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EFFECT OF THE INTERPARTICLE CONTACT CROSS SECTION ON SHS PROCESSES

T. V. Monasevich

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The relationships between the contact cross section and porosity as well as the regions of dense packing porosity are obtained for systems for which the dependence of the rate of combustion on porosity was investigated. The maximum rate of combustion in the course of the synthesis of intermetallic compounds, borides, carbides, and silicides is observed in the case of the dense packing porosity.

It is known that the speed of the propagation of the wave of synthesis in a powdery medium depends on the porosity of the pressed reaction mixture. Porosity determines the conditions of heat transfer for the chemical reaction to occur. Heat is transferred in a powdery medium through the interparticle contact cross section [1]. The large number of factors that characterize a powdery system prevented the establishment of a one-to-one dependence between the contact cross section of particles and porosity and correspondingly between the thermal conductivity and porosity. In this connection and also in view of the absence of a criterion for the boundary of the stages of packing it was not possible to unambiguously explain the character of the speed of propagation of the synthesis wave as a function of porosity.

The present work is aimed at a search for a simple dependence between the contact cross section of a particle in a packing and porosity and its relationship with the character of the propagation of combustion in the packing.

The relationship between the contact cross-section α and porosity was obtained in terms of the volume of pores V_p of a porous body of unit mass. The selection of V_p as a parameter for determining the contact cross section was based on a single functional dependence of α on V_p established empirically from the data of the present author and literature data for a number of materials. The contact cross section α was determined by a technique in the literature that involves the compressibility curves [2-4]. The volume of the pores of a porous body of unit mass was found by determining the porosity Π.

In Fig. 1, dependences of α on V_p are presented for powdery mixtures containing Ni, Al, Zr, Ti, B, and TiB_2 in various proportions. Note that all of the values of α fell on a single curve. When $V_p \le 0.22$ cm^3/g, the relation obtained can be approximated by the parabola branch [3]

$$\alpha = 20.7\, V_p^2 - 9.1\, V_p + 1\,. \tag{1}$$

When $V_p > 0.22$ cm^3/g, the value of α is close to zero. By substituting V_p into Eq. (1), we obtain the dependence of the contact cross section on two basic parameters of the system: the density of the compact material ρ_c and the porosity:

$$\alpha = \frac{20.7}{\rho_c^2}\left(\frac{\Pi}{1-\Pi}\right)^2 - \frac{9.1}{\rho_c}\,\frac{\Pi}{1-\Pi} + 1\,. \tag{2}$$

The curve of the function $\alpha(\Pi)$ plotted by using the compressibility curve has two qualitatively different portions: curvilinear and virtually rectilinear segments that correspond to the stage of packing and deformation. The plotting of the function $\alpha(\Pi)$ makes it possible to separate both stages graphically. The range of the boundary of the regions

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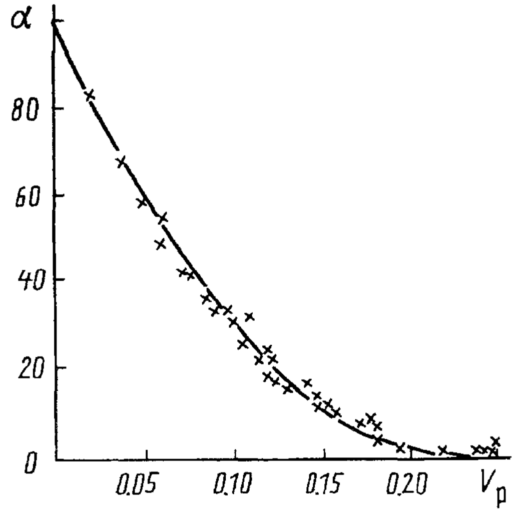

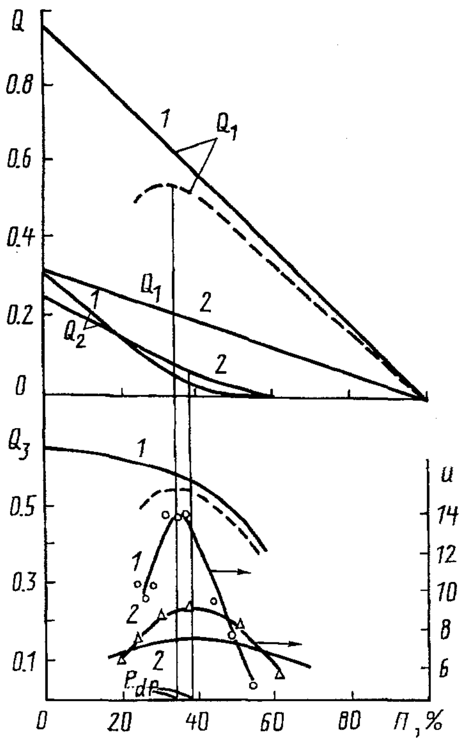

Fig. 1. Dependence of the relative contact cross section on the volume of the pores of a body of unit mass. α, %; V_p, cm^3/g.

Fig. 2. Dependences of heat release, heating, accumulation, and combustion rate of Ni+Al (1) and Ti+2B (2) on porosity. Q, kkal; Π, %; u, cm/sec.

was characterized by the region of dense packing of particles $\Pi_{\text{d.p}}$. Let us compare the familiar dependences of the rate of combustion on porosity with the graphs plotted by employing formula (2).

Table 1 lists the values of porosity that correspond to the maximum rate of combustion and $\Pi_{\text{d.p}}$ for systems investigated earlier. An exception is provided by coarsely disperse systems.

Let us try to explain the result obtained. The speed of the propagation of the synthesis wave depends on the quantity of heat released as a result of chemical reaction and on the quantity of heat transferred by conduction. We represent the quantity of heat released as a function of porosity

$$Q_1(\Pi) \simeq \rho_c H (1 - \Pi), \tag{3}$$

where H is the thermal effect of the reaction, which depends on the chemical nature of the reaction mixture.

We shall neglect the changes in the rate of the chemical reaction with the change in porosity. We will represent the quantity of heat needed for heating the reaction mass up to the combustion temperature as a function of thermal conductivity [2]:

$$Q_2(\Pi) \simeq \lambda_c \alpha B, \tag{4}$$

where B is a parameter taking into account the difference of temperatures at the ends of the conductor, i.e., of the zone of heating, and the time of heating at different values of porosity. We assume that $B \simeq$ const.

In Fig. 2 the functions $Q_1(\Pi)$ and $Q_2(\Pi)$, $Q_3(\Pi) = Q_1(\Pi) - Q_2(\Pi)$ are presented as well as the dependence of the speed of propagation of the combustion wave on porosity for Ni+Al and Ti+2B; their coefficients λ_c differ by an order of magnitude.

The maximum value of $Q_3(\Pi)$ for Ni+Al falls on $\Pi_{\text{d.p}}$, just as the value of the combustion rate u. Slow growth in the contact cross section at the stage of packing and, accordingly, slow growth in $Q_2(\Pi)$ as compared with that in $Q_1(\Pi)$ is conducive to the accumulation of heat in the zone of heating, expressed by the growth in

TABLE 1. Values of the Porosity for the Maximum Rate of Combustion and the Porosity of Dense Packing

Composition	$\Pi_{u_{\max}}$, %	$\Pi_{\mathrm{d.p}}$, %	Composition	$\Pi_{u_{\max}}$, %	$\Pi_{\mathrm{d.p}}$, %
Ni+Al	38±1	38±2	Ti+C	41±3	37±2
Co+Al	34±2	35±2	3Nb+Al	47±2	46±2
Ni+Ti	37±2	38±2	3Nb+Ge	40±3	44±2
5Ti+3Si	33±2	33±2	Ti-Cr-C-steel	42±2	40±1
Ti+2B	34±2	34±2	Co+20% S	40±2	37±1
3Nb+2B	54±3	53±2	Fe+20% S	40±5	38±2
Nb+B	50±2	48±2	Ti-B-Al	33±2	32±1
Nb+2B	46±2	44±1	Ti-B	36±2	38±1

$Q_3(\Pi)$, and causes growth in the speed of the wave of synthesis. Intense growth of the contact cross section at the stage of deformation promotes intense growth of heat transferred by conduction, which exceeds the quantity of heat released as a result of the reaction. This leads to a decrease in the quantity of heat accumulated in the zone of heating and in the combustion rate u.

For Ti+2B we obtained only growth in the quantity of heat accumulated $Q_3(\Pi)$. This corresponds to growth in the combustion rate with decrease in porosity. This character of the combustion rate as a function of the porosity is observed in the case of synthesis of borides and carbides at a high external pressure. When the external pressure is close to the normal one, the dependence of the combustion rate on porosity displays a maximum. As a rule, this difference in the behavior of the function $u(\Pi)$ is explained by the different behavior of the gas desorbed in the process of combustion. The function $Q_1(\Pi)$ was calculated without account for the action of desorbed gas. But why then does the maximum of the combustion rate fall on $\Pi_{\mathrm{d.p}}$? This is associated with the different macrostructure of pressing at the stage of packing and deformation. Open porosity dominates at the stage of packing, and at the stage of deformation one observes a sharp growth in closed porosity with a decrease in the overall volume of the pores. The efflux of gas at the stage of deformation is accompanied by ruptures because of sharp growth in the interstitial pressure. The ruptures of the reaction mass lower the quantity of the heat released (the function $Q_1(\Pi)$ is shown dashed in Fig. 2), and this leads to a decrease in the accumulation of heat in the zone of heating and, accordingly, in the combustion rate. In this case, the maximum of $Q_3(\Pi)$ is observed at $\Pi_{\mathrm{d.p}}$, just as the maximum of u.

Thus, the maximum rate of combustion of borides, carbides, silicides, and intermetallic compounds is observed at the porosity of dense packing.

REFERENCES

1. K. K. Andreev, Thermal Decomposition and Combustion of Explosives [in Russian], Moscow (1957).
2. V. V. Alexandrov, V. A. Gruzdev, and Yu. A. Kovalenko, Fiz. Goreniya Vzryva, **21**, No. 1, 98-104 (1985).
3. M. Yu. Bal'shin and S. S. Kiparisov, Fundamentals of Powder Metallurgy [in Russian], Moscow (1978).
4. Yu. A. Kovalenko, V. B. Gutin, V. V. Alexandrov, and V. I. Petrozhitskii, in: Problems of Technological Combustion, Chernogolovka, Vol. 11 (1981), pp. 85-88.