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EFFECT OF INITIAL HEATING OF SHAPED CHARGE LINERS ON SHAPED CHARGE PENETRATION

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An increase in the penetration capability of a laboratory shaped charge under initial heating, i.e., heating of the liner material before initiation of the explosive charge, is revealed in experiments. The results obtained confirm the theoretical hypothesis on the possibility of increasing the ultimate elongation of elements of a plastically fractured high-gradient, shaped-charge jet by increasing the initial temperature of the jet-forming layer of the liner.

An ordinary shaped charge (SC) is a brisant explosive charge with a cavity in one end lined with a rather thin metal layer, which is called the shaped-charge liner. Let, at the initial moment, the explosive charge be initiated at the end opposite to the cavity. The detonation products formed act on the shaped-charge liner, resulting in its collapse and formation of a jet from the inner (jet-forming) layer of the liner [1, 2]. Under certain conditions, formation of a plastically fractured, high-gradient metal jet is possible [3].

Plastically fractured, high-gradient, shaped-charge jets (SCJ) stretch in free flight under the action of the velocity gradient produced during jet formation. In the initial stage of existence, the jets undergo uniform stretching without marked concentrated deformation. Then, the deformation is localized in the regions of formation of necks. As a result, there is plastic fracture of the SCJ, i.e., breakup into a certain number of separate elements, whose length does not change further. This type of fracture is typical of copper, nickel, and niobium SCJ (Fig. 1). The elongation of such SCJ without breakup into elements is characterized by the so-called ultimate-elongation coefficient, which is defined as the ratio of the total length of the jet element after breakup to its initial length.

The effect of initial heating of the jet-forming layer of SC liners on the ultimate elongation of the elements of plastically fractured jets is studied theoretically in [3], where the following formula for the ultimate-elongation coefficient is obtained:

$$n(T_i) = (A + BR\,\mathrm{grad}\,V)[1 - (T_i - T_0)/(T_m - T_s)]^{-0.39} \quad [0 < (T_i - T_0)/(T_m - T_s) < 1], \qquad (1)$$

Here T_i is the initial heating temperature of the jet-forming material of the liner, T_m and T_s are the melting point and residual temperature of shock compression of the jet-forming material, $T_0 = 300$ K, A and B are material constants determined experimentally at temperature T_i equal to T_0, and R and $\mathrm{grad}\,V$ are the initial radius and velocity gradient along the SCJ.

From relation (1) it follows that with increase in the initial temperature of the jet-forming material of the liner, the ultimate-elongation coefficient increases. This allows one to use heating of the liner material before initiation of explosive charges to attain greater elongation of the SCJ elements and, hence, greater penetration capability of plastically fractured, high-gradient jets.

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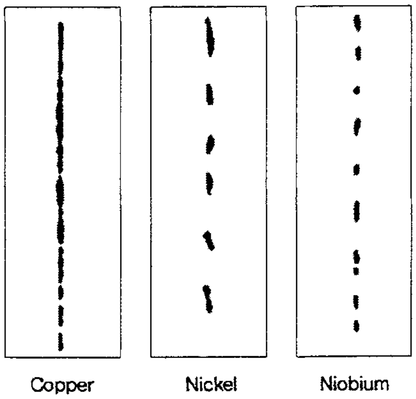

Fig. 1

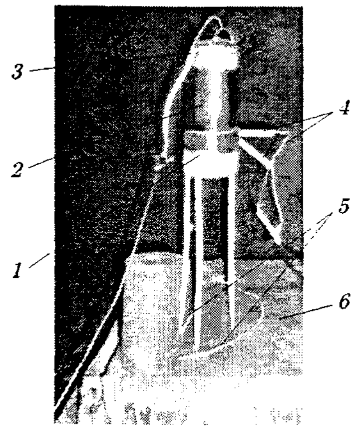

Fig. 2

Fig. 1. Plastic fracture of shaped-charge jets of various materials.

Fig. 2. Experimental setup: 1) device for heating shaped-charge liners; 2) SC model; 3) wires of the thermocouples embedded in the liner; 4) autotransformer wires; 5) control thermocouple wires; 6) armor plate.

In the present work, we studied experimentally the effect of initial heating of the jet-forming layer of liners on the penetration capability of SC. A photograph of the experimental setup is given in Fig. 2. The device for heating a shaped-charge liner consists of a heat conductor, which is butted to the end surface of the shaped-charge liner, electrical heater winding, and a casing, which is rigged on supports to ensure the required distance from the SC base to the armor plate. The setup was designed for laboratory SC. In the experiments, we used 50-mm-diameter charges of sensitized RDX having copper liners with a cone angle of 50° and thicknesses of 1 and 1.4 mm at the apex and base, respectively. The heat conductor in the device considered was a copper bushing with a 1-mm-thick wall in the region of contact with the liner end surface. The inside diameter of the bushing is equal to the inside diameter of the base of the shaped-charge liner. On the outer surface of the heat conductor there is winding. The heat conductor and the electrical heater winding are placed in the casing. The shaped-charge liner is heated by passage of an electric current through the heat conductor winding.

For safe investigation of the heat conduction process in the shaped-charge unit, we used the SC model shown in Fig. 2, which has the geometrical parameters of a laboratory charge and consists of a shaped-charge liner and an inert substitute of an explosive. Chromel–Copel thermocouples are placed in the base and apex of the shaped-charge liner to determine the temperature of uniform heating of the liner material. The temperature in the heating device is controlled by a Chromel–Copel thermocouple embedded in the part of the heat conductor that is in contact with the end surface of the shaped-charge liner. The voltage across the thermocouple leads was measured by a digital storage oscilloscope. The relative error of temperature measurements in the range 100–200°C was about 10%. The required temperature level in the liner by the ignition moment was attained by varying the voltage U across the leads of the electrical heater winding or the heating time. In the experiments, the voltage U was varied from 50 to 60 V by an autotransformer, as a result of which the time of heating of the liner material to 100–200°C was 100–350 sec. Under these heating conditions, the temperature distribution in the liner material is nearly uniform.

For identical values of the voltage U and the heating time, results from temperature measurements during uniform heating of the liner material T_i were reproducible only for the same electrical heater. Therefore, for each device at constant voltage U, we determine the dependence of the initial liner temperature T_i on the heating time t and, simultaneously, the dependence of the temperature T_* at the location of the control thermocouple on the time t. This made it possible to construct the dependence $T_i = T_i(T_*(t))$ at constant U for each electrical heater.

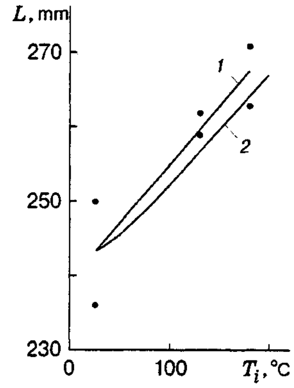

Fig. 3. SC penetration versus the initial heating temperature of the liner material: curve 1 refers to calculations using the empirical regression equation (points are experimental data) and curve 2 refers to calculations by an engineering procedure.

Before testing laboratory SC with initial heating of the liner material, we performed an experiment without heating to determine the focal distance at which the greatest penetration is reached for the SC used together with electrical heaters. Results of the experiment showed that the greatest penetration L with a confidence probability of 0.95 was (244 ± 9) mm at a focal distance of 250 mm (sample standard deviation was 5.6 mm). Then, at this focal distance, we performed an experiment for a laboratory SC with heating of the shaped-charge unit. The remaining conditions of the experiments, both with and without initial heating of the shaped-charge liner material, were identical.

An experiment on determining the dependence of the SC penetration on the initial temperature of the liner material was performed as follows. The SC model shown in Fig. 2 was replaced by a laboratory charge, and voltage was applied on the electrical heater winding. During heating of the liner, the temperature–time dependence was determined at the location of the control thermocouple. It differed from the dependence $T_*(t)$ obtained for the model only in a shift in time due to the difference in the moments when heating was begun. Ignition of the SC was performed when the temperature reached a value T_* that corresponded to the required heating temperature of the liner material $T_i = T_i(T_*)$.

In the experiments, the initial temperature of the liner material was varied from 27 to 200°C. However, at temperatures above 180–190°C, i.e., close to the melting point of the explosive, there was a partial change in the geometrical parameters of the charge. This was most pronounced at its base and led to loss of the axisymmetry of the charge and, as a consequence, to a decrease in penetration, and, in some experiments, to the absence of penetration capability.

The penetrations obtained at initial temperatures of 27, 130, and 180°C are shown in Fig. 3. These data were used to develop a linear regression model for predicting the penetration as a function of initial heating temperature from 27 to 180°C. Processing of the experimental data included the following stages [4]: check of the reproducibility of the experiment, estimation of the dispersion noise, calculation of point estimates of the unknown regression coefficients by the least-square method, check of the significance of the estimated regression coefficients, and test of the adequacy and applicability of the regression equation. The statistical hypotheses were tested at a significance level of 0.05. The obtained empirical dependence of the relative penetration of SC on the initial heating temperature has the form

$$L/d = 4.87 + 3.38(T_i - T_0)/(T_m - T_0), \qquad 0 < (T_i - T_0)/(T_m - T_0) < 0.145, \tag{2}$$

where L is the SC penetration and $d = 50$ mm is the diameter of a laboratory SC.

From the regression equation (2) it follows that an increase in the initial temperature of the liner material leads to an increase in the penetration capability of the SC.

Along with the experimental determination of the penetration capability of laboratory SC, we performed a calculation of the penetration using the engineering procedure described in [5]. This engineering procedure, in which relation (1) was employed, yielded obviously underestimated values of the penetration.

Curves of the SC penetration versus the initial heating temperature of the liner material calculated using the engineering procedure and the empirical equation (2) are given in Fig. 3 along with experimental data. A comparison shows satisfactory agreement between the results obtained.

An analysis of the possible causes of an increase in the penetration of laboratory charges under initial heating of the shaped-charge liner material shows that the elongation of the elements of the plastically fractured, high-gradient SCJ is the only significant factor that increases the penetrating capacity of the SC.

The results obtained confirm the theoretical conclusion that the ultimate elongation of the elements of a plastically fractured, high-gradient, shaped-charge jet can be increased by raising the initial temperature of the jet-forming layer of the liner. This, on the one hand, provides a better understanding of the shaped-charge affect, and, on the other hand, makes it possible to develop a new method for increasing the SC penetration [6].

REFERENCES

1. M. A. Lavrent'ev, "Shaped charge principles," *Usp. Mat. Nauk*, **12**, No. 4, 41–56 (1957).
2. F. A. Baum, L. P. Orlenko, K. P. Stanyukovich, et al., *Physics of Explosion* [in Russian], Nauka, Moscow (1975).
3. G. E. Markelov, "On the effect of initial heating of the jet-forming layer of shaped-charge liners on the ultimate elongation of jet elements," *Prikl. Mekh. Tekh. Fiz.*, **41**, No. 2, 32–36 (2000).
4. G. I. Krasovskii and G. F. Filaretov, *Planning an Experiment* [in Russian], Izd. Belarus. Univ., Minsk (1982).
5. V. M. Marinin, A. V. Babkin, and V. I. Kolpakov, "Procedure of calculating the shaped charge performance," *Oboron. Tekh.*, No. 4, 34–49 (1995).
6. A. V. Babkin, V. I. Kolpakov, G. E. Markelov, et al., Russian Federation Patent No. 2100761, MPK^6 F 42 B 12/10, "Method of increasing the penetration capability of shaped charges," *Izobreteniya*, No. 36 (1997), p. 393.