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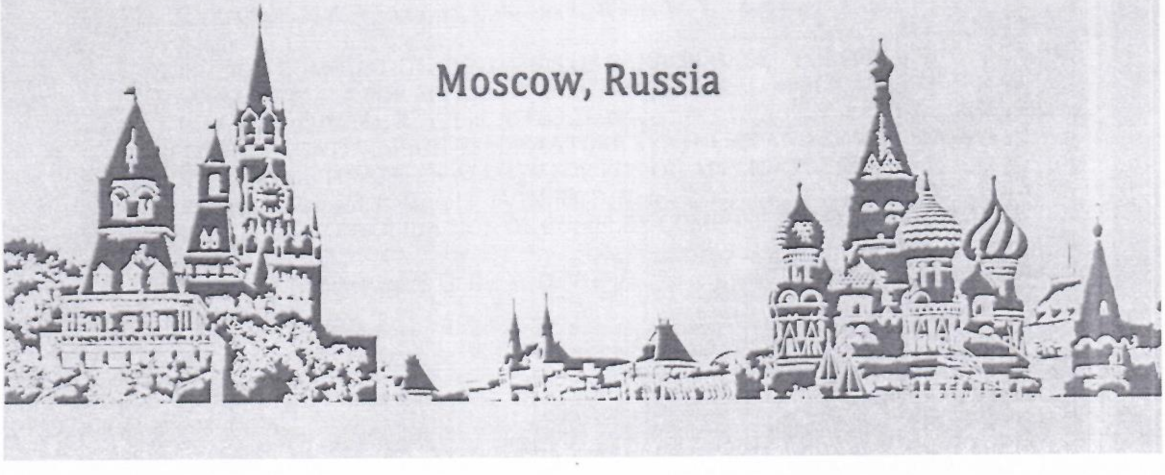

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THE EFFECT OF MAGNESIUM ON THE COMBUSTION PROCESS OF GAS GENERATOR MIXTURES

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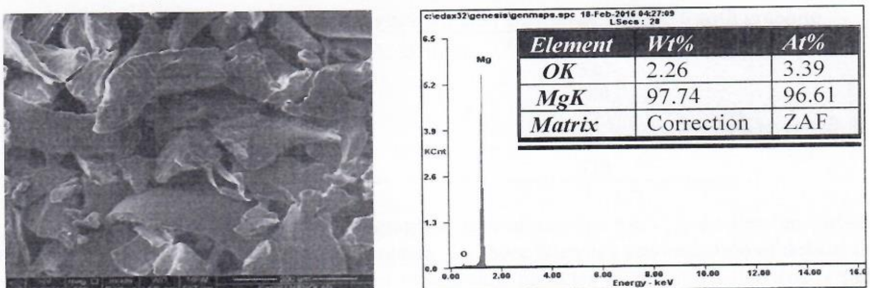
Metal powders are one of the most important components of combustible compositions of different composition and purpose. Their use is primarily due to the high thermal effect of metal oxidation, as well as a decrease in the average molecular weight of gaseous combustion products as a result of the deoxidation of H_2O and CO_2 during their interaction with the metal [1]. This is especially important for hydro-responsive fuel systems, in which the metal contains up to 80%, and it is the main fuel [2–4]. The most common and fairly energy-consuming metal fuel for fuel systems for different purposes is aluminum. In some fuels, primarily ballistic, aluminum particles due to the low oxidative activity of oxygen-containing combustion products ignite with a long time delay. In such cases, use is made of magnesium or its alloys with aluminum, the particles of which ignite faster than aluminum and burn completely [1, 3]. The most important characteristic of metal powders when used in combustible mixtures is the content of active (non-oxidized) metal, as well as the size and shape of particles. To obtain highly dispersed metal particles of magnesium with a modified surface of the particles, it is important to choose the optimal conditions of MCT for a specific modifying additive. This article presents the results and a comparative analysis of the studies on magnesium MCT in the presence of graphite. For the experiments, MPF-3 grade magnesium powder was used. The microstructure of the starting magnesium powder particles was investigated. The results of the microstructural analysis of the initial MPF-3 magnesium powder showed (Fig. 1) that the magnesium particles have a flaky shape and the average particle size of the sample exceeds 200 μm, while the thickness of the flakes is about 20 μm. The specific surface of such samples, according to the results of the BET method, is 0.181 m^2/g. The results of the EDX analysis showed the presence of 2.26% oxygen in magnesium, i.e. the presence on the surface of the particles of the oxide film. However, X-ray phase analysis of the original magnesium brand MPF-3 showed that 9.6% $Mg(OH)_2$ is present in its composition, i.e. the surface of the particles is covered with a hydroxide film.



Element	Wt%	At%
OK	2.26	3.39
MgK	97.74	96.61
Matrix	Correction	ZAF

Fig. 1. Electron microscopic image, energy dispersive spectrum and mass fraction of elements of original magnesium powder brand MPF-3.

Mechanochemical processing (MCT) of powders was carried out in the pulverisette 5 centrifugal planetary mill (manufactured by FRITSCH) with a volume of each working chamber of 500 mm^3, a platform rotation speed of 400 rpm, an acceleration of grinding balls 40g, power consumption 1, 5 kW/h. The MCT was performed in an air atmosphere with a powder/ball ratio ($M_P/M_{b\,r}$) = 1/4. During grinding, the amount of modifying additive introduced is different (5–20%).

The processing time was no more than 20 min to exclude self-ignition. The choice of the optimal time of the MCT was determined by the results of previous studies. In order to prevent the particles from oxidizing by atmospheric oxygen after the MCT and to estimate the changes actually associated with the mechanical action, the samples of the dispersed mixture were passaged with hexane (C_6H_{14}).

As a result, magnesium oxide with graphite particles retain a lamellar form. The specific surface for the composite particles (Mg 80% + C 20%) rises to 16.383 m^2/g. The results of the EDX analysis of the elemental composition of the Mg–C composite particles showed that after the MCT the mass fraction of oxygen atoms increases, so for (Mg 80% + C 20%) it is more than 6% (Fig. 2).

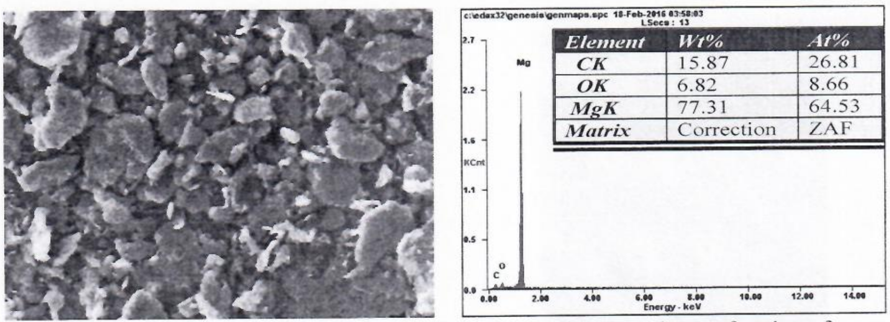


Fig. 2. Electron microscopic image, energy dispersion spectrum and mass fraction of elements in the composite (Mg 80% + C 20%) after 20-min MCT.

Consequently, on the surface of the magnesium particles after MCT, the thickness of the oxide layer increases. However, according to the results of X-ray phase analysis, no oxides are formed on the surface of the particles, and hydroxides, the amount of which can reach 15%.

To estimate the substructural features of aluminum particles after MCT, crystallite sizes were studied by XRD in the Mg/C composites obtained. According to the results of the analysis, in the process of mechanochemical processing, the size of the crystallites changes from the amount of the modifier used (Table 1).

Table 1. The size of the crystallites of magnesium after 20 min of the MCT with graphite

Graphite content in composites	Crystallite size L, Å
–	580
5% C	600
10% C	770
15%C	590
20% C	520

In the case of magnesium oxide with graphite, crystallites first grow, and when the carbon content is 15–20%, the crystallite size decreases, i.e. more intensive accumulation of defects in the volume of grains. The surface film of magnesium particles is destroyed (loosened) and saturated with highly dispersed carbon particles. Thus, the use of graphite with magnesium oxide according to all analyzed characteristics contributes to a change in the morphology and structure of the particles during the formation of metal/carbon composites. The observed changes in the size of the magnesium particles modified by the organic additive (graphite) in MCT are due to the fact that carbon, which is also dispersible in the MCT process, plays a significant role in the formation of the surface layer of the particles in all the cases considered.

Silicon dioxide in this case is used in an inactivated state. The mixtures were prepared with a stoichiometric ratio of components: Mg 44% + SiO_2 56%. For a mixture of quartz and composite (Mg/C) after the MCT, the induction period of ignition also decreases and the temperature and duration of combustion of mixtures with SiO_2 increase (Fig. 3).

Table 2 shows the indicators of the main characteristics of the combustion process and the strength of the synthesized samples. This is probably due to the optimal ratio of the particle size of the components of the mixture, and accordingly with an increase in the packing density, which ensures the density of contact between the oxidizer and the fuel.

The products of technological combustion of samples whose combustible component is a composite (Mg/C) have a low indicator of strength characteristics due to the porous, loose structure of the samples (Fig. 4). This is due to the fact that combustion proceeds in layers and in a large amount of gaseous products of synthesis are formed.

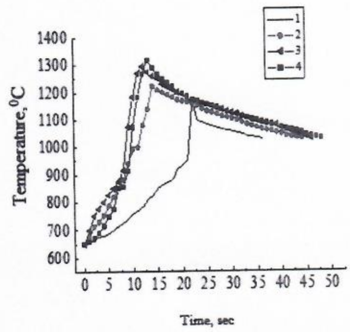


Fig. 3. Thermograms of combustion systems (SiO_2 + Mg) with magnesium in the initial state and after 20-min MCT with different amounts of graphite: *1* Me init.; *2* to 5%; *3* 10%; *4* 20% C.

Fig. 4. Fracture and external appearance of SHS samples obtained with magnesium modified at MCT with a content of 20% C.

Table 2. Approximate maximum temperature, burning rate of SiO_2 mixtures with modified magnesium, and strength characteristics of the synthesized samples.

Composition	T_{max}, °C	Burning rate, deg/s	σ, MPa
Mg init. + SiO_2	1170	23.6	50
Mg + 5%C	1295	40.9	5.8
Mg + 10%C	1318	58.6	1
Mg + 20%C	1223	51.4	1

The results of combustion of mixtures, in which aluminum and magnesium were used as a fuel component after MCT in the presence of graphite, showed the effectiveness of this method for improving the thermo-kinetic characteristics of the combustion process, and also determined the conditions for the preparation of combustible material and the combustion process. The latter fact is important when using the obtained nanostructured Mg/C composites as part of combustible systems, for example, for gas generators or for puffing up and producing porous systems of a specific purpose. Such compositions, as a rule, are heterogeneous condensed systems.

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