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The Defect Detection in Ceramic Materials Based on Time-Frequency Analysis by Using the Method of Impulse Noise

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In this study, it was achieved by using the method of impulse noise to detect internal or surface cracks that can occur in the production of ceramic plates. Ceramic materials are often used in the industry, especially as kitchenware and in areas such as the construction sector. Many different methods are used in the quality assurance processes of ceramic materials. In this study, the impact noise method was examined. This method is a test technique that was not used in applications. The method is presented as an examination technique based on whether there is a deformation on the material according to the sound coming from it as a result of a plastic bit hammer impact on the ceramic material. The application of the study was performed on plates made of ceramic materials. Here, it was made with the same type of model plates manufactured from the same material. The noise that would occur as a result of the impact applied on a point determined on the materials to be tested has been examined by the method of time-frequency analysis. The method applied gives pretty good results for distinguishing ceramic plates in good condition from those which are cracked.

Keywords: impulse noise, time-frequency analysis, defect detection in ceramic materials.

1. Introduction

Today, ceramic and porcelain industry is particularly active in the kitchen and construction sectors (Samborski, Sadowski, 2005). Before and after sales, visible or non-visible cracks/deformations that might occur inside the material are one of the most important problems that the manufacturers have to solve. These defects cause economical losses and losses of time. Therefore, it is essentially important to detect and remove such defects in the ceramic–porcelain industry (Kucuk, Akinci, 2006). In ceramic industry testing systems were rarely used to detect the presence of defects in ceramics tiles on-line. Defects in a ceramic body (De Andrade *et al.*, 1998a; 1999b) usually occur during the pressing stage because of faulty process parameters or not checked raw materials (Revel, Rocchi, 2006). Such defects commonly feature delaminating, heterogeneous materials or agglomerates decreasing the structural strength. Expensive available inspection systems (such as X-ray methods) that are able to detect information on the internal structure of ceramic materials, if compared with the low cost of the ceramic products, determine in most cases the choice of an experimental optimization of production parameters or visual inspection techniques (only for defects involving the tile surface). In many technological sectors, infrared (IR) inspection is used for damage detection and its resolution because of the easiness, full-field capability, in-field applicability and continuously decreasing costs of thermo-graphic systems. Thermo-graphic techniques (Maldague, 2001) are commonly applied to building inspections, process controls and monitoring, predictive maintenance, evaluation of material properties and medical diagnosis (Ranachowski, Rejmund, 2008). Different methods are used in the applications of detections of cracks of ceramic and porcelain materials. In this study; an impact method, which can be considered as ultrasonic methods, was used. A mechanic system was set up and a system was built that can apply the same impulse on the material. On the basis of the sound out of the material after the impulse, the deformation in the ceramic plate was distinguished by the time-frequency method.

The impulse noise from the measuring system was provided via the pendulum in use at the laboratories for impulse purposes. Pendulums have a quite interesting dynamic system. Pendulums are such physical devices that make angular movements and causing the same effects by forming the same movements (Bevivino, 2009).

Using Fig. 1, one can begin deriving the equation of motion for the pendulum.

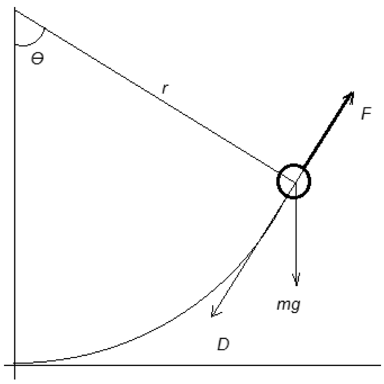


Fig. 1. Scheme of a Pendulum.

Equation (1) becomes

$$\mathbf{\Gamma} = \mathbf{r} \times \mathbf{F} \tag{1}$$

while taking into account

$$-\ \text{damping}_{\text{force}} = \text{gravity}_{\text{force}} + \text{driving}_{\text{force}} = I\ddot{\theta}, \tag{2}$$

$$-\ bvr \sin\theta + -mgr \sin\theta + Fr \sin\theta = I\ddot{\theta}. \tag{3}$$

Let the damping and driving forces be paralel to the motion of the pendulum. Let the driving force be a function of time and $D = bv$. Than so the damping force is dependent on velocity, v or $r\dot{\theta}$. Rearranging and substituting:

$$mr^2\ddot{\theta} + br^2\dot{\theta} + mrg \sin\theta = F(t)r, \tag{4}$$

$$\ddot{\theta} + \frac{b}{m}\dot{\theta} + \frac{g}{r}\sin\theta = \frac{F(t)}{mr}. \tag{5}$$

Equation (5) is a second order differential equation describing the dynamical system of interest (Bevivino, 2009).

2. Measurement system and data collection

In this study, a pendulum was used to produce a stable impulse. The impact Pendulum is an improved pendulum model used for creating equal magnitudes of impacts (Kater, 1818). Through a little plastic hammer attached to the end of the Impact Pendulum, it was provided to have equal magnitudes of impact hits without any damages to the ceramic plate and it was intended to analyze the sound coming from the plate.

In the study, the POE 2000 type Impact Pendulum was used and the effect was achieved to hit the ceramic plate with the same magnitude. Here, using the Impact Pendulum, the sound coming out as a result of applying equal impacts on the same type and model of plates with or without cracks (in good condition) was transferred to the data collection system, then from the data collection system to the computer and the data processing stage was started.

The output audio data of the amplifier is transmitted to the computer at a sampling rate of 0.0000125 seconds via an Advantech 1716L Multifunction PCI card and the data analysis is performed using Matlab (Fig. 2).

3. Application to the signals

The study is based on two basic applications. The first one is based on examining and comparing the time-amplitude of impact noise marks. The second application is based on the time-frequency analysis.

Time-amplitude marks on the left section of Fig. 2 show marks that display non-visible cracks under the glaze of the ceramic material. Time-amplitude marks are shown on the right section of the graphics, displaying plates in good condition, to which the same impact was applied.

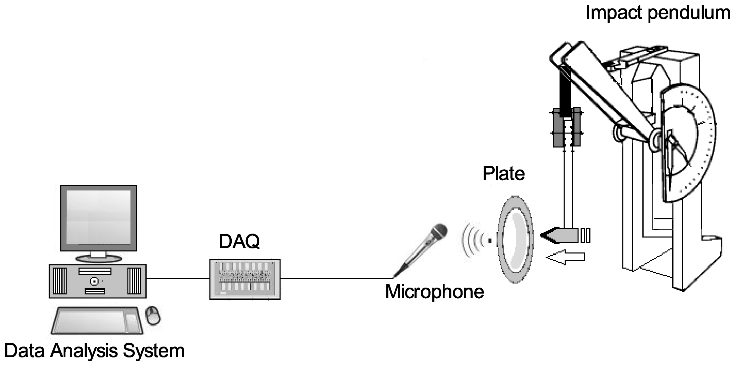
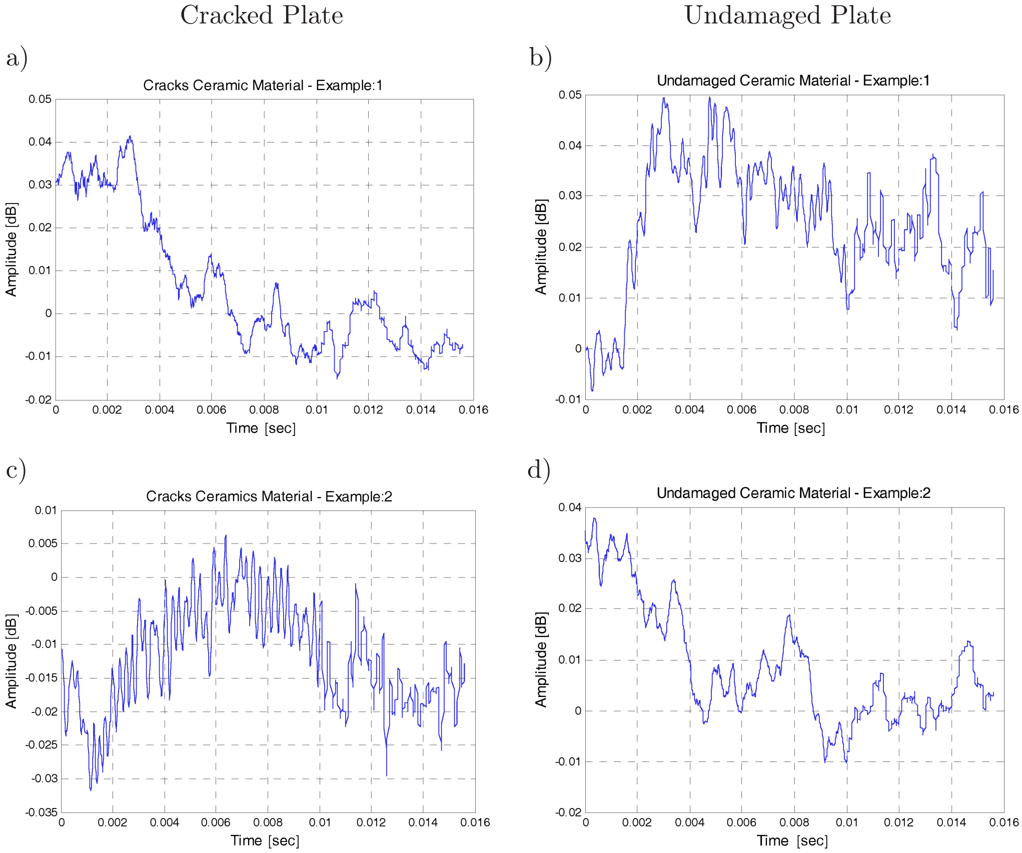


Fig. 2. Data acquisition and measurement systems.

Ten ceramic plates, including those in good condition and those that have different cracks, were determined and exposed to impacts of equal magnitudes. The differences of the sounds from the ceramic plates exposed to the same impacts are shown in Fig. 3.



[Fig. 3a–d]

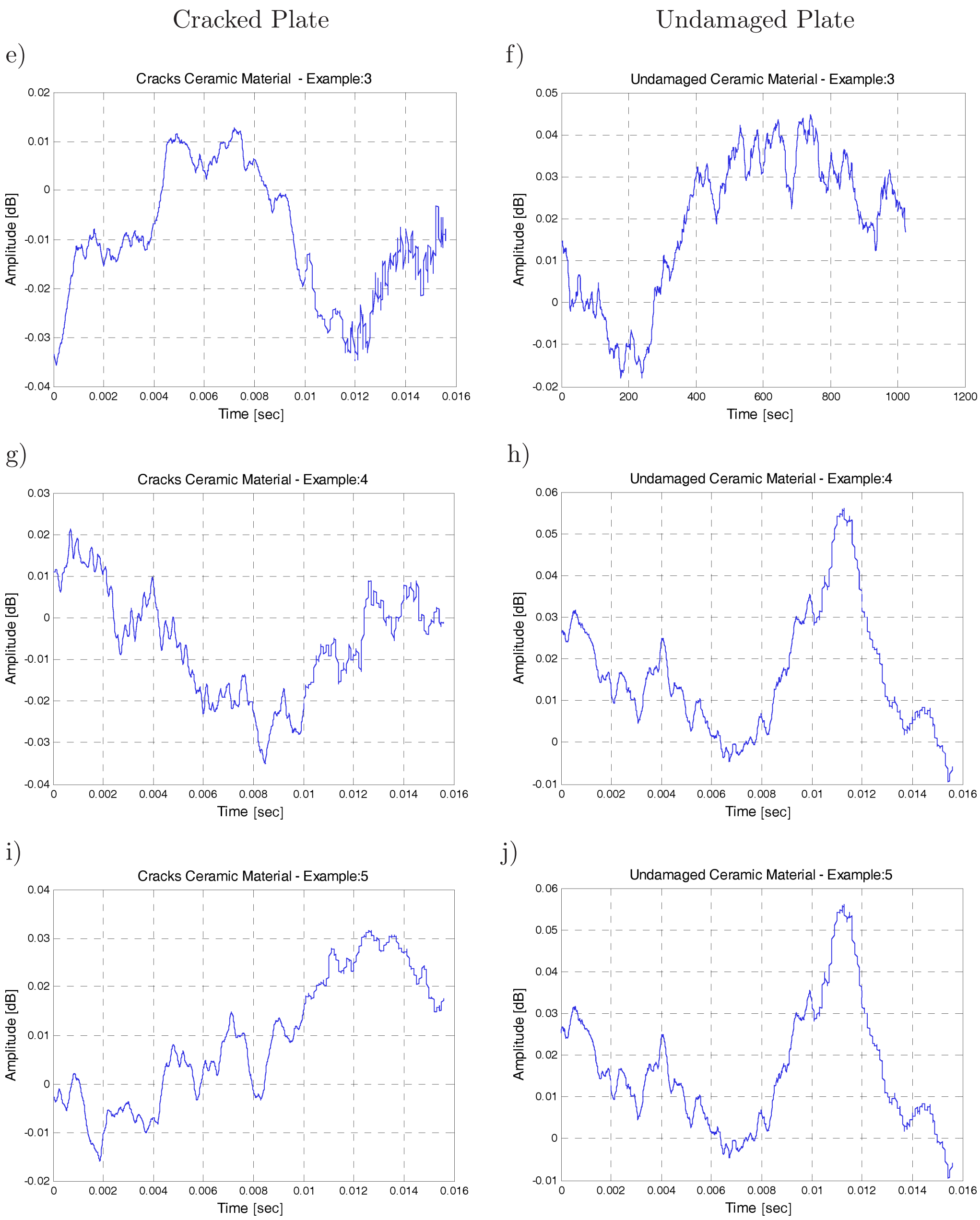


Fig. 3. Comparison of an undamaged plate to cracked one.

The assessments of the time-amplitude graphics of the cracked and good plates are given in Fig. 4. According to this graphic, there is a sound absorption through the crack openings in the cracked plate after the impact, and the vibration does not continue; on the contrary, the vibration in the plate in good condition continues for a longer period on the same level. This situation shows a similar trend in the other graphics though it changes according to the size and shape of the crack in the plates.

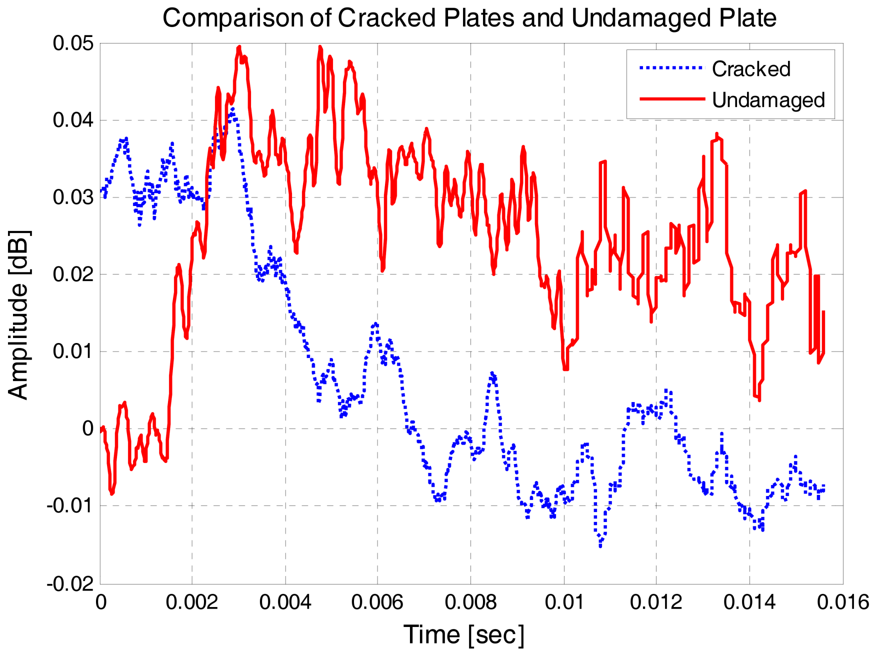


Fig. 4. Comparison of a carcked plate to an undamaged one.

4. Short time Fourier analysis

The short time Fourier transform (STFT) introduced by Gabor 1946 is useful in presenting the time localization of frequency components of signals. The STFT spectrum is obtained by windowing the signal through a fixed dimension window. The signal may be considered approximately stationary in this window. The window dimension fixed both time and frequency resolutions. To define the STFT, let us consider a signal $x(t)$ with assumption that it is stationary when windowed through a fixed dimension window $g(t)$ centered at time location τ. The Fourier transform of the windowed signal yields the STFT (Vaseghi, 1996; Seker, 2000; Taskin *et al.*, 2009).

$$\mathrm{STFT}\,\{x(t)\} \equiv X(\tau, f) = \int_{-\infty}^{+\infty} x(t) g(t-\tau) \exp[-j2\pi f t]\,\mathrm{d}t. \tag{6}$$

The equation maps the signal into a two-dimensional function in the time-frequency (t, f) plane. The analysis depends on the chosen window $g(t)$. Once the window $g(t)$ is chosen, the STFT resolution is fixed over the entire time-frequency plane. In the discrete case, it becomes

$$\mathrm{STFT}\,\{x(n)\} \equiv X(m,f) = \sum_{n=-\infty}^{+\infty} x(n)g(n-m)\,e^{-jwn}. \tag{7}$$

The magnitude squared of the STFT yields the "spectrogram" of the function.

$$\mathrm{Spectrogram}\,\{x(t)\} \equiv |X(\tau,f)|^2\,. \tag{8}$$

4.1. Frequency domain analysis

Time-amplitude displays of the data obtained from the experiment set, whose operational plan is shown in Fig. 4, are shown in Fig. 5. Additionally, in Fig. 5, impact noises of the two plates in good condition are compared. However, the time period marking characteristics do not contain sufficient information. For this reason, considering only one phase, its Short-Time Fourier Transform (STFT) is presented as given in Fig. 4.

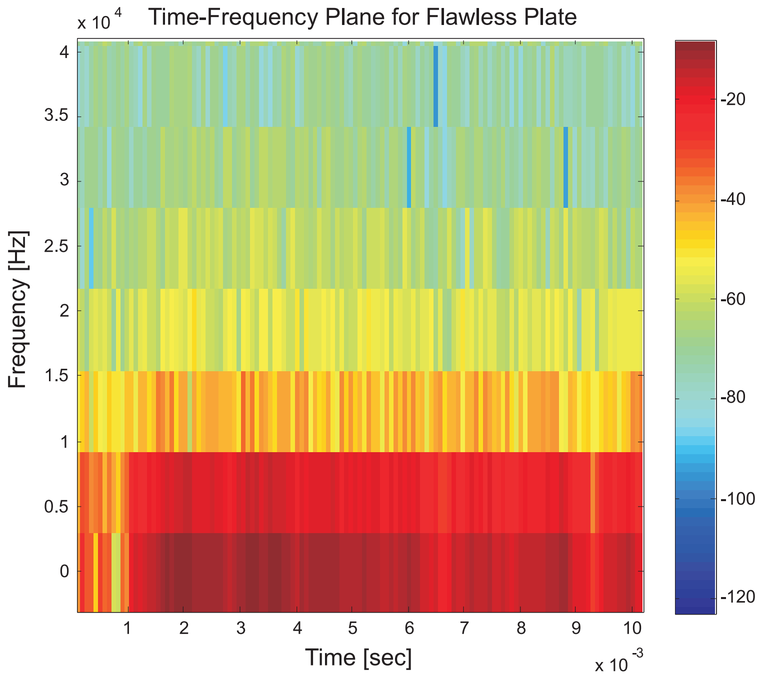


Fig. 5. Time-frequency analysis of an undamaged plate.

Figure 5 shows the time-frequency analysis made as result of the impact noise applied to the plate in good condition. Here, other than an average 10 kHz frequency around 1×10^{-3} seconds, an area with a lower frequency is not seen.

It is seen that the frequency distribution of the good plate has frequencies with higher amplitudes in comparison with those of a cracked plate.

Figure 6 shows the time-frequency analysis made as result of the impact noise applied to a ceramic plate known to be cracked. Here, it is seen that the area with a high frequency at 5 and 8×10^{-3} seconds is interrupted and has amplitudes with lower frequencies.

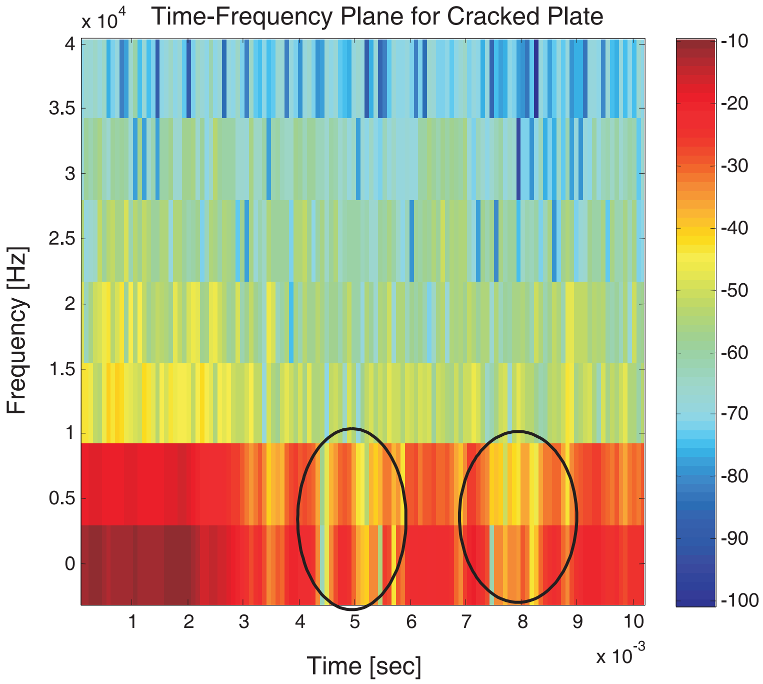


Fig. 6. Time-frequency analysis of a carcked plate.

5. Conclusion

In this study, a marking analysis was made on internal or surface cracks in ceramic plates by using the method of impulse noise. Defects such as deformations or cracks under the glazes of the ceramic materials produced as kitchenware become deeper or cause breakings after placing hot or cold food inside them. These situations are shown as undesired faults for manufacturers. XR and tests applied by experts are often used in the applications of quality assurances of ceramic materials. In this study, basing on the impact noise obtained according to the impact application on ceramic plates, an approach on finding out whether the ceramic plates were deformed was achieved. This method may also be presented as a new practical method. Here, first a time-amplitude analysis was performed by the impact noise method used on same type of plates made of the same materials; then, using the time-frequency method, the cracks on the materials were examined by spectrograms. The method applied gives pretty good results for distinguishing between ceramic plates in good condition and those which are cracked.

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