EPJ Web of Conferences **6**, 44003 (2010)
DOI:10.1051/epjconf/20100644003


# Aspects of the determination of residual stresses in ceramics by ultrasounds hole-drilling

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**Abstract.** The paper presents a method of drilling in ceramics materials, applied for the determination of macroscopic residual stresses. To this end, high frequency vibrations of the ultrasound waves exercised on a drilling device are utilized. The shape and dimensions of the resulting hole depend on the shape and dimensions of the drilling device. The advantages of this method are: no additional stresses result from the application of this drilling procedure, the resulting hole has a satisfactory precision and the experiment may be repeated, macrostresses' variation in the studied material's depth may be determined.

## 1 Methods for the determination of residual stresses in ceramics

For the determination of residual stresses in ceramic materials, the most largely applied method is based on X ray's diffraction, [1, 2, 3]. With this method, microdeformations are especially determined. Yet, the variation of macrodeformations versus depth is more difficult to determine. For the determination of macroscopic residual stresses in ceramics, the tensiometric rosette's drilling method may be applied [4, 5, 6]. Considering the difficulty involved by hole's execution - as a result of ceramics' high hardness several drilling methods have been tested. One of them might be that of drilling with high rotation sped cutter. In this case, the problems created by ceramics might refer to:

- detachment of the material in the beginning of drilling, when the device touches the ceramic material's surface;
- detachment of the material when the cutting device advances;
- additional erosion of the resulting hole's walls, as a result of the slower removal of the detached pieces and their driving into the rotation movement, by the device;
- determination of the cutting device during the advance, when the working device touches the surface of the ceramic material;
- occurrence of some additional residual stresses, as a result of material local heating.

All phenomena produced during drilling with cutters provoke quite significant deviations from the geometry of the resulting hole. Another method applied in such cases-i.e., drilling with a jet of abrasive particles - has the advantage of non - introducing additional residual stresses. However, here too, some significant deviation from the cylindrical shape of the resulting hole do occur, which, obviously, affect the precision of the results obtained. The deviations are larger with ceramic

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materials, comparatively with the metallic ones, as tearing in the material occur quite frequently, the torn grains having bigger dimensions, [7].

A method utilized by the author - drilling with ultrasounds - has been perfected in the Department of Materials' Resistance at the "Gh. Asachi" Technical University of Iassy. The ultrasound installation employed for drilling was that of the Institute of Technical Physics in Iassy.

The reasons that supported the selection of this method were the following, [8]:

- the extremely hard crust, present on the surface of the material, is taken into consideration;
- drilling with the usual devices - even diamonds - at high working speeds, is not possible, as local destruction in the cutting region occur;
- ultrasound drilling quite similar, from certain viewpoints, with the one involving an abrasive jet, does not introduce additional residual stresses;
- the hole resulting from such a procedure shows minimum deviations from cilindricity and assures the repeatability of the measuring process.

## 2 The method of tensiometric rosette's drilling in ceramic materials

Determination of residual stresses by the drilling method is established according to ASTM E-837-2001. It assumes soldering, on the material's surface, of a rosette with three tensiometric strain gages, as well as the realization of a hole at the section of the axes of the three marks forming the rosette. The three transducers of the grill measure the specific elongation on radial direction. There follows the calculation of the main stresses and directions. Hole's eccentricity influences considerably the precision of determinations, [9]. That is why one should have in view a correct centering of the drilling device versus the hole made in the rosette. For the determinations discussed in the study, a tensiometric RY 61-type rosette, made by Hottinger Company, was utilized, [10]. In center of such rosette, a guiding socket - which assures the device's central positioning versus the intersection of the strain gage axes forming the rosette - is provided.

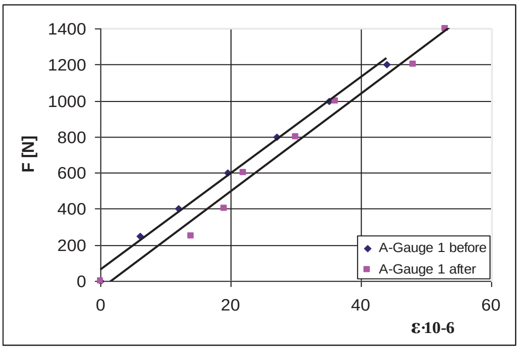
Determinations have been made on samples made of two types of ceramic materials, namely: aluminous CER-110-A and quartzous CER-110-C. Samples' dimensions (mm): 180x19x14. The minimum and maximum residual stresses are given by relation:

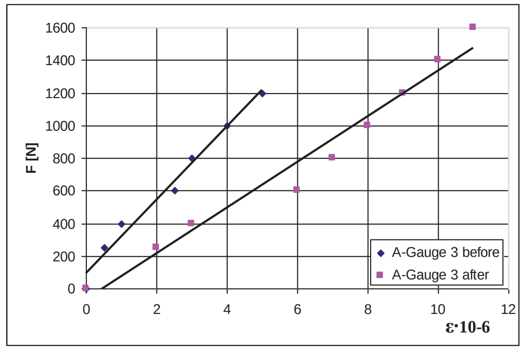
$$\sigma_{min,max} = \frac{\varepsilon_1 + \varepsilon_3}{4\bar{A}} \pm \frac{\sqrt{(\varepsilon_1 - \varepsilon_3)^2 + (\varepsilon_1 + \varepsilon_3 - 2\varepsilon_2)^2}}{4\bar{B}} \tag{1}$$

where $\varepsilon_1$, $\varepsilon_2$ and $\varepsilon_3$ are the deformations measured on the three directions of the tensiometric rosette, while $\bar{A}$ and $\bar{B}$ represent the calibration constants, determined by the tensile test, which is performed both before and after drilling. The indications of strain gage 1 (longitudinal) and 3 (cross) are then read. The test is made in the first third part of the elastic domain and, consequently, the sample may be prismatic in shape, without special catching heads. The experiment is necessary for eliminating the error given by the effect of strain gage integration and also by the possible geometrical imperfections of the resulted holes. Tensile forces F, are applied on the sample both before and after drilling, and the deformations on direction 1 and 3 are recorded, too, both before and after drilling. The variation graphs of the deformations are plotted versus of the tensile load, Figure 1. For the intermediate tensile load $F_{cal}$=800 N, $\varepsilon_{i,before}$ and $\varepsilon_{i,after}$ are determined from the equation of the straight which approximate the variation of deformation as a function of the tensile load. With these values, $\varepsilon_{i,\,cal}=\varepsilon_{i,\,after}-\varepsilon_{i,\,before}$ are calculated. The values of the calibration constants $\bar{A}$ and $\bar{B}$ are given by relation:

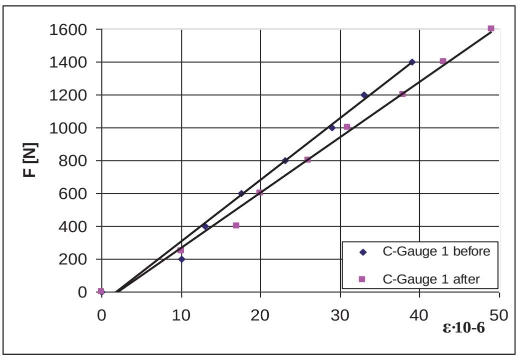
$$\bar{A} = \frac{\varepsilon_{3cal} + \varepsilon_{1cal}}{2\sigma_{cal}};\bar{B} = \frac{\varepsilon_{3cal} - \varepsilon_{1cal}}{2\sigma_{cal}} \tag{2}$$

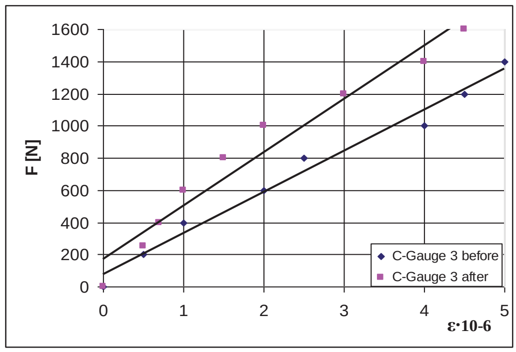
where $\sigma_{cal} = F_{cal}/S$, S being given by the area of sample's cross section (19x14) $mm^2$.




**a)** Specimen A, strain gauge 1 **b)** Specimen A, strain gauge 3




**c)** Specimen C, strain gauge 1 **d)** Specimen C, strain gauge 3

**Fig. 1.** Variation of deformation with the tensile load.

Table 1 lists the values of the deformations and of the calibration constants for the two samples.

**Table 1.** Values of the deformations

| $2\cdot\sigma_{cal}$ [N/mm$^2$] | Sample A | | Sample C | |
|---|---|---|---|---|
| 6.015 | $\varepsilon_1\cdot 10^{-6}$ | $\varepsilon_3\cdot 10^{-6}$ | $\varepsilon_1\cdot 10^{-6}$ | $\varepsilon_3\cdot 10^{-6}$ |
| after | 31 | 6.06 | 25.29 | 2.89 |
| prior to | 27.9 | 3.18 | 22.87 | 2.07 |
| calculated | 3.1 | 2.88 | 2.42 | 0.82 |
| Calibration constants | $\bar{A}_A=0.99\cdot 10^{-6}$ | $\bar{B}_A=0.036\cdot 10^{-6}$ | $\bar{A}_C=0.54\cdot 10^{-6}$ | $\bar{B}_C=0.26\cdot 10^{-6}$ |

Soldering of the tensiometric rosettes was performed according to the recommendations made for the adhesive. No readjustments were made on the sample's surface, so that no additional residual stresses should be introduced. In view of both calibration and measurement of residual deformations, the system plotted in Figure 2 was executed. One of the rosettes was glued on material C, and the other- on material A. Thermal compensation and, consequently, balancing of the tensiometric bridge were possible, if considering the very close value of the coefficient of liner thermal dilatation for the two materials. Operating of the connection system presented is possible due to the alternative feeding (which involves switching of the tensiometric bridge on each canal) of a pair of marks - belonging to different rosettes - which are reciprocally compensating). As a matter of fact, drilling of a rosette was performed, the other one being passive, the latter's strain gauge representing the compensation for the strain gauge of the active rosette; in a subsequent stage, and the situation got reversed.

## 3. Hole-drilling by means of ultrasounds

Drilling through the metallic socket occurring in the center of the rosettes was performed with an ultrasound producing device. To this end, the installation belonging to the Institute technical of Physics was employed, namely the one that utilizes, for the production of ultrasounds, a magnetostrictive transducer with a 19 kHz frequency and a variable power. Depending on the ceramic material's hardness, a certain working power is set for getting a slow advance of the working device's operation. Principally, ultrasound-induced drilling is plotted in Figure 2, with the following components:

- 1- piece made of a extra-hardened material;
- 2- guiding socket occurring within the tensiometric rosette;
- 3- tensiometric rosette;
- 4- protecting lute;
- 5- water-carborundum emulsion;
- 6- ceramic sample.

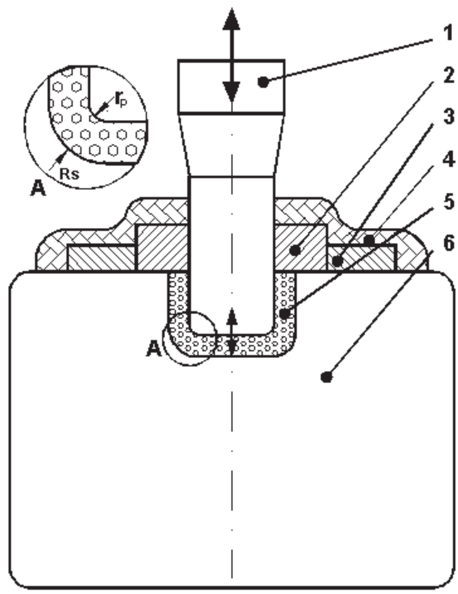
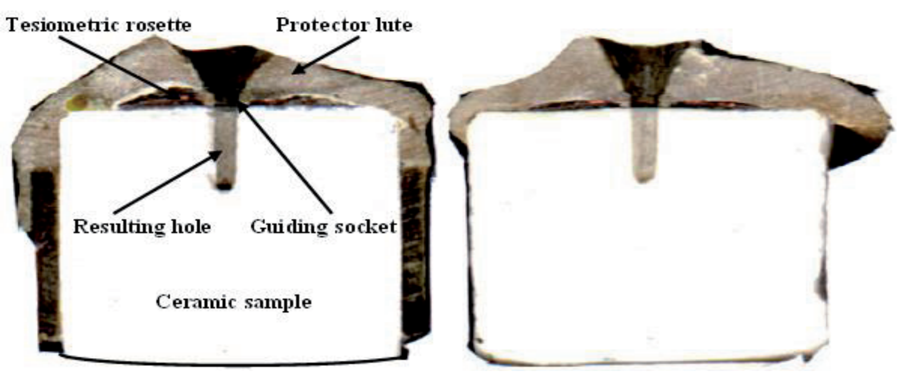



**Fig. 2**. Ultrasounds - induced drilling.

The vibration produced is transmitted longitudinally to the piece 1. The lower part of this piece made of a highly-hardening material, is shaped according to the hole that is to be executed. Between the frontal side of the vibrator device and the surface of ceramic material, a water-carborundum emulsion is inserted. The 20μm - sized carborundum particles, with very high hardness, are part in motion as a result of the device's vibration, thus causing detachment of particles of the basic material. A suitable precision is to be noticed as to the cylindrical shape of the hole resulted from the application of ultrasounds, Figure 3.




**a)** Sample C (quartzous) **b)** Sample A (aluminous)

**Fig. 3**. Shape of the resulting hole.

Actually, this drilling method produces the smallest deviation from the cylindrical shape of the resulted hole, comparatively with the above-mentioned methods. In this case, one should mention only a slight rounding in the hole's lower part, caused by a similar rounding occurring, too, in the device's frontal part, $r_p$ versus $R_s$, Figure 2. If the device's is made of an extra-hardened material, such deviations should not appear, any more.

Mentioned should also be made of the fact that, in this case, the diameter of the resulted hole would be larger than the device's diameter:, i.e., $\phi_{res}=1.15\cdot\phi_{device}$.

In view of maintaining a balanced tensiometric bridge during the whole operation of drilling, the tensiometric rosette had been isolated from a possible contact with the water-carborundum emulsion by means of a silicon lute layer. Knowing what small particles of the ceramic material are detached in the beginning of drilling, several trials had been made for attaining an optimum as to the power applied for ultrasound waves and also for the working advance applied.

**Table 2.** The values read for the strain gauge

| h [mm] | Sample A (aluminiums) | | | Sample C (quartzous) | | |
|---|---|---|---|---|---|---|
| | $\varepsilon_{1A}\cdot10^{-6}$ | $\varepsilon_{2A}\cdot10^{-6}$ | $\varepsilon_{3A}\cdot10^{-6}$ | $\varepsilon_{1B}\cdot10^{-6}$ | $\varepsilon_{2B}\cdot10^{-6}$ | $\varepsilon_{3B}\cdot10^{-6}$ |
| 0.5 | 12 | 11 | 5 | 8 | 5 | 2 |
| 1 | 19 | 17 | 10 | 11 | 7 | 4 |
| 1.5 | 21 | 19 | 14 | 11,5 | 9 | 6 |
| 2 | 23 | 21 | 19 | 12,5 | 13 | 7 |
| 2.5 | 25 | 22 | 22 | 15 | 16 | 9 |
| 3 | 28 | 22.5 | 24 | 17 | 18 | 10 |
| 3.5 | 28 | 23 | 26 | 20 | 21 | 11 |
| 4 | 30 | 25 | 32 | 28 | 24 | 13 |
| 4.5 | 26 | 24 | 32 | 27 | 25 | 12 |

The deformations have been measured for values read on taken at each 0.5 mm, up to a depth of 4.5 mm. The values read on the tensiometric bridge for the two tensiometric rosettes mounted on CER-110A and CER-110C materials, as a function of the penetration depth, being listed in Table 2. The observation to be made is that the value of deformation could not be read immediately after drilling. In time, a relaxation of the residual stresses occurred, so that the reading was made about 30 sec. later for each penetration depth, when stabilization of the tensiometric bridge's indication was noticed.

With the above values, with the values of the calibration constants listed in Table 1, and also with relation (1), the residual stresses may be determined for each value of depth h. Variation of the maximum residual stress versus depth - for the two ceramic materials CER-110A and CER-110C - is plotted graphically in Figure 4.

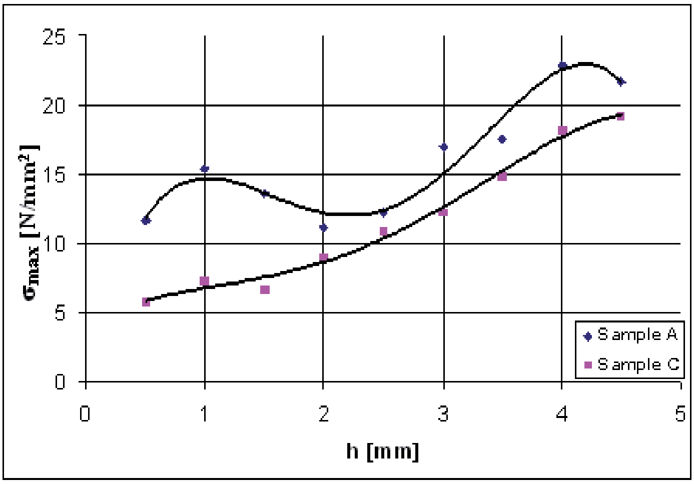



**Fig. 4**. Variation of maximum stresses with the drilling depth.

## 4 Conclusions

Drilling in ceramic materials by means of ultrasounds represents a technique leading to satisfactory results. In spite of the fact that the hole results also through tearing out of particles from the basic material - which is the case of drilling through an abrasive jet, too - nothing prevents drilling over a significant depth. For getting an as high precision as possible of the resulting hole, correlation of the ultrasound waves' power with the working advance is recommended, along with the utilization - for the active part of the working device- of an extra-hardening material for which rounding of the attack part's edges should be negligible.

Comparatively with the determination of residual stresses by means of X ray diffraction, ultrasound drilling of ceramic materials shown the advantage of permitting the determination of macrostresses over significant depths.

**Acknowledgements.** This work was supported by the National Council of Scientific Research - CNCSIS Romania - under Grant No ID_597/2007 for the study of the technical composite-ceramic materials used in the high technology.

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