Utilization of Microwave Radiation at the Heating of Magnesite

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Summary

The paper deals with an influence of microwave energy on magnesite heatEng. The understanding of dielectric properties of heated materials predicts the running of microwave heatEng. The values of real and imaginary component of the complex dielectric permittivity of magnesite are described. The temperature distribution in the sample of magnesite during microwave heating was described by COMSOL Multiphysics programme. It followed the influence of microwave pretreatment on magnesite failure. The comminution process intensification of studied samples was evaluated by relative work index.

Keywords: microwave, magnesite, permittivity

Introduction

In recent years, a growing interest in microwave heating in minerals treatment, has emerged and a number of potential applications of microwave processing have been investigated. These included microwave assisted ore grinding, microwave assisted drying, microwave assisted mineral leaching, microwave assisted pretreatment roasting and smelting of sulfide concentrate, microwave assisted pretreatment of recfractory gold concentrate, microwave-assisted waste management [1-7]. At Institute of Geotechnics of SAS was studied the application of microwave energy at the intensification of processes: coal desulfurization, extraction of inorganic and organic materials, smelting of ores, stabilization of wastes by vitrification, comminution processes of the raw materials as well as in pyrolytic processes of coal and biomass [8-13]. The attention of pyrolysis processes and flotation of energetic raw materials are currently devotes a considerable amount of research groups [14-17]. The microwave decomposition system was also used to determine the total content of metals in bottom sediments of Waterworks Ružín and in insoluble fractions of Eastern Slovakia atmospheric deposition [18, 19].

The interaction of microwaves with materials is mainly dependent on: complex dielectric permittivity, conductivity loss, intensity of the electric field, specific heat, density, thermal conductivity. This paper deals with the application of microwave heating in the processing of magnesite. It describes the influence of microwave irradiation on the failure and the comminution processes of raw magnesite. The modelling of microwave heating of magnesite ($MgCO_3$) was solved by using the Comsol Multiphysics programme according to (1).

$$\frac{\partial T}{\partial t} = \frac{55{,}65.10^{-12}\ f\varepsilon'' E^2}{\rho c} + \nabla\left(k.\nabla T\right) \qquad (1)$$

where:

T - temperature [K], t - time [s], ρ - density [kg.m^{-3}], c_p - heat capacity [J.K^{-1}.kg^{-1}], ε´´ - imaginary part of dielectric permittivity, E - intensity of electric field [V.m^{-1}], k - thermal conductivity [W.m^{-1}.K^{-1}].

Material and Methods

Samples of magnesite (locality Jelšava and Mútnik, Slovakia) were used in the experiments. The chemical compositions of the materials are introduced in Table 1.

The effect of temperature on the measurement of real and imaginary parts of permittivity was realized by the resonance cavity method in the TM030 mode at the frequency of 2216 MHz. The measurements were made at the Faculty of Engineering, School of Electrical & Electronic Engineering, University of Nottingham [20]. The measurements were carried out in a cylindrical resonator with a diameter of 373

Tab. 1 Chemical compositions of samples

Tab. 1 Skład chemiczny próbek

Sample	Locality	SiO_2 [%]	Al_2O_3 [%]	MgO [%]	CaO [%]	Fe [%]	Mn [%]	Loss on ignition [%]
Magnesite	Jelšava, SR	0.31	0.28	43.69	1.39	1.97	0.16	51.11
Magnesite	Mútnik, SR	4.14	0.89	46.10	1.71	1.76	0.13	46.47

mm and a height of 37.3 mm. The sample, placed in a fused silica tube with a diameter of 3 mm, was inserted into the resonator. During the measurement the initial temperature was 150° C, and heating rate 5°C/min. The measurements were taken every 50°C, the final temperature was 1000°C.

The rate of propagation of longitudinal waves in the irradiated materials was measured with an ultrasonic apparatus MATERIAL TESTER, type 543, with a digital time display with accuracy 0.01 μs and 0.02 μs. The ultrasonic method used is based on measurement of acoustic properties of the specimen investigated, namely the rate of longitudinal elastic waves of a wave field produced by a pulse method [21].

The rate of propagation of longitudinal waves in samples was determined according to the following formula (2):

$$v = \frac{l}{t} \tag{2}$$

where:
l – length of the sample [m]
t – propagation time of ultrasonic waves [s].

The wave frequency was 1 MHz. The size of sample was selected in such a way so the lengthwise dimension of the sample was at least 5-fold the length of the waves used. This ensured that the results obtained were independent of the geometry of specimens examined. According to the recommendations of the International Society for Rock Mechanics (ISRM), the coefficient of failure Kp was determined according to (3):

$$K_P = \frac{v_1}{v_2} x100 \tag{3}$$

where:
v1 – propagation rate of longitudinal waves in the sample after microwave heating [m.s^{-1}],
v2 - propagation rate of longitudinal waves in the sample before microwave heating [m.s^{-1}].

It is possible to quantify the extend of material failure on the basis of calculated failure coefficient. The quantitative evaluation of failure according to Jaeger [22] is introduced in Table 2.

The influence of microwave heating on crushability was followed in magnesite sample of grain size 8-10 mm, weight of samples was 150 g. Non-irradiated and microwave irradiated samples were subjected to crushing in vibratory laboratory jaw crusher VČM-3 (feed max. 15 mm, output 0.2–3 mm). The grain size analyses have been carried out using laboratory sieves by dry way. The mesh sizes were as follows: 3, 2, 1, 0.5, 0.25, 0.125 mm. A microwave oven with a power of 1000 W and 2500 W at frequency of 2.45 GHz was used for microwave heating of samples. The temperature was measured by means of infrared non-contact thermometer Raynger MX4.

The influence of microwaves on crushability was evaluated on the basis of Berry-Bruce test using relative work index derived from the Bond's work index [23, 24]. The test enabled to compare crushability of non-irradiated and microwave irradiated samples. Thus, the relative work index (RWI) was given as follows:

$$RWI = \left(\frac{10}{\sqrt{P_1}} - \frac{10}{\sqrt{F_1}}\right) \Big/ \left(\frac{10}{\sqrt{P_2}} - \frac{10}{\sqrt{F_2}}\right) \tag{4}$$

where:
F – 80 % passing grain size of the feed [mm],
P – 80 % passing grain size of the product [mm],
1 – non-irradiated sample,
2 – microwave irradiated sample.

In all cases the value $F_{(1,2)}$ = 10 mm was considered at calculations.

Experimental Results

Dielectrical properties of magnesite

Complex dielectric permittivity describes the behaviour of material in a microwave field. The imaginary part of permittivity (loss factor) can be used as a criterion for assessing the suitability of heating in

Tab. 2 The quantitative assessment of failure

Tab. 2 Ilościowa ocena wtrąceń

Kp [%]	100 – 90	90 – 75	75 – 50	50 – 25	25 – 0
Failure	very low	low	medium	high	very high

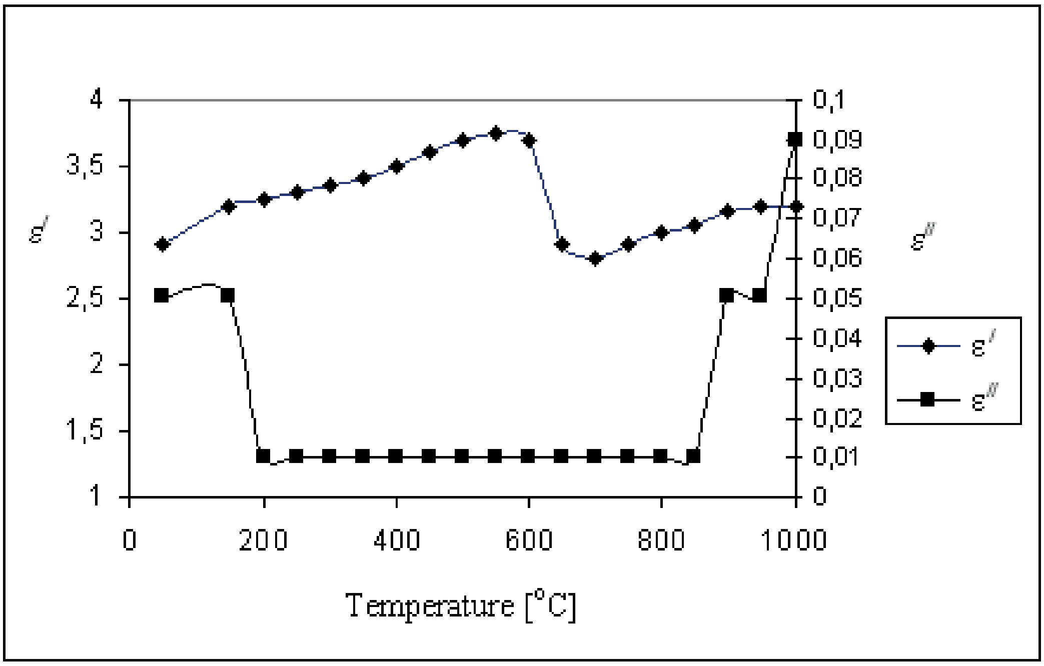

Fig. 1 The temperature influence on the real (ε´) and imaginary (ε´´) parts of dielectric permittivity of magnesite (Jelšava)

Rys. 1 Wpływ temperatury na liczbę rzeczywistą (ε ´) i jednostkę urojona (ε ´´) przenikalności dielektrycznej (magnezyt Jelšava)

a microwave oven. Both components of dielectric permittivity significantly affect the microwave heating process. The microwave heating of substances often leads to significant changes in values of the real and imaginary part of complex permittivity. The temperature influence on the change of real (ε´) and imaginary (ε´´) parts of dielectric permittivity of magnesite (Jelšava) is shown in Fig. 1. [20]

The significant changes mainly occur in the materials in which microwave heating leads to thermal decomposition and the forming of new phases. The decrease of imaginary permittivity (ε´´) occurs at a temperature of 180°C and it is joined with water evaporation. Then the value of imaginary permittivity increases at 950°C which could be connected with its thermal decomposition of $MgCO_3$ to MgO. The real permittivity grows until 600°C. Then the values decrease which could be explained by CO_2 loss.

On the basis of measured values of real and imaginary parts of dielectric permittivity and table values of magnesite (density 3000 kg.m^{-3}, heat capacity 78.74 + 57.74T J.K-1. mol-1, thermal conductivity 5.8 W.m-1.K-1) [25]. Modelling of microwave heating of magnesite sample was carried out using the Comsol Multiphysics programme. Distribution of temperature for the microwave heating of spherical particle of magnesite sample after 120 seconds is show in Fig. 2.

Microwave drying of magnesite

The microwave drying occurs in two fundamental interactions. The first type represents the effect of microwave on solid component of the system mineral – water. The second type represents the effect of microwave on water, which is heated by microwave field rapidly. In case when mineral is well heated in the microwave field, applies the first and the second kind of interaction. In the second case, when the mineral poorly absorbs microwave radiation, dominates the interaction of microwaves with water. The prog-

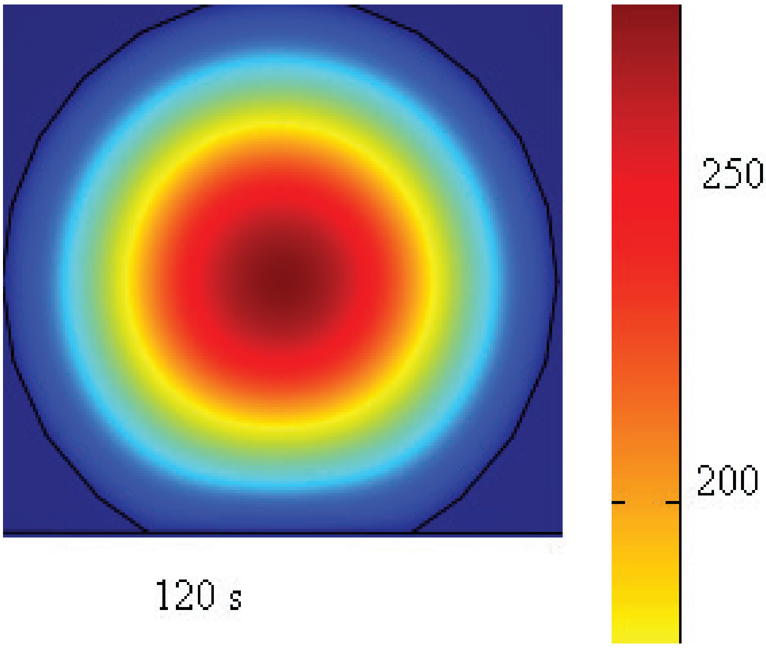

Fig. 2 The temperature distribution in magnesite (Jelšava) during microwave heating (power of microwave oven 1000 W, heating time 120 s)

Rys. 2 Rozkład temperatury w magnezycie (Jelšava) podczas ogrzewania mikrofalowego (kuchenka mikrofalowa o mocy 1000 W, czas nagrzewania 120 s)

Tab. 4 Propagation of ultrasonic waves before and after microwave heating of magnesite

Tab. 4 Propagacjia fal ultradźwiękowych przed i po ogrzewaniu mikrofalowym próbki magnezytu

Sample	Sample before Microwave heating		Sample after Microwave heating		Temperature [%]	Failure coeficient [%]	Failure (according to Jaeger)
	time t [μs]	rate v [m.s^{-1}]	time t [μs]	rate v [m.s^{-1}]			
1.	14.24	6 390.4	17.06	5352.9	175	83.76	low
2.	18.12	5 027.5	28.12	3 241.9	208	64.48	medium
3.	18.52	5 783.8	31.9	3 354.2	220	57.9	medium
4.	16.5	5 236.4	24.7	3 497.9	246	66.79	medium
5.	18.12	5 027.5	28.12	3 241.9	280	64.48	medium
6.	15.5	3 812.9	41.6	1 420.6	340	37.2	high

t –propagation time of ultrasonic waves, r – propagation rate of longitudinal elastic waves

Tab. 3 Characteristics of magnesite samples

Tab. 3 Charakterystyka próbek magnezytowych

Sample	Locality	Microwave heating Power [W]	Dimensions [mm]	Weight [g]	Measurement basis [mm]
1.	Jelšava, SR	500	92.6 x 39.2 x 40.5	569.4	92.6
2.	Jelšava, SR	700	101.6 x 39.3 x 40.2	624.3	101.6
3.	Jelšava, SR	900	107.0 x 39.0 x 41.0	658.0	107.0
4.	Mútnik, SR	500	87.3 x 39.2 x 39.3	487.3	87.3
5.	Mútnik, SR	700	60.3 x 39.5 x 40.7	335.6	60.3
6.	Mútnik, SR	900	59.1 x 39.6 x 38.5	329.9	59.1

ress of the microwave drying of magnesite (Jelšava) is shown in Fig. 3. The influence of microwave radiation was observed on progress of magnesite dryEng. The grain size was 0.1 – 1 mm, the power of microwave oven is 850 W, time heating is from 0 to 120 s.

After 120 second of irradiation, the drying of magnesite raw in the microwave field was reached. It was confirmed the velocity of progress process.

The influence of microwave energy on magnesite failure

The influence of microwave heating on failure in

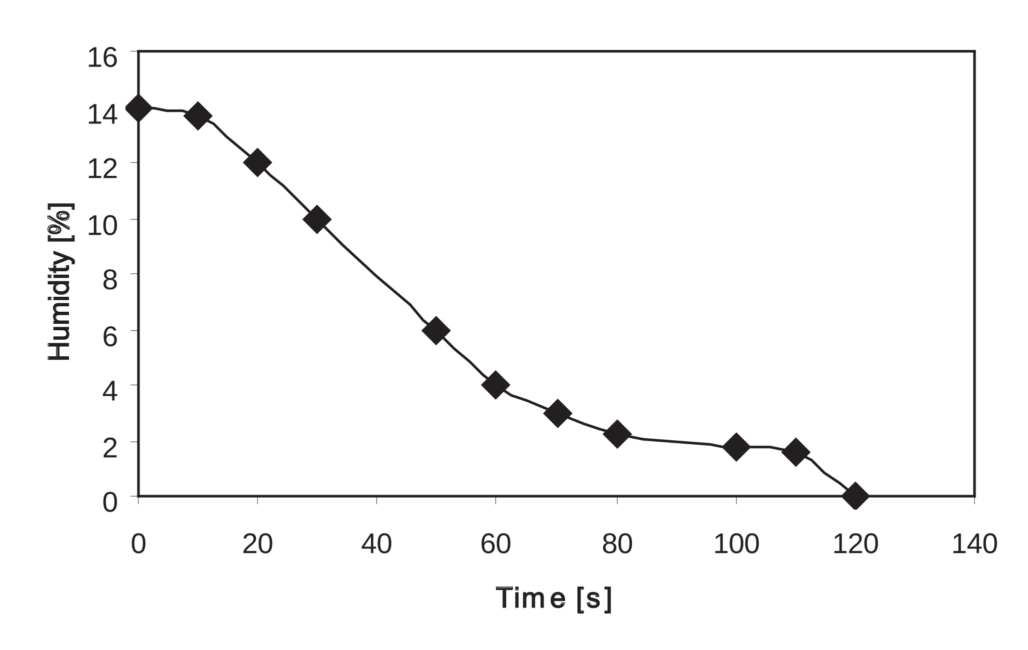

Fig. 3 The microwave drying of magnesite (Jelšava)

Rys. 3 Suszenie mikrofalowe magnezytu (Jelšava)

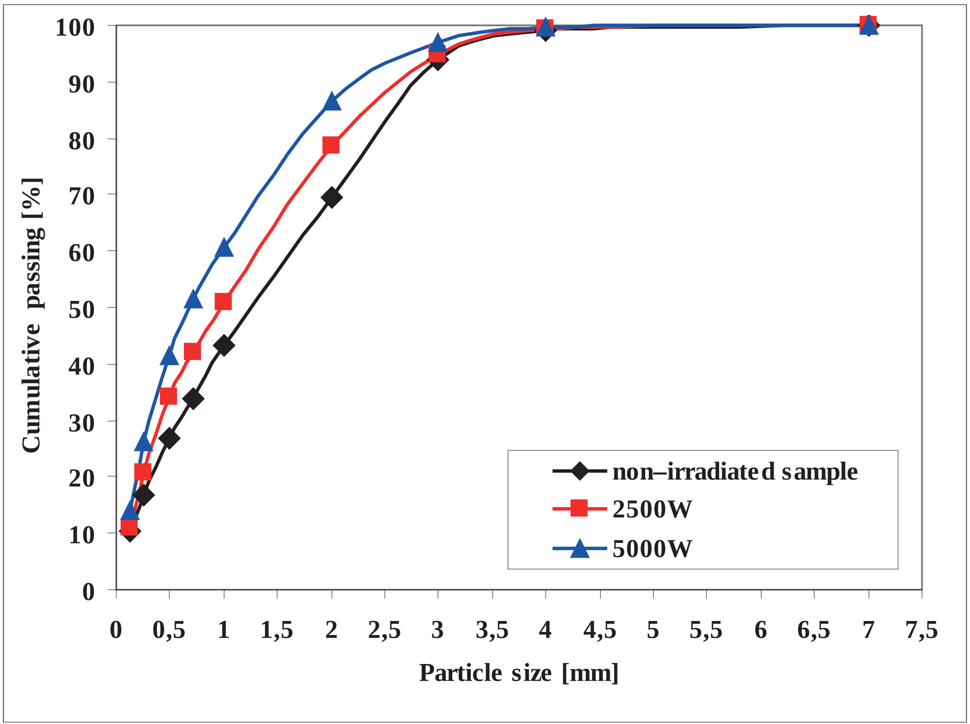

Fig. 4 Cumulative passing curves of magnesite (Mútnik) after crushing

Rys. 4 Skumulowane krzywe przejścia magnezytu (Mutnik) po kruszeniu the magnesite samples from locality Jelšava and Mútnik was observed. The characteristics of samples are introduced Table 3.

The samples roller were placed in a vertical posi tion at a height of 3 cm on the ceramic backEng. The samples were irradiated 5 minutes at 500, 700 and 900W. The temperature of the samples was measured after microwave heating using infrared thermometer with laser sightEng. The results are shown in Table 4.

The values of propagation rates of longitudinal waves in the rocks investigated before and after microwave heating served to calculate the coefficient of failure according to (3). On the basis of the calculated coefficients, the degree of failure of magnesite samples was determined according to Jaeger (Tab. 2). High degree of failure of magnesite sample (Mútnik) was observed after 5 min of microwave heating at 900W.

The influence of microwave energy on crushability of magnesite

The results of grain size analyses after crushing of irradiated and non-irradiated magnesite samples are shown in Fig.4. The reading values for 80% passing grain size are as follows: non–irradiated samples P1 = 2.45 mm, irradiated sample (at 2500 W) P2 = 2 mm, irradiated sample (at 5000 W) P2 = 1.7 mm. Thus, the values of relative work index for powers of 2500W and 5000 W are 0.82 and 0.72, respectively.

The microwave pretreatment of the magnesite samples confirmed their crushability improvement that was reflected by the decrease of relative work index by 18% at 2500W and 38% at 5000W.

Conclusion

On the basis of measured dielectric properties for describing the behavior of heat material in the microwave field was determined the temperature distribution of the magnesite raw material by using the Comsol Multiphysics programme. The failure of studied samples was determined by measurement of propagation rates of longitudinal waves before and after microwave heatEng. The medium and high degree of failure magnesite samples obtained from different areas depends on their ability to absorb the microwave energy. It was evaluated the influence of microwave heating on crushability of samples. After microwave irradiation of raw magnesite at the power 5000W, it was confirmed 38% decreasing of work index on the basis of Berry-Bruce test.

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Streszczenie

W artykule przedstawiono wpływ energii mikrofalowej na ogrzewanie magnezytu. Ogrzewanie za pomocą mikrofal pozwala na zrozumienie właściwości dielektrycznych materiałów. Opisano wartości składowej rzeczywistej i urojonej złożonej przenikalności dielektrycznej magnezytu. Rozkład temperatury w próbce magnezytu podczas ogrzewania mikrofalowego opisano wykorzystując program COMSOL Multiphysics .

Określono wpływ wstępnej obróbki mikrofalowej próbek na efekt rozdrabnianie magnezytu . Intensyfikację procesu rozdrabniania badanych próbek oceniono obliczając względny wskaźnik pracy.

Słowa kluczowe: mikrofale, magnezyt, przenikalność dielektryczna