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EXPERIMENTAL STUDIES REGARDING THE IMPLEMENTATION POSSIBILITIES OF A QUALITY CONTROL SYSTEM FOR CERAMIC PRODUCTS IN CONTINUOUS FLUX PRODUCTION

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ABSTRACT

In the current paper the authors studied the possibilities and limitations of a system intended to evaluate the quality of ceramic products directly on the production line. The system is based on a data mining specific approach in analyzing the sound produced by ceramic products when hit in a non-destructive manner.

The research showed that good results in discriminating among different quality grades can be obtained for products having similar shape and size even when working with up to six different quality grades. Reducing the number of quality grades to be discriminated increases the method's precision. In industry the number of necessary quality grades to be discriminated is usually no higher than three, thus the authors consider that the method is suited for industrial implementation.

KEYWORDS: Ceramics; continuous flux production, non-destructive online quality control, data mining.

1. Description of the sample set

In the current study coarse ceramic sample sets were used. They were made out of common clay using the moist fabrication method by extrusion. Six samples were chosen for testing. These were burned at the following temperatures: 600, 700, 800, 880, 920 and 970 ºC. For the studied clay different quality grades can be obtained starting from 600 ºC up to around 1000 ºC. In large production furnaces there is always a temperature gradient thus in a large batch there are always different quality grades depending on the local temperature in the area of the product. Thus having samples burned in a controlled manner at a specific temperature, different quality grades are obtained. From the six items sample set, two other sets were obtained by reducing the size of the items up to 113 mm and 75 mm. In ***Fig. 1*** a photograph showing the third sample set (75mm) is presented.

2. Recording and analysis of the sound pattern for non-destructive percussion

In order to record the sound pattern for non-destructive percussion the samples were held by a thin string from the center of gravity. For percussion a light metal round shaped instrument with a curvature of about 8 cm was used. The curvature of the instrument allows more energetic hits without damaging the sample.

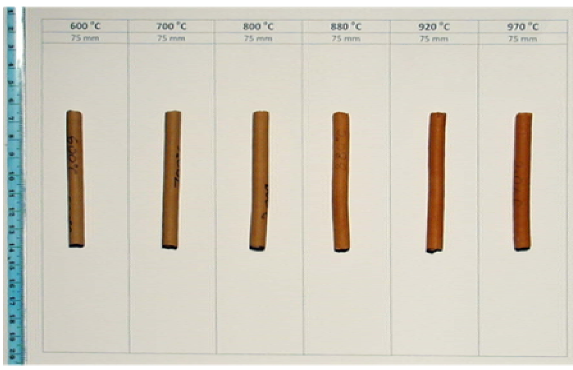

Fig. 1.1. *Third sample set, burned at: 600^{o}C-75mm, 700^{o}C-75mm, 800^{o}C-75mm, 880^{o}C-75mm, 920^{o}C-75mm, 970^{o}C-75mm.*

For every sample a number of about 100 percussions were recorded. Throughout the 100 hits set slight modifications were made the position the sample was held at relative to the center of gravity. Also, slight variations were made regarding the point of impact when hit (closer to the extremities, or towards the center).

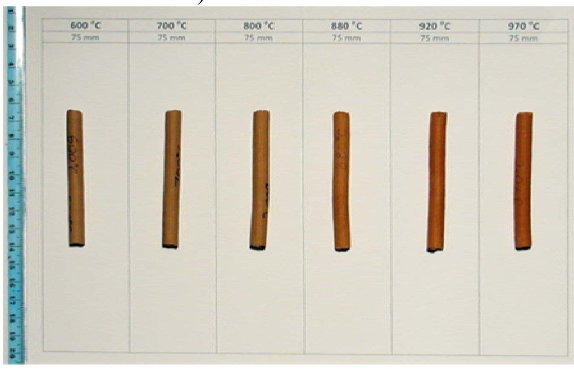

Fig.1.2. *Third sample set, burned at: 600^{o}C-75mm, 700^{o}C-75mm, 800^{o}C-75mm, 880^{o}C-75mm, 920^{o}C-75mm, 970^{o}C-75mm.*

Variations of percussion energy were also made. All these slight modifications were made in order to replicate the probable conditions that might be dealt with when working in industrial conditions.

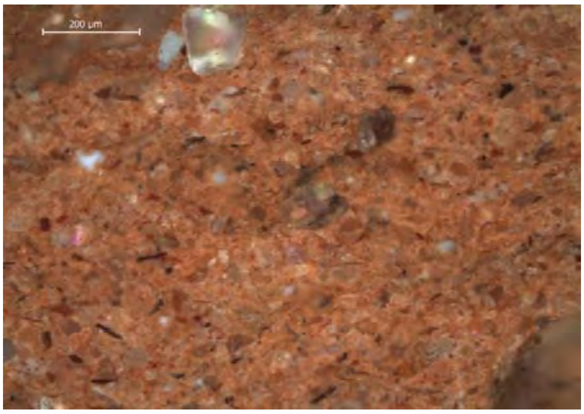

Fig.1.3. *The optic microstructure of the studied sample.*

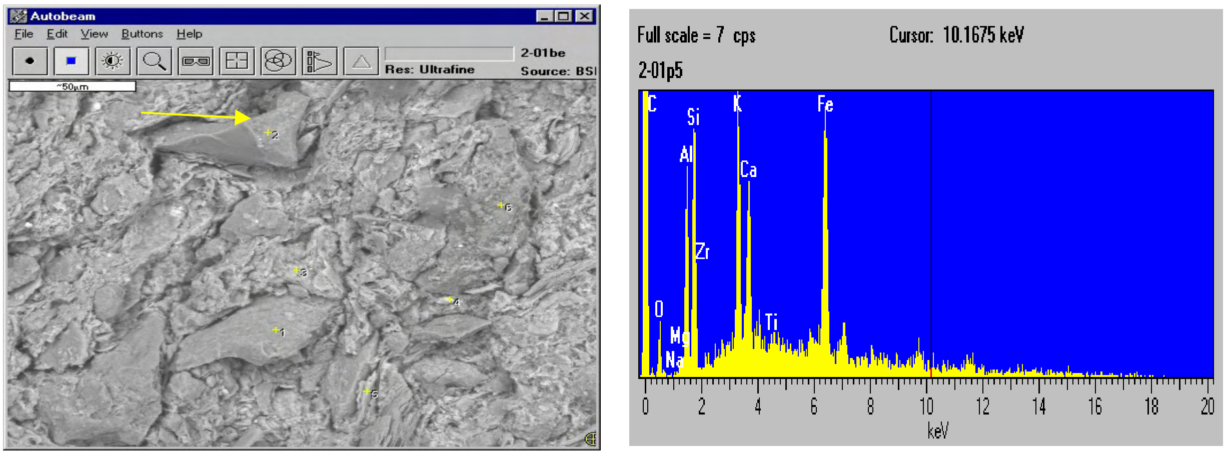

Fig.1.4. *The electronic microscopy of the studied sample.*

The recording of the sound patterns at non-destructive percussions was made in a silent environment in order to avoid the alteration of the power spectrum with non-specific elements.

2.1. Data preprocessing

For data preprocessing we have used Matlab 7.0. Matlab is a high performance technical computing language. It integrates calculus, visualization and programming in an easy to use environment where the problems and the solutions are expressed in a familiar mathematical notation.

2.1.1. Calculation of the power spectrum

The data recorded in .wav files were loaded into Matlab and the power spectrum was calculated and recorded in a structure with 18 records, one for each item (3_sample_sets x 6_items_per_set).

The Matlab code that calculates the power spectrum is:

```
…
[y,Fs,bits] = wavread(fisier);
N =2.^(ceil(log(length(y))/log(2)));
FFTY = fft(y,N);
NumUniquePts = ceil((N+1)/4);
FFTY = FFTY(1:NumUniquePts);
Pyy = conj(FFTY).*FFTY / N;
f=(99:floor(NumUniquePts/2)-1)*2*Fs/N;
frecvente{i} = f;
Pyy = Pyy(100 : floor(NumUniquePts/2));
putere{i} = Pyy;
…
```

2.1.2. Scaling the power spectrum in [0,1] domain and modification of the sampling step

In order to efficiently compare the data visually and in an algorithmic manner it was necessary to scale all the data in the same domain and to synchronize the power spectrum sampling rate. The chosen domain for scaling was [0,1], the choice being arbitrary without any special meaning; the sampling rate was chosen to be the highest in the data set.

2.2. Techniques for exploring the data set

The visual exploration of the data set is very important and needs to be realized in collaboration with a human expert. A strategy needs to be established in order to present the data in such a manner that is should be concise, easy to understand and representative for the aspects that need to be analyzed. Also after analysis it is possible to determine the direction that has to be followed for the algorithmic analysis of the data.

For the study regarding the possibility of implementation of a quality evaluation system through the sound pattern obtained through non-destructive percussion the following aspects have to be studied:

2.2.1. The homogeneity of the data set is good enough in order to observe common characteristics for the 100 recordings of one item of the data sets?

In order to answer this questions the approximately 100 recordings of each sample have been represented in graphical form in two dimensions using a color code for intensity, the ordinate for the number of the recording [1:100] and the abscissa for the frequency [250Hz:11000Hz].

In ***Fig. 2.1*** the least favorable case encountered in the data set is presented. As it can be observed, there is an important dispersion of the maxima, but at the same time a specific pattern can be distinguished. This pattern is more clearly highlighted in ***Fig. 2.3*** where on the abscissa there is the frequency [250Hz:11000Hz] and on the ordinate there is the sum of the power spectrum of all the 100 recordings for the sample. As a comparison in ***Fig. 2.2*** and ***Fig. 2.4*** the same representations are presented that can be considered as typical for the data set.

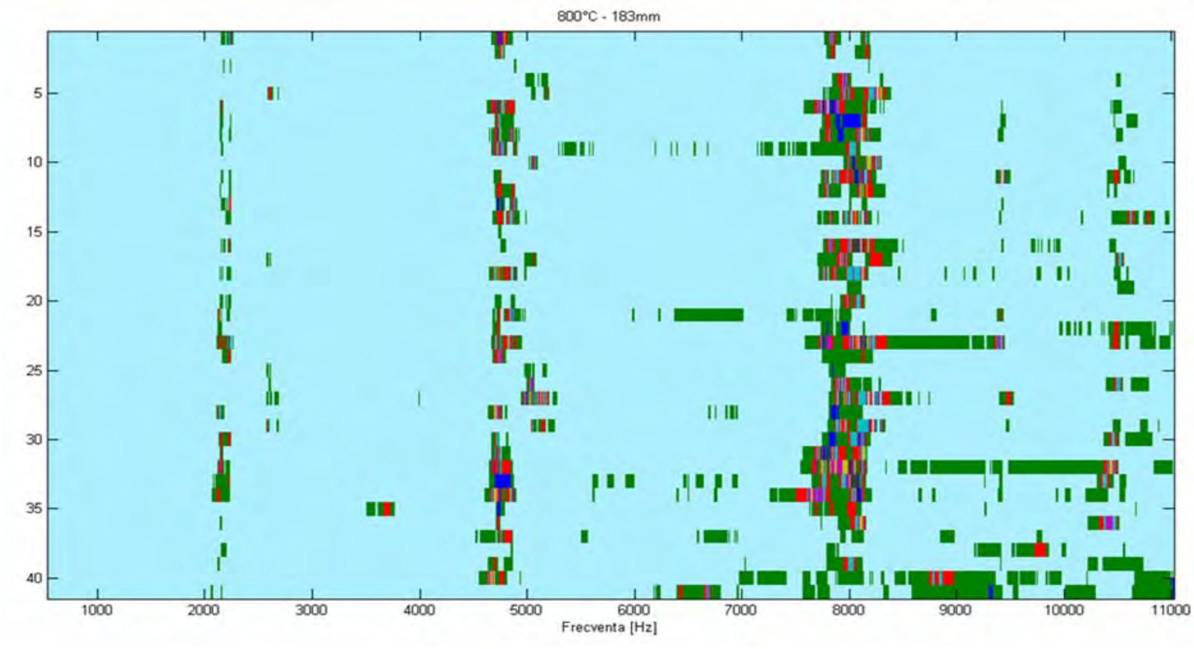

Fig.2.1. *The power spectrum for individual percussions for the sample burned at 800^{o}C having a length of 183mm.*

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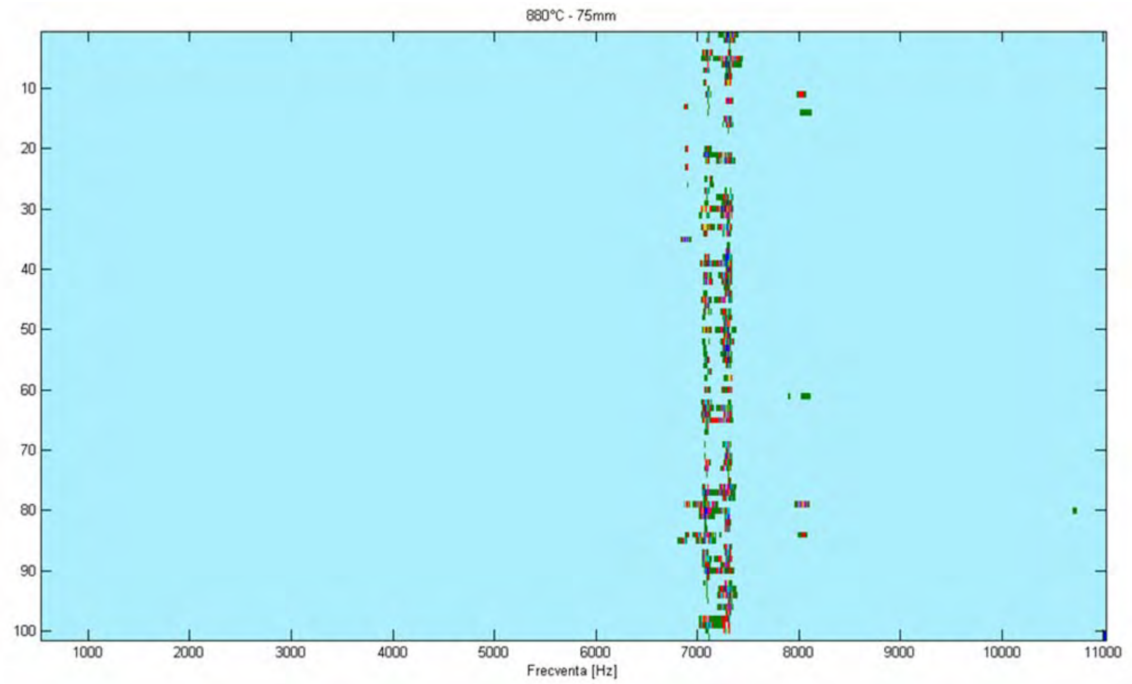

Fig.2.2.*The power spectrum for individual percussions for the sample burned at 880^{o}C having a length of 75mm.*

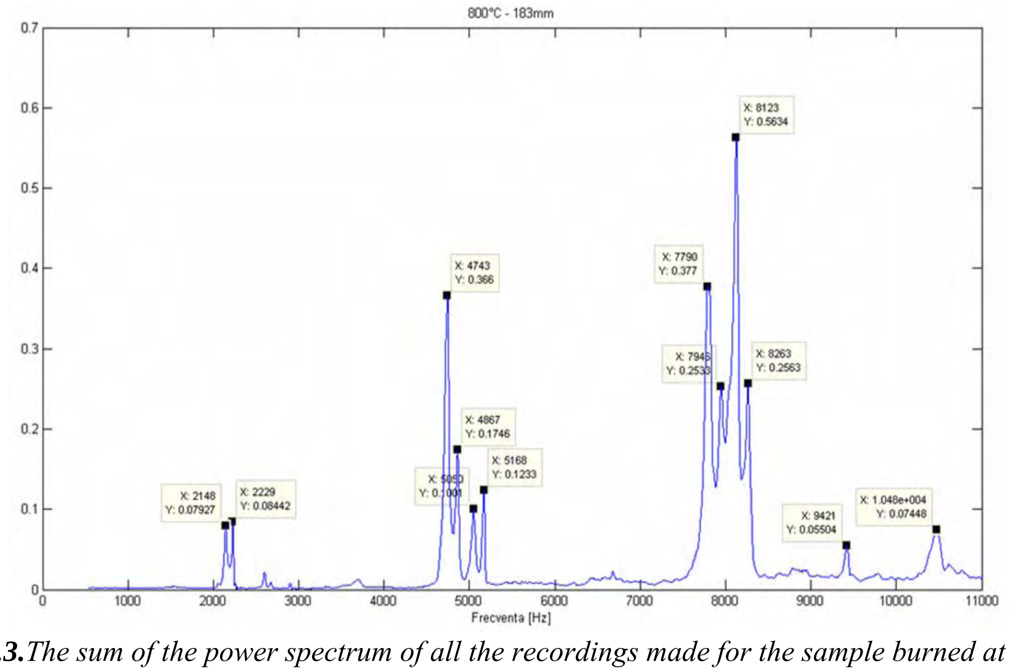

Fig.2.3.*The sum of the power spectrum of all the recordings made for the sample burned at 800^{o}C having the length of 183mm.*

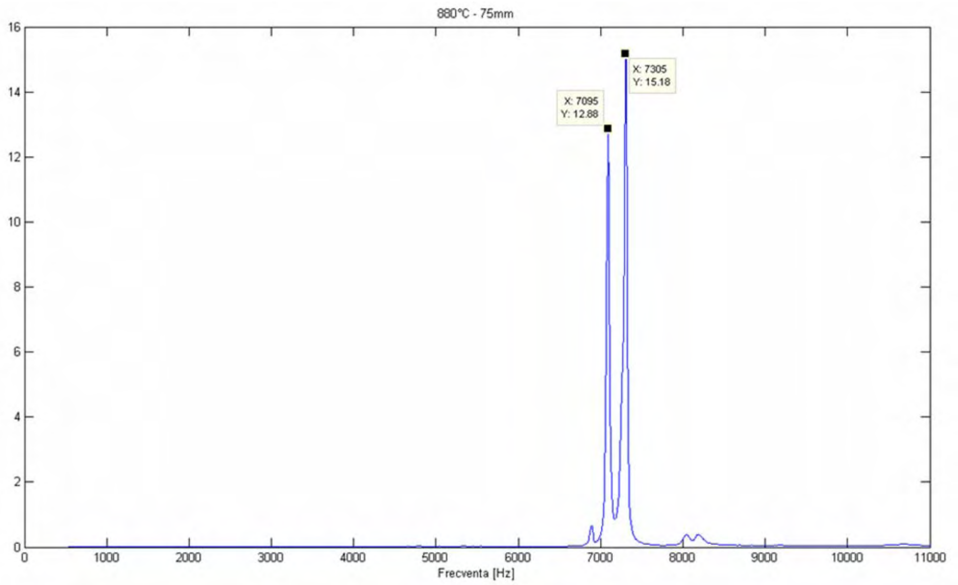

Fig.2.4.*The sum of the power spectrum of all the recordings made for the sample burned at 880^{o}C having the length of 75mm.*

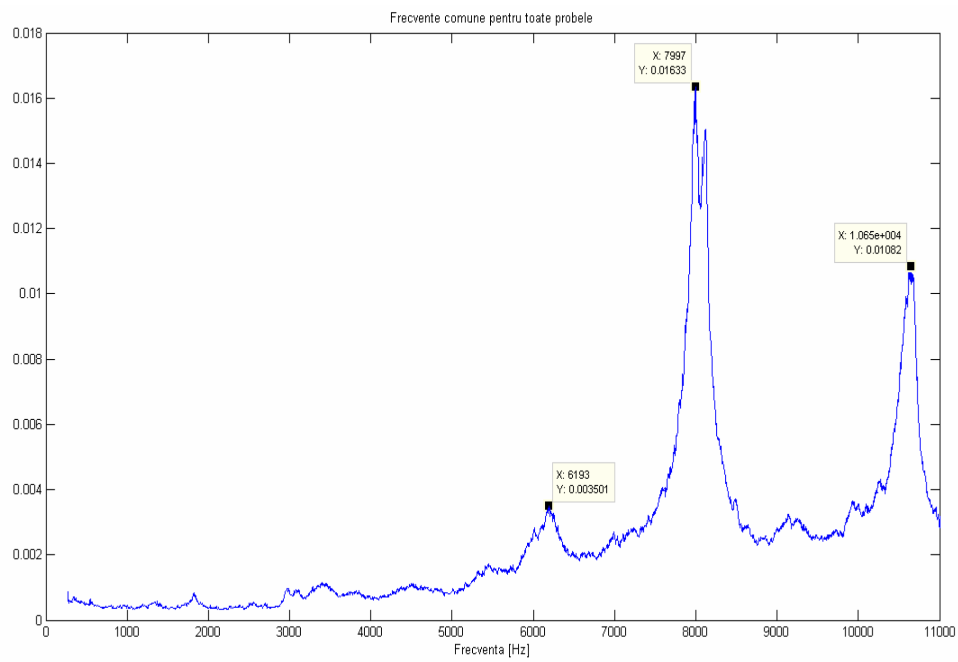

Fig.2.5.*Common frequencies for all the samples in the data set highlighted by calculating the median values of the power spectrums of every sample for each frequency point.*

2.2.2. Are there common characteristics for all the samples in the data set?

In order to answer this question it is necessary to calculate the median of the power spectrum of all the samples in the data base. This is presented in ***Fig. 2.5***. From the figure it can be observed that there are common frequencies around 6200Hz, 8000Hz and 10650Hz. The most important maximum being at the frequency of 8000Hz. These common frequencies represent an error source for discriminating among the different quality grades. This error is maximum for the sample burned at 600ºC having 113mm, where these maxima common for all the samples overlap the specific maxima for this given sample. Because of this overlapping we cannot filter the entire set to eliminate these common maxima.

2.2.3. Are there common characteristics for samples burned at the same temperature for all shapes and sizes?

This question can be answered by comparing the power spectrum of the samples burned at the same temperature and having different length.

In order to clearly put into evidence these common characteristics, two representations were used. The first one has on the ordinate the length of the sample and on the abscissa the frequency in the domain of [250Hz:11000Hz], the color lighting representing the value of the power spectrum at the given frequency. The second representation overlaps the power spectrums using different colors for different samples.

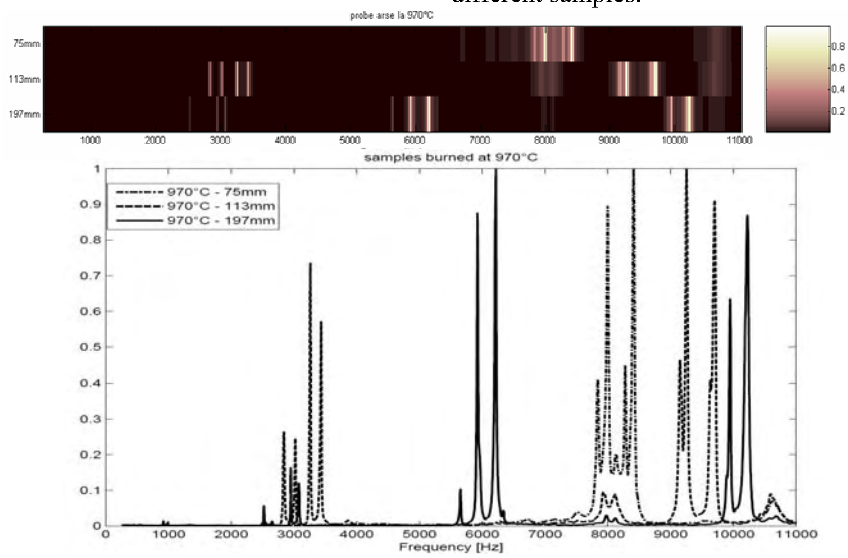

Fig. 2.6. *Comparative spectrums for samples burned at the same temperature 970^{o}C but having different lengths: 75mm, 113mm si 197mm.*

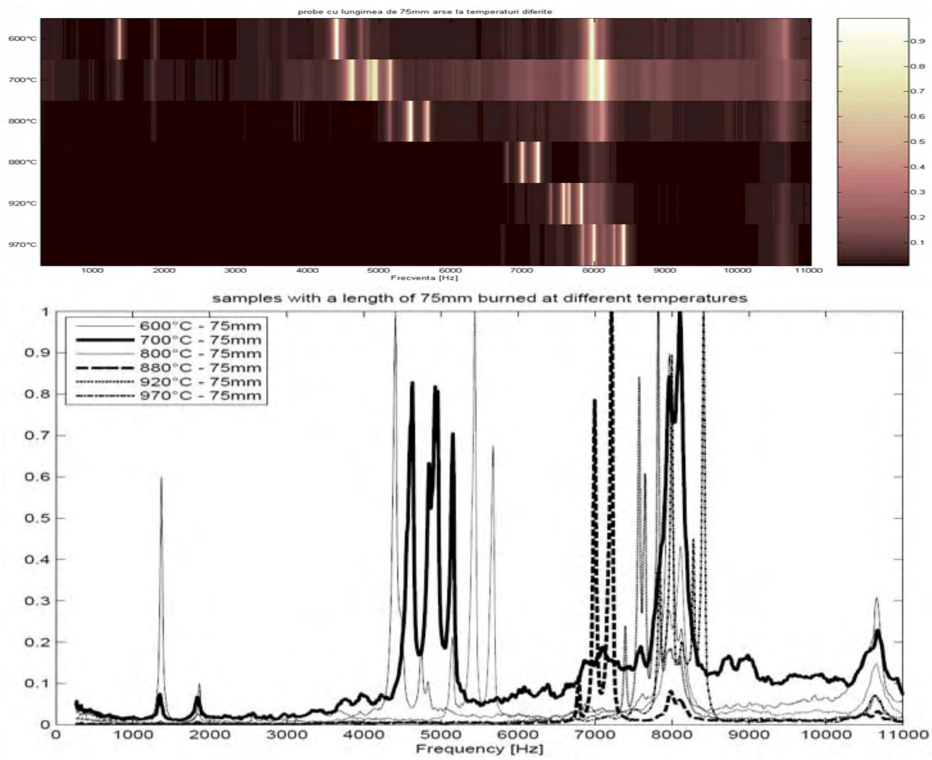

Fig. 2.7. *The compared spectrum for samples with the dimensions of Φ8x75mm burned at: 600°C, 700°C, 800°C, 880°C, 920°C and 970°C.*

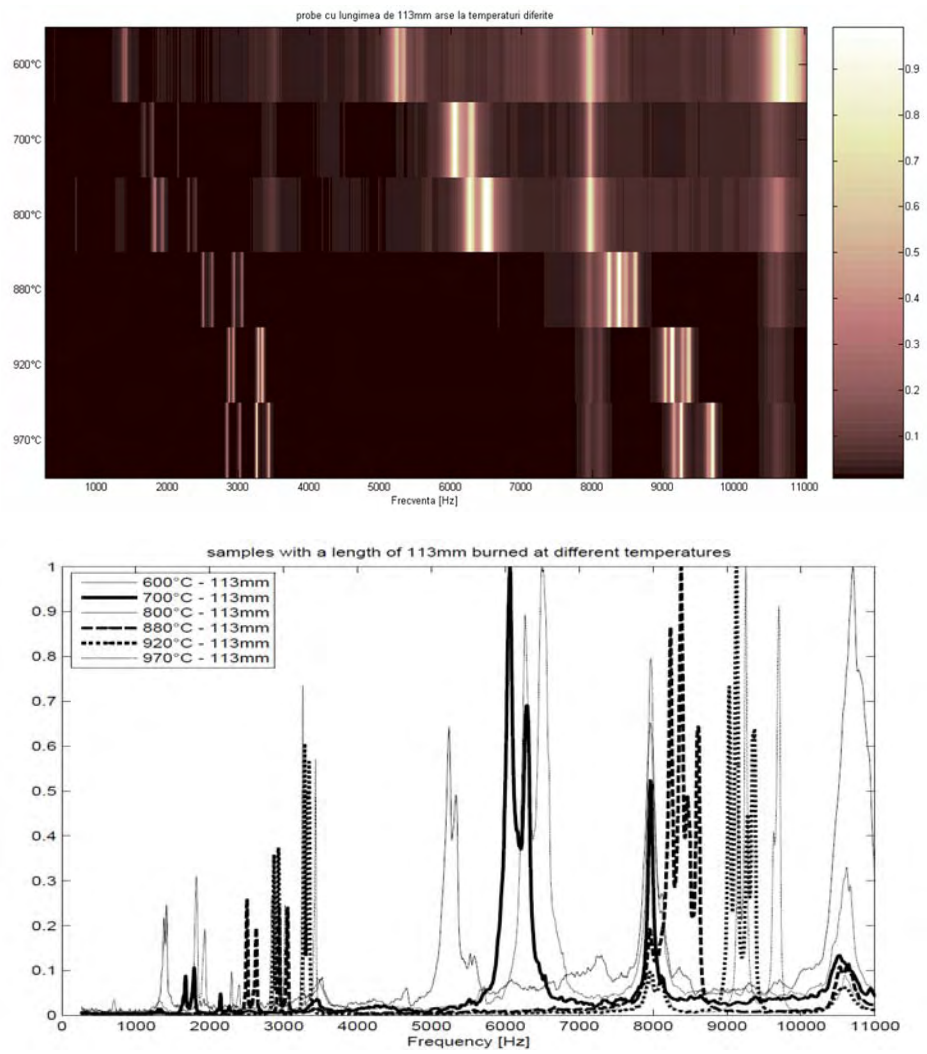

Fig.2.8. *The compared spectrum for samples with the dimensions of Φ8x113mm burned at: 600°C, 700°C, 800°C, 880°C, 920°C and 970°C.*

Analyzing these representations it can be observed that the only common frequencies that we can highlight using an algorithm in a robust manner would be the frequencies that were presented in the previous section as being common to all the samples in the data set.

Thus it can be stated that by analyzing the sound pattern at non-destructive percussion in the domain of [250Hz:11000Hz] it is not possible to highlight characteristics specific to the burning temperature without regard to the shape and size of the product.

In ***Fig. 2.6*** the comparative spectrum for the samples burned at 970ºC having the lengths of: 75mm, 113mm and 197mm is presented.

Besides the maximums in the vicinity of 8kHz and 10.6kHz which are common to all the samples there is also a slight overlapping near 3kHz for the samples having 113mm and 197mm but for the sample having 75mm there is no maximum in this vicinity.

2.2.4. Are there differences between the characteristic power spectrum for products with the same shape and size but burned at different temperature?

In order to analyze the possibility to differentiate between products with the same shape burned at different temperatures samples of the same length burned at different temperatures were used. In ***Fig. 2.7*** there are presented the compared spectrum from the samples burned at 600°C, 700°C, 800°C, 880°C, 920°C, 970°C that are 75mm long.

Also in ***Fig. 2.8*** there are presented the compared spectrum of the sound patterns recorded at non-destructive percussion for the samples burned at: 600°C, 700°C, 800°C, 880°C, 920°C, 970°C that have a length of 113mm.

The above shown figures prove that it is possible to distinguish between products having the same shape and size burned at different temperatures, and thus having different quality grades. It is however likely to have in isolated cases classification errors as a result of the overlapping of some sample characteristic maxima with maxima common to all samples. The phenomenon is most probably generated by limitations in the sound production and recording. More specific alloy, the percussion instrument will produce its own characteristic spectrum and the microphone might also work as an antenna and capture some electromagnetic noise in the frequency domain of the sound waves that are analyzed. All these perturbations will however be of relatively low amplitude, thus their influence on the sound pattern will be significantly lower than the influence of the characteristic spectrum.

3. Conclusions

As a result of visual data exploration it can be said that regarding the possibility to evaluate the ceramic products quality by using the sound pattern recorded at non-destructive percussion it is not possible to distinguish common characteristics of the power spectrum for products burned at the same temperature that have different shape and/or size.

It is however possible to evaluate the quality grade for products that have a given shape and size. In this case it is possible to improve the classification accuracy by choosing a low number of quality grades to be distinguished among (a maximum of 6 quality grades would give good results). Also improvements in the classification accuracy can be obtained by improving the quality of the sound recording system and choosing an appropriate percussion instrument.

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