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Influence of ultrasound assist during combined drying on ceramic materials quality and drying kinetics

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Abstract

Presented in this article studies show the investigation of ultrasound application as a new method for improvement of ceramic materials processing and their influence on mechanical properties of dried samples. Ultrasound were applied during convective and convective-microwave processes carried out in two different temperatures. Obtained results indicate increase of drying rate due to sonification and what's more interesting they affect the material strength parameter. The experiments indicate that the effectiveness of ultrasound assist depends on the drying temperature and such dependency is observed mainy when considering dry product quality parameter.

Keywords: *ceramics; hybrid drying; material strength*

1. Introduction

Drying of clay like materials is a very important industrial process which allow to achieve ceramics with very useful, specific properties like, e.g. high durability, electrical and thermal resistance and other. It is the first step after molding or casting which lead to reduction of the moisture content and gives a possibility to further calcination of such products. Dry product before calcination needs to have not only very limited moisture content but also can not have fractures. Thus why drying process is so important as it contributes into final product quality or possibility for postprocessing of such product.

To achieve a good quality of dried products the drying process needs to be carred out in the way which allow to reduce internal drying stresses, the main cause of material destruction[1-4]. Tension which appears in dried products are mainly the result of highly nonuniform distribution in temperature and moisture content throught the material, thus why using several drying techniques simultaneously or using nonstationary drying is presented as a method to diminish unwanted effects[5-7]. Application of such drying programs not only allow to achieve better quality of dry products but also if appropriately determined lead to reduction in energy consumption, which is one of the most important parameter considered when presenting new drying solution affecting their economical effectiveness.

In the mentioned hybrid drying processes in last years ultrasound were applied as one of the method to enhance the drying process, however they were considered mainly for thermal sensitive products like fruits and vegetables[8]. Nevertheless, described in the literature interaction with the material in the form of, e.g. heating or vibrating effect[9] could affect positively also other than biological products like for example ceramics[10]. The processes proposed in this work present modern drying technique in which high power ultrasound are used to affect drying kinetics and processed material propertiess.

2. Materials and Methods

The investigated material was kaolin KOC clay produced by Polish company Surmin Kaolin S.A. The material before preparing a moulding mass was dried for 24h in 120°C. Next, a dry powder was mixed with a specific amount of demineralized water which allows to achieve an initial moisture content of 40% $_{d.b.}$. Wet material was closed in a sealed box and left for 48h, so the moisture distribution in the mass became uniform. After that time the mass was portioned into 200g batch and stored separately in a sealed containers at temperature of 5°C. For each experiment from single 200g batch 7 samples in the form of cylinders with a diameter of 21mm and a height of 26mm were molded and placed in a dryer trace. The experiment were performed in a hybrid dryer according to 6 drying schedules presented in Table 1. The apparatus allowed to control and collect all important process parameters and is described in detail in other author work[9].

Table 1. Drying processes and parameters

Drying program	Convection	Microwaves	Ultrasound
CV_{80}	80ºC air flow 4m/s	-	-
$CVUS_{80}$	80ºC air flow 4m/s	-	200W
$CVMWUS_{80}$	80ºC air flow 4m/s	100W in 2 cycles	200W
CV_{50}	50ºC air flow 4m/s	-	-
$CVUS_{50}$	50ºC air flow 4m/s	-	200W
$CVMWUS_{50}$	50ºC air flow 4m/s	100W in 3 cycles	200W

Application of microwaves was performed periodically in a given number of cycles which last 5 minutes with the following 30 minutes relaxation periods. Such procedure allows not to destroy ceramics samples during processing with microwave appication.

As drying processes were carried out till the material reach $2\%_{d.b.}$ moisture content, before mechanical tests the samples were placed for 48h in exsiccator, so all examined cylinders would had exactly the same parameters. Compression tests were carried out axialy on Cometech strength machine with 20mm/min compression speed.

3. Results and discussion

The first series of experiments was carried out for higher drying temperature both as a single convective process as also with application of ultrasound and microwaves. The kinetics of such processes is presented in figure 1 and was evaluated on the basis of MR(time) curves where MR is defined as follows:

$$MR = \frac{X_t - X_{eq}}{X_0 - X_{eq}} \tag{1}$$

In the above equation X value indicates the material moisture content (kg/kg d.b.) and subscripts specify the time at which they were determined, that is: t - given time of the process, eq is the end of process (equilibrium moisture content) and 0 is at the beginning of the process (initial value).

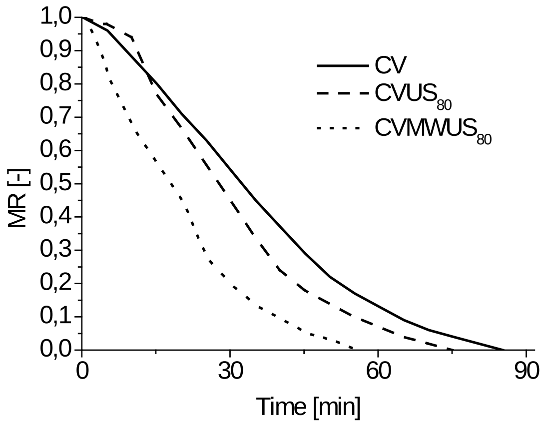

Fig. 1 Kinetics of processes carried out at 80°C

In Figure 1, one can see the characteristic behaviour of material dried only with ultrasound assist at the beginning of the process. In the heating period the water loss is visibly lower as compared to the CV process, however in the next period the drying rate increases significantly and leads to reduction of the overall drying time up to 11 minutes. This characteristic kinetics was observed in number of repeats thus why it can be stated that for such processes ultrasound application could be applied after heating period what allows to additional improvement of drying kinetics. In the second process assisted with ultrasound ($CVMWUS_{80}$) the kinetics showes the influence of short application of microwaves which allows to reduce the drying time significantly. Longer application of microwaves was not justified as earlier work of autor[10] indicates their negative effect on the material structure as also its strength.

The next series of experiments was performed in a lower drying air temperature to verify if ultrasound assist in other conditions transfer onto the drying kinetics and material properties differently. Figure 2 presents the drying curves achieved for processes carried out in 50°C. In opposite to process carried out in higher temperature, the $CVUS_{50}$ process do not show very slow drying tendency during heating period but from the beginning offer higher drying rates than pure convection. This reflects in higher reduction in drying time even up to 85 minutes. So high reduction in drying time could results also from the fact that a lower temperature of processing affects the air density which influence greately the reduction of acoustic wave attenuation.

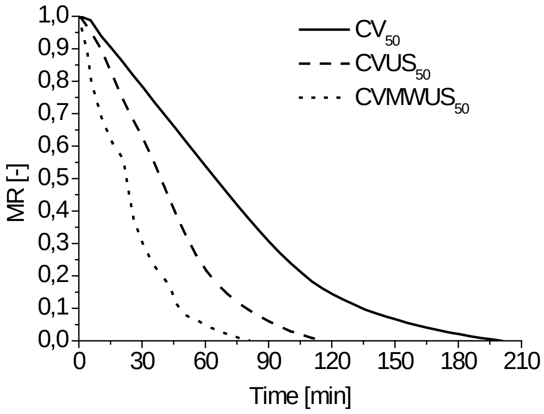

Fig. 2 Kinetics of processes carried out at 50ºC

Additional periodical application of microwaves in the $CVMWUS_{50}$ process allows to increase the average drying rate and in total reduces the drying time to the level achieved during $CVUS_{80}$. Similar drying time for those processes affects also similar appearanece of the sample surface with small number of narrow cracks. The samples achieved after drying are presented in Figure 3.

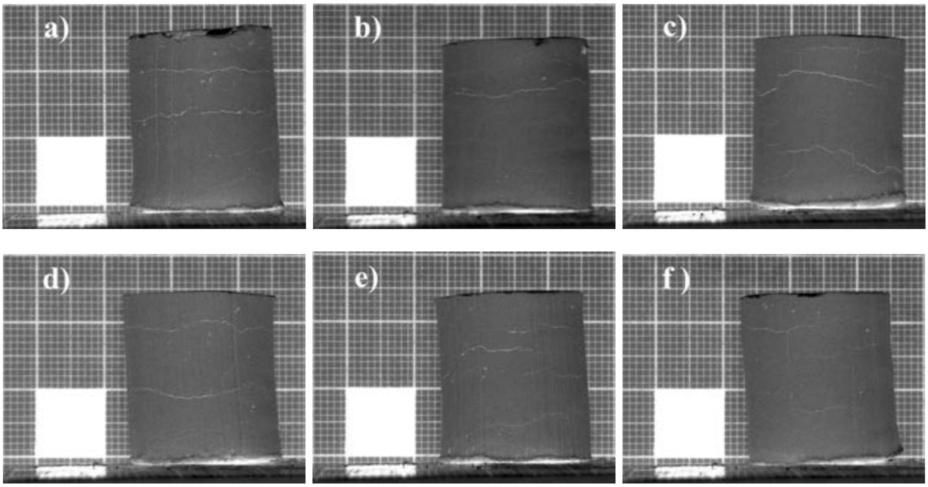

Fig. 3 Dry samples structure achieverd after different dryingprocesses; a) CV_{80} , b) $CVUS_{80}$, c) $CVMWUS_{80}$, d) CV_{50}, e) $CVUS_{50}$, f) $CVMWUS_{50}$

The presented above pictures show that ultrasound application affects positively the sample quality, however beter results were observed at higher drying air temperature, especially without microwave application. Slightly other influence of ultrasound was observed at lower air temperatures where the best quality was observed in case the samples dried by $CVMWUS_{50}$. In this temperature application of ultrasound itself do not cause visible improvement of product structure. The above investigation of samples appearance does not however investigate their mechanical properties, thus why the results of strength tests for the dried samples are tabulated in Table 2.

Table 2. Material strength and energy consumption in different drying processes

Drying program	**Strength [N]**	**Standard deviation [N]**	**Energy consumption [kWh]**	**Standard deviation [kWh]**
CV_{80}	180,38	23,78	2,28	0,01
$CVUS_{80}$	199,77	13,51	2,44	0,08
$CVMWUS_{80}$	196,27	22,61	1,87	0,18
CV_{50}	260,06	15,57	1,95	0,04
$CVUS_{50}$	203,38	23,42	2,07	0,17
$CVMWUS_{50}$	206,15	17,96	1,63	0,28

The results of compression test correlates fully with a sample appearance for processes carried out at temperature of 80^oC. In those processes ultrasound assitst reflects in the increase of material strength both for pure convective dryng and also for the process enhanced with microwaves. However the mechanical properties determined during strength tests do not cover with visual quality determination for samples dried at a lower temperature. It is observed that application of ultrasound as also microwaves during convective drying in 50^oC affects significantly reduction of material strength, nevertheless without negative influence on product appearance. The reason of such specific behaviour could be tracked back into varied acoustic wave propagation and attenuation in different air temperatures, however it exact explanation is very difficult. From one side the vibration carried by mechanical wave could affect the clay particles arrangement and its strength, but from the other side it do not explain why the improvement of drying rate at lower temperature is greater. Nevertheless, when considering the material strength and drying time for particular processes it can be stated that $CVUS_{80}$ and $CVMWUS_{50}$ give almost identical, very good results. Thus why to indicate the most effective process in which ultrasound are applied it is necessary to consider the energy needed to remove a specific amount of water from the material. As all samples have the same volume and initial moisture content the overall energy consumed during specific process can be compared directly. The energy consumption presented in Table 2 showes that the most similar processes from quality and kinetic point of view ($CVUS_{80}$ and $CVMWUS_{50}$) differ significantly by the energy consumption. The process carried out at a lower temperature consumes more than one third less energy what shows its great advantage. Also other processes carried out at a lower temperature are more effective from energy point of view comparing with the ones carried out at 80ºC, where the only expception is the $CVMWUS_{80}$ process which offers similar energy consumption.

4. Conclusions

The application of ultrasound shows different influence on both drying kinetics and material strength depends from temperature in which they were applied. Application of acoustic waves in all cases affects in reduction of processing time, however at a lower air temperature their influence on drying rate is greater probably due to a lower wave attenuation. Ultrasound affect also the material strength, however their influence is ambiguous and depends on drying air temperature. At a lower temperature sonification affects negatively on the material resistance, whereas at a higher temperature it improves product strength. However, for both temperatures ultrasound improve the product appearance as the sonificated samples had a better surface quality with a lower amount of narrow cracks.

Considering all of the processes and material parameters the $CVMWUS_{50}$ program can be pointed as the best drying process due to a quite short drying time and also a lower energy consumptionless energy, and a reasonable material strength and product appearanece. Nevertheless, the ultrasound enhancement during all drying schemes brings some advantages in the process, but sonification should be applied with a grate care and determination of the most important parameters onto which we would like to affect using ultrasound.

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