E3S Web of Conferences **288**, 01071 (2021) https://doi.org/10.1051/e3sconf/202128801071
SUSE-2021

Prospects for the use of a microwave electromagnetic field for the creation of an ecological technology for the production of firing materials and the development of microwave energy

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Abstract. The article considers the causes of environmental problems in the energy sector. The increased demand for energy resources and the increasing shortage of natural fuels are leading to the search for renewable energy sources. The prospects of energy transmission by microwave radiation without wires as an alternative to traditional energy sources are considered. The article provides information on the results of research on obtaining a high level of energy transfer by a microwave beam from a geostationary orbit to the earth's surface in the near future, as well as developments in the field of creating a solar space power plant (SSP). The results of research on the sintering of inorganic substances in an electromagnetic field are presented, the prospects for this direction in materials science are considered. The results of sintering natural raw materials in a microwave field are considered. The formation of nanoscale phases in sintered compositions has been established. The effect of a low-melting mineralizing additive on the sintering process is shown. The increased strength characteristics of the samples obtained by high-speed firing in the microwave electromagnetic field, the prospects for developments in this direction for various types of materials are noted.

1 Introduction

At all times, energy has been the basic foundation for ensuring the life of society. The economic growth of modern society is associated with an increase in demand for energy resources, which are currently represented by natural fuel, the extraction and use of which inevitably leads to environmental problems of the human environment. Emissions of pollutants into the atmosphere, waste water discharges, waste from the fuel and energy complex, together with production waste, create negative impacts on the environment at all stages of human production. The growing needs of society for energy resources are forcing the most efficient use of natural fuel and the potential of the energy sector, the use of renewable energy sources. At the same time, world experience shows that the energy crisis will grow over the years [1, 2]. This is due to the growing needs of mankind for energy, the rise in prices and the growing shortage of fossil fuels, environmental problems associated with its use in industry. In addition, problems in the power system associated with increasing losses during the distribution and distribution of electricity lead to the need to determine the direction of future changes in the energy structure. This problem is associated with the loss of the importance of traditional and the search for the most efficient alternative renewable energy sources, among which the transmission of energy by microwave radiation without wires is one of the most promising technologies.

Already in 1968 by Peter E. Glazer - an American specialist in the field of space research, it was proposed to use solar batteries in stationary stations in space, and the energy generated by them is transmitted by a microwave beam to the Earth's surface, converted into current energy and redistribute to consumers [3]. The current level of development of microwave electronics and research carried out in this direction suggest the possibility of obtaining in the near future a high level of microwave energy transfer - by a bunch from a geostationary orbit to the earth's surface [4].

Developments in the field of creating a solar space power plant (SSP), begun in 1978 in the United States under the leadership of the Department of Energy (DOE) and NASA, are currently actively and systematically carried out in Japan at the Space Research Institute under the leadership of professors M. Nagatomo (Makoto Nagatomo) and S. Sasaki (Susumu Sasaki), project Solar Power Satellite (SPS2000) [5].

In 2003, Kyoto University received the status of a promising center for research in the field of renewable energy sources (Center of Excellence on Sustainable Energy System), and research in the field of SSP became a dynamically developing area. Scientists from different countries, including Russia, are working in this direction. The implementation of this direction will become possible with the advent of new generation vehicles with a low unit cost of delivering goods to orbit.[5].

Studies of wireless transmission of energy using a microwave beam have shown its efficiency and advantages over traditional technologies in power engineering. Significant successes have been achieved by Russian scientists who own the method of wireless energy transmission using ceramic dielectrics [6].

The environmental problems of industries using roasting technologies that traditionally operate on the combustion of fossil fuels lead to the need to search, study and develop innovative areas in materials science. Among the most promising areas, one can name microwave heating, which is already being used in various industries.

In connection with these problems in the energy sector and industry, the ecological feasibility of using microwave energy in the production of materials and wireless transmission of energy in the energy sector have great innovative development potential. The use of the latest technological developments and innovative solutions can significantly reduce the cost of production of firing materials and move to new ecological principles of organizing the production process, develop an economically viable replacement for traditional technologies in the near future, create improved materials, various types of ceramics and composites necessary for use on earth and in space.

The study of the features of sintering powder compositions and natural polymineral raw materials in the microwave field shows the possibility of obtaining materials with special, often extreme properties. The study of the structure of materials obtained by this technology showed the formation of nanoscale phases in the sintered composition. In ceramic technology, this is the level of the passage of the main processes between phases during sintering, which is realized with the nanoscale dispersion of the initial components of the sintered composition. With the traditional technology of sintering with long exposure at the final firing temperature, recrystallization processes in the composition prevent the formation of the nanoscale structure of the material.

One of the most important parameters of microwave energy is the rate of energy transfer when interacting with matter. The study of the heating of solid particles in the microwave field showed that there is a selection and leveling of surface defects, a decrease in the size of the grain and defect structure of the material, the structure of the material with increased strength and toughness at fracture is formed [7-14].

Heating in a microwave field leads to accelerated movement of ions to higher energy levels, an increase in temperature in the interfacial region and, as a result, an increase in the reaction rate, and the formation of a microcrystalline structure of the material. The high rate of energy transfer leads to an increase in the reaction rate and the formation of the final phase composition of the material. An increase in the temperature gradient in the interfacial region due to dielectric losses leads to an increase in the sintering temperature. In a microwave field, this happens much faster due to the instantaneous heating of the substance to the temperatures of phase transformations. This is especially important for reactions requiring high activation energies.

Sintering at a high heating rate in an electric field produces a microcrystalline material with special properties such as an unusually high density and strength of the material [15-16]. The most important characteristics for traditionally brittle ceramics are properties such as superelasticity and ductility [17].

The greatest difficulty for studying sintering in a microwave field due to the multicomponent composition is presented by raw materials based on natural raw materials. This applies to silicates and aluminosilicates as the main raw material for a wide range of clay ceramics, refractories, and clinker. When studying the activation of raw clay compositions in the microwave field in a fine fraction of clay suspensions, structures were found that, upon subsequent conventional convective heating, form compositions from nanosized formations [18, 19].

Sintering of clay compositions occurs in the intergranular region after the decomposition of the initial components of the charge. The study of microwave heating of dielectrics and clay minerals showed the beginning of the process in the interfacial region, which, due to diffusion, covers the entire volume of the material [20, 21].

The composition of the ceramic material includes nanoscale phases and shows increased material strength [18, 19]. The influence of the mineral composition of the clay composition on the sintering process and the presence of a mineralizer, which enhances the interphase interaction and promotes the formation of an amorphous phase, is noted. [21].

In recent years, a lot of research has been devoted to the development of ceramic microwave energy absorbers, which include oxides SiO_2, Al_2O_3, CaO, MgO, which are the main components of clay compositions and, first of all, marls - clays with a high content of calcium and magnesium carbonates. These rocks are widely used for the production of building ceramics, refractories, and cement clinker. The main requirement for such materials is the volumetric absorption of microwave energy, its transformation into heat and dissipation of excess energy [22].

The increased activity of nanoscale particles due to the high surface energy is known. Among such dispersed systems, condensed microsilica, the main component of which is amorphous silicon dioxide, is of interest [23].

Traditionally, ceramic materials for various purposes were prepared by convection heating in ovens. The study of the features of microwave sintering of polymineral compositions is of great importance for the development of the fundamental principles of the technology for obtaining materials with special properties and the technology for producing ceramic composites.

The aim of this work was to study the features of heat treatment in the microwave field of compositions from natural polymineral raw materials with a large amount of carbonates activated by additions of amorphous silica.

2 Materials and methods

In this work, the study of the process of sintering in the microwave field of samples from a natural clay composition with a large amount of carbonates - marl with active silica, for comparison with NaCl. Condensed microsilica and diatomite were chosen as active silica. The final structure of the fired material in the microwave field and the structure after convective firing in a muffle furnace is compared.

The Maksimkovskoe clay deposit with the composition in wt% was chosen as marl: 33.2% SiO2, 11.4% Al2O3, 26.1% CaCO3 + MgCO3, 3.6% Fe2O3, 3.6% Na2O + K2O. Condensed microsilica produced by OJSC Kuznetsk Ferroalloys, Novokuznetsk, was chosen as silica - gray powder, with an average particle size of 0.005-0.015 microns, which have a developed system of pores of the nanometer level [23]. For comparison with microsilica, we investigated natural amorphous silica - diatomite from the Inza deposit (98.7% SiO2), as an activator of sintering - salt NaCl due to its ability to form low-melting mixtures with silicates and improve the sintering of polymineral natural mixtures.

To prepare the molding mixture, marl and diatomite were ground and sieved through a sieve with a hole diameter of 1 mm. Marl with additives was mixed in a ball mill for an hour. The mass was moistened until a plastic dough was obtained, and specimens with a size of 20 × 20 × 20 mm were molded from one composition for firing in a muffle and microwave oven. In the furnaces, the maximum temperature rise rate was maintained: in a muffle furnace for 4 hours, in a microwave oven - 30 minutes. Heat treatment was carried out up to a temperature of 1000 ° C with holding at the maximum temperature in a muffle furnace for 30 min, in a microwave for 5 min.

Used for sintering a muffle furnace PVK-1.4-17 and a microwave furnace (Samsung m 1711 NR) with an output radiation power of 800 W at an operating frequency of 2.45 GHz. The magnetic field is created by a 50 Hz power frequency current that flows through the furnace power supply system. For sintering, a muffle made of mullite-silica plates is installed inside the microwave oven. The temperature was monitored with a thermocouple with a radiation-protected junction coating installed near the sample.

X-ray phase analysis of the fired samples was carried out on a Shimadzu XRD 6000 diffractometer in CuK_{α}-radiation (PDF 4+ base, POWDERCELL 2.4 full-profile analysis program), sampling of sample breaks - on a system with an electron and focused ion beam (Quanta 200 3D) in the Tomsk Regional center of collective use of NU TSU.

3 Results

Samples with active additives were sintered without destruction. The greatest strength was obtained by sintering in a microwave field, and the most significant increase in strength was shown by the composition with microsilica. Samples of marl without additives in the microwave field had small cracks on the surface, and some samples had spalls. In a muffle furnace, all samples were sintered without defects, but showed a low level of strength.

The greatest increase in strength was obtained for a composition based on marl with the addition of microsilica, which was fired in a microwave oven (Figure 1).

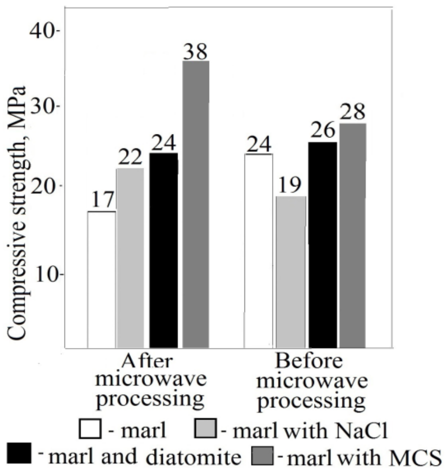

Fig. 1. Compressive strength of specimens fired at 1000 ° C from marl with additives: NaCl salt, diatomite, microsilica.

The X-ray diffraction pattern of the marl composition with the addition of microsilica is shown in Figure 2. A large halo is seen in the zone of the highest quartz reflections, characteristic of the amorphous phase.

According to the data of X-ray phase analysis of the sample with the addition of silica fired in the microwave field, the presence of nanoscale phases and a large percentage of the amorphous phase, shown in table 1, were found. The presence of an amorphous phase can be associated with the formation of a large amount of a liquid phase during sintering. The structure of the sintered composition with the presence of nanoscale formations and a glass phase shows the high strength of the material.

Table 1. Phase composition of the samples after firing.

Composition	Weight percent	Maintenance of phases, mass%	Crystallite size, nm
Marl + micro-silica	SiO_2	6.9 ± 1.7	48.3
	$Al_2Si_2O_5$	9.6 ± 2.4	12.8
	Fe_2O_3	0.4 ± 0.1	-
	AlSiO-mullite	5.9 ± 1.5	43.1
	$CaCO_3$	1.2 ± 0.3	43.7
	Amorphous phase	76	

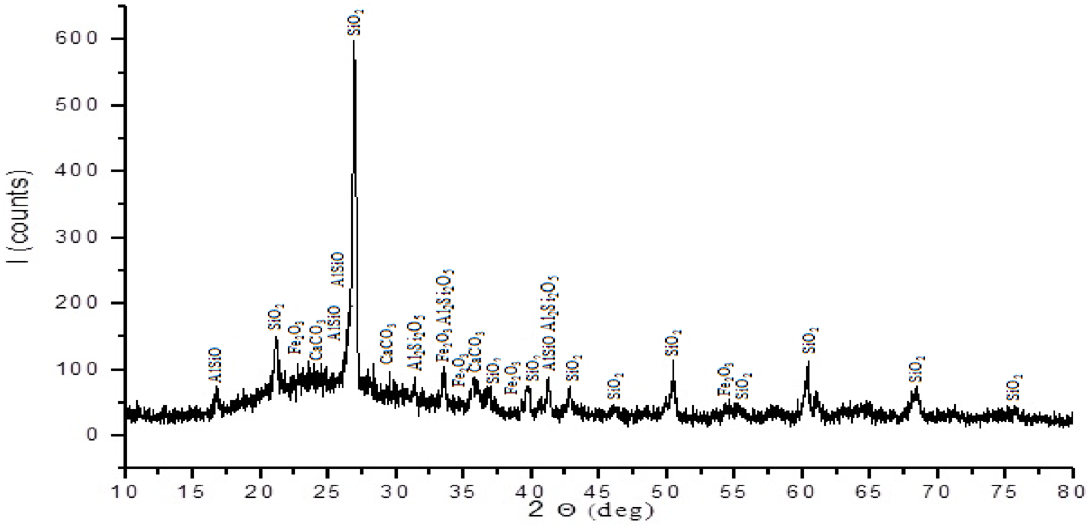

Fig. 2. Results of the X-ray phase analysis of a sample from composition: marl-microsilica with interpretation on phase.

The microstructure of an alloy based on marl and microsilica is shown in Figure 3.

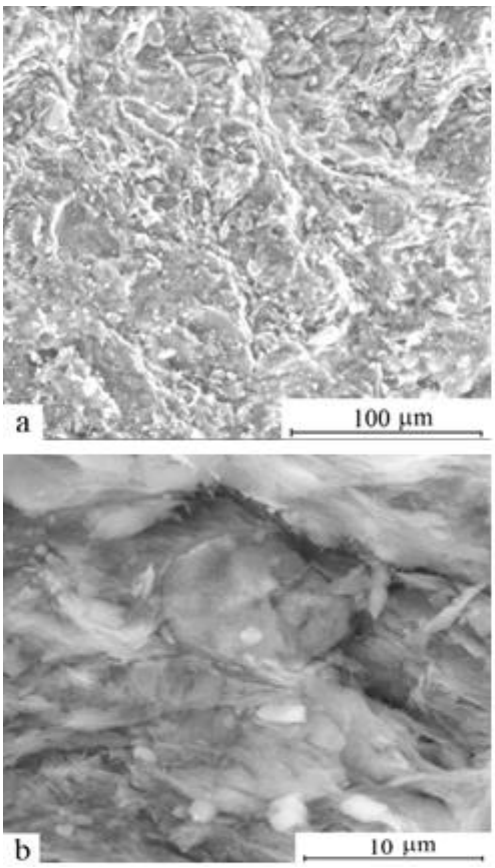

Fig. 3. The microstructure of an alloy based on marl and microsilica.

A dense structure of the composition (a) with the presence of fibrous inclusions (b), presumably mullite, reinforcing the entire structure of the sintered composition is visible. Such a structure must have high strength, which is confirmed by the test results

4 Discussion

The paper analyzes the literature data on energy problems caused by the growing needs of mankind for energy resources, the economic growth of modern society, the associated environmental problems of the fuel and energy complex and growing losses in the distribution of electricity. At the same time, research in the field of renewable energy sources and wireless transmission of energy using a microwave beam that has been developing in recent years has shown the near future of these areas over traditional technologies in energy.

The prospects for a possible solution to the ecological problem of traditional roasting technologies are shown. Listed are studies on the synthesis of materials in an electromagnetic field, which are distinguished by special, often extreme properties. The study of the sintering process at a high heating rate in an electric field has shown the possibility of obtaining a material with an ultrafine, increased density and strength of a material with a microcrystalline structure, which has increased viscous fracture rates. This is especially important for strengthening traditionally brittle ceramics and composite materials based on it, the demand for which increases with the development of nuclear power and space.

An analysis of the research results of the sintering of polymineral compositions under the action of a microwave electromagnetic field outlined the prospects for research in this direction for the production of roasting materials, the obtaining of special properties of which is associated with the formation of nanoscale phase structures. Materials with extraordinary mechanical and physical properties based on low-component mixtures have been obtained. The prospects of research in this direction in materials science and the importance of research for the development of the fundamental foundations of the technology for obtaining materials with special properties, especially from polymineral raw materials, are shown.

The presented work is devoted to the study of sintering in a microwave field of a carbonate-clay polymineral natural composition - marl and the influence of sintering activators on this process

5 Conclusion

The result of the study was the process of sintering samples from natural carbonate-clay raw materials with active additives in the microwave electromagnetic field.

As a result of the research it was found:

- the fundamental possibility of sintering a polymineral composition from natural raw materials with carbonate inclusions in a microwave oven;
- the dependence of the process on the additive and the type of sintering activator;
- the presence of a sintering activator in the composition of the marl contributes to the production of defect-free samples of increased strength;
- microsilica has the greatest efficiency during sintering;
- formation of a nanosized and glass phase during sintering of the marl-microsilica composition in the microwave electromagnetic field;
- when sintering the marl-microsilica composition in the microwave electromagnetic field, a uniform dense microstructure of the material with inclusions of a fibrous reinforcing phase is formed.

The results of the study on sintering in the microwave field of natural carbonate-clay raw materials showed prospects for the technology of obtaining many roasting materials.

The results obtained confirmed some of the conclusions made earlier on the sintering of low-component mixtures and compositions based on carbonate and silica raw materials. An increase in the strength of the material is associated with the formation of a special structure of the material, the presence of nanoscale phases.

In the process of firing, samples without defects from a polymineral carbonate-clay composition were obtained due to the addition of a sintering activator, among which silica fume was the most effective.

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