Combustion of layers inorganic systems under rotation to produce composite and gradient materials

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Abstract. The new way of production of gradient materials is presented. Course of self-propagating high-temperature synthesis reactions in layered systems under the influence of centrifugal force and some methods of analysis of the process and products of reaction is described.

1. Introduction
This method is based on carrying out SHS in a centrifugal installation – a high-temperature centrifuge [1]. Three identical cylindrical reactors rotate at up to three thousand revolutions per minute (see figure 1). The horizontal orientation was chosen to avoid the non-uniformity of the mass forces field [2]. As usual, the ignition is made from the center and then the SHS reaction wave moves to the edge of the circle, but the reverse option is also possible. A quartz tube is placed inside the reactor, and the sample, the mixture of the base metal oxide powders and aluminum, is placed in the tube. The reaction of restoring metal with aluminum occurs. The process proceeds very rapidly and usually requires the retardation by adding a dilutant to the initial mixture – the final reaction product, or one of the components in excess.

2. Formulation of the problem and method of solution
Under steady-state conditions due to the effect of gravity, we obtain a layered product. In rotating, the picture changes and it is possible to obtain gradient materials. In the rotating system, the clusters of combustion products have a large initial acceleration [3]. The less inert ones fly to the walls of the reactor, and the heavy ones rush along the radius. They hit the surface of the compressed mixture of powders. As the mixture has porosity, the clusters go inside the sample, through a surface layer. The penetration depth depends on the size and temperature of clusters, i.e. their viscosity. The kinetic energy of these particles at the time of blow is converted into the thermal energy and along with a simple heat and mass transfer, it increases the temperature of the pre-reaction mixture. Getting on the boundary between two grains of different components, the glowing clusters originate the point fire hazards (see figure 2). All this leads to the continued expansion of the combustion boundaries, the acceleration of its progress along the axis of the sample, the continuous increase in temperature (the accelerated super adiabatic regime – a non-chain distribution of the SHS reaction) [4].

Due to the high-energy efficiency of the reaction, we have the opportunity to make the experiments with such pairs of components that cannot be ignited under normal conditions. Placing the two different reaction mixtures consistently, we initiate combustion in the combustible pair of the components, and the clusters of this reaction’s products ignite the second flash-resistant layer.
can be a few such layers there. In the high-energy active layers, the mixture of tungsten oxide, nickel, and iron with powder aluminum is used, and in the low-energy ones, the mixture of boron oxide or silicon aluminum is used. The sample of the four-layer system is shown in figure 3. The final product is a gradient material with a gradual transition between metal and ceramic. The composition is selected due to the relative value of the heat effects of the reaction [5].

Samples of the gradient materials received at different compositions of initial mix and different frequencies of rotation of installation are given in figure 4.

After the active reactive layer, the attacked layer, for example nanographite, can be considered. To estimate the kinetic energy of the metal clusters, we have sought to catch, get, and examine the particles. As the screen the compacted graphite, boron oxide and a plexiglass tablet were used. The experiment with plexiglass gave the interesting results, the metal clusters of different sizes went to the different depths, and are easily visible to the naked eye. After sawing the sample, we got the pictures of the particles (see figure 5), it gave an impression of their average size, let to calculate the estimated kinetic energy component, which can then be used for the theoretical calculations of the SHS wave temperature.
additional data on the frequency of the reactors’ rotation. To shoot in one of the three reactors there is one slot and another slot is made in the cover of the installation (see fig. 1), in the course, we obtain the images at the moment of the geometrical coincidence of these two "windows”. At the speed of 400 shots per second, every 14th or 22th shot is informative depending on the rotational speed. In some pictures, the flame boundary is distinctly seen. Graphic way of measurement of speed of the front of burnings given in figure 6. The task of measuring the temperature was more difficult. We cannot use the thermocouples due to the inertia of their reaction and too high values of the measured temperature. The pyrometric method also takes time, and the reaction is too fast for it. We attempted to use pictures of the process in real time, to treat them in software and thus to measure the temperature.

![Figure 7](image)

**Figure 7.** Graphs of dependence of movement and speed of the front from time ($\Delta$ - quantity of empty frames between two informative ones, as number of frames per second is 400 that each frame- 1/400 seconds; in this example time interval is equal 14/400 or 15/400 s)

3. **Conclusion**

For better visual representation of the process, we give some numbers. The increasing of the speed from 500 to 5000 revolutions per minute gives an advantage over the force of gravity settling from 80 to 1000 times. The normal front propagation velocity at rest is up to 10 centimeters per second. At the boundary width of 2 millimeters the characteristic time of the process is 20 milliseconds, and the time of contact of the metal particles on the boundary is 20-60 nanoseconds. The maximum temperature of the aluminothermy process reaches 2500-3500 Kelvin. The tungsten particle radius of 1 millimeter has a mass of 80 milligrams, the kinetic energy 718 mill joules per second, speed of 90 meters per second. If the content of tungsten metal in the first part of the reactor is 45 grams, the total capacity of the stream of particles passing through the attacked layer of the thickness of 2 millimeters per 20 milliseconds is 2 mega joule per second.
References
[1] Ksandopulo G.I. 2011 Int. J. Self-Propag. High-Temp. Synth. 20, 220
[2] Ksandopulo G.I, Baideldinova A.N. 2011 Combustion and Plasma Chemistry. 9 No 4. 241
[3] G.I. Ksandopulo, V.N. Shevchenko, A.N. Baideldinova. High-temperature centrifuge / RoK Patent No 68317 as of 26.05.2010
[4] Ksandopulo G., Baydeldinova A., Ainabaye A., Arkhipov M., Omarova K 2011 Eurasian ChemicoTechnological Jornal. 13, №3-4 155
[5] Ksandopulo G., Aynabaev A., Arkhipov M., Baydeldinova F., Omarova R. 2013. Out-of-furnace synthesis of high-temperature ceramic materials in the revolving reactor, IOP Conference Series: Materials Science and Engineering (MSE) 47