PRESSURE MEASUREMENTS AT THE COMBUSTION FRONT OF GAS-FREE PYROTECHNIC MIXTURES WITH LOW GAS PERMEABILITY

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It is shown that the method of continuous measurement of pressure at the combustion front using an axial-force gauge is applicable to gas-free pyrotechnic systems producing solid reaction products and characterized by low gas permeability of specimens in the initial state. Small inclusions of a high-energy material producing gas combustion products are placed in the specimens to check the reliability of the result. These inclusions are located near the inlet to the main line going to the pressure gauge. The results of experiments on Ti+C+20% TiC specimens containing inclusions of pyroxylin powder are given.

Knowledge of a number of parameters, in particular, the gas-phase pressure is required to describe processes at the combustion front of pyrotechnic systems. This is especially important for systems with solid reaction products, in which material is displaced primarily by the action of pressure at the combustion front. The pressure in such systems is conveniently determined by measuring the axial force [1]. In this case, it is often required to extend the region of application of this method. For example, the method of [1] is inapplicable for combustion of specimens with free ends, and also for specimens with low gas-permeability in the initial state. The first circumstance is due to the fact that one cannot measure the axial force without loading the ends of the specimen, and the second is due to the difficulty of checking the reliability of the results. (Checking by the method of [1] is performed by comparison of the gas-phase pressure measured simultaneously by an axial-force gauge and a pressure gauge at the moment the combustion front approaches the inlet of the pressure-gauge line). The fact is that for systems with low gas permeability, the pressure level of the gas phase which penetrates through the pores of the still unburned part of the specimen into the pressure-gauge line is extremely low. The first restriction can be eliminated by ignition of specimens using pads with "pliable" slags, which allow the specimens to stretch partially during combustion [2]. Then, the pressure-measurement results are extrapolated to the total elongation of the specimen, which corresponds to combustion with free ends. The second restriction requires upgrading the method itself to ensure checking of the reliability of the results. This problem is solved in control experiments by using specimens that contain small amounts of a high-energy material (for example, powder) at the closed end. Upon combustion, this material produces an amount of gas that ensures pressure elevation to the required level at the moment of checking.

Experiments were performed on experimental setups which were equipped with either axial-force and pressure gauges (Fig. 1a) [1] or with an axial-force gauge and a photodiode [2]. Specimens were prepared from a Ti+C+20% TiC mixture [2] by pressing it into steel tubes to an initial density of 0.7. In most experiments, 10 to 30 grains of pyropowder with a total mass of 0.1–0.3 g were placed at the perforated bottom of the tubes (Fig. 1b) before the experiments. The specimens had a diameter of 25.2 mm and length l = 12, 22, or 44 mm. Specimens 22 and 44 mm long were pressed in portions, each 11 mm long. In some cases, 10 to 20 pyropowder grains with a total mass of 0.1–0.2 g or a continuous carbon-black layer with a mass of 0.2 g were
Fig. 1. Laboratory setups: specimen with no foreign inclusions (a), powder inclusions at the closed end of the specimen (b), and powder inclusions at the closed end and powder and carbon black inclusions at the boundaries of pressings (c); 1) axial-force gauge; 2) specimen; 3) steel tube; 4) pressure gauge; 5) pad; 6) pyroxylin powder; 7) carbon black.

Fig. 2. Schematic oscillograms of pressure $p$ (at the closed end of specimen) and axial force $F$ for combustion of Ti + C + 20% TiC specimens: (a) specimen with no foreign inclusions; (b) powder inclusions at the closed end; (c) powder–carbon-black–powder inclusions at the boundaries of pressings.

placed between the pressings (one variant of placement of inclusions is shown in Fig. 1c). The specimens were ignited by pads 0.7 mm thick, pressed from a Zr + WO₃ mixture [3] to an initial density of 0.6.

To decrease the force of friction of the pad slags and the specimen on the walls of the steel tubes, the inner surface of the latter was coated with a thin graphite layer before pressing.

The initial axial force $F_0$ produced by the setups of [1, 2] was 3 kN.

Typical oscillograms obtained on the setup of [1] are shown in Fig. 2. The characteristic point $L$ of the oscillograms of the axial force $F$, as shown by the experiments performed on the setup of [2], corresponds to the arrival of the combustion front at the closed end of the specimen.

As a result of the low gas-permeability of the specimens, the gases that evolved at the combustion front enter the atmosphere primarily through the solid reaction products — slags. The gas begins to enter the measuring line of the pressure gauge only after completion of the specimen combustion. The situation is complicated by the low gas evolution of the Ti + C + 20% TiC mixture (< 15 cm³/g). As a result, when the gas-phase pressure in the pressure-gauge line becomes equal to the decreasing gas-phase pressure in the zone of slags at the closed end of the specimen and reaches a maximum value, the readings of the pressure gauge $p_c$ and the axial-force gauge $F_c$ to be compared turn out to be very small (see Fig. 2a). In experiments with specimens that do not contain powder inclusions at the closed end, $F_c = 0.3$–0.8 kN and $p_c = 0.2$–1.0 MPa, whereas the nominal values of the axial force $F_n$ obtained in these and subsequent experiments are within 4.8–6.6 kN.

The presence of powder grains at the closed end of the specimens ensured an increase in the values of $F_c$ and $p_c$ to the appropriate level (see Fig. 2b): 2.5–13 kN and 5–26 MPa, respectively.

Placement of powder grains and a carbon-black layer on the boundaries of the pressed specimens ensured an adequate response of the setup in the form of a sudden increase or increase in the axial force to values $F_t$ and $F_s$, respectively, relative to its nominal value (see Fig. 2c), according to the location of these