THE INFLUENCE OF HEAVY ADMIXTURES ON THE DETONATION SYSTEMS OF CONDENSED EXPLOSIVE SUBSTANCES

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The influence of heavy metallic additives on the detonation systems of condensed explosive substances is investigated. The considerable reduction of the pressures of the detonation was established. The effect is explained by the occurrence of systems with increased detonation speeds, which do not fulfill the Chapman–Zhuge condition. An additional reduction of the pressure caused by the cooling influence of the admixtures was discovered for compositions with a large metal content. Experimental results have been compared with calculations carried out in an additive approximation.

The introduction of heavy metallic admixtures considerably influences the parameters of the detonation waves and the gas dynamics of the explosion products. The present investigation is devoted to experimental study of the first of these problems.

As already known [1], the conditions of the detonation of condensed explosive substances are determined by the equation of the adiabatic curves of Hugoniot

$$\varepsilon = Q + {}^1\!/_2 p (v_0 - v) \tag{1}$$

and the conditions of Chapman–Zhuge

$$-\left(\frac{\partial p}{\partial v}\right)_s = \frac{p}{v_0 - v} \tag{2}$$

Here ε is the specific internal energy of the explosion products, Q is the heat of the reaction, p is the pressure of the explosion products, $v_0 v$ is the initial specific volume of the explosive substance and the specific volume of the explosion products, and s is the entropy.

Neglecting the possible effects of overdistribution of thermal energy, we will calculate the compressibility of mixed compositions in what is known as an additive approximation [2, 3]. With this approach the specific volume of the mixture

$$v_c(p) = \alpha v_t(p) + (1 - \alpha)\, v(p) \tag{3}$$

represents the sum of the specific volumes of the explosion products, and the heavy fractions responding to their individual impact adiabatic curves at one and the same pressure.

The condition of Chapman–Zhuge of heterogeneous mixtures on the basis of (3) is the equation

$$-\left[\left(\frac{\partial v}{\partial p}\right)_s + \frac{\alpha}{1-\alpha}\left(\frac{\partial v_t}{\partial p}\right)_s\right]^{-1} = p\left[v_0 - v + \frac{\alpha}{1-\alpha}(v_{0t} - v_t\right]^{-1} \tag{4}$$

In (3) and (4) α is the weight quota of the inert additives; v_{0t} and v_t are its initial and final specific volumes.

In two idealized situations the addition of heavy additives which increase the dispersion time of the explosion products does not vary the pressure of detonation of the initial explosive substance. In fact, as

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TABLE 1. Calculated Parameters of Detonation of Mixed Compositions

α, %	ρ_{0c}, g/cm^3	v_{0c}, cm^3/g	n	v_*, cm^3/g	p_*, kbar	U_*, km/sec	D, km/sec
0	1.82	0.55	2.65	0.399	395	2.44	8.9
20	2.22	0.45	2.70	0.328	395	2.20	8.1
40	2.85	0.351	2.77	0.258	395	1.92	7.23
60	3.98	0.251	2.98	0.188	395	1.58	6.28
70	4.95	0.201	3.12	0.152	395	1.39	5.71
70	(4.92)	(0.203)	3.12	(0.154)	(385)	(1.37)	(5.69)
80	6.61	0.152	3.30	0.116	395	1.20	5.08
80	(6.42)	(0.156)	3,30	(0.12)	(371)	(1.16)	(5.01)
90	9.84	0.102	4.31	0.082	395	0.91	4.62
90	(8.20)	(0.122)	4.31	(0.099)	(171)	(0.63)	(3.32)

TABLE 2. Experimental Results of Determination of the Detonation Parameters of Mixed Compositions

α, %	ρ_{0c}, g/cm^3	W_{Al}, km/sec	U_*, km/sec	D, km/sec	p_*, kbar	v_*, cm^3/g	ΔD, km/sec
0	1.82	3.97	2.44	8.90	395	0.399	0
20	2.22	2.87	1.55	8.47	291	0,368	0.37
40	2.85	2.47	1.21	7.78	268	0.296	0.55
60	3.98	2.06	0.91	6.65	241	0.217	0.37
70	4.92	1.81	0.77	5.80	220	0.176	—0.11
80	6.42	1.59	0.66	4.70	199	0.134	—0.31
90	8.20	—	—	3.08	—	—	—0.24

follows from Eq. (4), the pressure of Zhuge is invariant in the case of uncompressed and linearly compressed additives. In the first case the invariability is retained owing to the reversion of the expressions $(\partial v_t/\partial p)_s$ and $(v_{0t}-v_t)\,p^{-1}$ to zero, in the second case, owing to their equality. These results characterize the influence of the additives from the slightly compressed metals in the framework of the additive approximation. The real additions, which have a final specific heat and thermal conductivity, absorb part of the energy of the explosion. As the evaluations show, in the case of 50% content of heavy metals, the establishment of a thermal equilibrium in the mixture reduces the temperature of the products of the explosion of the original explosive substance and the pressure by 6-9% and 4-6%, respectively.

For experimental checking of the hypothesis based on the additive approximation, and in order to discover the actually realized systems of detonation, a study of the mixtures of a high explosive substance with tungsten was undertaken. The main component of the mixture was an experimental composition with an initial density of $\rho_0 = 1.82$ g/cm^3 ($v_0 = 0.55$ cm^3/g), a speed of detonation $D = 8.9$ km/sec, and an effective index of the adiabatic curve $n = 2.65$, found according to the method of obstacles [4].

With these parameters, the equation

$$p \cdot 10^{-1}\ \text{kbar} = 16.9\,(v_0/v)^{2.65} \tag{5}$$

describes the adiabatic curve of the explosion products close to the Zhuge condition.

Tungsten in a powder form with a crystalline density of 19.17 g/cm^3 ($v_{0t} = 0.052$ cm^3/g), was used as the admixture; the adiabatic curves of the tungsten, according to [5], can be represented by the expression

$$p \cdot 10^{-1}\ \text{kbar} = \frac{3.97^2\,(v_{0t} - v_t)}{(1.27v_t - 0.27v_{0t})^2} \tag{6}$$

which corresponds to the linear D−U relationship of the tungsten $D_W = 3.97 + 1.27\,U$ [6], which connects the speed D_W of the impact waves in the tungsten with the mass speed U of the substance behind the front of the waves. (Here and further on D and U are given in km/sec.)

According to Eqs. (5) and (6), on the basis of the ratio of additivity (3) the adiabatic curves of the products of the explosion of the mixed compositions were also obtained, and according to the inclination of the graph $\ln p - \ln v_c$ their effective indices n were found. The parameters of the adiabatic curves and the expected characteristics of the Zhuge conditions are given in Table 1, in which the concentrations of tungsten are given as α %, the initial densities ρ_{0c} and the initial specific volumes of the mixtures v_{0c}, the indices n,

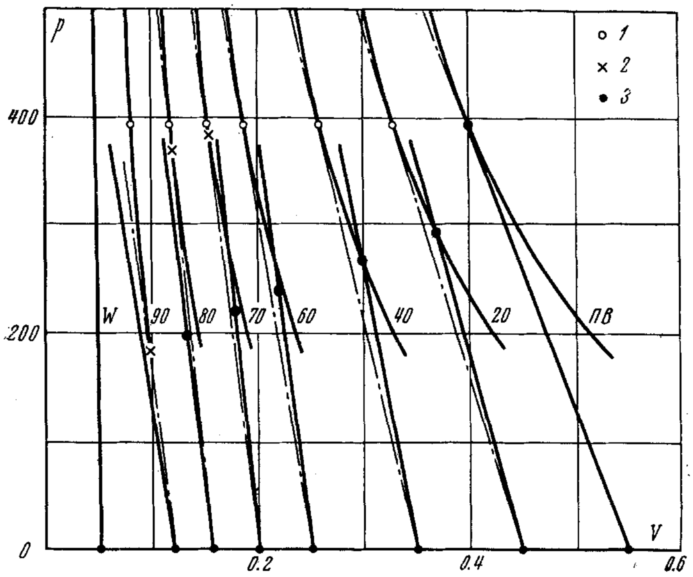

Fig. 1

the specific volumes at the points Zhuge $v_* = nv_{0C}/(n+1)^{-1}$, and the pressure p_* corresponding to them, the mass velocities U_*, andthe detonation speeds D. For compositions with a high tungsten content, the initial densities obtained appeared less than the calculated ones, calculated according to Eq. (3). The data, corresponding to the actual densities, are given in Table 1 in brackets. The calculations show in practice the constant pressure of the detonation for all the nonporous compositions and a sharp decrease in their expected velocities of detonation and the mass velocities.

The experimental program of investigations consisted of measurement of the velocities of the detonations and determination of the Zhuge conditions according to the method of obstacles.

The explosive substance in powder form and the dispersed tungsten powder (grain size 5-10 μ) were carefully mixed in the necessary proportions before pressing. The mixed compositions were prepared in the form of charges with a diameter of 60 mm and height 20 mm, from which charges of the necessary length were built up (60-80 mm). The noticeable porosity of the specimens appeared with a weight content of tungsten exceeding 60%. Measurement of the speeds of detonation was carried out by two methods: photochronographic and oscillographic methods by using electrocontacts. In all the experiments the blasting charges of the investigated mixed composition were initiated by a charge from the alloy TG40/60, with a diameter of 60 mm and a height of 60 mm. The electrocontacts (a copper foil 0.04 mm thick) were located between the charges near to their axis and were subsequently closed up by the detonation wave.

In order to determine the pressures and the mass velocities on the front of the detonation waves on the assemblies, similar to those described in [5, 6], the velocities W_{Al} of the movement of the free surface of aluminum obstacles were recorded at a distance of 5 mm from the boundary line of the metal–charge. In these experiments a plane detonation wave was created in the initiating charge made from the alloy TG 40/60 by using an additional rectifying lens. The magnitudes obtained were then extrapolated to the boundary of the explosive substance. The magnitude of the correction for extinction, which was found by calculation, was taken as equal to 5%. Aluminum with a density of 2.7 g/cm^3 whose adiabatic curve was in accordance with [7], taken in the form of the ratio $D_{Al} = 5.25 + 1.39$ U, was used as the material of the obstacles. The parameters of the detonation were found by the structures on the pressure–velocity diagrams. For this purpose, straight lines were produced up to intersection with the corresponding detonation beams $p = \rho_{0C}DU$ of the mixed compositions through the conditions of the aluminum obstacles at an angle of $\beta = \text{arc tan}(-\rho_{0C}D)$.

The results of experimental determination of the parameters of the detonation waves for different compositions are given in Table 2. The last column gives the differences ΔD of the experimental and calculated velocities of detonation.

Analysis of the experimental data and their comparison with theoretical evaluations lead to the following conclusions. In the case of weight concentrations of tungsten up to 60% inclusive, a slight exceeding of the experimental velocities of detonation above the theoretical velocity takes place, but in the case of large metal contents, there is approximately the same reduction. In spite of the increase of the velocities of the detonation of the mixtures in comparison with calculation in the case of concentration of tungsten up to 60%, the pressures and mass speeds deviate sharply from the calculated ones to the lower side. For a mixture with a 20% tungsten content the reduction of the pressures is 26%, and in the case of 40% tungsten it is 32%.

In order to interpret these paradoxical results on the diagram (Fig. 1), adiabatic curves of the mixtures were plotted with the calculated conditions of Zhuge for monolithic (points 1) and porous (points 2) composition, and the experimental wavy straight lines

$$\frac{p}{v_{0c}-v_c}=\frac{D^2}{v_{0c}^2} \tag{7}$$

were also applied with the points at which they touch or intersect with the mixed adiabatic curves, which determine the occurrence of the detonation system. For compositions with 20, 40, and 60% tungsten, the experimental recording of the Zhuge condition (points 3) practically coincides with the points of intersection located lower than the points of contact. Here the systems of forced detonation predicted by Ya. B. Zel'dovich in [8] are carried out; their velocities exceed the velocity of the detonation processes which fulfill the Chapman–Zhuge condition. The propagation of the explosive process in a series of compositions with too high "nonhydrodynamic velocities" is explained by the authors as a leading propagation of the detonation along the grains of the explosive substance between the particles of metal. It is remarkable that the slight increase of the wave velocities leads to a very strong reduction of the pressure of the detonation.

In the case of high tungsten content (70, 80, and 90%), the wave beams and the experimentally established states are located substantially lower than the calculated adiabatic curves. This circumstance is obviously explained by the cooling of the explosive products by the tungsten component and by displacement of the equilibrium adiabatic curves as a result of this, in relation to those calculated, to the side of the lower pressures.

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