯ ОЦЕНКА СКОРОСТИ СХЛОПЫВАНИЯ КУМУЛЯТИВНОЙ ОБЛИЦОВКИ

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Инженерные методики расчета кумулятивного действия (смотри, например, [1, 2]) широко применяются в исследовательской и инженерной практике. Главным достоинством инженерных методик является быстродействие при проведении расчетов, а основной недостаток заключается в использовании большого количества допущений и приближений при построении математических зависимостей, лежащих в их основе. Такие допущения оказывают негативное влияние на точность проведения расчетов, особенно при анализе кумулятивных зарядов сложной конструкции (например, использующих торцовые поджимные гайки, облицовки с цилиндрическими “юбками”, толстостенные корпусные детали и др.).

Численные расчеты, основанные на методах конечных разностей и конечных элементов, позволяют провести всестороннюю проверку инженерных методик, включая основные положения и допущения, положенные в их основу. Такая проверка особенно важна для создания алгоритмов и программ оценки влияния технологических погрешностей на пробивное действие кумулятивного