THERMAL IMAGING ANALYSIS OF THE STRUCTURE OF MULTILAYER CERAMIC MOULDS

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Abstract

The paper presents the results of research aimed at the use of thermal imaging as the method of assessing changes in the structure of multi-layered ceramic forms, intended for the investment cast parts of air blades. Analysis of infrared radiation allows to notice anomalies resulting from incorrect temperature distribution, which, in combination with other methods of quality control, creates the possibility of developing an innovative system for monitoring unit processes of producing jet engine components. FLIR T640 thermal camera and dedicated FLIR software was used for the tests. The moulds were heated in a laboratory dryer to the temperature of about 200 °C, and then changes in radiation intensity were registered. The image generated by the camera served as input for analysis with use of Research IR software. As a result, of research and analysis, the relationship between the thickness of the moulds wall and the percentage decrease in temperature over time was determined and a comparative analysis of thermal images with prepared castings of the blades was carried out in order to detect visible real defects. The paper presents also innovative test bench, which feature is active thermovision equipment. Test stand was used to create comparison analyze between thermo-images from passive and active laboratory tests. Results of these tests lead to continuation of research in field of using thermovision methods as a new way to check quality of multi layered ceramics moulds.

Keywords: Thermovision, ceramic moulds, metal cast, aviation, non-destructive testing

1. INTRODUCTION

Thermovision is an advanced technique based on physical process of detecting a wave of a certain length, which directly leads to non-contact temperature measurement. This technique is based on the detection of infrared radiation, which is a type of electromagnetic wave, of a length higher than the visible light. All objects with temperature over absolute zero transmit beam of infrared radiation. Due to the fact that the human eye is not able to register infrared radiation, thermal imaging cameras are used for this function [1]. There is a separation into passive and active thermography. Passive thermovision is based on observing the object without interfering in the object during the measurement. In the case of active thermal imaging, observations going in object in which dynamic changes are made, it is possible because of external signals. The object can be activated by: vibrations, IR radiators, halogen lamps, hot or cold air and others. The actions caused by the mentioned signals lead to the supply of heat energy to the object, and thanks to that, a controlled temperature measurement of the tested object can be made, simultaneously with observing of possible anomalies [2]. Among the non-destructive tests, the thermovision is the only one that allows observations of objects in real time when temperature is change in them. Thermovision in various configuration, both active and passive [3], is used in many fields, including non - destructive testing of ceramic materials such as concrete [4]. Production is an important field of thermovision applications because temperature anomalies can indicate potential hazards that can be detected and repaired early enough. Thanks to the control of individual parts of the processes, many quality errors can be prevented in a non-invasive way. Thermo analysis was used by Dresser [2] to inspect printed circuits to detect non-soldering joints. Medicine is another field of application. Tomasz Rok and others worked on the analysis of the image from the thermal imaging camera in order to create an alternative way of detecting allergies by observing the temperature changes on human skin subjected to allergens [5]. In the construction industry, thermovision has already been used for long time e.g. for the analysis of steel elements in reinforced concrete [6]. Thermovision is also used in the automotive industry [7], historical research [8-9], agriculture [10], paper industry [11], as well as in the maintenance in production and service plants [12]. The authors of this publication used thermovision in the application of NDT testing. Camera was used to detect potential defects of multi-layer ceramic moulds for precision casting. Thermovision can be a type of non-destructive testing in an industrial application, and in combination with other NDT tests, can be a part of a system to effectively detect defects before metal casting. In the era of growing demand for aircraft engines parts, complicating the process by introducing an additional quality control process is troublesome, however in the case of thermovision it is possible to handling research during the mould making process and to detect defects ongoing. In the case of ceramic forms, it is important to develop a universal testing method that allow for quick and effective measurements without invasion into the casting production process. This is very important because casting of air blades involves the use of expensive nickel or cobalt alloys which is why it is important to know whether the ceramic form has the right parameters and whether the cast made of it will be free from defects.

2. METHODOLOGY

For the production of ceramic moulds, mixtures of ceramic powder, water or alcohol binder and other ingredients providing the required properties were used [13]. The forms created for the needs of the research are structures composed of layers applied on a wax model set, consisting of four model blades. The ceramic mixture based on quartz sand combined with alcohol binder was used to make moulds with different layer thickness. To achieve that, different number of ceramic layers were applied on wax model. There was 1, 3 (**Figure 1 - A**), 5 (**Figure 1 - B**) and 7 (**Figure 1 - C**) layers applied, where the single-coated part of form was not tested. In order to determine the thickness of individual layers, the 3D scanning method was used. Digitization of real objects was made using GOM ATOS CORE scanner (**Figure 2**). Subsequent scans of the model set and finished form were made.

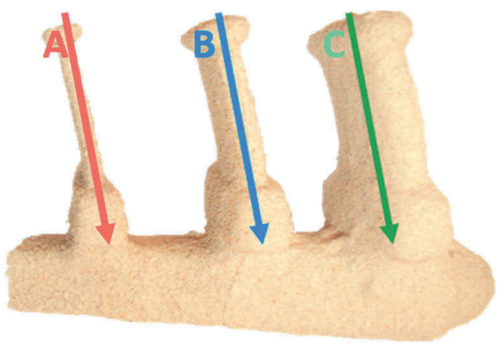


Figure 1 Ceramic form A - 3 layers, B - 5 layers, C - 7 layers

Figure 2 Diagram of digitizing the ceramic form using the GOM ATOS CORE system

The collected data was superimposed on each other which allowed to determine the exact thickness of the form and its variation depending on the number of layers. These data served as a reference to the thermographic analysis. The assumption of thermovision studies under this article was to determine the percentage temperature drop in time for a given thickness of the ceramic layer. This type of test can be used to analyze anomalies in mould thickness in industrial conditions by using only the thermal imaging method without use of 3D scanning, which significantly shortened the test time. Thermovision studies were accomplished with a FLIR thermal imaging camera model T640 (**Figure 3**). The parameters of the device allow for making accurate analyzes due to the high sensitivity of the matrix and good class IR detectors. In addition, the camera has a recording resolution of 640x480 pixels, which gives 307 200 measurement points per one frame of the thermal image. The tests were carried out in laboratory conditions, where appropriate research parameters were maintained, including: emissivity coefficient for ceramic materials - 0.95, constant ambient temperature of 25 °C, distance from the tested object - 1m. Ceramic moulds were heated to temperature 200 °C in a laboratory dryer. After removing from heating device, a motion picture from the course of cooling the mould in the air to the ambient temperature was recorded, and then analyzed using the FLIR Research IR software. Dedicated program of the camera manufacturer allows for the exact interpretation of the recordings made. The software allows to define clearly the analysis area and export data needed to perform calculations.

Figure 3 Diagram of thermovision tests

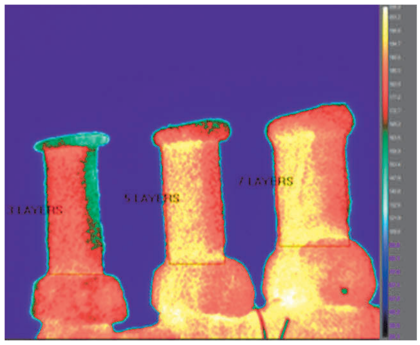


Figure 4 Ceramic form during tests

In order to collect relevant results from conducted tests, assumptions were made which optimized the research method in terms of the suitability of the thermographic recordings made. The pictures were made at the proper angle between the camera lens and the side surface of the blade. **Figure 4** shows the arrangement of the mould during the tests, as well as the areas that were analyzed.

3. RESULTS AND DISCUSSION

Using software FLIR IR Research prepared an analysis of thermal images. **Figures 5-6** shows designated areas of research that have been analyzed to determine the drop temperature over time for different thickness of the ceramic.

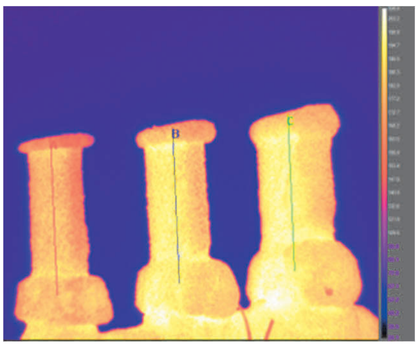


Figure 5 Areas of initial analysis

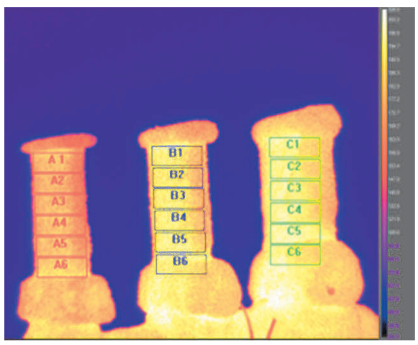


Figure 6 Areas of extended analysis

Figure 5 presents the method of narrowing the research area with lines A, B, C with the same parameters. Each line measures an equal number of measurement points distributed parallel along the blades of the tested form. As a result, it is possible to roughly investigate how the temperature distribution over time occurs for individual blades with different thicknesses of ceramic layers. In contrast, **Figure 6** presents a thermogram and selected areas of analysis that will be used to determine the percentage decrease in temperature over time. Each of the areas marked with letters A, B and C and numbers from 1-6 has the function of measuring the average temperature in this area. Data from the mould cooling process were collected for 5 minutes in 1-minute intervals, and then the percentage accumulated temperature drop over time was calculated, taking into account temperature changes in each of the marked areas. The comparison of thermograms from the cooling process of the mould for 5 minutes is shown in **Figure 7**.

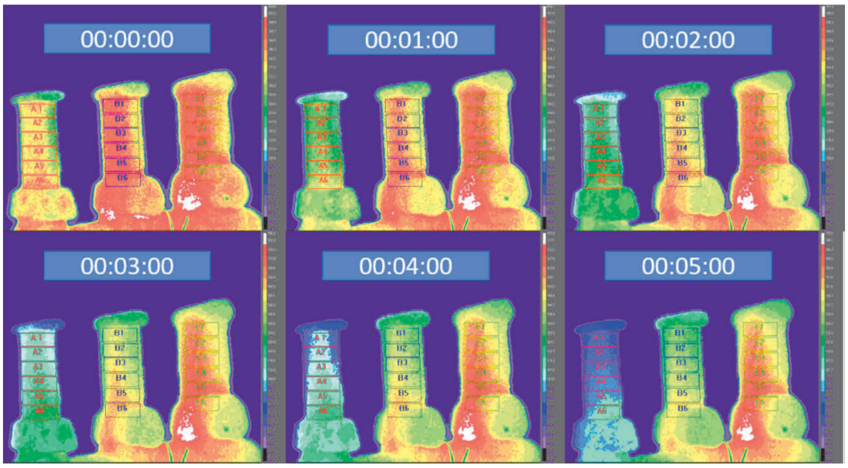


Figure 7 Thermograms showing the process of cooling the mould

Figure 8 shows the course of mould cooling in time. It is easy to notice that the thinner the thickness of the ceramic coating the temperature drops at a faster rate. Form A, consisting of 3 ceramic layers, is cooled as most rapidly, within 400 seconds the average temperature from the determined measuring line has dropped from about 179 °C to about 82 °C. Form B, consisting of 5 ceramic layers, cooled from about 193 °C to about 119 °C at the same time. The smallest temperature drop from about 193 °C to about 140 °C was noted for mould C consisting of 7 ceramic layers.

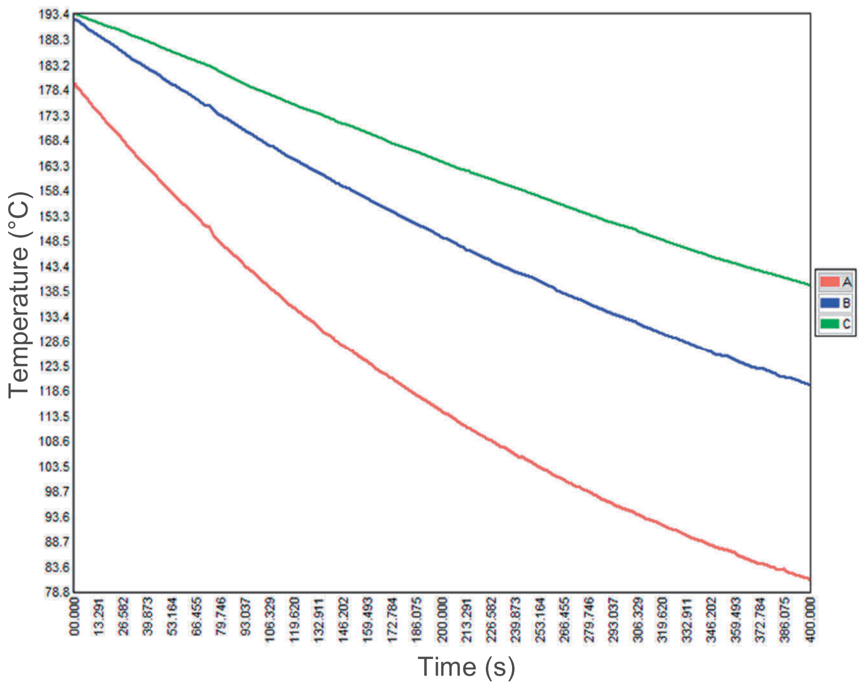
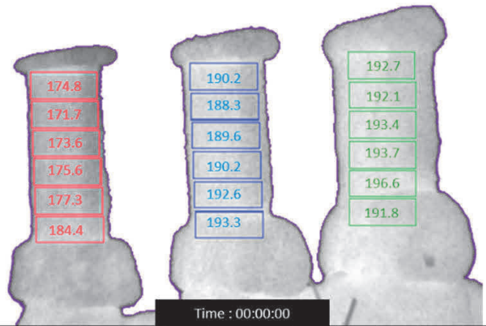


Figure 8 Graph showing drop of temperature during time for different thicknesses of ceramic layers

The calculations were based on the data presented in **Figure 9**. Temperatures from each area were imported, and then compiled and submitted to computational analysis. **Figure 10** shows the percentage cumulative temperature drop for each of the blade forms.



A1	B1	C1	A2	B2	C2	A3	B3	C3	A4	B4	C4	A5	B5	C5	A6	B6	C6
174.8	190.2	192.7	171.7	188.3	192	173.6	189.6	193	175.6	190.2	193.7	177.3	192.6	196.6	184.4	193.3	191.8
148.4	174.8	182.8	147	173.8	182.8	149.3	175.3	183.9	151.8	176.7	185.9	154.9	180.2	189.6	162.3	180.3	183.7
127.2	160	172.3	127.1	160.4	173.3	129.8	162.4	174.8	132.7	164.3	177.5	136.4	168.2	181.4	143.3	168.2	175
111	147.3	162.7	111.8	148.6	164.6	114.6	151.1	166.6	117.8	153.4	169.7	121.4	157.4	173.6	127.6	157.4	167
97.7	135.9	153.6	98.9	137.8	156.2	101.9	140.7	158.7	105.1	143.3	162	108.7	147.3	165.9	114.2	147.5	159.3
87	125.9	145.2	88.5	128.3	148.3	91.5	131.4	151.1	94.6	134.2	154.6	97.9	138.1	158.4	102.9	138.5	152.1

Figure 9 Input data for calculations

PERCENTAGE DROP OF TEMPERATURE [%]			
TIME	3 LAYERS	5 LAYERS	7 LAYERS
00:01:00	13.6	7.3	4.4
00:02:00	12.8	7.3	4.9
00:03:00	11.6	6.9	4.8
00:04:00	11.0	6.9	4.8
00:05:00	10.2	6.9	4.8
SUM	**59.3**	**35.0**	**23.7**

Figure 10 Temperature drop in percent

Form A consisting of 3 ceramic layers showed an almost 14 % drop in temperature with respect to the initial temperature after 1 minute, Form B, 5 - layer, showed a 2 times smaller decrease by about 7.5 % and for the C form - 7 layers value this amounted to 4.4 %. For form A, the temperature dropped every minute by more than 10 % and the accumulated percentage temperature drop during the 5-minute period was 59.3 %. Analogously for form B, the temperature dropped every minute with oscillating values ranging from 6.6- 7,3 %, and the final cumulative value was 35 %. Form C showed the smallest decrease, by about 4.4 - 4.9 % every minute, and the accumulation after 5 minutes was 23.7 %. Knowing the percentage value of temperature drop for individual mould thicknesses, it is possible to evaluate the mould thickness only on the basis of thermographic analysis of the heated mould. The test consisting in heating the form and recording the course of its cooling allows to determine whether the form has no defects in the form of thinning or thickening of the material. It is important to analyze numerical data, because the analysis of a thermographic image in the case of such complex structures is an insufficient center giving information about the quality of the form.

4. CONCLUSION

The use of thermovision in various fields is becoming more and more popular. Thanks to the advances in technology, the thermal imaging camera is an increasingly common tool. Its application in the foundry industry for thermal imaging is an innovative idea that will not only eliminate foundry defects, but can also bring many economic benefits, both by eliminating quality losses and speeding up the production process. Comparative studies of temperature drop for different thicknesses of ceramic moulds will allow detection of mould defects in the form of thinning or thickening affecting the crystallization conditions of the casted material. Further analysis using active thermovision and collecting more data will allow for more complex observations that will be able to be full-value tools

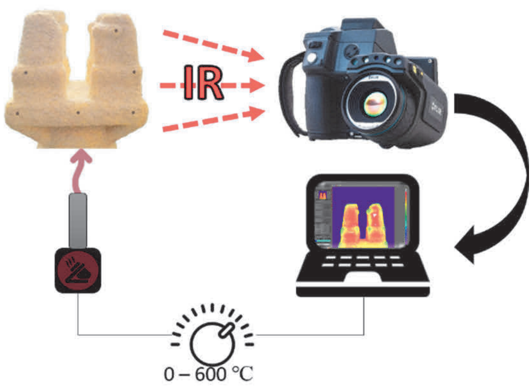


Figure 11 Scheme of active thermovision test bench

for qualitative and quantitative testing of ceramic moulds in the foundry industry. For further measurements, an active thermovision station will be used (**Figure 11**). The use of additional independent heat inductors will allow for the observation of dynamic temperature changes in the form.

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