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The Control of Solidification Kinetics of the Vacuum-cast Thin-wall Nickel-based Superalloys by Changing the Geometrical Characteristics of the Ceramic Mold

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Abstract

This paper provides an analysis of experimental research and results of investment casting process. Temperature field in a ceramic mold is one of the problems during numerical simulation. Reducing the costs of production in precision casting involves the reduction of scraps, which is one of the fundamental problems of the foundry industry. Reducing these costs is associated with optimization of precision casting technology of aircraft engines critical parts, including control of the solidification front in thin-walled castings of nickel super alloys cast in a vacuum. It is achieved by changing the geometrical characteristics of the ceramic mold. The results of the tests were used to optimize the industrial production of aircraft components in Precision Foundry of WSK Rzeszów. Temperature distribution gained in the conducted tests allowed verification and optimization of computer simulations.

Keywords: Nickel-based superalloys, Ceramic mold, Thin-walled castings, Investment casting

1. Introduction

The important technological problems occurring in the production of nickel-based superalloy casts include: developing conditions for pouring and solidification of casting and, what's involved, determining the effect of all factors on the orientation of the liquid metal solidification front and the cooling of it [1-3].

The problem of defects appearance in precision castings, despite the use of advanced technology, is not yet solved. There is no comprehensive study and evaluation of changes in temperature field in the cross-section of the ceramic mold during annealing, pouring and solidification processes of molten metal in the area of

thin-walled castings, such as the trailing edge of nickel-based superalloy blades cast in vacuum. These elements are used in low-pressure turbine aircraft engines. Lack of an access to knowledge about the distribution of temperature in the cross section of the ceramic mold during annealing, casting, solidification and cooling of the casting makes it impossible to determine the causes of defects, especially in thin-walled castings. This is due to a reserve of technological knowledge by global foundries which produce components for hot engines. In many precise foundries it is necessary to address these issues in case of changing types of castings as well as in the introduction of new types of materials [4-8].

The results of researches will allow to determine a precise effect of the ceramic layer thickness (the number of layers made) on the ceramic mold temperature distribution during annealing process as well as during the pre-filling process and solidification of nickel-based superalloy super thin-walled cast components. These data are necessary to determine the impact that the change of geometrical characteristics has on the temperature distribution of the ceramic mold. Hence, also on the direction of the solidification front. Obtained results will also be helpful to determine the correct annealing time of the ceramic mold. This knowledge will significantly contribute to the labour reduction, thus, to a substantial reduction of the cost of manufacturing of casting, not just airlines ones, but also other casting machine components manufactured by precise casting.

2. Methodology

The molds were performed at the precise foundry WSK PZL Rzeszów. Methodology for the molds execution was similar as in the case of production ones keeping all the process parameters so that the molds were made as similar as possible to the production ones in the means of physico-chemical properties.

Two model sets for casting wax plates were designed and built with dimensions shown in (Fig. 1). The shape of this cast provides enough flat surface for the precise placement of thermocouples. Four wax models with H-type gating system were combined into a model set. In order to stabilize and strengthen the model set and for better wax melting, 4 vents were applied in a further stage (Fig. 2a).

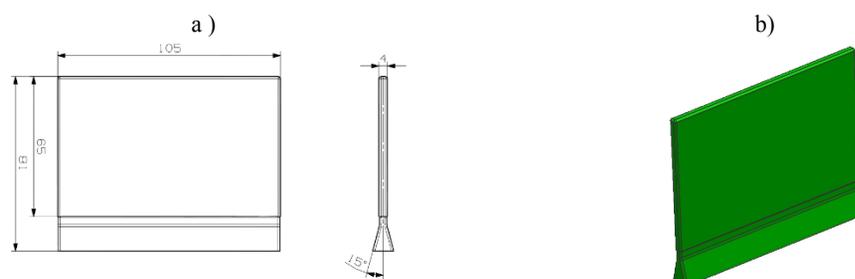


Fig. 1. Plates models a) geometrical dimensions, b) 3D model

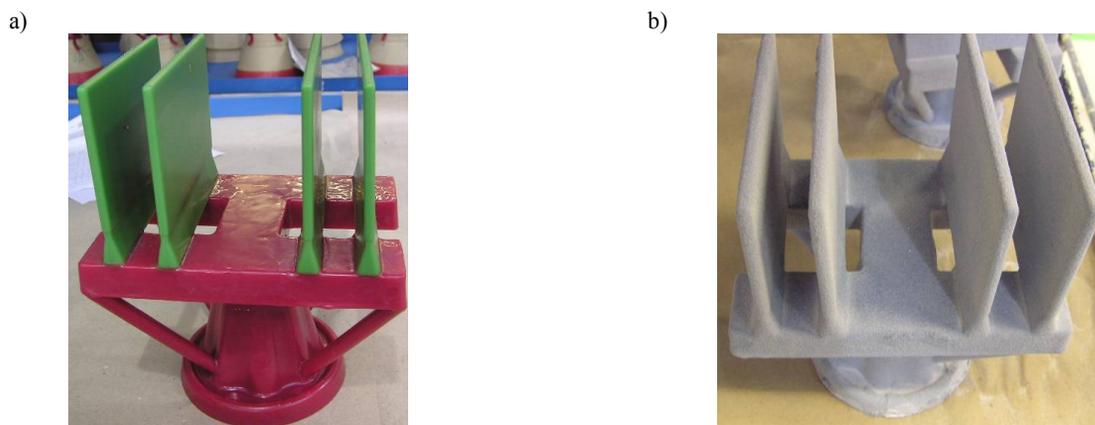
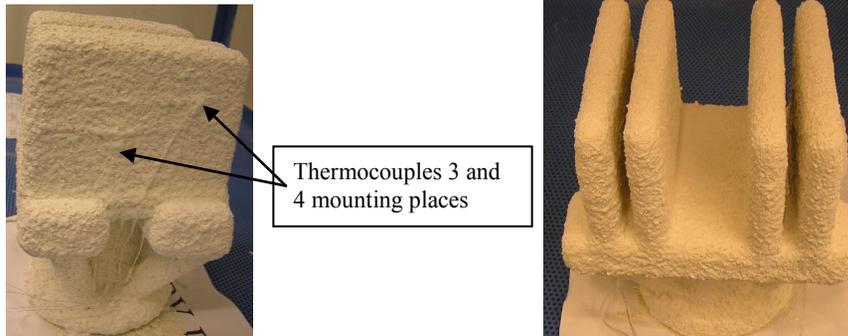


Fig. 2. a) Wax model set b) ceramic mold - after first layer application

Two wax sets formed the basis for the implementation of multi-layer ceramic molds. Ceramic molds were made with the use of alcohol coating. For the first layer $\text{CoAl}_2\text{O}_4 + \text{ZrSiO}_4$ were used (Fig.2b). This layer is characterized by good thermal conductivity and durability, and prevents the reaction of molten metal with a ceramic material. Afterwards, the next layers were applied with

placing thermocouples: Thermocouple #1 after 2nd layer, thermocouple # 2 after 3rd layer, thermocouple #3 after 4th layer and thermocouple #4 after 7th layers. Two molds fabricated with 9 and 11 layers coated. B-type thermocouples with 0.8 mm wire diameter were used for the measurement.

a)



b)



Fig. 3. Ceramic mold a) with 9 ceramic coatings, b) with 11 ceramic coatings

When all the sets of ceramic layers were ready, the assembly was dried for 48 hours at a suitable temperature and humidity. After drying the ceramic mold was placed in high-pressure autoclave to fuse out the wax. Pre-annealing was performed at 600°C for 2 h in order to remove the wax model residue. Then, insulating of the mold and pouring were performed (Fig. 4).

The solidification process of nickel-based superalloy IN713C castings was performed in Research and Development Laboratory for Aerospace Materials at Rzeszów University of Technology, in

a vacuum oven VIMIC 2 E - DS / SC produced by ALD Vacuum Technologies company. 6 kg load was inductively melted in vacuum - 2×10^{-3} [Pa]. Ceramic mold was placed in the heating chamber of the furnace and annealed at 1250°C in 110 min time. The molds were poured with nickel-based superalloy IN713C at a temperature of 1470°C and moved from the heating to cooling zone of the furnace in about 10 seconds. Afterwards, the cooling chamber was ventilated in about 60 seconds. The molds were cut (Fig. 5) removing the remains of the ceramic mold.

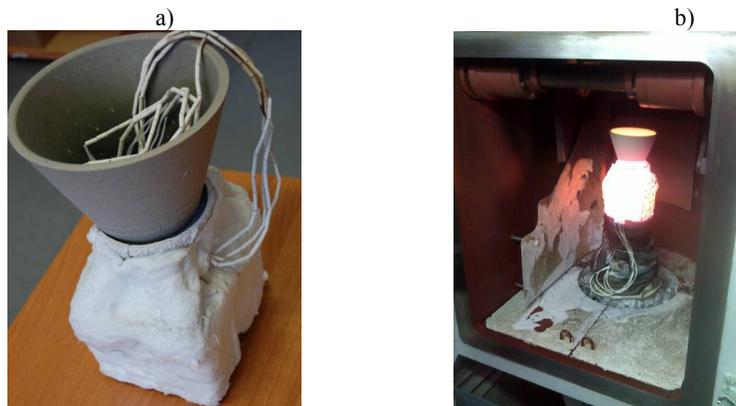


Fig. 4. a) insulated ceramic mold, b) mold after pouring

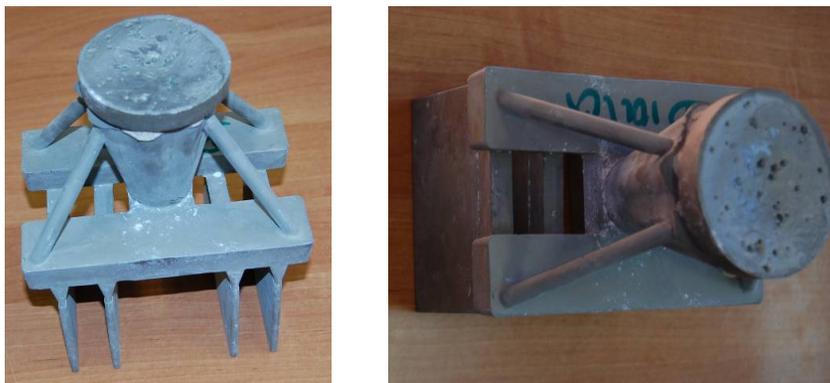


Fig. 5. Molds after pouring with molten metal and the removal of ceramics.

3. Results and discussion

After the experiment, the temperature change on the cross-section of the mold during annealing, pouring, solidification and

cooling was received. Depending on the quantity of the ceramic layers in the mold, temperature distribution was as follows (Figures 6-8):

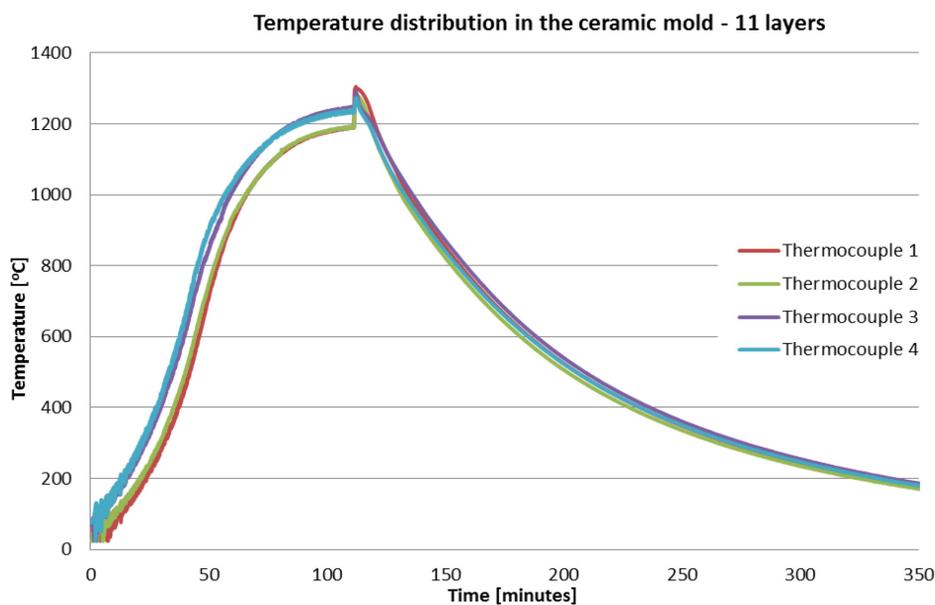


Fig. 6. Temperature distribution in the ceramic mold - 11 layers

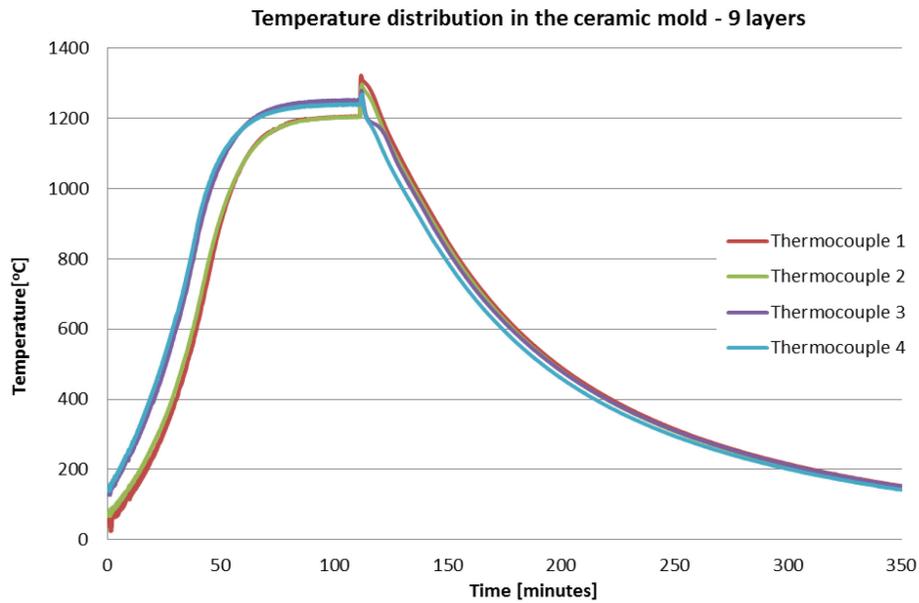


Fig. 7. Temperature distribution in the ceramic mold - 9 layers

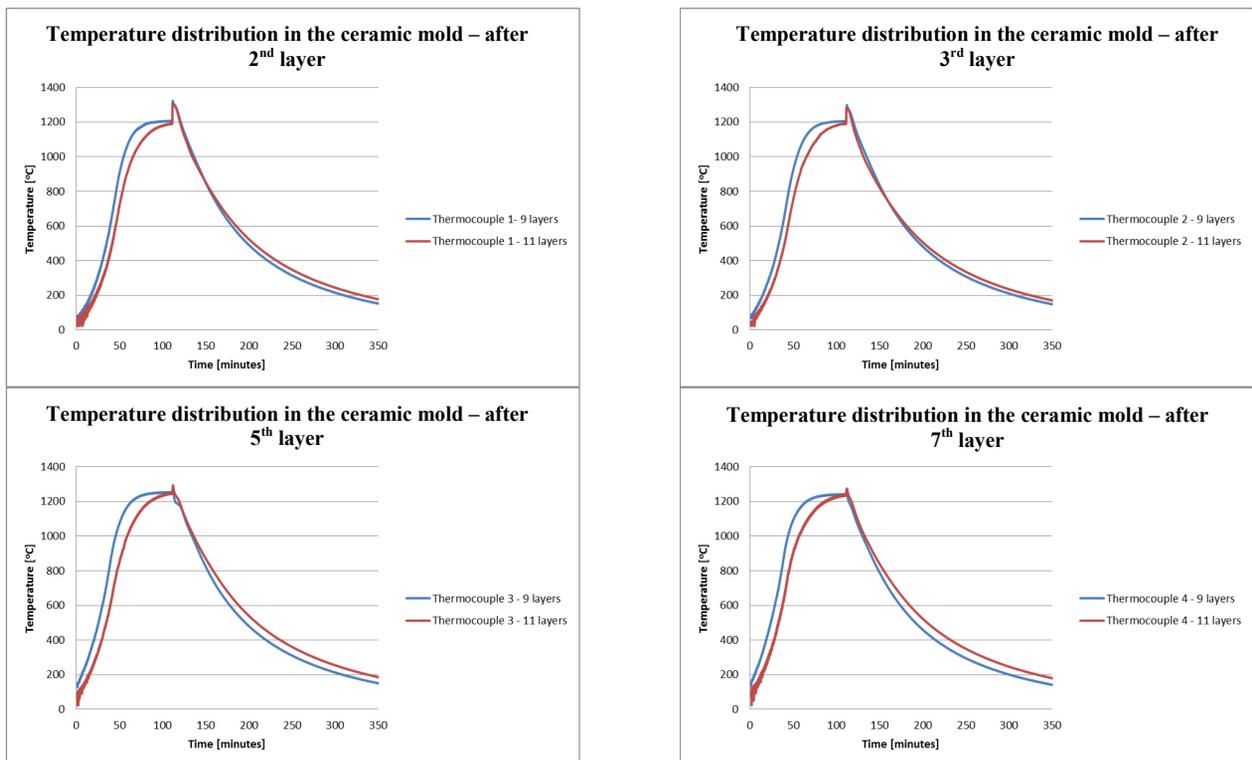


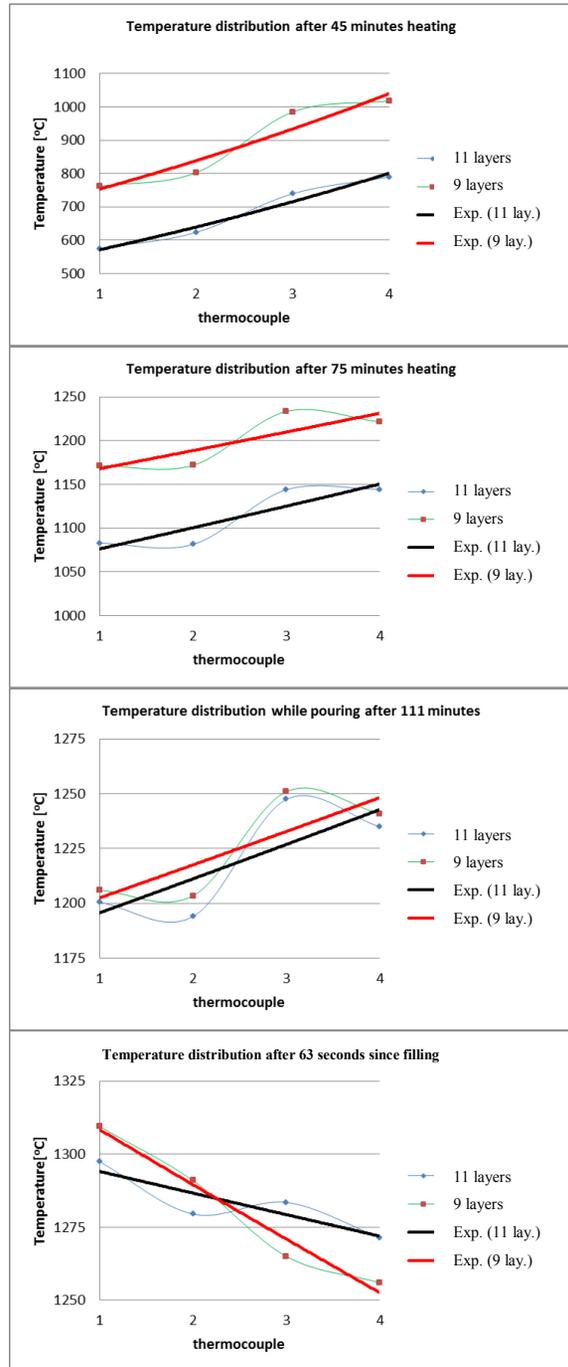
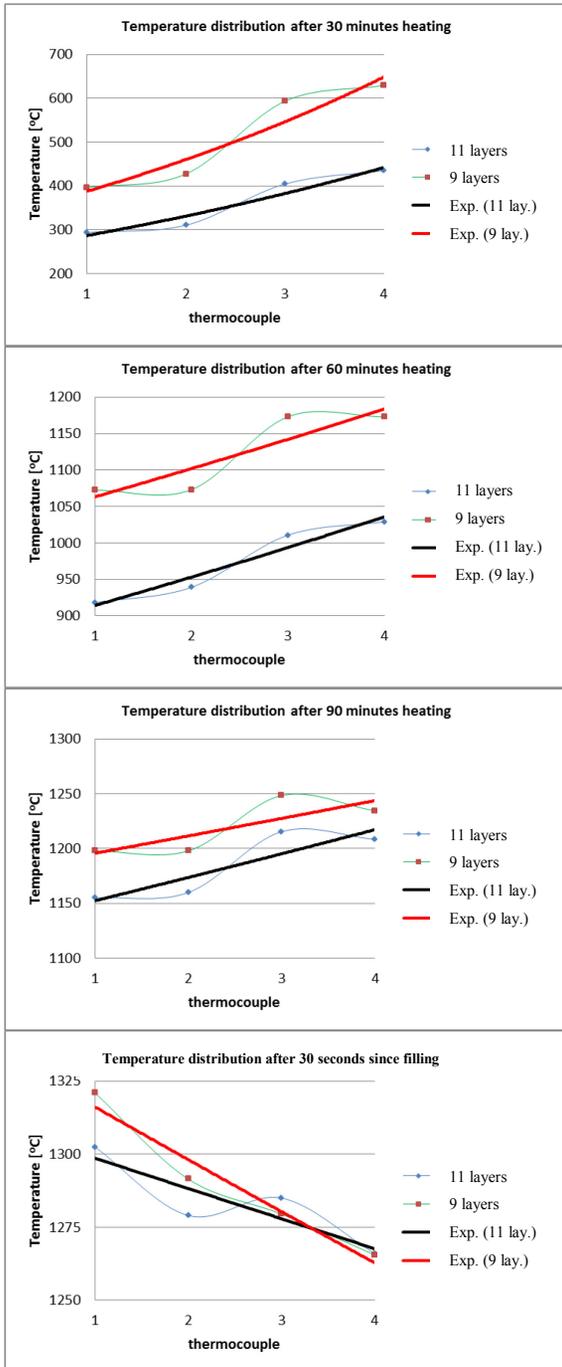
Fig. 8. Comparison of temperature distribution in the ceramic molds

The next step was to analyse the distribution of temperature on the cross-section of the ceramic mold during annealing, pouring of molten metal, solidification and cooling (Fig. 9). The aim of the study was:

- Determination and comparison of the temperature distribution in tested ceramic molds during annealing process after 30, 45, 60, 75 and 90 [min].
- Determination and comparison of the temperature distribution in tested ceramic molds during pouring of molten metal.

c) Determination and comparison of the temperature distribution in tested ceramic molds during solidification and cooling processed after 0 [s], 63 [s], 93 [s], 123 [s], 153 [s], 213 [s], 49

[min] 89 [min], 189 [min] and 268 [min] from the moment of molten metal pouring.



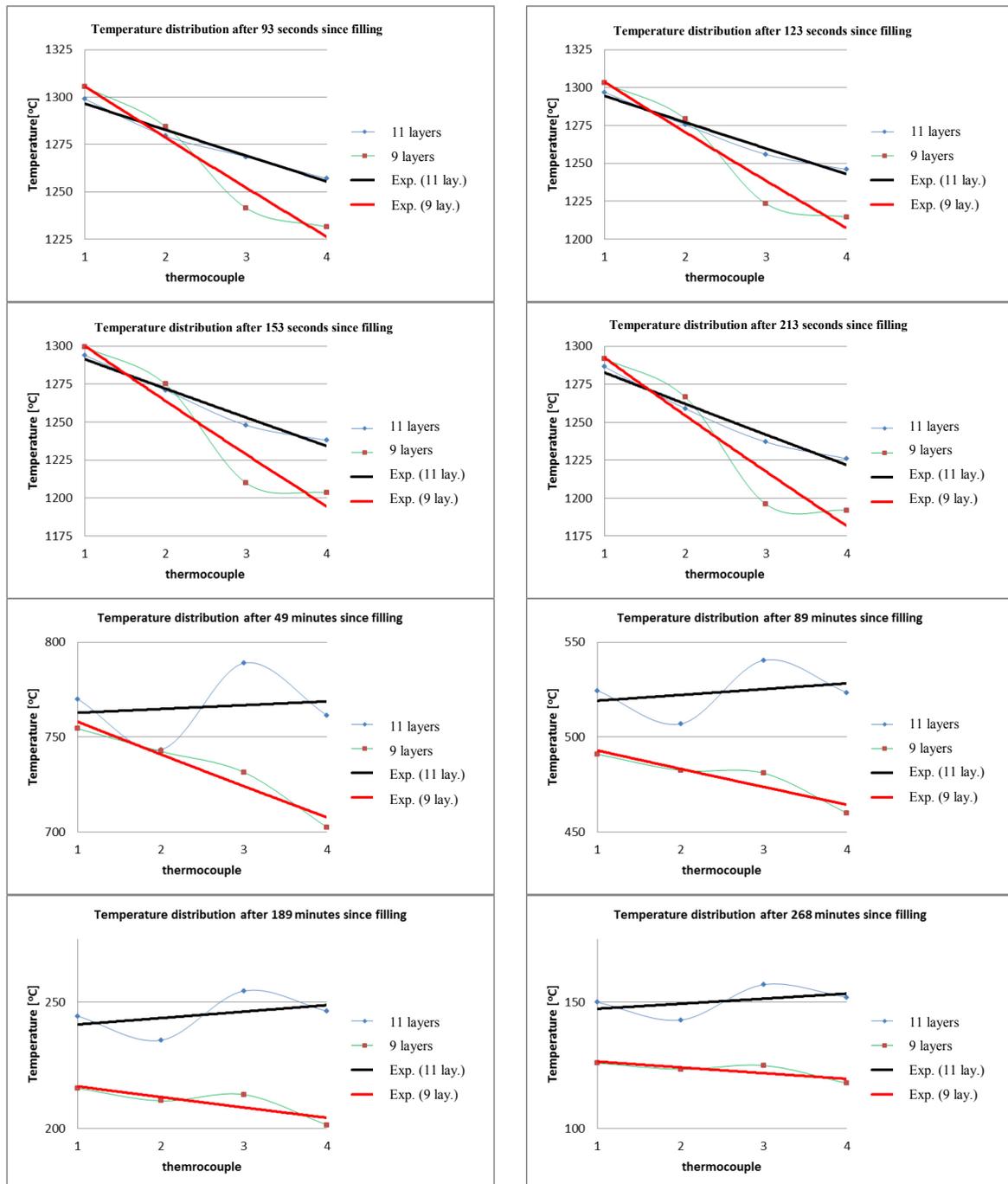


Fig. 9. Comparison of the temperature distribution in the studied sections of the ceramic molds

4. Summary

As a result of the experiment, the temperature distribution curves of ceramic molds with 9 and 11 layers (shells) were made. These curves allowed to determine the effect of selected geometric features changes on the temperature distribution in the studied

ceramic mold system, during annealing, pouring, solidification and cooling processes.

In the molds with 9 ceramic layers after 80 minutes of heating, temperature had been stabilized, however, it had not reached the ambient temperature (1250°C) throughout the section.

In the molds with 11 ceramic layers after 110 minutes of heating, temperature had been stabilized, however, it had not reached the ambient temperature (1250°C) throughout the section.

The temperature difference in the molds while pouring was slightly higher for the mold with 9 ceramic layers.

The maximum temperature recorded by the measuring system during pouring was 1305°C for 11 layers and 1322.5 °C for 9 layers.

For the mold with 9 layers a much larger temperature gradient was observed.

Mold with 9 layers cools down much faster by handing over the accumulated heat to the surroundings.

The results of the tests were used to optimize the industrial production of aircraft components in Precision Foundry of WSK Rzeszów. Temperature distribution gained in the conducted tests allowed verification and optimization of computer simulations. The results will also be used when designing the ceramic molds for new implemented products.

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References

- [1] Cygan, R., Sobczak, N. & Suchy, J.S. (2010). Thermal and physical properties of nickel superalloy and ceramic mold used for computer simulation. *International Foundry Research*, 62, No.1, 30 – 34.
- [2] Cygan, R., Sobczak, N. & Suchy, J.S. (2009). Interaction: Ceramic mold – metal in nickel superalloy casting. *International Foundry Research*, 61, No.3, 16 – 21.
- [3] Furgał, G. & Cygan, R. (2009). Quality problems root cause identification and variability reduction in casting processes. *Archives of Foundry Engineering, Volume 9, Issue 1/2009*, 13 – 16
- [4] Budzik, G., Matysiak, H., Cygan, R., Bąk, S. & Cygnar, M. (2010). Rapid prototyping process of monocrystal aircraft engine blades. *Journal of Kones Powertrain and Transport*, Warszawa, 81-86
- [5] Moskal, G., Cwajna, J., Bińczyk, F., Cygan, R., Witala, B. (2010). Influence of measurement results of thermal conductivity and heat transfer coefficients on the simulation results of casting process of aircraft engine elements made of monocrystalline and directionally crystallized superalloys, 6th International Conference on Diffusion in Solids and Liquids: Mass Transfer, Heat Transfer and Microstructure and Properties, DSL 2010, Paris, France 5-7 July, pp. 266
- [6] Sieniawski, J. (2002). Development of design methods and the assessment of the microstructure and properties of structural materials for aircraft technicians, Red. M. Hetmańczyk: *Postępy nauki o materiałach i inżynierii materiałowej*. Wyd. Pol. Śląskiej, Katowice (in Polish),
- [7] Sieniawski, J. (1995). *Criteria and methods of evaluation of the components of turbine aircraft engines*, Oficyna Wydawnicza Politechniki Rzeszowskiej, Rzeszów
- [8] Beeley, P.R., Smart, R.F. (1995). *Investment casting*, University Press, Cambridge UK,