Materials Science Forum
ISSN: 1662-9752, Vol. 1052, pp 399-404

Submitted: 2021-09-26
Accepted: 2021-10-04
Online: 2022-02-03

Modeling of High Module Power Sources Systems Safety Processes

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Keywords: tungsten, cobalt, tool, hard alloy, metal ceramics, recycling, heterogeneous medium.

Abstract. The paper provides an assessment of the safety processes of high-modulus energy sources systems during the initiation of flat and cylindrical high-modulus energy sources. The expressions, which establish the relationship between the parameters of flat and hollow cylindrical charges of explosives under the only condition of equality of the developed pressure pulse on the surface of the charge of explosives, provided all other things being equal, were obtained. In contrast to the earlier studies, which assert the existence of a direct relationship between the parameters during the initiation of flat and cylindrical surfaces, the current study demonstrates energy consumption during the initiation of cylindrical surfaces is higher than the initiation of flat surfaces, all other things being equal.

Introduction

At present, the research and development methods in the field of explosion welding [1-3] and the application of shock-wave treatment as a factor stimulating the processes of any configuration powder products destruction are clearly defined to obtain high-quality powder for further molding, sintering, and production of various purpose tools [4-7]. Carbide powder is intended for the manufacture of tools used in metallurgy and mechanical engineering. Currently, the scrap of superhard alloys is exported to Russia, and the tool is imported by Ukrainian import enterprises [8-11]. Ukraine has production facilities for the scrap processing and manufacture of tools of guaranteed quality from the obtained carbide powders. The demand for hard-alloy powders in Ukraine is estimated at 600-700 tons per year.

Numerous studies have established that the implementation of the criterion for explosion welding does not depend on the type of structure [12-15]. The physical conditions of the ongoing processes must be adequate for the selected welding or grinding modes. If this is the case, then it is possible to use the methods for calculating the technological parameters of welding flat surfaces and upon certain correction, to apply them for welding axisymmetric cylindrical surfaces and vice versa [16-19].

The Goal of the Research

To assess the safety processes of high-modulus energy sources systems when initiating flat and cylindrical high-modulus energy sources.

Materials and Results of the Research

The first such attempt was made to correct the welding of flat and cylindrical surfaces in the research [20-21]. Later research [22] asserts the existence of a direct relationship between the parameters of welding of flat and cylindrical surfaces.

It is known [23] that the expression for determining the explosion pressure can be described by the Becker-Kistyakovsky-Wilson equation:

$$P = \frac{\xi \cdot R \cdot T}{v} \cdot (1 + x \cdot exp(\Psi \cdot x)), \quad (1)$$

where $x = \frac{S\cdot\sum_i S_i\cdot\xi_i}{v\cdot(T+\theta)\cdot\eta}$; S_i - covolume factor of the *i*th gaseous explosion product; ξ - number of kilogram-moles of gases in explosion products (EP); ξ_i - number of kilogram-moles of the *i*th product; T – EP temperature; v - specific volume of gases per 1 kg of EP; η, ψ, S, θ - empirical coefficients obtained from comparing the calculated and measured values of explosive materials (EM) detonation parameters; R – gas constant.

Based on the type of the functional dependence (1), approximating the pressure change according to the exponential law, depending on the value of the peak pressure P_{max} in detonation products (DP), characteristic explosion time T, as well as the current value of the time parameter:

$$P = P_{max}\left[c + exp\left(-\frac{t^m}{a\cdot T^m}\right)\right], \tag{2}$$

where, a - unitless coefficient, which considers the shape of the EM charge; m - empirical coefficient, which considers the rate of pressure drop behind the detonation wavefront; c – some constant.

Pressure P_{max} rise time (approx. 10^{-10} seconds for hard object [24-25]) compared to the action time of EP (approx. 10^{-5} seconds) can be neglected [26, 27], which allows for the “c” coefficient to equal zero. At first approximation, the "m" coefficient can be considered to equal 1.

In general, the value of the force impulse can be represented as follows:

$$J = F_0 \cdot \int_0^T P dt\,, \tag{3}$$

where F_0 - area covered by explosive detonation products.

Placing (2) into (3) and integrating, the result comes to:

$$J = F_0 \cdot P\left(1 - exp\left(-\frac{1}{a}\right)\right)_{max}. \tag{4}$$

Coefficient "a" is determined considering the previous assumption from (4), in this case, the error is around 2%:

$$a = \frac{J}{P0_{max}}. \tag{5}$$

The value of the parameters of the expression (5) can be found from the relations (2,4,5,6):

force impulse :

$$J = (\alpha \cdot m_{BB}) \cdot u_{BB}; \tag{6}$$

charachteristic explosion time:

$$T = \frac{\alpha\cdot h}{u_{BB}}; \tag{7}$$

DP expansion speed:

$$u_{BB} = \frac{D}{k+1}; \tag{8}$$

DP gases density:

$$\rho_{BB} = \rho_0 \cdot \frac{k+1}{k}; \tag{9}$$

DP maximum pressure:

$$P_{max} = \rho_{BB} \cdot D \cdot u_{BB} = \rho_0 \cdot D^2 \cdot \frac{1}{k}. \tag{10}$$

Here m_{BB} – total explosive charge mass; D – detonation speed; h - characteristic explosive charge thickness; ρ_0- initial charge thickness of the explosive; k - detonation adiabatic exponent; α - coefficient, which determines the active part of the explosive [28, 29]. In this case, the value of the "a" coefficient for a flat explosive charge from expression (5) will have the form of:

$$a = \frac{k}{k+1}, \tag{11}$$

equation (2) transforms to:

$$P_L = \frac{\rho_0 \cdot D^2}{k} \cdot exp\left(-\frac{(k+1) \cdot D \cdot t}{\alpha' \cdot k \cdot h_L}\right). \tag{12}$$

Here and below, the prime refers to the parameter of the plane explosive charge.

Therefore, the values "a" and P_R for a hollow cylindrical explosive charge with a wall thickness h_L and an inner radius R_B will equal to:

$$a = \frac{\left(1+\frac{h_R}{2 \cdot R_B}\right) \cdot k}{(k+1)^2}, \tag{13}$$

$$P_R = \frac{\rho_0 \cdot D^2}{k} \cdot exp\left(-\frac{(k+1) \cdot D \cdot t}{\alpha \cdot k \cdot \left(1+\frac{h_R}{2 \cdot R_B}\right) \cdot h_R}\right). \tag{14}$$

Let's establish a correlation between geometrical parameters h_R and h_L of the hollow cylindrical and flat explosive charges provided that the pressure impulse is equal for different characteristic times T^L and T^R of their DP:

$$\int_0^{T^L} P_L dt = \int_0^{T^R} P_R dt, \tag{15}$$

Putting correlations (12) and (14) into the expression (15), integrating against time, and bringing the terms to similarity, we shall obtain

$$h_L = \frac{\alpha}{\alpha'} \cdot \left(1 + \frac{h_R}{2 \cdot R_B}\right) \cdot h_R \cdot \frac{exp\left(-\frac{(k+1)^2}{k \cdot \left(1+\frac{h_R}{2 \cdot R_B}\right)}\right)-1}{exp\left(-\frac{(k+1)^2}{k}\right)-1}. \tag{16}$$

Expression (16) must satisfy the following limiting relation: when the inner radius R_B of a hollow cylindrical explosive charge tends to infinity (a straight line is a circle of infinite radius) h_R should tend to the h_L thickness of a flat charge. Substituting $R_B = \infty$ in the expression (16), we obtain that $\alpha = \alpha'$, therefore, the active masses of the flat and hollow cylindrical explosive charges are equal.

Carrying out similar transformations of expression (5) under condition (15) for a hollow cylindrical explosive charge of h_R thickness and outer radius R_B, we obtain the following values "a", PR and the dependence of h_L on h_R:

$$a = \frac{k}{(k+1)^2} \cdot \frac{2 \cdot R_H - h_R}{2 \cdot (R_H - h_R)}; \tag{17}$$

$$P_R = \frac{\rho_0 \cdot D^2}{k} \cdot exp\left(-\frac{2 \cdot (k+1) \cdot (R_H - h_R) \cdot D \cdot t}{\alpha \cdot k \cdot (2 \cdot R_H - h_R) \cdot h_R}\right); \tag{18}$$

$$h_L = \frac{\alpha}{\alpha'} \cdot \frac{2 \cdot R_H - h_R}{2 \cdot (R_H - h_R)} \cdot h_R \cdot \frac{exp\left(-\frac{(k+1)^2}{k \cdot \left(1 - \frac{h_R}{2 \cdot R_H - h_R}\right)}\right) - 1}{exp\left(-\frac{(k+1)^2}{k}\right) - 1}, \tag{19}$$

where $\alpha = \alpha'$.

Thus, the obtained expressions (16) or (19) establish a relationship between the parameters of the flat and hollow cylindrical explosive charges under the only condition of equality of the developed pressure pulse on the explosive charge surface, all other conditions being equal (ρ_{BB}, D, k, T^L, T^R) [30].

Let's introduce a parameter β as the ratio of the detonation velocities D_L of flat and D_R hollow cylindrical explosive charges $\beta = \frac{D_L}{D_R}$. This way, detonation products expansion speed (8) from the surface of a cylindrical charge can be represented by the expression:

$$u_{BB} = \frac{\beta D_R}{k+1}. \tag{20}$$

Replacing expression (8) by (20) and performing transformations similar to (6) - (19), we obtain (Fig. 1).

$$P_R = \beta^2 \frac{\rho_R D^2}{k_R} \cdot exp\left(-\frac{(k_R+1)\beta D t}{\alpha k_R \left(1 + \frac{h_R}{2 \cdot R_B}\right) h_R}\right); \tag{21}$$

$$P_R = \beta^2 \frac{\rho_R \cdot D^2}{k_R} \cdot exp\left(-\frac{2\beta (k_R+1)(R_H - h_R) D_R \cdot t}{\alpha \cdot k_R \cdot (2 \cdot R_H - h_R) \cdot h_R}\right). \tag{22}$$

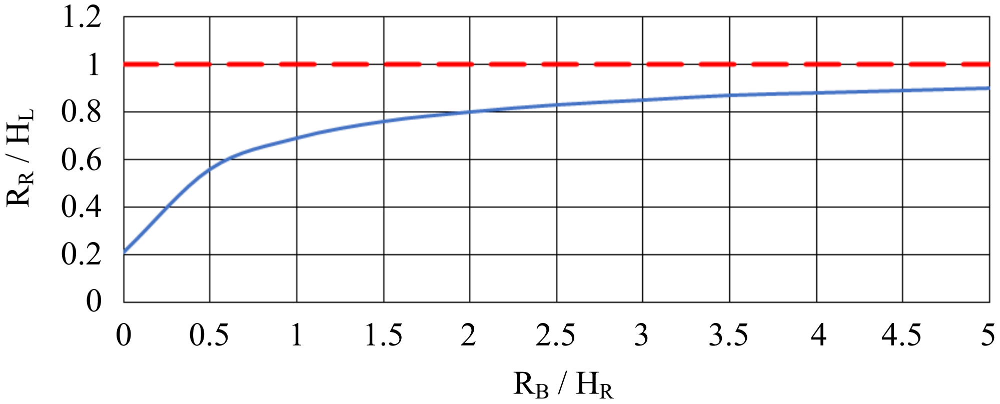

Figure 1. The change of the relative thickness of a cylindrical explosive charge from the stiffness of the charge

Summary

In contrast to the previously performed studies of high-modulus energy sources systems safety processes when initiating flat and cylindrical high-modulus energy sources, which assert a direct relationship between parameters when initiating flat and cylindrical surfaces, the current study demonstrates that, provided other things being equal, the energy intensity when initiating cylindrical surfaces is higher than the initiation of flat surfaces.

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