NANOTHERMITES WITH CONTROLLED COMBUSTION CHARACTERISTICS — NEW FEATURES FOR MICROTRASTERS

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Abstract: Experimental studies of the propagation of high-speed combustion of a nanosized thermite mixture of Al + CuO were conducted. New data obtained using high-speed video recording of the combustion process and simultaneous measurement of pressure in the reacting mixture confirmed the previously made preliminary conclusion that the propagation rate of the nanothermite combustion reaction is determined, first of all, by the pressure gradient of the intermediate gaseous reaction products and the porosity of the initial composition. The experimental results confirm the main provisions of the previously developed model of the propagation of the combustion process in porous charges of nanothermites. To test the possibilities of controlling the combustion characteristics of the nanothermite mixture, the effect of a gas-generating additive (nitroguanidine) on the combustion rate in a steel tube and the developed specific impulse was studied. It was found that the introduction of 15 %(mass) of nitroguanidine into the initial composition of the nanothermite more than doubles the combustion rate and almost quadruples the specific impulse of the nanothermite mixture.

Keywords: nanothermites; porosity; ignition zone; burning rate; pressure gradient; nitroguanidine; specific impulse; microthruster

DOI: 10.30826/CE25180311 **EDN:** JCMYAP

Figure Captions

Figure 1 Gas-generating additive nitroguanidine (NQ)

Figure 2 Schematic diagram of the main experimental setup: *1* — control computer; *2* — 4-channel oscilloscope; *3* — 4-channel pyrometer; *4* — 808-nanometer laser (not more than 1 kW/cm^2); *5* — lens; *6* — protective screens; *7* — experimental assembly; *8* — light guides (up to 4); *9* — PCB pressure sensors (up to 2); and *10* — high-speed video cameras (Phantom Miro LC-310 (USA) and Photron Fastcam SA-Z 2100K (Japan))

Figure 3 Photograph of experimental assemblies: *1* — quartz tube; *2* — target with a hole defining the initiation point; and *3* — pressure sensor(s)

Figure 4 Schematic diagram of the setup for measuring the thrust characteristics of the NT-mixture: *1* — control computer; *2* — digital oscilloscope; *3* — pyrometer; *4* — laser; *5* — lens; *6* — protective screen; *7* — mirror; *8* — mixture ignition control light guide; *9* — duralumin container with NT-mixture (with and without nozzle); *10* — force sensor (FS); and *11* — power supply and matching device for FS

Figure 5 Typical oscillograms from the strain gauge: (*a*) NT-mixture with 15% NQ, mass 118 mg; and (*b*) strain gauge calibration signal

Figure 6 Oscillograms from a piezoelectric force sensor: (*a*) falling ball test, mass 2.023 g (*1* — 4.21 N·ms and *2* — 4.16 N·ms); and (*b*) combustion of NT-mixture without a nozzle (*1* — explosive mass 125 mg and *2* — explosive mass 75 mg)

Figure 7 Filmogram of burning in a quartz tube filled with an NT-mixture: A — initial mixture; B — ignition zone; and C — combustion zone

Figure 8 Change in the width of the ignition zone along the tube axis. Time from the moment of initiation μs / distance along the tube axis from the initiation place: *1* — 28/4,8; *2* — 40/9,8; *3* — 105/47,1; *4* — 113/52,1; *5* — 115/53,6

Figure 9 Determination of the width of the ignition zone using the barrier method: (*a*) there is the transmission of the propagation of the combustion reaction; and (*b*) there is no transmission of the combustion reaction

Figure 10 Pressure profile during combustion propagation in a quartz tube with $d_{\mathrm{in}} = 5.2$ mm

Figure 11 Photograph of 100-millimeter thick burnt protective copper foil

Figure 12 Initial section of pressure profile in the combustion zone

Figure 13 Correspondence of pressure profile to combustion zones in 2.5-millimeter tube, $\varepsilon = 0.89$; $u = 500$ m/s

Figure 14 Determination of the specific impulse of the NT-mixture in a microthruster without nozzle: *1* — without additives; *2* — with the addition of 5% NQ; and *3* — with the addition of 15% NQ

Figure 15 Thrust profiles with (*1*) and without (*2*) Laval nozzle during combustion of NT-mixture with 15% NQ: (*a*) during combustion of 75 mg fuel; and (*b*) during combustion of 120 mg fuel

Figure 16 Photographs of the operation of the microthruster with open tube (*a*) and the trace of its jet on the protective glass (*b*)

Table Captions

Table 1 Specific impulse of NT-mixture measured by strain gauge

Table 2 Effect of NQ additive on the combustion rate in a steel tube

Table 3 Combustion characteristics of fuel for microthruster

Acknowledgments

The main part of this work was carried out at the N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences (Program of Fundamental Scientific Research of the Russian Federation "Chemical Physics of Oxidation, Combustion, and Explosion," No. 1024040200065-4), part of the work on the preparation of samples and determination of the structure of nanothermites was carried out at the Joint Institute for High Temperatures of the Russian Academy of Sciences as part of the implementation of the state assignment for conducting fundamental scientific research No. 075-00269-25-00.

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Received December 23, 2024
After revision January 30, 2025
Accepted February 10, 2025

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