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New Use of Instruments for More Accurate Wax Pattern Blade Segment Production

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Abstract

Precision casting is currently motivated by high demand especially for castings for the aerospace, automotive and gas turbine industries. High demands on precision of this parts pressure foundries to search for the new tools which can help them to improve the production. One of these tools is the numerical simulation of injection process, whereas such software especially for investment casting wax injection, process does not exist yet and for this case must be the existing software, for alloys or plastic, modified.

This paper focuses on the use of numerical simulations to predict the behavior of injected models of gas turbine blades segments. The properties of wax mixtures, which were imported into the Cadmould simulation software as a material model, were found. The results of the simulations were verified using the results of 3D scanning measurements of wax models. As a supporting technology for verifying the results was used the Infrared Thermography. .

Keywords: Innovative foundry technologies and materials, Application of information technology to the foundry industry, Investment casting, Gas turbines, Infrared thermography, Simulation

1. Introduction

The aim of this paper is examining the deformations of the wax blade segment model. It is a large and geometrically complicated component with significant varying wall thicknesses. Wax models of this type tend to vary in size from the desired shape.

Parameters of the injected wax were obtained in the previous experiments and follow [1]. These experiments include measuring the strength characteristics of waxes (mechanical properties), rheological properties, determination of specific heat capacity, determination of specific thermal conductivity, comparison of viscosity of waxes, and investigation of changes in the volume of waxes in relation to temperature.

For research was used filled wax Remet Hyfill B478. This type of wax is designed for a wide range of applications and contains 30% or more inert polymer filler content. REMET Hyfill wax is characterized by excellent dimensional reproducibility and the parts should thus have high dimensional stability and reduced shrinkage.

Table 1.
Remet Hyfill B478 parameters

Property	Method	Result
Melt Point	IP 371	70 °C
Congealing Point	IP 76	64,5 °C
Penetration 25 °C	IP 49	4 dmm
Brookfield Viscosity 80°C	DCF.1	830 cPs
Ash Content	DCF.2	<0,005 %
Filler Content	DCF.3	30,4 %
Color	DCF.4	green

In order to be able to describe in details where the production is due to inaccuracies of parts, it was important to map all the critical points that could affect the future quality of the blades segments and bring inaccuracies into the simulation. For this case were the infrared thermography and 3D scan measurement used.

2. Analysis of wax pattern blades segment manufacturing cycle

In order to be able to faithfully simulate the part injection process and to take into account all the additional influences during the evaluation, it was first necessary to analyze the wax injection process. The table below shows the basic parameters under which the blades were injected.

Table 2.
Injection parameters

Parameter	Value
Injection time	80 s
Injection pressure	2,5 Mpa
Packing time	180 s
Packing pressure	10 Mpa
Nozzle cleaning time	15 s
Wax temperature in the nozzle	68 °C
Cooling time	10 min

After injection and solidification in the mold, wax models are remove and placed in a jig, which is designed to stabilize the required shape in Figure 1. Once the reformer model is secured, the whole system is sink in a water bath at a temperature of between about 5 and 12 ° C for a period corresponding to about one production cycle. [6]

Fig. 1. Wax blades segments in the jigs

The main idea is to ensure the production cycle in such a way that one operator is able to control injection molding and manipulation with wax models without undue delay. The times for removing the molds from the molds demonstrate relatively stable handling mainly due to the ejectors which are part of the mold. In the Figure 2 it is possible to see a part of the assembled segment.

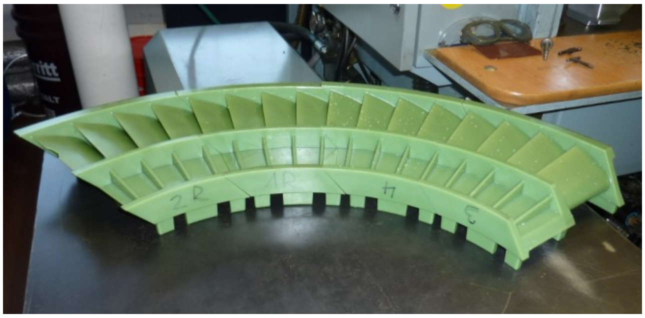

Fig. 2. Assembled wax patterns blade segment

In Figure 3 are the wax blades patterns segments already assembled.

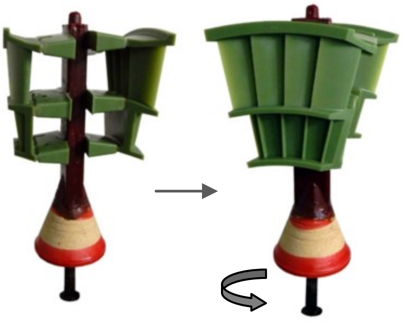

Fig. 3. Wax blades patterns segment assembled into patter cluster and prepared for coating (left – view how is model fixed on cluster, right – view on wax blade pattern segment)

At the beginning of the analysis of the production cycles were two first models injected, which served just to temper the whole system. During the entire experiment, the production of the camera was recorded, the thermal moments of the key moments were recorded and the entire cycle of the eight cycles of the experimental wax models was recorded.
In Figure 4 there is shown the real casting made of nickel alloy Inconel 713 only for making an idea.

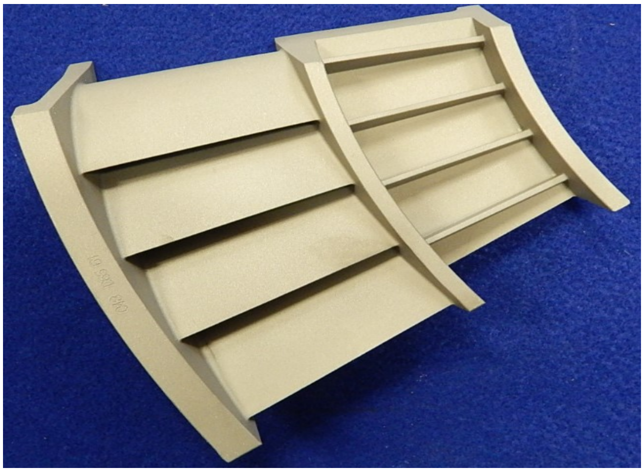

Fig. 4. The final casting

3. 3D scan measurement results compared to CAD values

For 3D scan measurement was used 3D scan ATOS Compact Scan 2M and evaluation software ATOS Professional V7.5 SR2. The models surfaced were not prepared for scanning to be as accurate as possible like in production. To measure 3D dimensions, the blade models that were the most different at the time of removal were deliberately chosen.

The reason for this selection is the basic assumption that dimensional stability in the wax modeling process affects the removal of the blades from the mold. During this operation, the blades are unstable, soft and therefore easily deformed. [3]

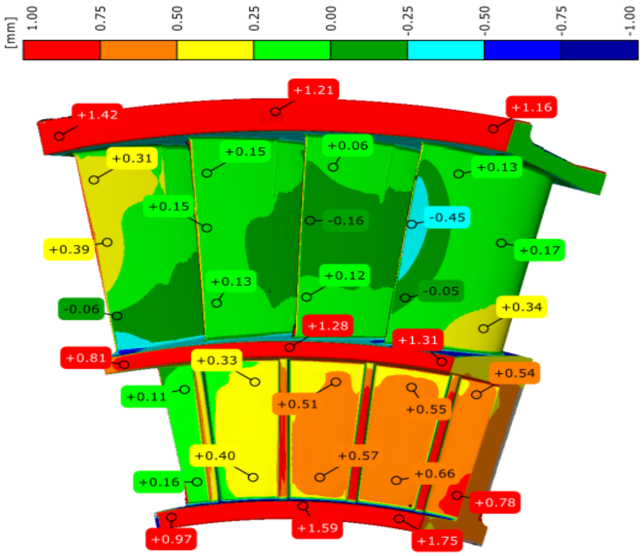

Fig. 5. First run piece – color map of dimension deviation (side B)

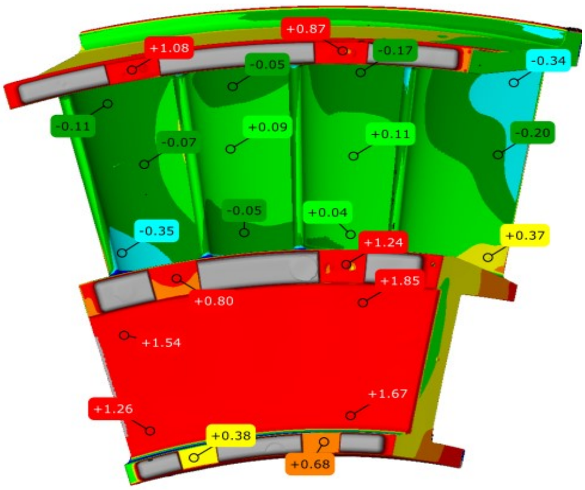

Fig. 6. First run piece – color map of dimension deviation (side A)

The results of the deformations shown on the color maps of the deviations from the CAD model for the 1st run piece and the last tested model are shown in the following Figures 5 to 8. It can be seen that the outer blade part has less deformation for the last piece, placed in a reformer and cooled in a water bath. The results of the internal area are affected by machining tolerances. However, in terms of overall deformations, they are better off in the case of the run-off piece.

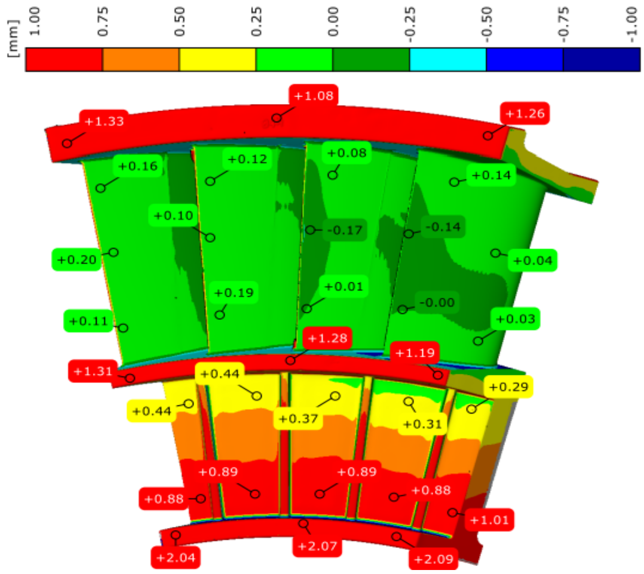

Fig. 7 Last run piece – color map of dimension deviation (side B)

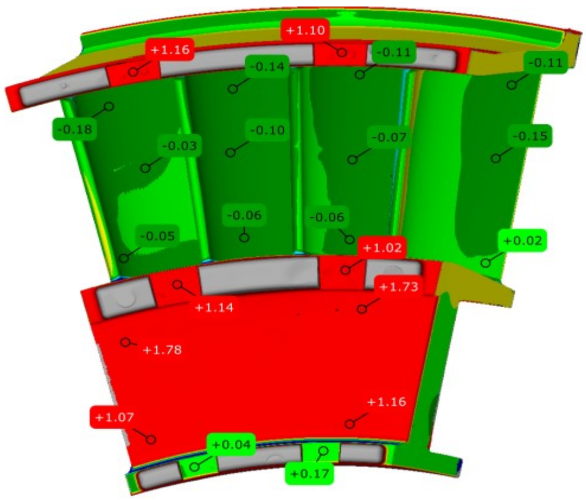

Fig. 8 Last run piece – color map of dimension deviation (side A)

The entire blade segment can be divided into two basic parts. The outer part is made up of blades where the ratio of the cooled surface to the blade volume is significantly higher than that of the inner part made up of significantly more massive elements. For this reason, there is considerable tension during the cooling of the model as a whole.

4. Infrared Thermography analysis

Another tool used to ensure accuracy of production was infrared thermography. [4] The Figures 9 and 10 capture the surface temperatures of the wax model at the time of its removal from the mold. Maximum temperatures are around 47 ° C and minimum around 25 ° C.

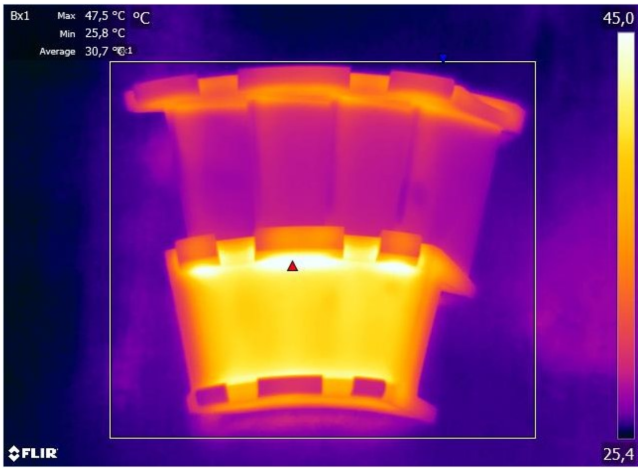

Fig. 9. Temperature on the A side after removal from the mould

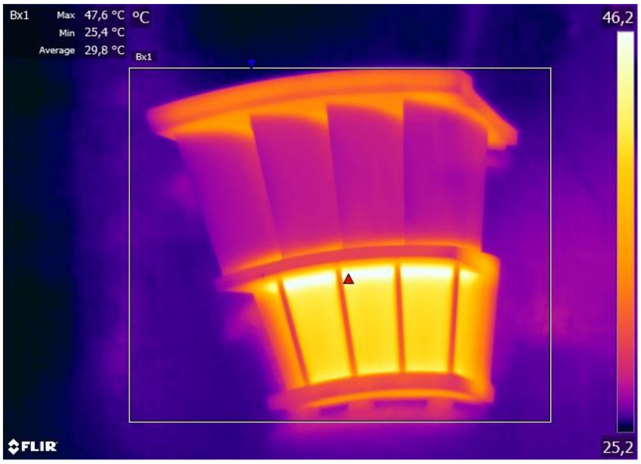

Fig. 10. Temperature on the B side after removal from the mould

The following Figures 11 and 12 describe temperature differences of the surface of the component after 10 minutes of cooling in the water bath. First of all, Figure 8 is the apparent mass difference between the two parts of the blade segment. The temperature of the inner part, after 10 minutes of cooling, still reaches about 40 °C from the outlet side, the blade part already being cooled to 11 °C. This temperature difference must cause tension throughout the part and it is a big problem to achieve dimensional requirements.

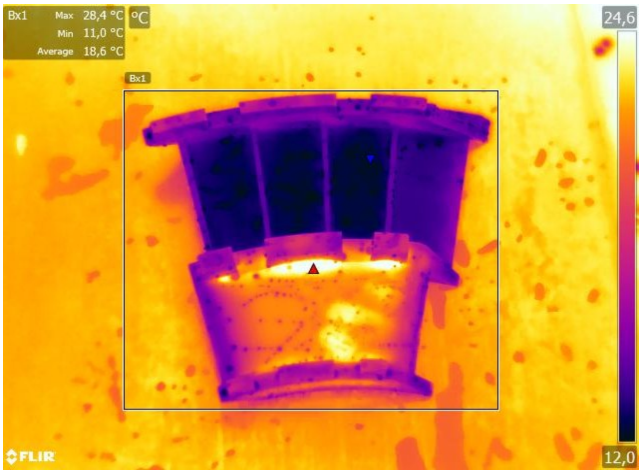

Fig. 11. Temperature on the A side after 10 minutes of cooling

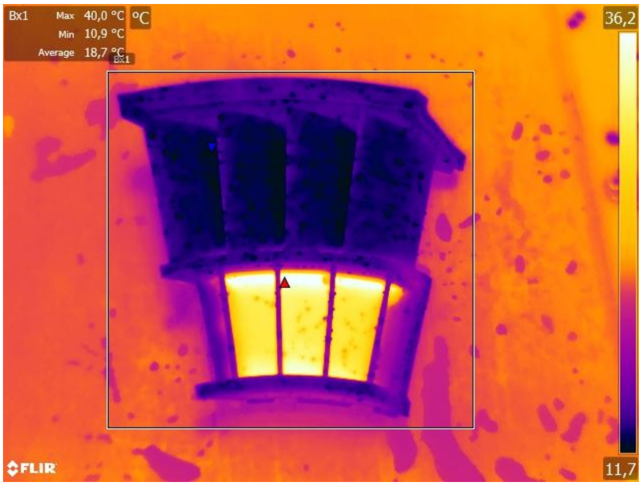

Fig. 12. Temperature on the B side after 10 minutes of cooling

For better interpretation of the results of infrared thermography analysis shows the geometric construction of the model. This construction was generated from Cadmould software. [7]

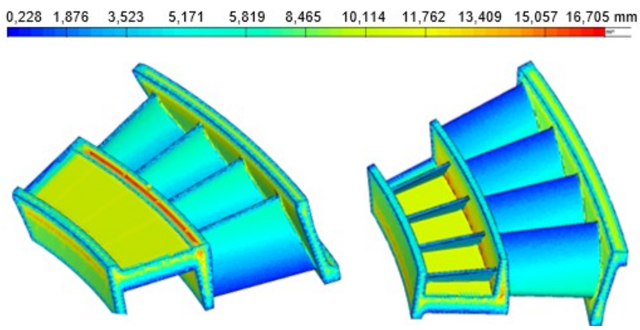

Fig. 13. Wall thickness analysis

5. Simulation in Cadmould Software

The task of the experiment was to compare the measured values with the simulation results. Simulation parameters were set to the same parameters as for real production. Parameters are in the Table 2. Because the Cadmould program needs for simulation more parameters, than the ones listed by the manufacturer, the remaining parameters were determined experimentally [2].
The mold filling process was experimentally performed in the Cadmould simulation software.[8]

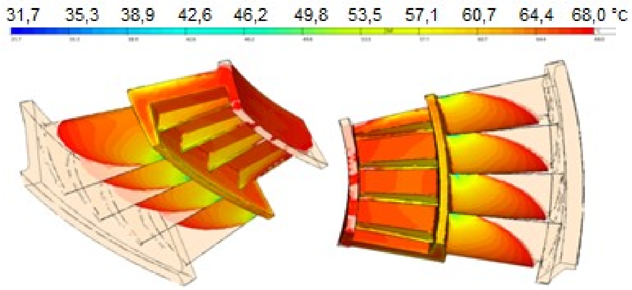

Fig. 14. Mold filling

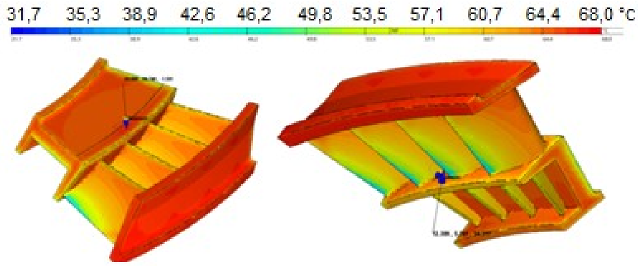

Fig. 15. Maximum and minimum part temperature after filling

In Figure 14 is the max. temperature after mold filling 67,2° C and the min. temperature is 32,8° C.
Except infrared thermography analysis there were numerical simulations performed which should predict the overall process of filling. [5] The simulated temperature immediately after opening the mold (completion of the filling cycle + 150 s of cooling time) is presented in the Figure 16 and Figure 17. The results show that the maximum temperature is about 60 °C in the area of inlet. The area corresponds to the measured values. The measured temperature is lower but there is a time shift between the simulation and the real measurement. The part made up of blades has a temperature bellow 30 °C.

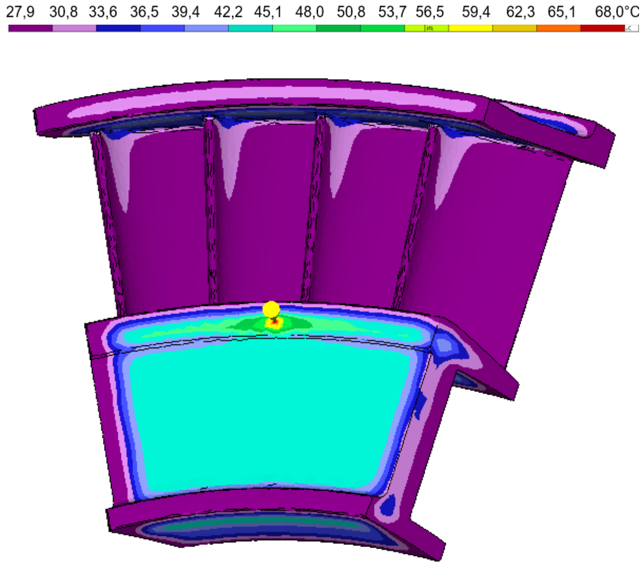

Fig. 16. Simulated temperature on the A side immediately after opening of the mould

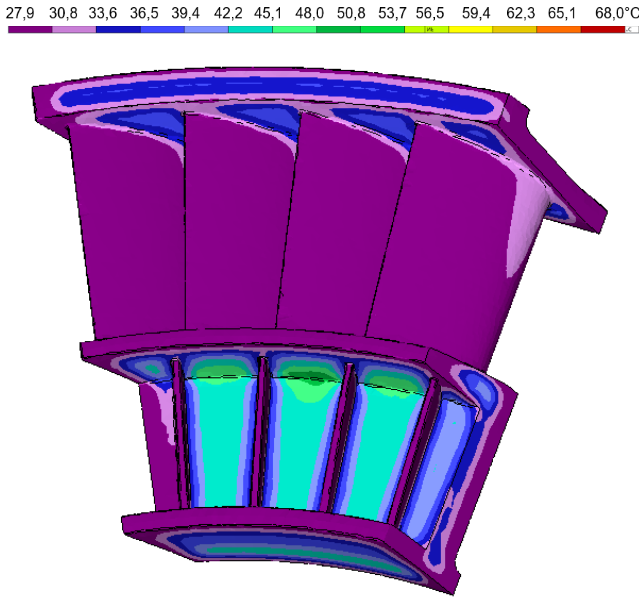

Fig. 17. Simulated temperature on the B side immediately after opening of the mould

Another very interesting result which is able to be reached from the simulation software is the prediction of predeformation of the wax model as it is seen in following Figures 18 and 19. [8]

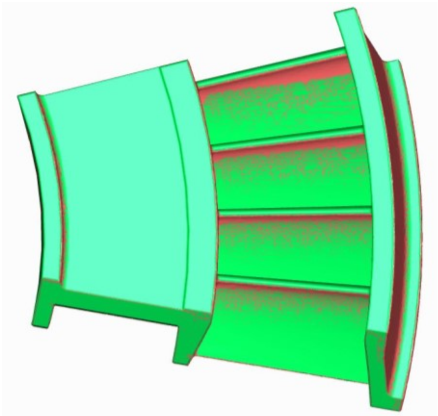

Fig. 18. Prediction of the predeformed model (A side)

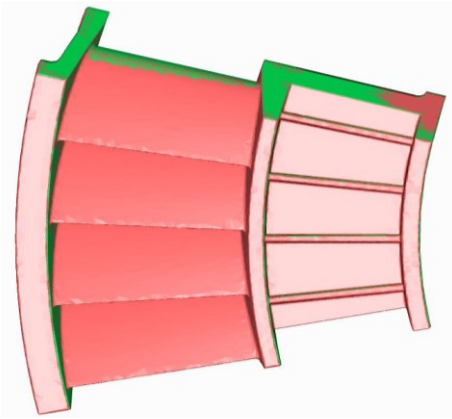

Fig. 19. Prediction of the predeformed model (B side)

The red color represents the shape of nominal CAD model and the green color shows the shape which should be reached from the mould. After following deformation process the wax model should get into the required shape. From the Figure is obvious that the blades have the tendency to get open, therefore the predeformed model requires to be closed.

6. Conclusion

The article presents the results of a part of extensive research focused on the use of simulation software for predicting the behavior and defects of wax models.

Based on the results of partial experiments, the following conclusions were reached:

The main insight is, that it is necessary to reduce the temperature differences between the parts of the blade segment, which can be achieved in several ways:

1. Significantly higher wear time for the requirement to leave the wax model in the dimension stabilizer (disadvantage - prolongation of the duty cycle)
2. During injection, use a casting to reduce the differences in wall thickness across the entire volume of the segment
3. Remove the material from the inside of the segment - for example, the pressed model would have circular cross-section holes in which the wax rollers would be rolled again after cooling to eliminate the temperature differences throughout the system (disadvantage: mold intervention + consequent labor).

Acknowledgements

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