SELECTED METHODS OF NDT UNCERTAINTY ANALYSIS FOR QUALITY RATING IN MULTILAYER CERAMIC MOULDS

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Abstract

Paper presents characteristics of thermovision, 3D scanning and tomography methods used for quality rating in multilayer ceramic moulds used for purposes of aircraft turbine blades casting. Moulds measurements were performed with thermovision camera, 3D scanner and tomography. Results were converted via dedicated software for each method and were saved in compatible file format that allowed to perform an analysis. One of the decisive factors of these measurement methods usefulness are accuracy and measurement error. For obtained measurement results quality rating selected statistical methods, Measurement System Analysis MSA and R&R index were used. Analysis allowed to estimate uncertainty and efficiency for applied non-destructive measurement systems for multilayer ceramic moulds rating.

Keywords: Methods NDT, thermovision, 3D scanning, tomography, uncertainty, multilayer ceramic moulds

1. INTRODUCTION

The development of technology and market demand caused that the companies not only must produce at an increased pace, but also at the best quality, to satisfy the consumers and stand out. One of the most important parameters of the manufactured product is its quality which results in customers satisfaction, thus company income. In order to determine the quality of a manufactured product, it is necessary to make product measurements, a process that provides reliable information and determine the measurement uncertainty. This knowledge is necessary to make a reference to product quality by comparing the results of measurements to a given nominal value. It is possible to determine the uncertainty of the device, the method or the operator, i.e. the person performing the measurements [1]. The article presents the results of tests carried out on multi-layered ceramic molds, used for air blades casting and by use of statistical tools, shows measurement uncertainty of selected methods. Because the product obtained after pouring ceramic forms is very specific, it must be characterized by excellent properties and precision of dimensions, errors are unacceptable [2]. To be able to prevent them, not only the products obtained, but also the forms in which they are created are subjected to non-destructive testing (NDT). Selected NDT methods will be presented later in the article.

2. NON-DESTRUCTIVE TESTING

According to Zientek [3], two groups of tests can be identified, which enable detection of damage or defect of the tested object. They are so-called destructive and non-destructive tests. As the name suggests, the second group of research does not interfere with the examined object, does not destroy it, does not damage it, and allows one to examine it and obtain results to assess their quality. NDT test methods are mainly used to assess the properties of materials, they can detect and locate existing defects or discontinuities, determine material parameters or determine the thickness of the tested object. NDT research is mainly used in the automotive, aerospace and power industry, due to the need to ensure high quality products. This research allows to control not only finished products, but also their individual stages during the production process [4]. The research was carried out in order to determine the uncertainty of measurements using non-destructive methods such as: thermovision, tomography and photogrammetry.

2.1. Thermovision

Thermovision is one of the methods of non-contact measurements based on a remote assessment of the temperature distribution on the surface of the body, object or test item. This method was discovered and developed in the second half of the nineteenth century. The measurement is based on observation and registration using appropriate devices, and on the distribution of infrared radiation. Each body that generates radiation can be subjected to the test, and its temperature has a temperature higher than absolute zero, or 0 K. Ultimately, this radiation is transformed into visible light. Thanks to this, the use of thermovision as a non-destructive test can be used wherever the surface temperature can be measured [5]. Thermovision is used in many areas, such as: industry, medicine, electronics, energy, construction, metallurgy, agriculture, environmental protection, as well as mechanics. When assessing the thermovision test, you can distinguish many of its advantages: it is very fast, and the results in the form of a thermogram can be obtained immediately thanks to special software. The great advantage is the ability to perform tests without destroying measured object. Having a camera, a computer system dedicated to it and skills, it is possible to self-treat and analyze thermograms [6].

2.2. Tomography

Computed tomography commonly known for medical applications has also found application in industry. This unique method of NDT non-destructive testing by means of object x-raying and then receiving feedback information can create a digital equivalent of the cross-sectional image of the subject under study. It consists in creating images of the examined object in a 2D section and 3D space, by means of projection of the object. The tomographic image is created by passing the beam of X-ray radiation through the object under study, and then a precise measurement. It is made through a detector and it depends on the accuracy as well as the quality of the image obtained. To obtain the final result of the image, the data obtained in the form of two-dimensional cross-sectional images and 3D models should be combined [7]. The advantage of using the tomographic method as a non-destructive examination is that it can be used in many areas for measurement, control and examination of the structure of the material of the tested object, which makes it universal. It also allows assessment of porosity, detection of material discontinuities, determination of the wall thickness of the tested object, and even an internal image can be obtained to assess the quality of, for example, mechanical or electronic assemblies [8].

2.3. Photogrammetry

Through the development of technology, today's 3D scanners allow measurements of objects from the smallest size to large dimensions, ensuring their exact parameters, deviations on the entire surface or in cross-section, but also allow for very accurate measurement data. Photogrammetry is one of the fields of study of materials for contactless spatial measurements. The field of photogrammetry itself deals with the reproduction of shapes and sizes, it allows for quick and accurate transfer in the form of a three-dimensional image of the geometry of an object to a computer screen, through specialized software and the appropriate equipment such as a 3D scanner [9]. Depending on the equipment, image processing is based on the fact that the object is casting light in the form of stripes, then the cameras record the deflection of the stripes, so the appropriate software can create a point cloud in which each of them corresponds to a single pixel matrix. At the end, the point cloud can be transformed into an object model in the form of triangles. Photogrammetry can be used in industry, architecture, archeology, urban planning, and medicine [10].

3. UNCERTAINTY MEASUREMENT

Measurement data is currently used much more frequently than it was previously not only in industry but in various other fields. It is possible to compare the data obtained using statistical tools with designated control limits, and based on these results, a manufacturer can decide on the adjustment of the production process.

Uncertainty is a measure of the dispersion of values, results obtained, repeated on the same objects or similar, in reproducible measurement conditions [11]. The determination of uncertainty is crucial when making measurements, especially when making measurements needed for scientific and technical work [12]. There are many factors that can affect the correctness of the measured data to determine the uncertainty of measurement using thermovision, tomography and photogrammetry. Factors that may affect later received data may be related to poor device assembly, lack of proper calibration or inappropriate test environment. Also, the quality of the received measurement data is influenced by a person operating given device, who should undergo appropriate training in order to be able to deal with it. The essence of the measurement is its accuracy, which concerns both the measurement, the device, the method, the measurement tools, as well as the operators (persons responsible for conducting the tests). In the tests carried out for the purposes of the article, the uncertainty of direct measurements was assessed, the standard uncertainty of a single measurement was calculated, and the average obtained from all series of measurements was calculated. The uncertainty calculated using such a method is called the standard uncertainty of the A method [13].

4. MSA AND R&R INDICATOR

The literature presents the analysis of the MSA measurement system as a tool used to determine the quality of the measurement system of the obtained test results. An efficient measuring system is one where several successive results are identical or close together [13]. The errors of the measurement system can be described in five categories: accuracy, repeatability, stability, reproducibility and linearity. In addition to MSA, can be also use the R&R reproducibility ratio. It allows evaluation by determining its percentage, and thus presenting the measurement system as acceptable or not. According to certain standards, the R&R ratio below 10%, allows to accept the system, in the range of 10 to 30%, it can be accepted conditionally, while if the value exceeds 30%, then it is necessary to improve the measurement system. Both methods are used to check whether the measurement system under test is acceptable and reliable. They are relatively easy to perform, the costs are not large and they are extremely useful because they allow to quickly locate the source of problems [14].

5. RESULTS

The uncertainty of measurements of individual non-destructive testing methods was analyzed. The tests were carried out on a multi-layered ceramic mold used for casting of air blades. In each of the methods, the measurements were performed by two independent operators. The results were developed in the STATISTICA program, where plots showing the spread of results, deviation and average were plotted. As mentioned before, the MSA tool was also used and the R&R ratio for each method was determined. The procedure for assessing the measurement system using the R&R ratio based on the Ford methodology has specific guidelines. Data registration was performed twice in 20 places on the site examined by two operators. At the beginning, basic statistics were calculated from the results obtained, and repetitiveness and reproducibility were calculated in later steps. Using the thermovision method, the temperature distribution was recorded for a period of 20 minutes of mold cooling from 200°C. For the tests, the FLIR T640 thermal imaging camera was used, which uses the latest precision measurement technology. After the FLIR TOOLS+ program dedicated to the camera, thermograms were created, where the mold cooling temperature was observed, which allowed to observe whether the ceramic molds were well made or not. **Figure 1.1** presents the measurement points on the thermogram, from which data was collected to evaluate the quality of a multi-layer ceramic mold. Photogrammetric tests were carried out using the ATOS Triple Scan scanner, it provides fast and accurate measurement and complete measurement data. The data received was analyzed in the GOM Inspect program. Operators using the software determined the thickness of the form in precisely defined places, as shown in **Figure 1.2**. Thicker form spots are marked on the form scan, so one can observe thickness deviations, to check whether spots are within the tolerance range and thus determine whether quality is acceptable or not. The tomographic examinations were carried out on the Phoenix Nanotom S tomograph, which ensures high precision. The tomographic method is the most labor-intensive of these NDT studies, because the first data obtained should be generated in the ImageJ program using 2D images, and then with the myVGL software one can start processing them into 3D images. The porosity of the surface of a multi-layer ceramic mold was examined by the tomographic method. An exemplary image obtained as a result of tomographic examinations is shown in **Figure 1.3**.

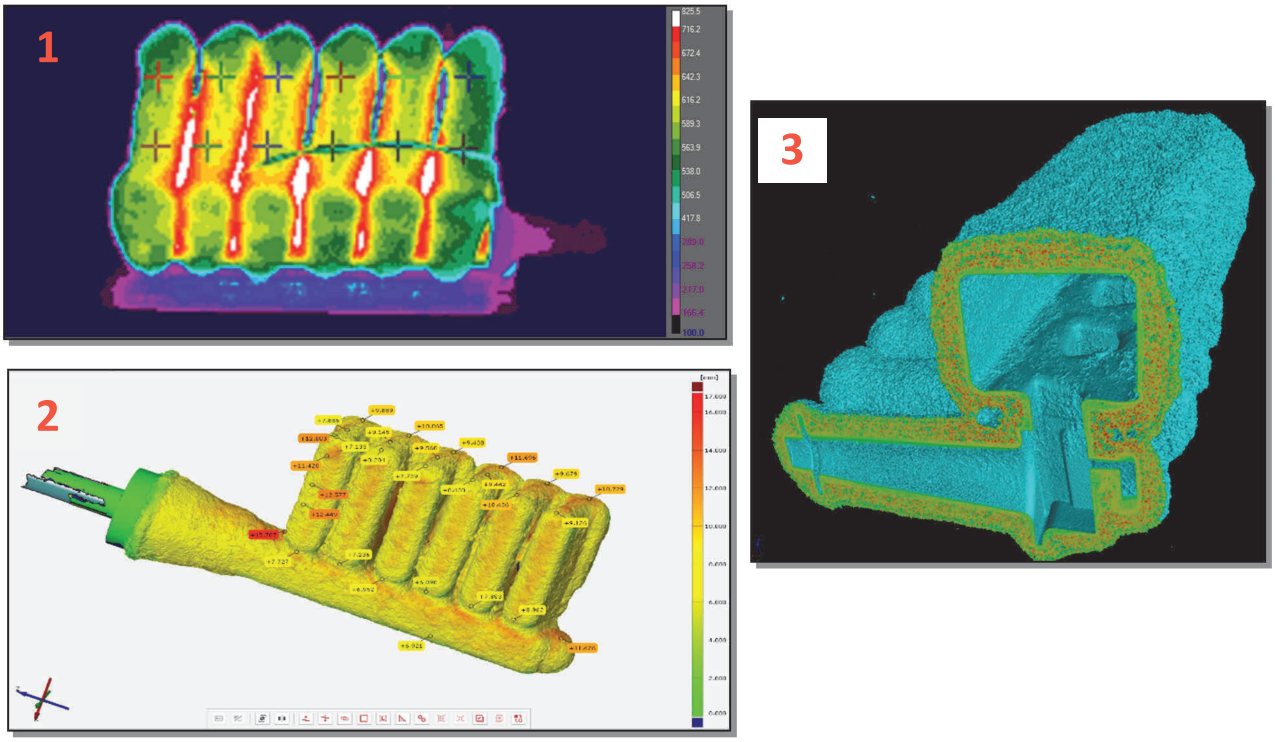

Figure 1 Presentation of images received in dedicated programs for processing the results of selected NDT tests, 1) thermovision studies, 2) photogrammetric studies and 3) tomographic examinations

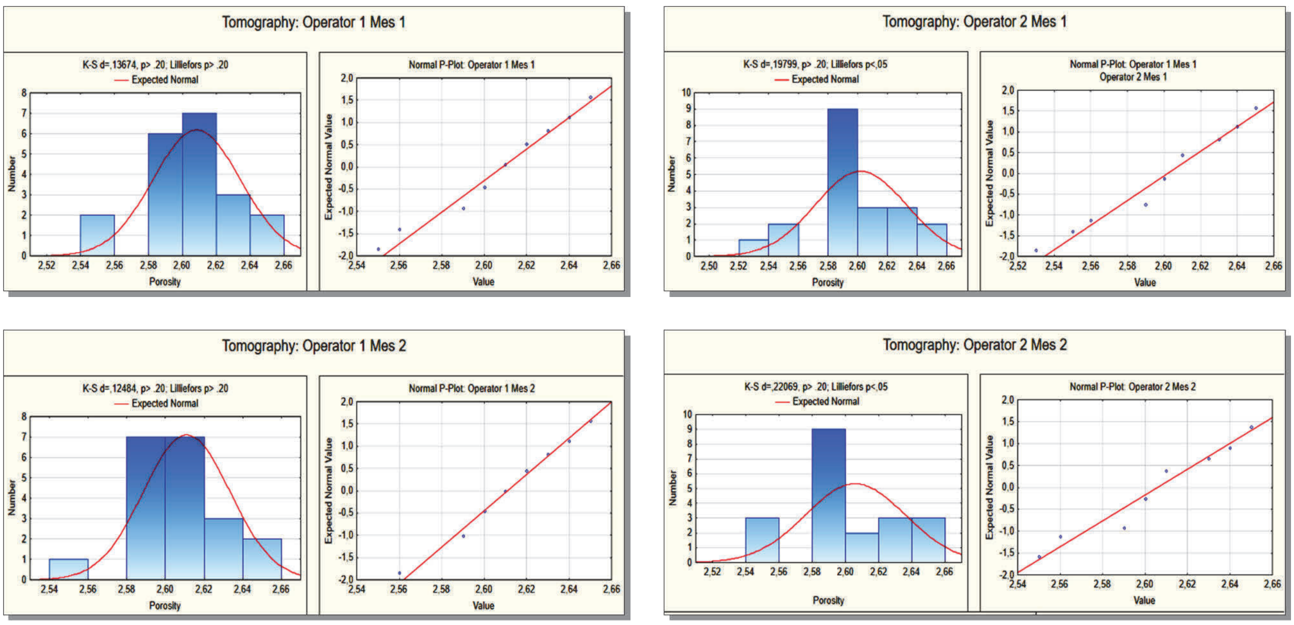

Figure 2 Graphical representation of measurement results for individual operators using the tomography method

The results of research for particular methods are presented below, which show the spread of results obtained by operators. **Figure 2** shows the results for operators for the tomography method, in **Figure 3** the scatter results for the photogrammetric method and in **Figure 4** for the thermovision method. It can be observed that the obtained results do not have a large discrepancy between the operators, and the differences between the values read are within tolerance. It means there were no places on the mold with overflowing or slipping, which could affect at a later stage the poor quality of molded airfoils from multi-layered ceramic molds.

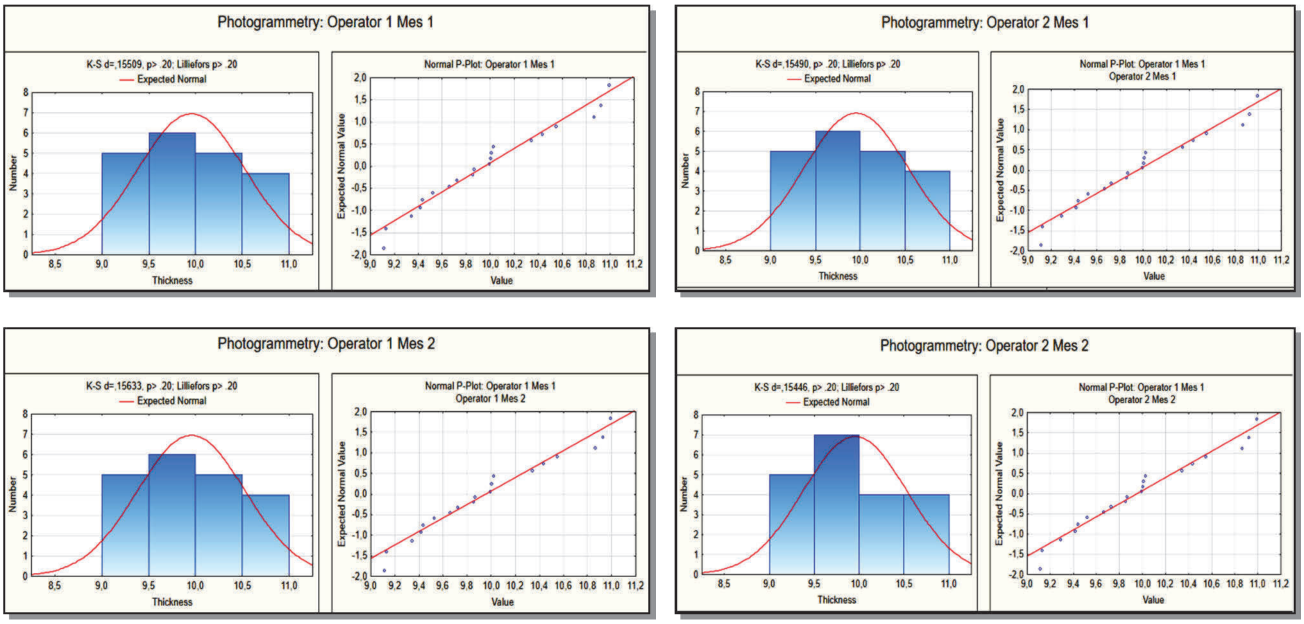

Figure 3 Graphical representation of measurement results for individual operators using the photogrammetry method

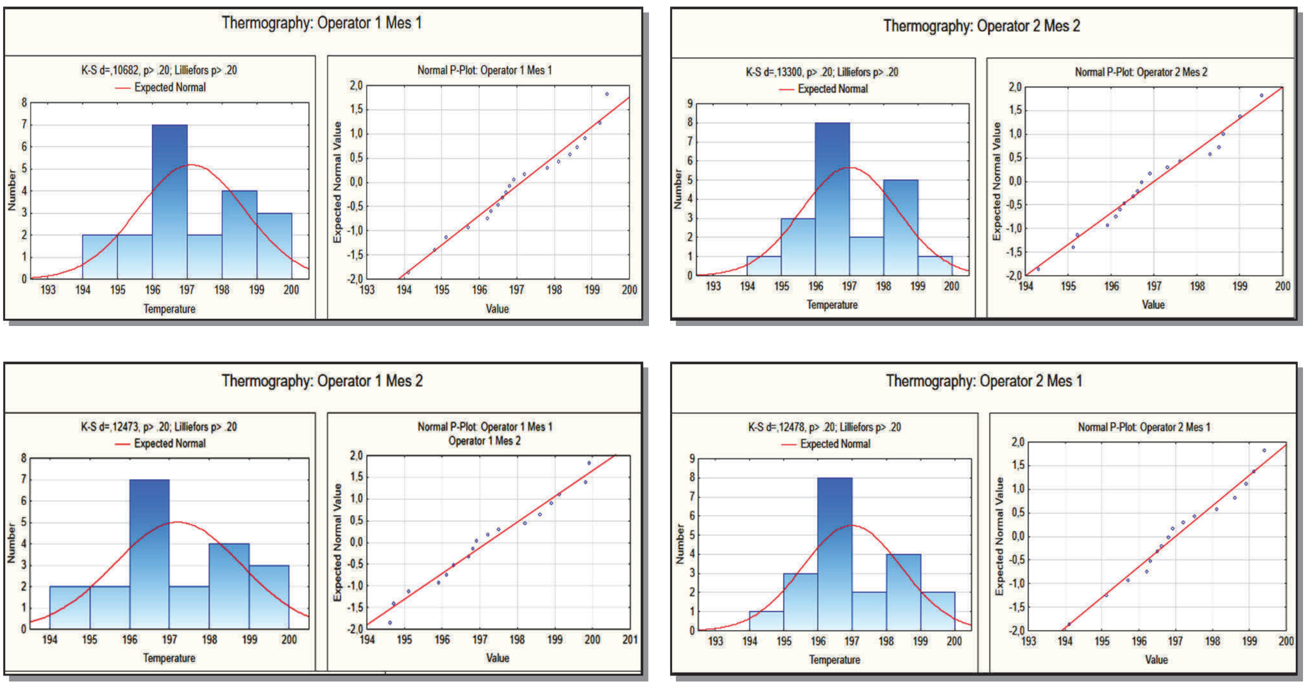

Figure 4 Graphical representation of measurement results for individual operators using the thermovision method

The conducted study showed that the molds are made accurately and correctly, their quality is acceptable, as indicated by the calculated R&R ratio, which results are presented in the **Table 1**.

Table 1 Numerical presentation of the results obtained from the R&R analysis for each of the non-destructive testing methods.

Indicator	Thermovision	Photogrammetry	Thomography
Mean range	5.35	1.87	0.12
Repeatability	1.27	0.42	0.02
Reproducibility	0.57	0.06	0.14
%R&R	5.84	0.10	5.10

6. CONCLUSION

The uncertainty of measurements of non-destructive tests used to assess the quality of multi-layered ceramic forms has been analyzed. The results obtained after the thermographic, photogrammetric and tomographic examinations have confirmed the positive effect of NTD methods to detect defects in the object. When applying and comparing results from three methods, it was noticed that deviations occurring in the same places on ceramic forms can be observed. The use of the R&R study also proved to be extremely effective, allowing estimation of reproducibility and repeatability of results. The non-destructive testing and statistical analysis made it possible to confirm the correctness of the operation of methods for assessing the quality of multi-layered ceramic forms. After combining these three methods, quality of the form can be easily determined, confirming effectiveness of non-destructive testing.

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