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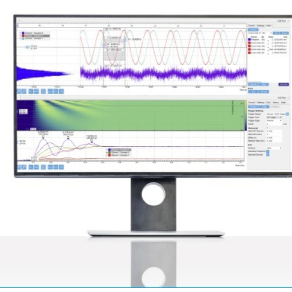

A Mathematical Model of the Layered Plate Throwing by Detonation Products

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Abstract. The problem of the layered plates throwing in the conditions of incomplete dispersal of detonation products (DP) is devoted to quite a lot of work, but this problem is usually solved either by various numerical methods, which in practice are not applicable due to the significant difficulties for calculations, or in one-dimensional form, that does not allows for the correct determination of pressure in DP and turn angles after the impact of the plates. This paper provides a mathematical model of multi-layered throwing calculation using fairly simple analytical equations to determine the above parameters when solving various applications for explosive processing of materials by a sliding detonation wave.

INTRODUCTION

When solving problems in the field of metalworking by explosion: welding, hardening and compacting due to the collision of plates accelerated by means of a sliding detonation wave, the problem of correctly determining the dynamic parameters of throwing is one of the main issues. The main such characteristics are the magnitude of the pressure of the detonation products (PD) and the throwing (turning) angles of the plates before and after their collision. A lot of works have been devoted to the problem of layer-by-layer throwing of plates under conditions of partial expansion of the PD, however, this problem was solved either in a one-dimensional form [1], which does not allow to determinate correctly pressure and rotation angles after collision of the plates, or by various numerical methods that are not applicable or cause significant difficulties for engineering calculations [2-8]. The aim of this work is to develop a mathematical model of the process based on analytical equations that allow us to determine the above parameters when solving various applied problems of explosive processing of materials with a sliding detonation wave. This model will allow, in particular, calculate the momentum of the PD reflecting from the rigid wall, after the collision of the throwing layer with it in the mode of incomplete acceleration.

THE THEORETICAL PART

Consider a diagram of several successively impacted plates moving at the expense of the detonation wave sliding along the surface of the first plate (striker) in a layer of H – thick explosives (EXP), parallel to each other (Figure 1). Let's assume that the detonation corresponds to the Chapman-Jugue condition [9], and DP is a polytropic gas with a constant indicator of k. At the same time, the plates, as well as the composition of those parts of the plates that have already been collided (the package), consist of a set of absolutely rigid not interconnected elements of zero thickness, the mass of which is equal to the sum of the mass of the original plates. The movement of a single element of the package will be considered both in the system of Cartesian coordinates ($\boldsymbol{x, y}$), associated with the detonation front (basic system countdown), and in the system of Cartesian coordinates ($\boldsymbol{x_c, y_c}$) associated with the beginning of movement (current system countdown) of the last plate (target) in the package. The process of

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throwing is considered at a rather large distance from the edges of the casting plates, excluding their effect on the movement trajectory of a single element of the package (acceleration curve). In the base system countdown, the ***x*** axis will direct along the initial position of the striker to the opposite direction from the detonation front movement and ***y*** axis - towards plate displacement. The $\boldsymbol{x_c}$ and $\boldsymbol{y_c}$ axis will be pointed so that the current system countdown is turned against the base system at an angle equal to the starting corner β_0 (see Figure 1), which is formed at the moment of collision with the target of the set of previous plates after their sequence oblique impact with each other (throwing layer). This initial angle is determined from the law of maintaining momentum.

Pressure in DP after impact will be called pressure in residual DP (part of DP, which continues to affect the package from the moment the throwing layer is hit with the target), and its initial p_0 value – peak pressure in residual DP (see Figure 1).

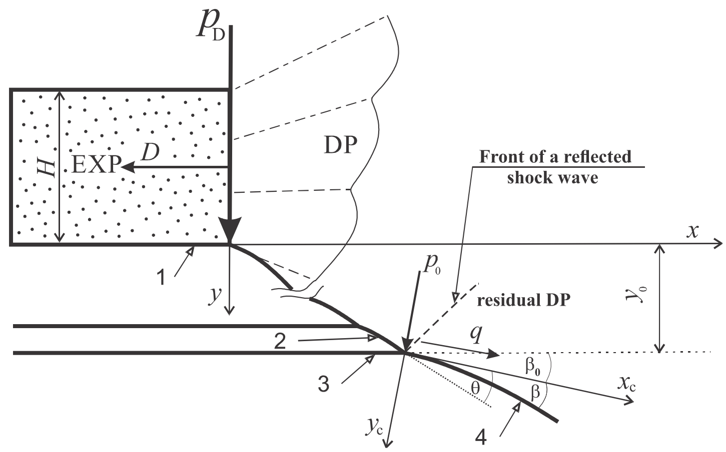

FIGURE 1. The Scheme of layered throwing of plates in the formation mode in DP of an oblique shock wave ($\theta \le \theta_{crit.}$). D - the detonation velocity of the EXP charge; q - the speed of the DP flow after it turns to the angle θ behind the reflected shock wave; $\theta_{crit.}$- a critical rotation angle of the DP flow behind the reflected shock wave; 1 - striker; 2 - throwing layer; 3 - target; 4 - package.

In calculations, all the values will be taken in a non-size form. For linear values, we select the thickness of the explosive layer as a unit: $\boldsymbol{X} = \boldsymbol{x}/H$, $\boldsymbol{Y} = \boldsymbol{y}/H$, $\boldsymbol{X_c} = \boldsymbol{x_c}/H$, $\boldsymbol{Y_c} = \boldsymbol{y_c}/H$. For the mass of the pack, we take the mass of the original explosive. For a unit of p pressure at a given point in the acceleration curve is p_D pressure in the detonation wave: $P = p/p_D$. The transition between the reference systems is made by formulas:

$$X - X_0 = X_c \cdot \cos\beta_0 - Y_c \cdot \sin\beta_0\,,\;\; Y - Y_0 = X_c \cdot \sin\beta_0 + Y_c \cdot \cos\beta_0. \tag{1}$$

Here X_0, Y_0 – the coordinates of the beginning of the movement of a separate package element in the base system countdown. Note that $Y_0 = y_0/H$ is a distance from the striker to the target in a dimensionless form (see Figure 1).

The angle β at which the package rotates in the current system countdown (current throwing angle) can be imagined as a function from r (load factor - the ratio of the EXP mass to the mass of the package), X_c и k. Now, by introducing the function $F(r, X_c, k) = \frac{\text{tg}\beta}{\text{tg}\beta^*}$, where β^* is the maximum angle of the package's throwing in the current count system, we get a general kind of dependency for the current throwing angle:

$$\text{tg}\,\beta = F(r, X_c, k)\text{tg}\,\beta^*, \tag{2}$$

where F changes in range of 1÷0. The equation (2) meets the following conditions:

$$\begin{gathered} \lim_{X_c\to\infty}\beta = \beta^*, \quad \lim_{X_c\to\infty}F = 1; \quad \lim_{X_c\to 0}\beta = 0, \;\; \lim_{X_c\to 0}F = 0; \\ \lim_{r\to\infty}\beta = \beta_{\max} = \lim_{r\to\infty}\beta^*, \quad \lim_{r\to\infty}F = 1; \\ \lim_{r\to 0}\beta = \lim_{r\to 0}\beta^* = 0, \;\; \lim_{r\to 0}F = E(X_c, k). \end{gathered} \tag{3}$$

Here βmax is the maximum angle of DP scatter to the environment, $E(X_c, k)$ – some function, the physical meaning of which is revealed below. By differentiating the equation (2) on X_c, and given that $dX_c = dS\cos\beta$ (S - the path traveled by the package element in the current system countdown to a given point), we will get $\frac{d\beta}{dS} = \text{tg}\,\beta^*\frac{dF}{dX_c}cos^3\beta$. On the other hand, it is known [10] that $\frac{d\beta}{dS} = \frac{r}{k+1}P$. Hence, $\frac{r}{k+1}P = \text{tg}\,\beta^*\frac{dF}{dX_c}cos^3\beta$. Where from, $\frac{P}{cos^3\beta}\left(\frac{r}{(k+1)\text{tg}\beta^*}dX_c\right) = dF$. Introduce the option:

$$\alpha = \frac{r}{(k+1)\text{tg}\beta^*} X_c. \quad (4)$$

Then we get a general kind of dependency for pressure:

$$P(\alpha) = \frac{dF}{d\alpha}\cos^3\beta \quad (5)$$

By integrating the equation (5) with (4), (2) and making simple conversions, we will receive: $\int_0^{X_c} \frac{P(r,X_c)}{k+1}\, dX_c = \frac{\sin\beta}{r} = F\frac{\cos\beta}{r/\text{tg}\beta^*}$. Then, by rushing r to zero and considering (1), (3), we will come to the expression:

$$E(X,k) = E(X_c,k) = \int_0^{X_c} \frac{P(X_c)}{I_0(k+1)} dX_c = \int_{X_0}^{X} \frac{P(X)}{I_0(k+1)}\, dX, \quad (6)$$

where $X_c = X - X_0$, $P(X_c) = \text{P(X)}$ – pressure in residual DP along a hard wall. Here, $I_0 = \int_0^{\infty} \frac{P(X_c)}{k+1} dX_c = \int_{X_0}^{\infty} \frac{P(X)}{k+1} dX = \mathbf{lim}_{r\to 0} \frac{\sin\beta^*}{r}$ – a full impulse of residual DP reflected from the hard wall. From (6) it is clear that $E(X_c,k)$ in (3) is a fraction of the full impulse of residual DP, which is acquired by these products when they are reflected from a hard wall during the time of $t = \frac{x-x_0}{D}$.

We will find a general kind of dependency for the $Y_c(\alpha)$ acceleration curve. From (2), taking into account the $\text{tg}\beta = \frac{dY_c}{dX_c}$, we have $\frac{dY_c}{dX_c} = F\ \text{tg}\beta^*$. Replacing the variable with the help of (4), we get: $\frac{r}{(k+1)\text{tg}\beta^*}\frac{dY_c}{d\alpha} = F\text{tg}\beta^*$. Where from:

$$Y_c(\alpha) = \frac{k+1}{r}\text{tg}^2\beta^* \int_0^{\alpha} F(\alpha) d\alpha, \quad (7)$$

Now we'll find F. In force (2), (3) we'll present the F function as

$$F(\alpha) = \frac{\alpha}{\alpha + \mu}, \quad (8)$$

where μ is a certain parameter. Analysis of this equation, taking into account (2) – (5) shows that it is always positive and meets the following limit conditions:

I. When $r \geq 0$: if $X_c \to 0$ $(\alpha \to 0)$, then $\lim_{\alpha\to 0}\frac{d\mu}{d\alpha} = -\frac{1}{2P_0^2}\lim_{\alpha\to 0}\frac{dP}{d\alpha} - 1$, $\lim_{\alpha\to 0}\mu = {}^1\!/_{P_0}$;

if $X_c \to \infty$ $(\alpha \to \infty)$, then $\lim_{\alpha\to\infty}\frac{d\mu}{d\alpha} = 0$, $\lim_{\alpha\to\infty}\mu = 0$;

II. When $X_c > 0$: if $r \to 0$ $(\alpha \to \alpha_0)$, then $\mathbf{lim}_{\alpha\to\alpha_0}\frac{d\mu}{d\alpha} = \frac{E-\alpha_0\cdot P}{E^2} - 1$, $\mathbf{lim}_{\alpha\to\alpha_0}\mu = \frac{\alpha_0}{E} - \alpha_0 \geq 0$, where $\alpha_0 = \frac{X_c}{(k+1)I_0}$, $I_0 = \mathbf{lim}_{r\to 0}\frac{\sin\beta^*}{r}$;` if $r \to \infty$ $(\alpha \to \infty)$, then $\lim_{\alpha\to\infty}\frac{d\mu}{d\alpha} = 0$, $\lim_{\alpha\to\infty}\mu = 0$.

III. When X_c=0: if $r \to \infty$ $(\alpha \to \infty)$, then $\lim_{\alpha\to\infty}\frac{d\mu}{d\alpha} = -\infty$.

IV. When $X_c \longrightarrow 0$: if $\alpha \geq 0$ $(r \to \infty)$, then $\lim_{r\to\infty}\frac{d\mu}{d\alpha} = 0$.

From the results, it is clear that the μ parameter changes from 1/P0 to 0 with an increase of α from 0 to ∞. On infinity, on the same of α and r, the μ parameter jumps from the upper limit to zero. From first condition (I), there are two rows of values $\lim_{\alpha\to 0}\frac{d\mu}{d\alpha}$ with opposite signs:

1. $\lim_{\alpha\to 0}\frac{d\mu}{d\alpha} > 0$ when $\lim_{\alpha\to 0}\frac{dP}{d\alpha} < -2P_0^2$; 2. $\lim_{\alpha\to 0}\frac{d\mu}{d\alpha} < 0$ when $\lim_{\alpha\to 0}\frac{dP}{d\alpha} > -2P_0^2$.

If we assume that the pressure in the DP along the plate decreases monotonously, in the first case there been growing the μ parameter from $1/P_0$ to its some limit value ("strong" pressure slump mode) then it down to zero ("weak" pressure slump mode) when the α increase from 0 to ∞. In the second case, μ decreases monotonically from $1/P_0$ to 0, that is, from the beginning to the end of the packet acceleration process there is only a mode of “weak” pressure drop in the residual DP.

$$\mu = \frac{m/P_0}{m+\alpha}, \quad (9)$$

where m is the parameter responsible for the pressure slump mode. If m<0 и $|m| > \alpha$, then we have a "strong" and if m>0 we have a "weak" pressure slump mode in the residual DP. From (8) and (9) will get the final equation for F:

$$F = \frac{\alpha^2 + m\alpha}{\alpha^2 + m\alpha + m/P_0}. \quad (10)$$

Expressions (2), (5), (7) are the main motion equations of the package, which are shared with (1), (10) and taking into account (4) create a closed system relative to X, X_c, Y_c, β, P for known values r, k, Y, X_0, Y_0, β_0 and pre-defined m, P_0, β^* (or I0 if r=0). Analysis of numerous experimental data on casting plate (see, for example, [11] and the experimental part of this article) allowed us to believe that m is not dependent on α. Then, differentiating (10) on α, we get:

$$\frac{dF}{d\alpha} = P_0 \frac{1+2\frac{\alpha}{m}}{\left(\frac{P_0}{m}\alpha^2+P_0\alpha+1\right)^2}\ . \tag{11}$$

Introduce the symbol: $A = \frac{(k+1)\mathrm{tg}\beta^*}{r}$. Let A=const. Then (11) given (4) will take the look of: $A\frac{dF}{d\overline{X}} = \frac{P_0+\frac{2P_0}{m}\frac{X_c}{A}}{\left[\frac{P_0}{m}\left(\frac{X_c}{A}\right)^2+P_0\frac{X_c}{A}+1\right]^2}$. Divide the variables: $AdF = \frac{P_0+\frac{2P_0}{m}\frac{X_c}{A}}{\left[\frac{P_0}{m}\left(\frac{X_c}{A}\right)^2+P_0\frac{X_c}{A}+1\right]^2}dX_c$. After integrating in the $\overline{X}$ interval from 0 to ∞ and the corresponding transformations, we will finally get: $2\cdot\sqrt{1-\frac{4}{mP_0}} = \ln\frac{1+\sqrt{1-\frac{4}{mP_0}}}{1-\sqrt{1-\frac{4}{mP_0}}}$.

From where, mP_0=4. Since P_0>0, it is m > 0, so (9) makes physical sense only for the "weak" slump mode in the residual DP. Using (2), (4), (5), (7), (10) and m = 4/ P_0 will get the only solution in the form of obvious analytical equations for the movement of the package in the current system countdown:

$$Y_c = X_c\frac{P_0\alpha}{P_0\alpha+2}\mathrm{tg}\beta^*, \tag{12}$$

$$\mathrm{tg}\beta = \frac{P_0\alpha(P_0\alpha+4)}{(P_0\alpha+2)^2}\mathrm{tg}\beta^*, \tag{13}$$

$$P = P_0\left(\frac{2\cos\beta}{P_0\alpha+2}\right)^3. \tag{14}$$

The P_0 is generally equal to the amount of pressure before the throwing layer is collided with target and pressure increments in the reflected shock wave. This wave is formed by DP braking, when the throwing layer turns in the opposite direction at the θ angle during it impact with the target (see Figure 1). The first is calculated by (14), the second is determined from the problem of leaking the blunt corner by supersonic gas flow [9], using, for example, a technique [12]. If the package consists only of a striker, then P_0 = 1.

The values of β* and I0 can be determined in the following original way. Introduce the symbol $P(r1, X)$ - pressure in DP, acting on a striker with a load factor of r1. Let us when $X = X$ * we have P(r1, X *) = ε, where ε - pre-set as small as possible the value. At the same time, P(r1, X *) < P(r, X *) because r1 > r. If you assume that in practical cases it is a condition X_0 >> 0, then it can be assumed P(r, X *) – P(r1, X *) << ε . Then from (13) and (14) when r > 0 or only (14) when r = 0, considering (1) and (4), we find β* or I0 accordingly.

EXPERIMENTAL PART

To test the calculation method used experimental data on the throwing of plates using the following EXP compositions bulk density (table): ammonites No.6ZHV (mixture of 21% powdered TNT and 79% finely shredded ammonia nitrate brand ZHV(ANS)) and AT-1(consists of powdered TNT 3% and a mixture of waterproof crystal ammonium nitrate brand ZHV (ANC) with ammonium nitrate brand A), mixture of ammonite No.6ZHV with ANC, as well as ANS and its mixtures with industrial oil (IO), technical glycerin (Gl) and wood flour the 200mkm (WF) fraction. Since these EXP appear to have a significantly stretched area of chemical reaction - comparable to the acceleration base of throwing package, within which the composition of DP can significantly change, it seems not quite correct to use for calculation k at Chapman-Juge point, found by electromagnetic method by detonation rate and mass DP speed measured on the charge axis. In this case, it is better to use the integral value of k found by the method of "sloping procrastination" [13] in calculations, which is a flat analogue of the known "cylinder-test" [9]. Using this method with some changes [11], in this work k was selected by combining the calculation charts y(x) with the profiles of plates built on experimental data, throwing in both a single-layer version and two-three-five-layer variants on welding modes by explosion. The limit $\beta^*_{r_1}$ angle on which the striker tries to turn around on during the free flight, was found through a well-known ratio: $v = 2D\sin\left(\beta^*_{r_1}/2\right)$, where v is the striker's speed limit. This speed was calculated by the Gurney's equation [14], presented in the form of [15]: $v = \sqrt{2E_G}\frac{r_1\sqrt{3}}{\sqrt{r_1^2+5r_1+4}}$, where E_G is Garni's energy (part of the heat of the explosion, which is used to throwing DP and plates), which was determined by a formula similar to the expression for the heat of the explosion: $E_G = D^2/\left(2(k^2-1)\right)$.

Figures 2 and 3 show graphs based on calculated (solid lines) and experienced data. How do you see their good match when used the corresponding k in the calculations (see TABLE 1.). The k values obtained in this work for ammonites No.6ZHV, AT-1 and 6ZHV/ANC mixtures correlate well with the integral indicators of polytrope found in the works [11,13] with the help of a well-known two-dimensional model [16].

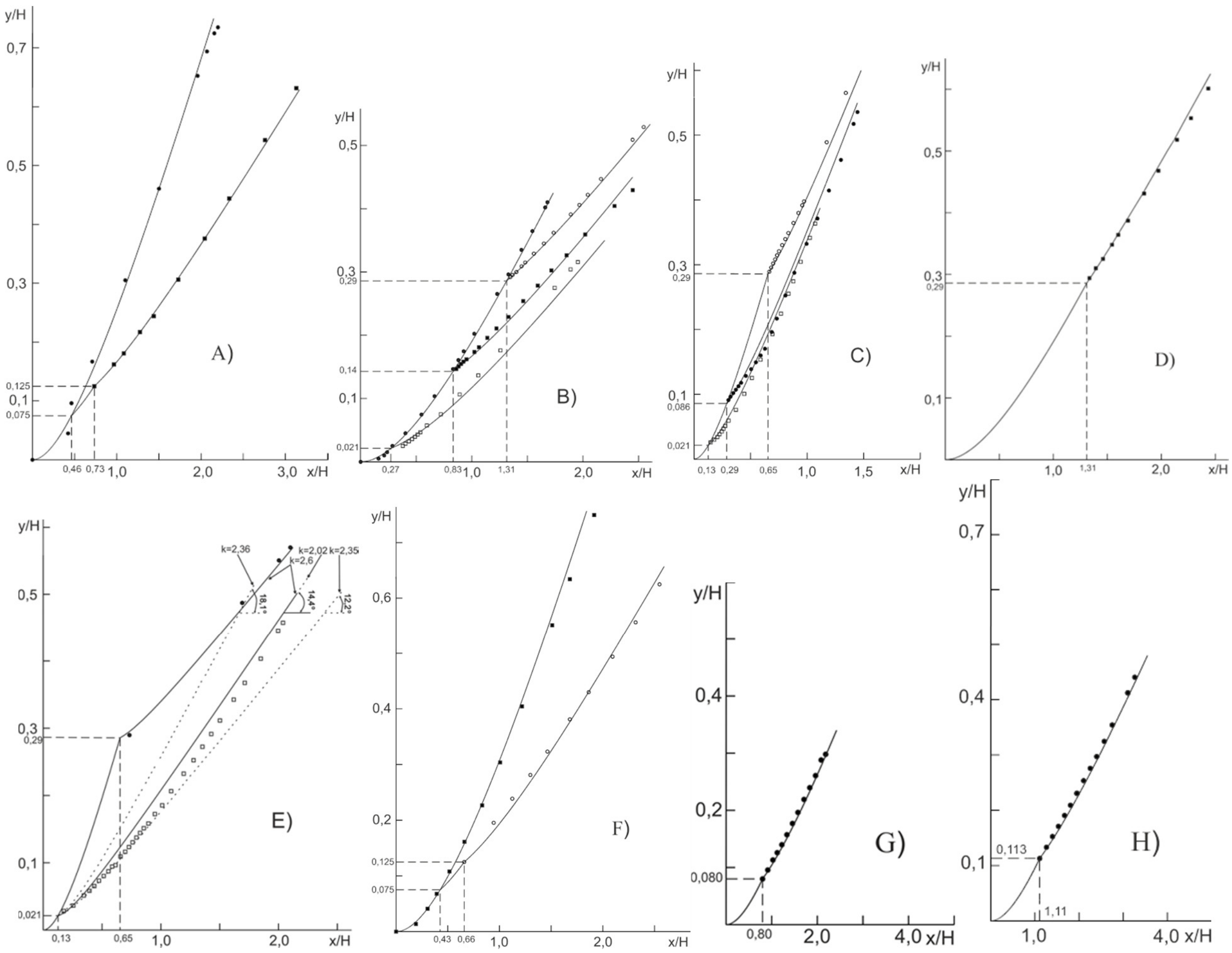

FIGURE 2. Graphs of the acceleration of plates in experiments: A) 1, 2(6ZHV); B) 3, 4, 5, 6(AT-1); C)7, 8, 9(AT-1); D) 10(AT-1); E) 11, 12(AT-1); F) 13, 14(ANS). G) 15(6ZHV/ANC=1/6); H) 16(6ZHV/ANC=1/5);

For all multi-layered throwing experiments, calculations have shown that when the plates are collided an oblique shock wave is formed in DP, that is, the condition $\theta<\theta_{crit.}$ is fulfilled (see Fig. 1), except for the experiments 11 and 12, where $\theta>\theta_{crit.}$, that is, the impact wave becomes a direct one (the front of the wave shifts some distance from the top of the corner towards the DP stream and is set to it perpendicularly). According to the calculation made on the initial data to experience 11, here a direct shock wave is formed at $k \geq 2.36$. On Figure 2e dotted lines show the calculated acceleration curves, built at $k = 2.36$ (direct wave) and $k = 2.35$ (oblique wave). From how you can see that the calculated curves are located on different sides of the experimental graph and on the final section significantly differ with it. If you reduce k to 2.02 (oblique wave), the calculation (dotted line) and the experiment will converge, as with $k = 2.6$ (direct wave). Since the results of the remaining 9 experiments for AT-1 show a match between calculation and the experiment at $k = 2.6$, including experience 12, where the condition of the formation of a direct shock wave is performed for any k, it becomes obvious that for the experience 11 should choose a solution at $k = 2.6$.

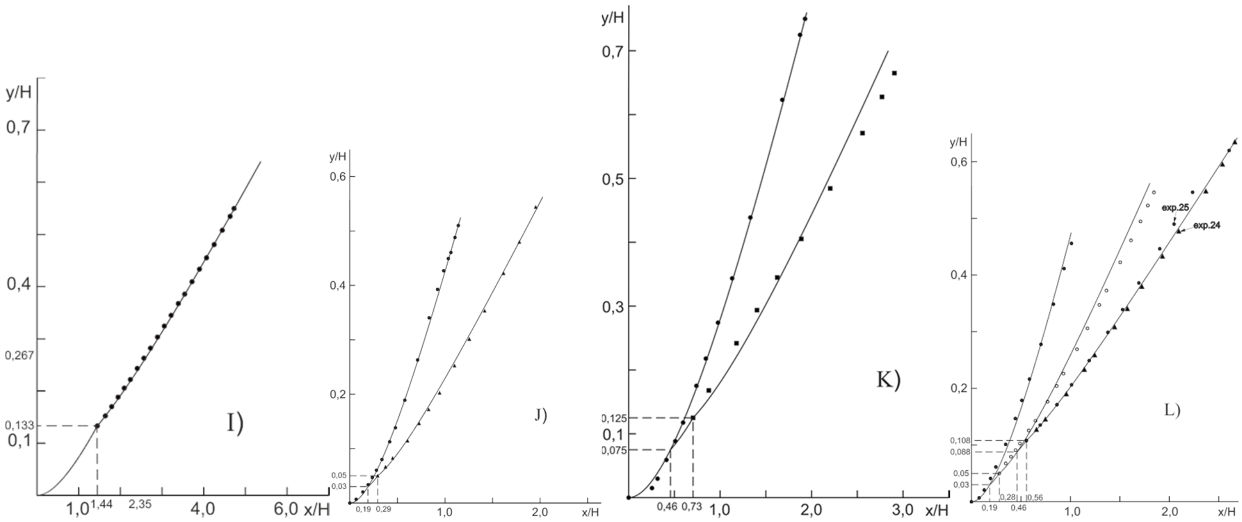

FIGURE 3. Graphs of the acceleration of plates in experiments: I) 17(6ZHV/ANC=1/4); J) 18, 19(ANS+5%IO); K) 20, 21(ANS+5%Gl); L) 22, 23, 24, 25(ANS/WF=3/1).

TABLE 1. EXPERIMENTAL RESULTS

N exp.	*EXP* (charge density x10^3, kg/m^3)	*H* x10^3, m	*D*, m/s	Brand the material plate (starting on top of the charge)	Plate thickness x10^3, m	*r*	*h* x10^3, m	*k*	$\beta_{calc.}$, degree
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	Ammonites No.6ZHV (0.90)	20	4065	Alum. alloy	1.9	3.53	-	2.45	-
2			3970	AMg2 (AlMg2)	1.9	3.53	1.5	2.45	15.2
				Aluminum A6 (1060)	1.5	4.44			
				Alum. alloy	1.9	3.53	1.0		12.2
3	Ammonites AT-1 (1.0)	70	2860	Aluminum AD0 (Al99.5)	10	2.59	-	2.6	-
4			2975		10	2.59	1.5	2.6	8.1
					10	2.59			
5			2730		10	2.59	10	2.6	15.2
					10	2.59			
6			2730		10	2.59	20	2.6	17.7
					10	2.59			
7			2970		2	12.9	1.5	2.6	16.7
					2	12.9			
8			3000		2	12.9	6.0	2.6	25.2
					2	12.9			
9			2930		2	12.9	20	2.6	31.3
					2	12.9			
10			3070		10	2.59	20	2.6	16.1
					2	12.9			
11			2850		2	12.9	1.5	2.6	16.7
					10	2.59			
12			2900		2	12.9	20	2.6	31.3
					10	2.59			
13	ANS (0.85)	20	1515	Alum. alloy	1.9	3.34	-	2.0	-
14			1510	AMg2 (AlMg2)	1.9	3.34	1.5	2.0	17.1
				Aluminum A6 (1060)	1.5	4.44			
				Alum. alloy	1.9	3.34	1.0		14.4

TABLE 1 (Continued). EXPERIMENTAL RESULTS

N exp.	***EXP*** **(charge density x10^3, kg/m^3)**	***H*** **x10^3, m**	***D*, m/s**	**Brand the material plate (starting on top of the charge)**	**Plate thickness x10^3, m**	***r***	***h*** **x10^3, m**	***k***	**$\beta_{calc.}$, degree**
15	6ZHV/ANC =1/6 (0.87)	50	2270	Copper soft	4	1.22	4.0	2.3	9.5
				Titanium BT1-0	4	2.42			
16	6ZHV/ANC =1/5 (0.87)	40	2330	Copper soft	4	0.98	4.5	2.3	9.4
				Titanium BT1-0	4	1.93			
17	6ZHV/ANC=1/4 (0.87)	30	2210	Copper soft	4	0.73	4.0	2.3	8.3
				Titanium BT1-0	4	1.45			
1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
18	ANS +5% IO (0.72)	50	3235	Alum. alloy AMg2 (AlMg2)	1.9	7.07	-	2.35	-
19			3200		1.9	7.07	1.5	2.35	15.6
				Aluminum A6 (1060)	1.5	8.89	1.0		13.2
				Alum. alloy AMg2 (AlMg2)	1.9	7.07			
20	ANS +5% Gl. (0.70)	20	2315		1.9	2.75	-	1.9	-
21			2255		1.9	2.75	1.5	1.9	16.1
				Aluminum A6 (1060)	1.5	3.46	1.0		13.6
				Alum. alloy	1.9	2.75			
22	ANS /WF= 3/1 (0.70)	50	3085	Alum. alloy AMg2 (AlMg2)	1.9	6.87	-	2.15	-
23			3125		1.9	6.87	1.5	2.15	16.3
				Aluminum A6 (1060)	1.5	8.64	1.0		14.0
				Alum. alloy AMg2 (AlMg2)	1.9	6.87			
24			3070		1.9	6.87	1.5	2.15	16.3
				Aluminum A6 (1060)	1.5	8.64	1.0		14.0
				Alum. alloy AMg2 (AlMg2)	1.9	6.87	1.9		14.3
				Aluminum A6 (1060)	1.5	8.64	1.0		12.7
				Alum. alloy AMg2 (AlMg2)	1.9	6.87			
25			3145		1.9	6.87	1.5	2.15	16.3
				Aluminum A6 (1060)	1.5	8.64	1.0		14.0
				Alum. alloy AMg2 (AlMg2)	1.9	6.87	1.9		14.3
				Aluminum A6 (1060)	1.5	8.64	1.0		12.7
				Alum. alloy AMg2 (AlMg2)	1.9	6.87			

Notes:

1. The content of components for mixed *EXP* is given in a volume ratio, the content of liquid components – from the volume of ammonium nitrate.
2. Designations: *H* – the thickness of the *EXP* charge; *h* – gap between the adjacent plates; β_{calc}. - the calculated angle in the base system countdown, which turns around the corresponding throwing element

(striker or layer) to take into account its additional acceleration by the residual detonation products at a distance of *h*.

CONCLUSION

The motion equations are invariant for any set of casting plates, i.e. there is symmetry of movement in multi-layered throwing, in which the product of the pressure slump parameter and pressure in the residual detonation products is retained for each throwing layer.

The original way to calculate the full impulse of the residual detonation products reflected from the absolutely rigid wall is given.

Good alignment of the integral politrope indicators found using independent calculation methods and the coincidence of calculated and experimental data on multi-layered plate throwing, indicate in favor of choosing the integral politrope indicators as the universal characteristics of the throwing ability of the explosive charge, regardless of the calculation scheme, if it adequately reflects the throwing process.

Since the integral politrope indicators can be defined by a formula similar to the expression for the heat of the explosion, as far as numerically it should be more than the polytrope at Chapman-Juge point, as Garney's energy is part of the heat of the explosion.

For the first time, welding modes by explosion were descriebed in which a direct shock wave was implemented in the residual detonation products.

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