Investigation of hollow ceramic structures by contactless computer-tomographic non-destructive method

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Abstract: *This article deals with the study of the cavity of ceramic constructional elements for the construction of beehives and carriers for electric furnace heaters. Unlike the traditional practice of performing tomography studies to determine the structure and harmful defects in the interior and surface of specimens, in the present studies, the non-destructive non-contact method is used to assess the nature and volume of deliberate fulfilled cavities in ceramic specimens. The role of well-shaped and regulated cavities is to reduce the coefficient of thermal conductivity in the hives to the inside, and in the carriers for heaters to the outer walls of the furnace, i.e. heat loss. The cavity samples are obtained from an aqueous dispersed colloidal system based on patent-protected quartz glass-ceramics by the "pouring" method. The obtained structural details are fireproof, thermally stable and with high physical and mechanical characteristics. They are composed of amorphous* SiO_2*, mullite and cristobalite. The study of the cavity at different beam depths was performed using a NIKON XTH 225 device, and the data processing Volume Graphic, My VGL.*

Keywords: *HOLLOW CERAMIC CONSTRUCTIONS, WATER DISPERSION COLLOIDAL SYSTEMS, NON-CONTACT NON-DESTRUCTIVE METHOD, TOMOGRAPHIC METHOD*

1. Introduction

The hollow ceramic constructions (plates for beehives and supports for heaters for electric furnaces) obtained, studied and presented in this article consist of three layers - two dense outer and an intermediate air layer formed between the two dense layers. Of importance for the practice are the thicknesses of the two supporting thick layers, the top and the one of the air cavity in order to provide the necessary thermal insulation. Achieving the necessary requirements is associated with the combination of different factors determining the construction of the individual layers in the molding process. The first factor is the composition of the solid phase in the aqueous dispersed colloidal system, from which the samples are made in gypsum molding equipment. From this composition depends, the molding, as well as physical and mechanical properties of ceramic products. The second factor is the amount of water, the added liquefied separators, and mainly the residence time of the system in the molds. The evaluation of the obtained details after drying and firing at 1240°C is realized by evaluating the cavity and the thickness of the bearing layers. One of the analysis methods is destructive, which is expensive, inefficient and time consuming. A promising maximum automated and undamaged method of ceramic constructions is the Tomography method, which has not yet been used for the comprehensively analysis of the described specimens as well as the other similar samples.

It is known that tomography comes from the word "tomo", which means "cut" or the basis of absorbent X-rays, which allows the visualization of the internal micro and macro structure of the materials. CT scanning and cavity assessment technology can also be used by evaluating the size and properly shaping the cavities in the samples.

Computed tomography is a method by which from multiple X-ray images of the object, taken from different angles, a three-dimensional image is obtained by computer processing, and the examination is performed in successive sections [1, 2, 3, 4]. The Micro CT system consists of an X-ray source, a sample rotation stage and a detector. The X-rays that are received by the detector are directed to certain places in the sample. They have a high resolution, which depends on the specimen size. In the process of the sample scanning, it is rotated 360 degrees and the resulting 2D images are recorded. These images are processed with specialized software to obtain 3D images from for volume pixels.

Due to its powerful and precise equipment, CT scanning technology is a very useful research technique with very wide possibilities in the field of ceramic production.

2. Experimental part

The article presents the study of the macrostructure of 6 separate ceramic parts - carriers of the heaters building the working space of a furnace for melting aluminum alloys. (fig. 1, 2, 3, 4, 5, 6, 7) and part of constructional details (fig. 8) (ceramic beehive plate) similar in structure for all walls making the fruit tree, the shop and the drawer of the beehive (fig. 9). The material from which both types of details are made is quartz glass-ceramics, which is one of the most thermally resistant ceramics with CTE $5.10\text{-}7K^{-1}$. The fire resistance is particularly important in carriers and according to the claims used is 1450°C. The compressive and tensile strength is 500 MPa and the bending strength is 70 MPa [5]. The composition includes 70% amorphous SiO_2 and 30% washed kaolin.

The non-destructive mapping of the internal structures of the cavities in the ceramic products provides information about the perfection of the air intermediate layer and possible imperfections in the two outer dense supporting layers, such as cracks, inhomogeneities, etc.

Experimental studies to determine the structure of kitchen products are carried out on real ceramic kitchen products. CT allows the study of a wide range of materials and sample sizes with a range from 20 to 225 kV. CT tomography is equipped with a five-axis positioning system. The maximum weight of the sample is 15 kg, and the maximum dimensions are 15x15x15 cm. The obtained maximum resolution of the detector is 1900x1500 with an active area of 467 cm and an accuracy of 3µm. The system is equipped also with specialized software for reconstruction of the internal structure of the sample in 3D [6].

3. Results and Discussion

The experimental studies were performed in the Smart Lab laboratory, Institute of Information and Communication Technologies at the Bulgarian Academy of Sciences, Sofia.

Tests were performed on 7 samples described above. The thicknesses of the supporting layers and cavities were measured. Defects in the dense layers have been identified, such as cracks, damages, cavities and inadmissible deviation in the construction of the elements.

Each sample is scanned and reconstructed by 3D. The inside structure is also presented. The descriptions of the cartographies are presented from detail 1 up to detail 7.

Detail 1.

From fig. 1 it is obvious that the cavity of the material is uniform for the most part. The walls of the part have an average size of 8 to 16 mm. The walls have a porous structure. An exemplary pore size is shown in fig. 2.

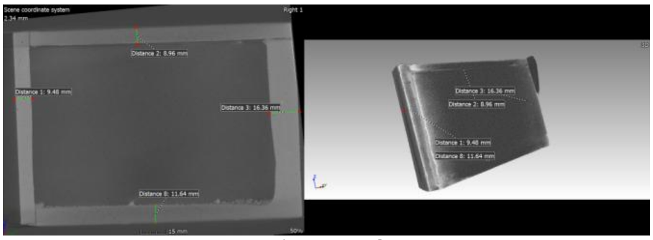


Fig. 1. *Detail.*

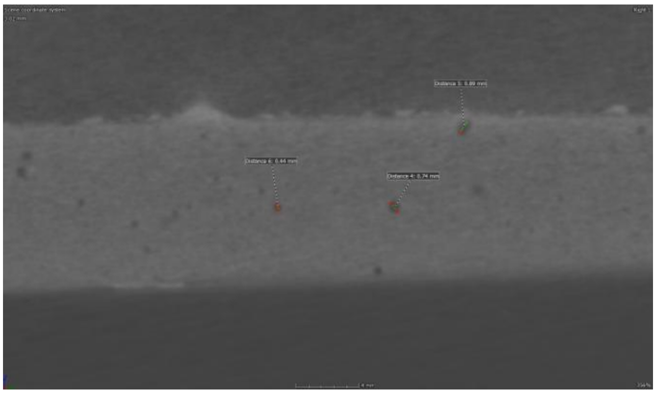


Fig. 2. *The porosity of the walls.*

Detail 2.

In fig. 3 the cavity of the detail is shown, as for the most part it is homogeneous. In the middle of the detail, there is an artifact (hollow/additional material) with a size of 1.71 mm in its most protruding part.

In fig. 4 the dimensions of the walls of detail 2 are shown. The average dimensions are in the range of 7.85 mm to 9.62 mm. Due to the specific of the detail (ribbing) for one wall are given 2 sizes.

In fig. 5 is shown part of the porosity of the walls of the detail. The pore sizes are in the range from 0.69 to 1.17 mm.

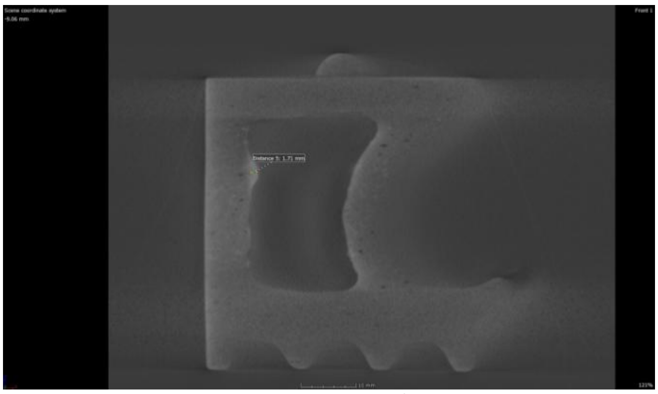


Fig. 3. Hollowness of the part.

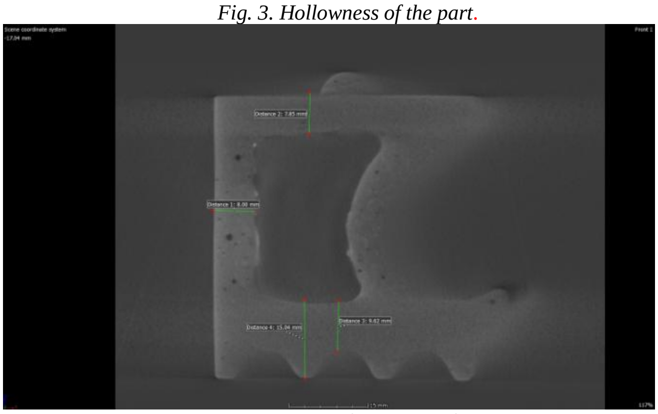


Fig. 4. *Dimensions of the walls of detail 2.*

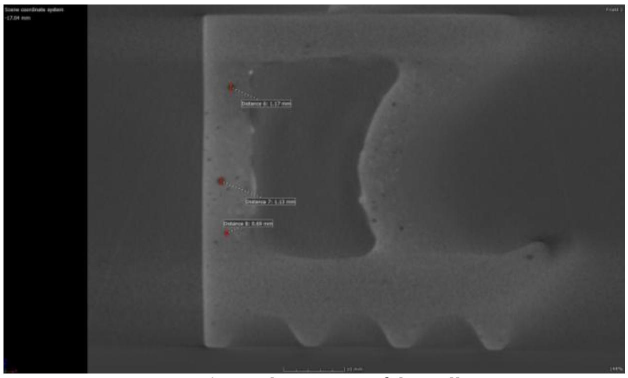


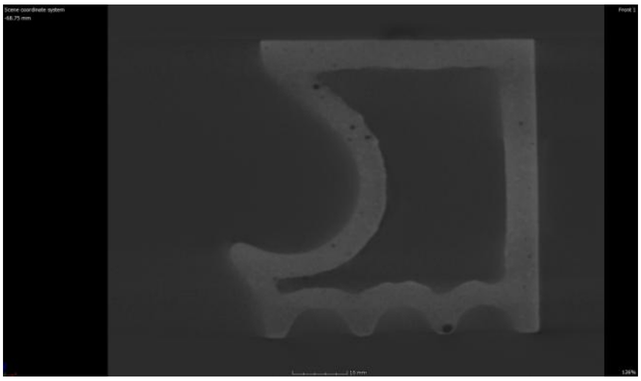
Fig. 5. *The porosity of the walls.*

Detail 3.

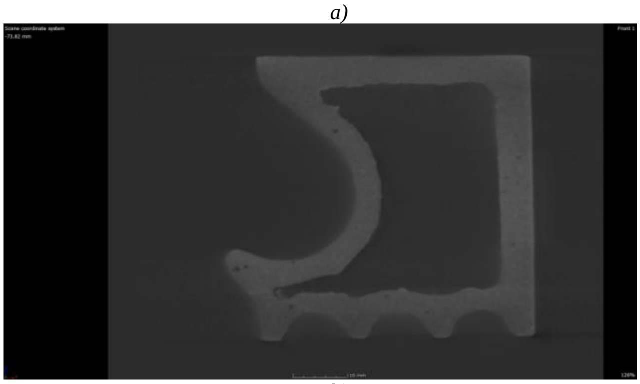
Uniformity of the cavity is observed for the most part. During the ribbing, an unevenness is observed in the cavity following the ribbed wall, shown in figures 6 a) and b).

In fig. 7 is shown the average dimensions of the walls in the range from 4.22 mm to 8.33 mm, and due to the specific of the detail (ribbing) for one wall are given 2 sizes.

The average size observed at the porosity of the material is in the range from 0.5 to 2.08 mm, shown in fig. 8. They are most strongly exhibit expressed in the beginning - fig. 8 a) and in the end of the detail -fig. 8 c).



a)



b)

Fig. 6. *Hollowness of the detail.*

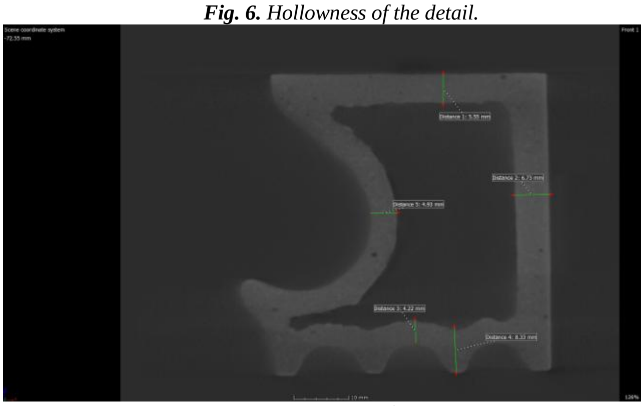
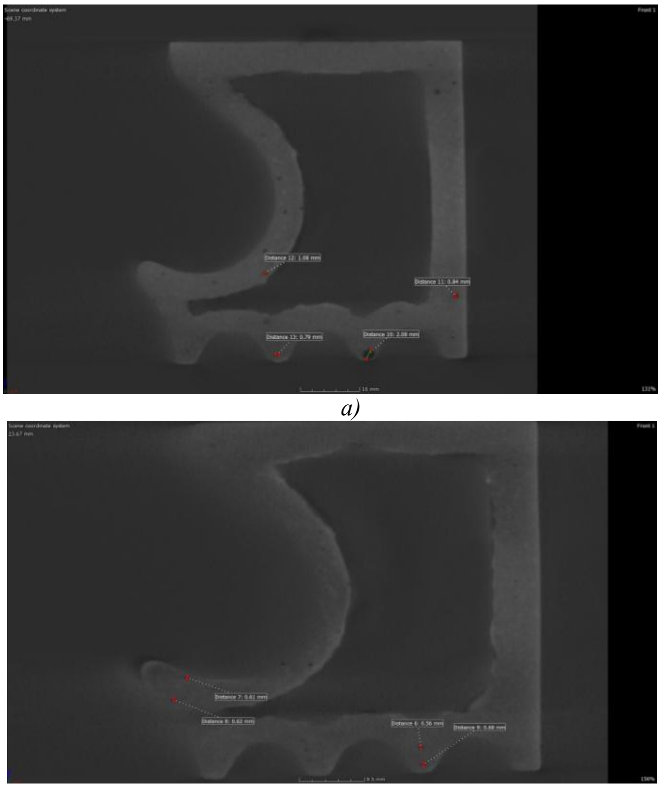


Fig. 7. *Dimensions of the walls.*



a)

б)

Fig. 8. *The porosity of the walls.*

Detail 4.

Homogeneity of the cavity part is observed in detail 4.

In fig. 9 is shown the average dimensions of the walls in the range from 4.39 mm to 8.17 mm, and due to the specifics of the detail (ribbing) for one wall are given 2 sizes.

The average size observed in the porosity of the material is in the range of 0.26 to 0.8 mm. Shown in fig. 8, being most strongly expressed at the beginning of fig. 8 a) and the end of the detail - fig. 8 c).

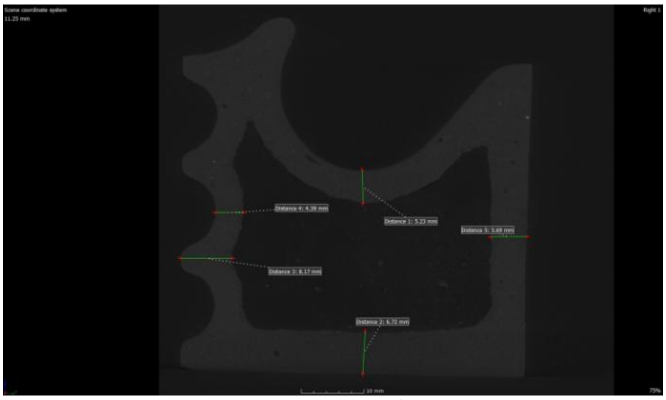


Fig. 9. *Dimensions of the walls.*

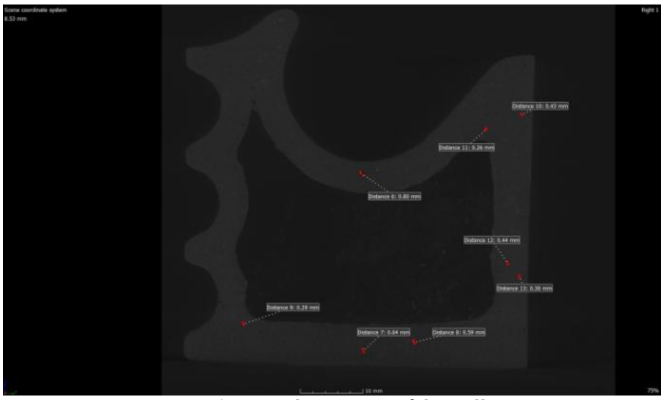


Fig. 10. *The porosity of the walls.*

Detail 5.

In detail 5, the uniformity of the cavity part is shown in fig. 11. A slight form of porosity of the material is also observed

Fig. 12 shows average wall sizes in the range from 3.42 mm to 4.8mm. Due to the specifics of the part (ribbing), additional dimensions are given, including the ribbing. The dimensions range is from 6.03 to 6.88 mm.

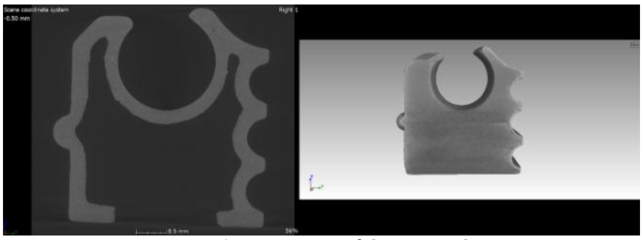


Fig. 11. *Cavity of the material.*

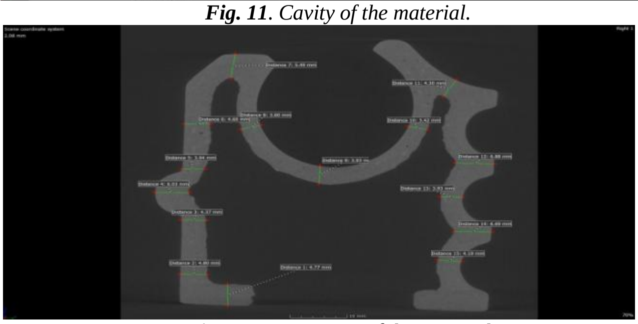


Fig. 12. *Dimensions of the material*

Detail 6.

Homogeneity of the cavity part is observed in detail 6, except for the area at the heater trap shown in fig. 13. In fig. 13 a) is shown the cavity at the beginning of the part, 13 b) - the middle and 13 c) the end of the detail. A slight form of porosity of the material is observed. The left part of the images shows the section in which the cavity is located, and the right part shows the location on the 3D part with a line.

In fig. 14 is shown average wall sizes in the range from 3.42 mm to 4.8 mm. Due to the specifics of the part (ribbing), additional dimensions are given, including the ribbing. The dimensions range is from 6.03 to 6.88 mm.

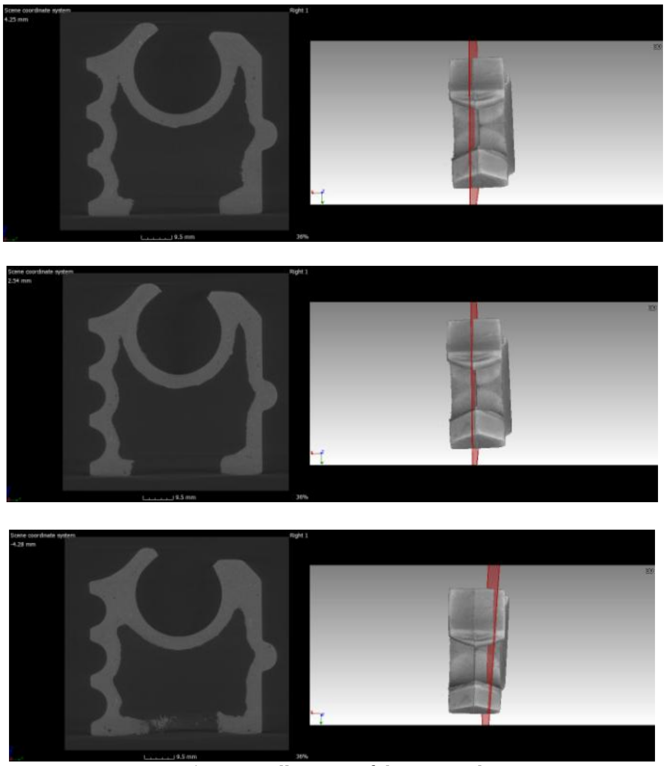


Fig. 13. *Hollowness of the material.*

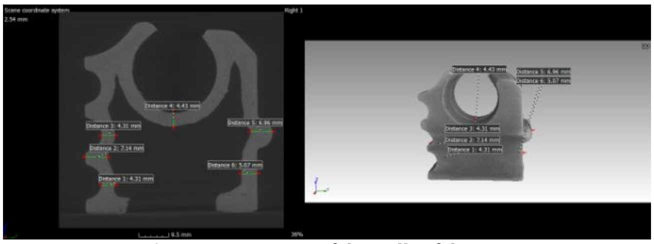


Fig. 14. *Dimensions of the walls of the part.*

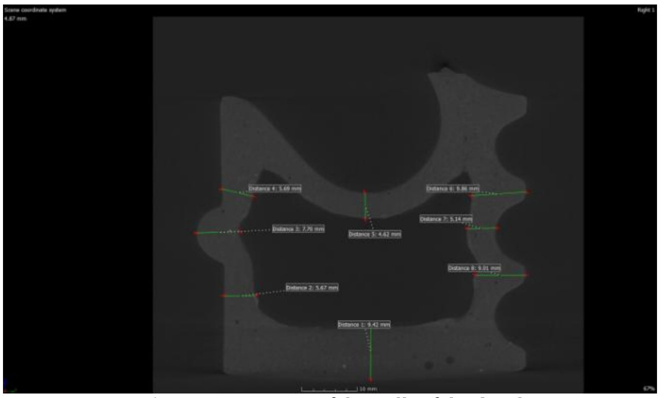


Fig. 15. *Dimensions of the walls of the detail.*

In detail 7 (presented in fig. 15) the dimensions of the walls of the detail are shown.

Pores with dimensions (up to 10 mm) larger than those in the other details are observed in fig. 16

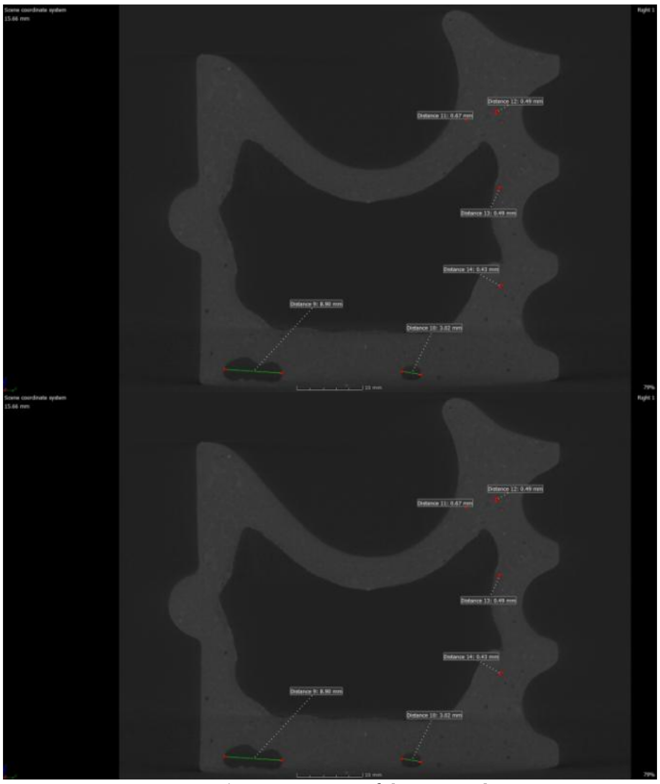


Fig. 16. *Porosity of the material*

4. Conclusions

From the analyses realized by the method of non-destructive 3D examination of the internal structure of the details, it can be concluded that in most details there is a porosity of the walls of the details. The cavity is homogeneous. In the future it is planned to measure the volume of the hollowness of the details, to determine the minimum, average and maximum sizes of the porosity of the material of the details as a result of the performed analyzes.

Studies show that computed tomography is effective in assessing, monitoring and diagnosing the actual condition of hollow ceramic products. Quality images suitable for processing are obtained. The main disadvantage is the requirements for the size of the tested samples and the time for collecting data for large images.

5. References

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