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CHANGES OF THE COMBUSTION REGIMES OF NONGASIFYING AND LOW-GAS SYSTEMS OVER THE PARAMETER RANGE

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The process of combustion of homogeneous and heterogeneous nongasifying and slightly gasifying systems over the range of a number of parameters characterizing the reactive composition and the conditions for the arrangement of the combustion process is studied by using thermocouple and optical methods. The regions of the implementation of different combustion regimes, namely, steady, pulsating, multiple-point, and spin, are determined experimentally.

Works [1-11] are concerned with the study of the processes of combustion of a variety of nongasifying and slightly gasifying thermite compositions. The study was performed with the use of optical (photorecording, motion-picture filming, pyrometry, visual observations during combustion and after it) and thermocouple (one or several tungsten-rhenium thermocouples were embedded at certain places of a cylindrical sample pressed from the test thermite composition) methods.

The combustion process was realized at various parameters of the reactive composition:

1) the calorific value of the composition was controlled by adding various amounts of the inert diluent (reaction product) [1, 4, 8] to the initial stoichiometric mixture;

2) compositions having various particle sizes of the components [4] were used;

3) reactive thermite compositions were pressed in the form of cylindrical samples of various diameters and shapes [5, 7, 11];

4) in the case of low-gas compositions (a nongasifying thermite composition, to which a special gasifying agent was added) the amount of the addition [10] was varied.

Combustion was performed under the conditions of various compositions of the environment [4], initial temperatures equal to the ambient one [9], and levels of heat losses from the burning sample to the environment [2, 3, 6].

During the combustion process the combustion rate and temperature were recorded. The mean combustion front velocity was taken for the combustion rate, and the maximum value on the plateau of the thermogram, for the combustion temperature.

Below, the results obtained are generalized. The regions of realization of different combustion regimes, namely, steady, pulsating, multiple-point, and spin, are determined. Steady and pulsating combustion corresponds to one-dimensional displacements of the front (steady - with a constant velocity; pulsating - with an abruptly changing velocity), multiple-point and spin combustion, to multidimensional displacements (multiple-point combustion — random motion of a set of luminous points in the plane of the front; spin combustion — ordered motion of the reaction site along a spiral trajectory).

Experimental Results. The dependence of the combustion rate of chromoaluminum thermite on the amount of inert diluent is plotted in Fig. 1 (n is the percent content of inert reaction product in 100% of the mixture of the product with the stoichiometric initial composition). An increase in n means a reduction in the calorific value of the composition. Similar dependences for a variety of thermite compositions are cited in [8]. Analysis of the results shows that:

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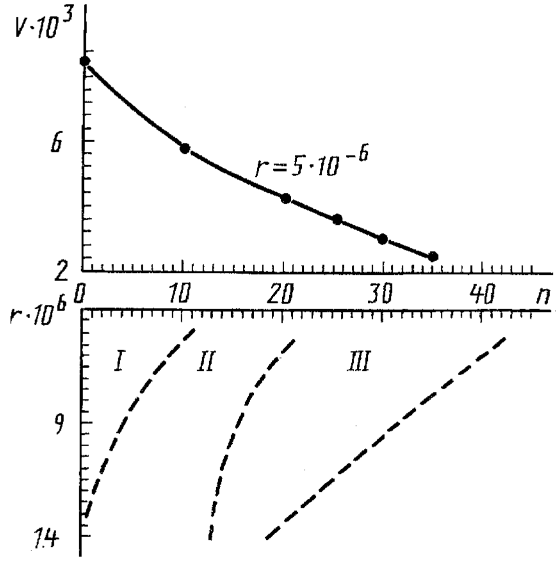

Fig. 1. Mean combustion rates and change of the combustion regimes of chromoaluminum thermite with different particle sizes of aluminum and at different degree of dilution of the initial stoichiometric composition with the reaction product. V, m/sec; r, m; n, %.

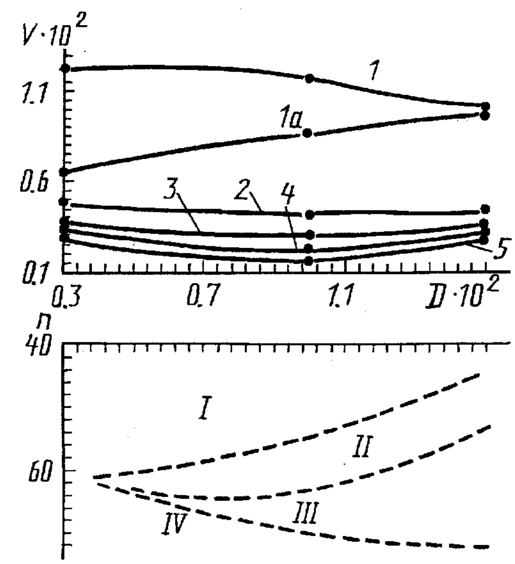

Fig. 2. Influence of the diameter of cylindrical samples pressed from ferrozirconium thermite of different calorific values on the mean combustion rates and the character of change of the combustion regimes. D, m.

1) as the calorific value of the compound is reduced, the change of the combustion rate is much weaker in unstable combustion regimes than in the steady regime;

2) a certain succession of the change of the combustion regimes exists: from steady (I) combustion to pulsating (II), from pulsating to the multiple-point regime (III).

This figure also shows the range of the values of the inert diluent n corresponding to the realization of one or another combustion regime of chromoaluminum thermite composed of aluminum powder with particles of different sizes (particle sizes are 5, 7, and 14 μm).

As the sizes of the metal particles increase, the region of the steady and multiple-point combustion regimes is reduced in size; attenuation of the combustion process is realized in the case of compositions having a higher calorific value (for smaller values of n). Attenuation of combustion is preceded by the multiple-point regime.

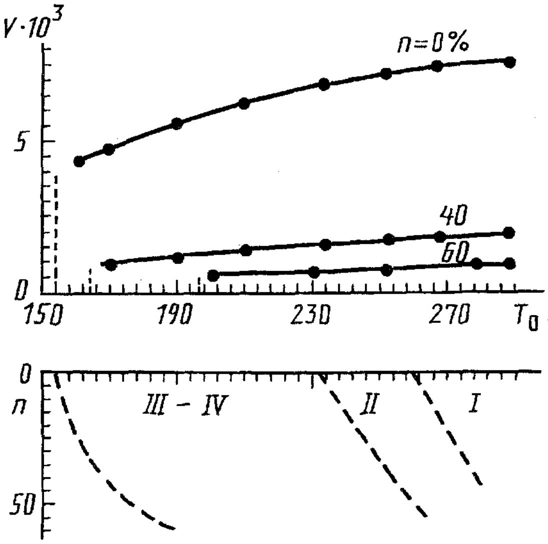

Fig. 3. Mean combustion rates and change of the combustion regimes of chromozirconium thermite with different initial temperatures. T_0, K.

The character of combustion and the change in regimes in the region of unsteady combustion depend substantially on the topology of the surface of the burning sample and its geometrical size. For example, when thermite compositions pressed in the form of rectangular samples burn, the regime of ordered multidimensional (so-called corner) combustion is seen. Combustion of disc-shaped samples initiated at the disc center is an essentially unsteady process. As the radius of the burnt part of the disc increases, the regimes change from one-headed spin to two-headed and then to multiple-point and pulsating combustion. The change of the combustion regimes is seen during one experiment with the conditions of the process unaltered. In the region of the site regimes the change from one regime to another (e.g., from one-headed to two-headed spin) is realized after substantial reduction of the rate of dispacement of the reaction site and is a distinctive emergence from a depression state.

The mean combustion rates of cylindrical ferrozirconium thermite samples of different diameters and the combustion regimes realized are shown in Fig. 2. Curves 1-5 correspond to the values of the combustion rate when samples are burning in air; curve 1a, for combustion in inert argon. The character of change of the combustion regimes depends substantially on the sample diameter. Actually, if for small diameters spin combustion (IV) is established immediately after stability has been lost by the steady front (I), then as the diameter increases, the change from steady to spin regime occurs through pulsating (II) and multiple-point (III) regimes. As the sample diameter increases, the region of the steady regime is reduced in size and that of the site regime (III) is widened substantially.

The study of the processes of change of the combustion regimes of slightly gasifying systems under the conditions of a variable degree of gasification was carried out on model compositions: nongasifying ferrozirconium thermite with added molybdenum trioxide. As before, the width of the parametric region with a certain combustion regime was estimated by the range of the inert diluent n in the initial stoichiometric composition. The results obtained allow the following conclusions to be made:

1) as the amount of the gasifying agent increases the combustion stability of the low-gas systems (LGS) studied is reduced;

2) a change of the combustion regimes of the LGSs and attenuation of the process occur in combustion of compositions having a calorific value (with a smaller amount of the inert diluent).

The influence of the environmental composition on the combustion process of thermite systems is most pronounced in the region of unstable regimes near the combustion limit. If the width of the region of site (multiple-point, spin) regimes is estimated by the range of dilution of the initial components with the reaction products, then the behavior of this region under combustion in different media can be followed.

Experiments with ferrozirconium and chromozirconium thermites burning in air, nitrogen, or argon showed that the region of site regimes was the widest in combustion in an inert argon medium. However, in combustion in a vacuum medium the region of site regimes is moved toward compositions having a lower calorific value (more diluted with the reaction product). Apparently, besides the redox reaction inherent in any thermite system, there is in addition the side reaction of interaction of the components of the thermite system with the oxygen of air. This is also supported by the behavior of the combustion rate of the pressed thermite composition (see Fig. 2). Actually, combustion of ferrozirconium thermite in inert argon occurs at a higher rate in the case of larger-diameter samples (curve 1a, Fig. 2), and in air, in the case of smaller-diameter samples (curve 1, Fig. 2).

The dependence of the combustion characteristics on the initial temperature is determined on the model of ferrozirconium and chromozirconium thermites over the range of temperatures less room temperature (see Fig. 3). As the initial temperature decreases to some critical values marked by the vertical dashed straight lines, the drop of the combustion rate is common to the combustion process of both thermite systems studied. At temperatures below critical the composition is not capable of self-maintaining combustion. As in the previous figures, I-IV denote regions of realizing different combustion regimes. Analysis of the results given in Fig. 3 shows that the site regime of combustion of the thermite systems is most probable over the range of initial temperatures considered.

Study of the combustion process of thermite systems under the conditions of controlled heat losses was successful in experiments conducted by an original method [2]. A cylindrical sample of the test composition was heated by a heat flux from an incandescent coil or cooled by inert gas flowing past the burning surface. As the heating time of a ferrozirconium thermite sample 10 mm in diameter increases from 10 to 60 sec, spin, multiple-point, pulsating, and steady combustion are realized in succession. The higher the degree of compaction of the pressed sample, the longer the heating must be. As the velocity of the cooling inert gas flowing past the thermite sample increases, other composition parameters being fixed, the pulsating, multiple-point, and spin regimes are obtained up to the point of attenuation of the combustion process (the blowing velocity is 80 m/sec for chromozirconium thermite).

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