Modern technologies of composite materials' heat treatment

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Abstract. Mainstreams of microwave technologies' development and applications both in Russia and abroad are presented. Such directions as energetic efficiency of microwave technologies, ceramics and polymer heat treatment, basalt melting, drying of thermo-insulating materials, treatment of wastage are examined. Experimental studies were carried out on the electromagnetic field frequency oscillations of 2450 MHz. Polymer composite materials' thermal conductivity is very small and their heat treatment with gas or other known methods does not lead to the entire volume uniformity of heating, which leads to various flaws in the finished products during production. Future trends of different microwave technologies are shown especially in the part of even temperature field creation in materials as a pacing factor of quality goods production.

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Introduction

Improvement of technological processes of composite materials heat treatment is related to decrease in power expenses and improvement of quality of let-out production.

Current trends in technological processes' development of materials' heat treatment are directed on use the energy of microwave radiation as a heat source [1].

The use of microwave radiation for composite materials production allows to improve operational characteristics of processed materials at the expense of volume and uniform nature of heating and to rise on a higher level indicators of the technological processes, being characterized by ecological purity and high efficiency [1].

Application of composite materials is connected with increasing requirements to environment and reduction of power expenses for their production [2].

Experimental research of the composite materials' heat treatment was held in the radial type of microwave device. Microwave device is a camera with connected sources of microwave energy. The frequency of oscillations of electromagnetic field in the sources of microwave energy was 2450 MHz , and output power within 0,6 kW to 4,8 kW.

The way the sources of microwave energy on the camera are situated forms a uniform temperature distribution throughout the material. The maximum temperature deviation in the material from the nominal values of the temperature did not exceed 8%. Temperature measurement of the material was performed after switching off the source of microwave energy.

The obtained characteristics of materials (structure, strength and other characteristics) were measured in special devices. Composite materials have low thermal conductivity and the use of microwave technology helps reduce energy costs, increase the speed of technological processes and reduce the cost of production. Currently, the volume of the market of composite materials' consumption is not limited [3].

The largest world consumer of composite polymer materials are the USA - 44%, followed by Europe -26%, Asia -24%, other countries of the American continent - 3.4%, Russia - 1.4%. In Europe, the main consumers are Germany, Austria - more than 30%, Italy - more than 20%, France - about 18% [2-3].

Results and discussion

The main consumers of polymeric composite materials in the Russian Federation are the nuclear and aviation industry, and the largest consumers abroad - construction, automobile and aircraft industry, as well as mechanical engineering and road construction (bridges and other constructions).

Composite materials are used by Japanese firms for fittings manufacturing for concrete designs, and also at construction of bridges, residential and industrial buildings in seismically dangerous areas.

Use of composite materials in aircraft building allows to lower a total cost of a product for 20-30 % at the expense of reduction of power expenses. Various composite materials, for example, carbon fiber composites, will receive wide application in automotive industry. Use of such materials will allow to reduce weight of a car and therefore to increase its profitability. Use of polymeric composite materials in bridge constructions will ensure qualitatively new durable designs [2].

Scientific researches in the field of creation of highly effective microwave technological processes of heat treatment of composite materials are directed on quality achievements of received products which depends first of all on temperature distribution in the volume of a processed material, rate of heating and time of maintenance of the set temperature in a material.

The most perspective microwave technological heating processes: polymerization of plastics, production of ceramic materials, concrete and foam concretes, production of heatinsulating materials and many other.

Application of microwave technologies for heat treatment of composite materials allow to reduce duration of technological process; to lower a specific expense of the electric power; to reduce the areas of production rooms; to reduce number of the service personnel and to improve sanitary-and-hygienic conditions of their work; to reduce the sizes and weight of equipment; to increase controllability of technological process and to create conditions for automation of production [1].

Scientific researches in scopes of microwave energy are directed on power efficiency increase in processes of heat treatment of products from ceramics, glasses, minerals and polymeric materials, and also on production of new materials and recycling of various productions.

Power efficiency of microwave radiation application for heat treatment of composite materials is defined by reduction of emissions of carbon dioxide in environment, decrease in power expenses in comparison with other technologies, cost of the microwave equipment and efficiency of use of floor spaces.

Low value of heat conductivity of ceramic materials and need of volume and their uniform heating to high temperatures (up to 2000ºC) assumes use for these purposes microwave radiation as a source of heat and is the most effective way of receiving quality products [4-7].

When using microwave technologies of heat treatment of products from ceramics, essential economic effect in comparison with traditionally applied technologies of heating is reached, its durability raises, and the crystal structure of ceramics becomes more fine-grained [8].

Efficiency of application of microwave technologies for the polymeric materials' heat treatment is caused by the low heat conductivity and need of obtaining uniformity of heating on all volume of a polymeric material for completeness realization of polymerization reaction.

The microwave technological process efficiency assessment of polymeric materials heat treatment is defined by the short time of heating and polymeric material microstructure change, and also possibility of polymeric materials heating process management [9-11].

Priority development of the microwave technologies providing significant improvement of qualitative characteristics received composite (polymeric, on the basis of carbon and basalt fiber, fiberglass, melting of basalt and the accelerated concrete and foam concrete baking) materials, will allow to provide in the short term world leadership of the Russian production and technologies.

The review of the market of reinforcing products and materials from continuous basalt fiber, fiber glass and carbon fiber in Russia is presented in the Technological platform “New polymeric composite materials and technologies”. The increase of polymeric composite materials production and sale in Russian market to 10 % is planned, and now this market does not exceed 3 % [3].

Use of fiberglass fittings in concrete products has the niche in the field of production of construction materials as it increases service life due to the absence of corrosion, increases durability of concrete products, does not render hindrances on the radio engineering equipment, possesses high degree of stability to chemical impact of acids, salts and alkalis.

The fiberglass fittings are 2,5 times stronger than steel, and its density in comparison with fittings from steel is less in 4 times, the fittings from fiberglass materials practically does not carry out heat, and are dielectric. Therefore in winter in the buildings constructed with the use of this construction material, is warmly, and the cool in the summer remains.

Extent of influence of microwave process on characteristics of received composite and construction materials is carried out on such parameters, as mechanical durability and temperature firmness of materials, and also possibility of influence on change of a microstructure of a composite material from the point of view of obtaining the set properties.

It is shown on concrete examples that microwave technological processes in comparison with traditional technological processes make essential impact on characteristics of received products:

- during production of ceramic materials their structure becomes more fine-grained and more dense, and durability on a break increases in 1,2 - 1,3 times [8];

- process of fibreglass products polymerization occurs instantly on the whole volume as the temperature deviation in a material from nominal rate does not exceed 8 % when heating a material to temperature 180 $^{\circ}$C, thus durability of products from fiberglass fittings increases in 1,5 times at the expense of completeness of polymerization reaction course [2];
- experimental data (the weight and volume of a sample of basalt, time of heating to final temperature, capacity of a source of microwave energy, frequency of fluctuations of an electromagnetic field of 2450 MHz) allowed to determine the power expenses brought to weight of the heated-up sample of basalt which made 0,8 kW·h/kg by technological process of basalt melting. It should be noted that electroarc basalt melting furnaces have average power expenses 7,08 kW·h /kg [12];
- highly effective drying of a heater in the form of a cardboard from basalt fiber in thickness of 24 mm with use of microwave radiation showed that power expenses decrease by 45 % in comparison with heater drying on traditional technology [12];
- for acceleration of foamed concrete mix baking process, its temperature rose to $(70 \div 80)^{0}$C. Using microwave radiation as a source of heat energy allowed to refuse the use of expensive foreign additives for foam concretes baking acceleration which lead to deterioration of their strength characteristics because of acidity increase [13];
- on the basis of pilot studies the main characteristics of microwave technological process of receiving a paving on the basis of ashes and sulfur mix (a waste of productions) are received;
- the use of microwave radiation energy allows to carry out effective destruction of insects without drawing of harm to a processed material. Pilot studies on woolen blankets disinfecting from a clothes moth and khapra beetle are carried out at a temperature of 50 $^{\circ}$C, on frequency of electromagnetic field fluctuations of 2450 MHz in the beam type chamber within 5 minutes [14];
- pilot studies on microwave heat treatment of materials of various humidity (wood) showed that the maximum deviation of temperature value in a material from nominal rate of temperature in a material did not exceed 6 %. The method which allows to form the set distribution of temperature in material volume is developed. It is shown that the material structure, in particular, wood, when using microwave technologies is condensed, and strength characteristics of a material raise [1].

Pilot studies of heat treatment of composite materials with use of various designs of electrodynamic systems on 2450 MHz frequency of electromagnetic field fluctuations showed that microwave technologies allow to reduce power costs of (45-50) % and to increase speed of technological processes in 7-8 times in comparison with modern traditional technological processes [1, 12-14].

It is shown that microwave technological processes allow to improve characteristics of received materials (increase of density and durability of received materials etc.) [1, 2, 8, 12, 14].

The developed models and methods of the temperature distribution calculation in application to composite materials showed that the maximum deviation of temperature in a material from nominal rate did not exceed 8 %. The divergence of the calculated and measured values of temperature in composite materials did not exceed 6 % that meets modern requirements of composite materials heat treatment technological processes.

The received experimental results of composite materials heat treatment with use microwave radiation microwave radiation as a source of heat correspond to scientific results of the world level.

Table 1 shows the comparison of traditional technologies and microwave technologies for various technological processes of materials thermal treatment.

Table 1. Comparison of traditional and microwave technologies

Technological process	Economic benefit of microwave technologies application
Heat treatment of ceramics	Increases the density of ceramics is 1.1-1.2 times, increases wear resistance and durability
Polymerization of fiberglass plastic armature	Increases the strength rebar in 1,2 - 1,5 times, increases the speed of the process in 7 times, lower energy costs by 50%
The foam concrete production	The increased speed of a concrete durability set in 8-10 times, no mechanical stress
Melting of basalt	Reduction of energy costs in 10 times
Production of heat-insulating materials	The heat treatment speed increases in 7-8 times
Disinfection of wool products	The rate increases in 7-8 times, the material preserves its properties
Wood drying	The drying rate increases in 10 times, increases the density and durability of wood, no mechanical stresses, sterilization of timber, disinsection

Conclusion

Microwave technology has volumetric nature of heating materials regardless of their thermal conductivity. This property enables to heat the material evenly throughout the volume, that leads to the absence of internal stress and to the fullness of polymerization reactions. Some properties of the materials that result from their interaction with microwave radiation, such as sealing structures (higher density), are still insufficiently studied.

However, such characteristics of materials as increased strength, durability, wear resistance, are confirmed by numerous experimental results.

Microwave technology has environmental cleanliness, do not heat the surrounding air, and in combination with high efficiency are promising for many technological processes.

From the economic point of view the cost of production depends on the price of microwave equipment for the heat treatment of materials.

Gratitude

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