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Monitoring of Manufacture Stability of Large Turbine Blades Using Infrared Thermography (IRT) in Investment Casting Technology

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Abstract

With increasing technology development, an increasing emphasis is placed on the precision of products, but cannot be guaranteed without a stable production process. To ensure the stability of the production process, it is necessary to monitor it in detail, find its critical locations and eliminate or at least control it. With such a precise manufacturing method as investment casting, such a process is a must.

This paper therefore deals with monitoring the production process of wax models of large turbine blades using infrared thermography. The aim was to evaluate the critical locations of this production and to propose recommendations for their elimination or, at the very least, significant mitigation of their impact on the final quality of the large turbine blade casting.

Keywords: Castings Defects, Product Development, Investment Casting, Wax Pattern, Turbine Blades, Thermography, Deformation

1. Introduction

The reason for focusing on the production process to produce wax models was the fact that after the casting of this type of component the casting had a deviation from the required dimensions. Research has revealed that the effect on the resulting dimensional imbalance is not only the casting process but also the wax blade model injection process itself. The turbine blade is one of the most important parts of turbine machines. Deformation of castings is an important parameter for evaluating the quality of the turbine blade. In order to control the deformation of the turbine blade during investment casting, infrared thermography was used in this experiment to determine the heat fluxes during cooling of the wax blade models and their temperature influence, which contributes to their deformation. In addition, the influence of the human factor during blade production on their deformation was also investigated.

2. Evaluation of thermograms from wax pattern blades injection process

This experiment deals with the production of wax blades model with a length of 400 mm.

2.1. Manufacturing cycle

The manufacturing cycle has been designed as follows: mold assembling, wax blade model injection for 60 and 180 s. Further, removal from the mold, removal of the inlet, insertion into the reformer, immersion in water, starting the injection of the next blade, after 600 seconds of removal of the reformer from the cooling bath, removal of the wax blade model, placing in the preparation and preparation of the mold for further injection.

Table 1.
Injection cycle

Activity	Parameter
Wax temperature	60 °C
Intensity of pressure	3,4 MPa
Wax flow	200 cm^3/ sec
Pressing time	60 s
Cooling time in water bath	600 s

2.2. Thermographic record of production cycle

Experimentally, thermograms of continuously pressed wax models were recorded. The Thermocamera FLIR T640 with emissivity coefficient 0,96 and evaluating software TOOLS+ were used for the measurement.

To include all the possible heat effects on the blade, attempts were made to record reformer temperatures after tempering in the chilled bath and after removing the first wax blade model. By comparing the two thermograms, a change in temperature between 2 and 5 degrees is evident. Due to the surface finish of the glossy aluminum reformer, the temperature of the surrounding objects is reflected, so surface temperature cannot be objectively evaluated. The temperature analysis of the mold cannot be done for the same reason as the reformer. It reflects the temperature of surrounding objects and people, which leads to thermograms degradation.

After being removed from the injection molding machine, a large blade is transferred to the stabilizing fixative, where it is allowed to cool for 10 minutes and then transferred to a straightening preparation, where it is cooled for another 10 minutes.

Figure 1 shows how the wax blade model is located in the fixative. Can be observed that the temperature distribution corresponds to the temperature field after the removal, recorded on the free-flowing blade in the stand. It can be seen from Figure 2 that despite the use of the fixation device, the temperature is practically at a maximum of 36 ° C. That is 2 ° C more than it was inserted.

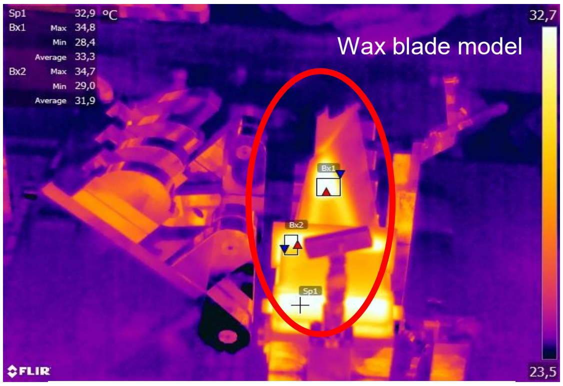

Fig. 1. Insert a wax blade model into the fixative

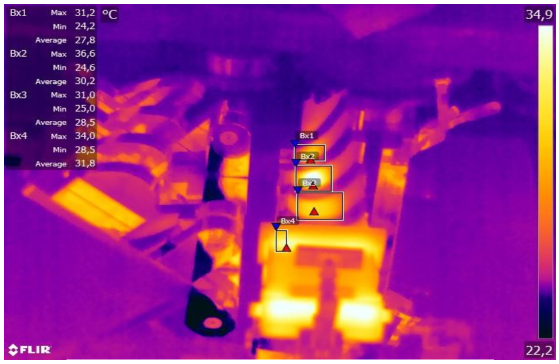

Fig. 2. Opening the fixative after 10 minutes

In the places where the fixation device touches the vanes, it can be seen that the heat dissipation was more pronounced, but the space between the fins of the fixative is still extremely high. It can be seen from Figure 1 and 2 that it is necessary to quench in a different and substantially faster manner, because the pressing cycle is about 4 minutes and the cooling in the preparation was tested 2.5 times longer than the production cycle of the new wax model of the blade. This results in the need for more products, which is extremely costly in nature (there must be at least 3 fixing and 3 straightening products). Therefore, it is advisable to perform a fixation of the preparation in the cooling water at 10 ° C after removal. This should balance for the temperature field and the maximum temperature in the blade should not exceed the ambient temperature. This will then ensure dimensional stability of the wax blade model during the process.

The first 9 wax blade models were placed in horizontally position Figure 3 in preparations for the total production cycle of 2 wax blade models due to the assumed stabilization of the dimensions. They were then transferred to the preparation. The thermocouple record showed the temperature influence of the cooled wax blade model with the product itself. This is not a significant influence that should affect the resulting deformation of wax models, mainly due to the same temperature of the product as ambient temperature. However, the horizontally position is unsuitable for deformation. It is recommended after cooling in the bath to hang the products directly into the hinge.

Fig. 3. Horizontally position

On the figure 4 the wax blade models are inserted into the hinge. The first two blades were not cooled in the water bath, and there is a difference in temperature in comparable areas of about 4 ° C.

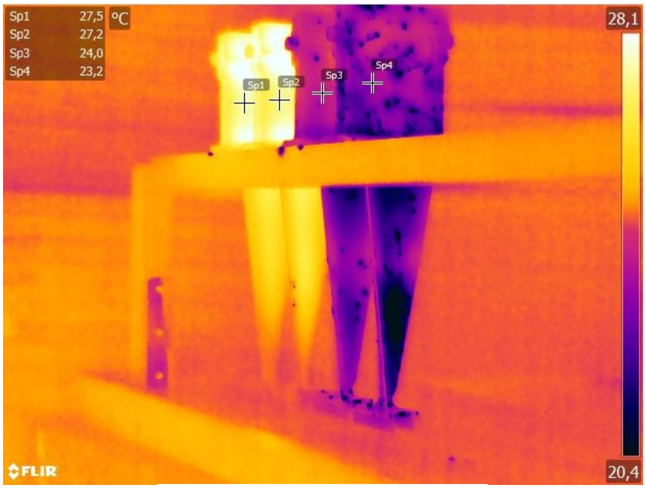

Fig. 4. Wax blade models in hinge

Temperatures of comparable areas are recorded on individual thermographs. The first two wax blade models 10 and 11 were in the water bath for lunch all the time, that is 3000 and 2400 seconds, which is why the thermographs appear cooler over time than blades 12 and above. After the model is removed from the cooling bath immediately, its surface temperature is very low, up to around 13 ° C. The temperature is then increased and the temperature rises to ambient temperature. This is particularly noticeable on thin portions, such as a blade sheet. For wax blade models 10 and 11, it has been observed that the balancing of the temperature of the massive areas, such as the lock part, takes substantially longer and that after the pressing of the next 7 blades the temperature is between 21 and 22 ° C.

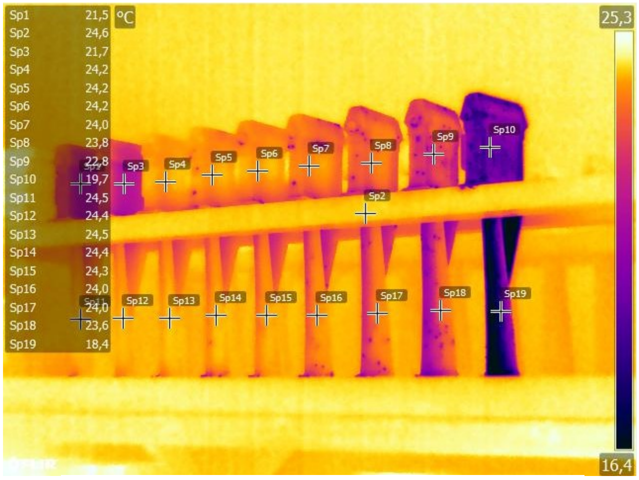

Fig. 5. Blades Nr. 10, 11, 12, 13, 14, 15, 16, 17 and 18

2.3. The thermal influences during gluing process

As part of the blade production process, the glue blades were glued to the grommets after pressing and cooling of the wax models. Both the handling of the camera and the temperature field of the blades and their surroundings were recorded. In Fig. 6 shows one of many potential causes of thermal influence during wax modeling. It is a scalpel and wire heating and bonding tool and a wax modeling pad. This effect would be noticeable only in the case of immediate contact with or in the vicinity of objects. There was no contact during the gluing of all 6 trees.

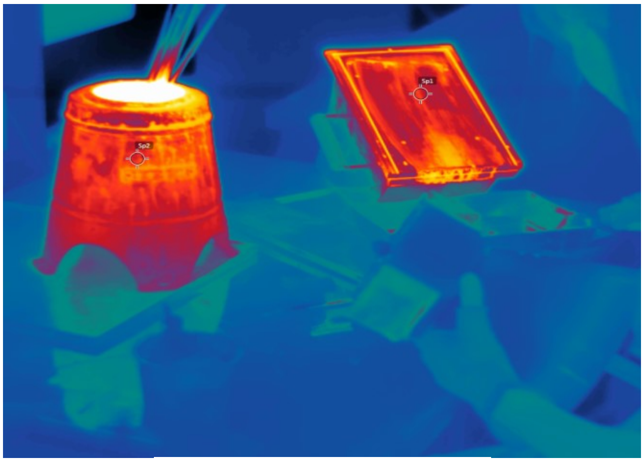
Fig. 6. Potential thermal influences

Perhaps the greatest thermal effect occurs during bonding itself with the use of heated tools. Because thermograms capture only surface temperature, the magnitude of the effects can not be directly detected. In Fig. 7 is the temperature of the bonded joint up to 43 ° C. Waxing must occur when bonding occurs. The rate of subsequent cooling is relatively large, therefore it is only supposed to affect the surface.

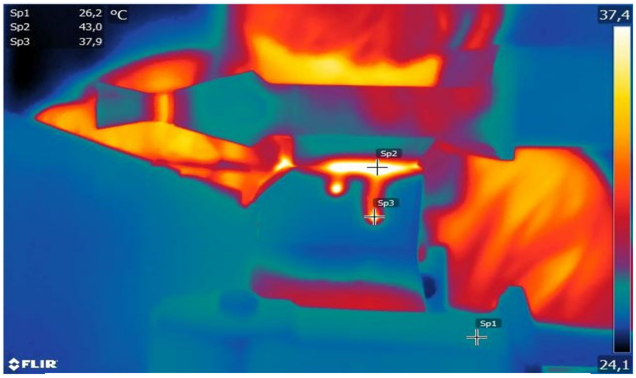

Fig. 7. Thermal influences of wax model during bonding

2.4. The thermal influences during moulding process

Another process, during the production of blades, where a significant thermal effect can occur, is the soaking and coating process in ceramic slurries. During the production of the first ceramic layer should not affect the dimensions of the resulting product. The temperature when soaking in the slurry and the backfill is equal to the ambient temperature, and there is no other influence on the production. Handling the tree was done exactly according to the technology. Consequently, the manufacture of the first ceramic package should not affect the dimensions of the resulting product.

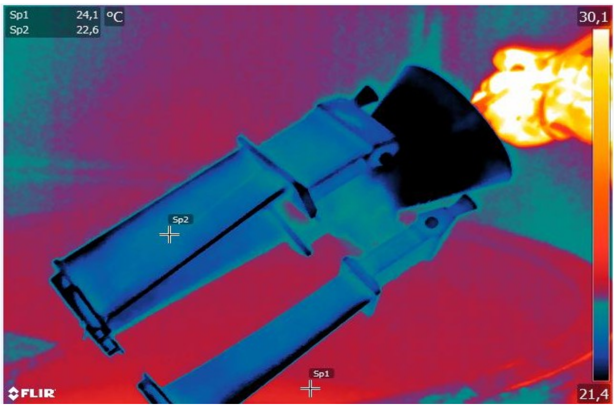

Fig. 8. The process of producing the first ceramic package

The production of the second package is the same as for the first wrapping manually. Both packs are water-based, so the curing times of each wrapper must be kept around 24 hours. During soaking in the ceramic slurry, there is no thermal influence again, however, when the tree is suspended from the engine. All show thermograms in Fig. 9 where the affected area is highlighted with black oval. Recommendation is to find a more suitable location within the workplace.

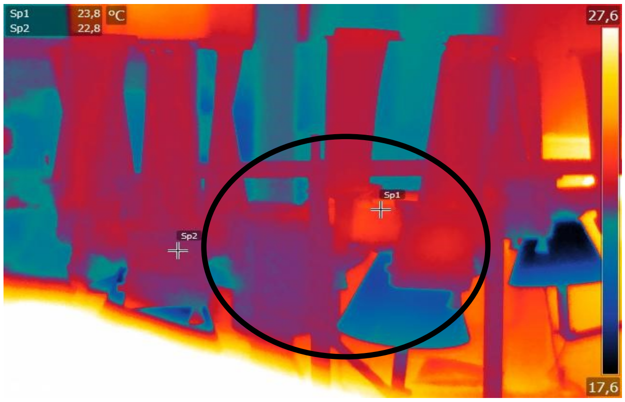

Fig. 9. The process of producing the second ceramic package

The recording of the temperature field of the automated production of the following ceramic layers did not show any significant thermal effects that would have a greater impact on the dimensional stability of the wax models.

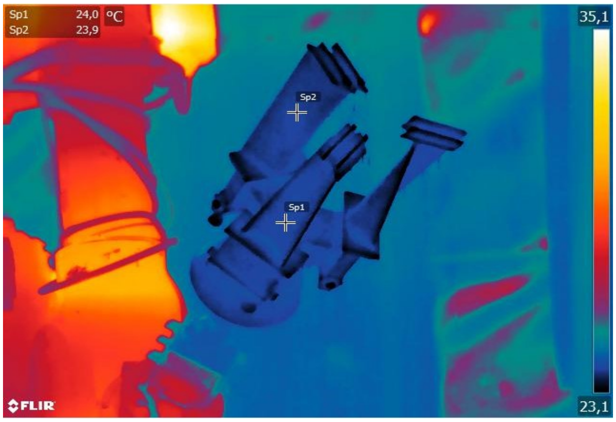

Fig. 10. Automatic production of the following ceramic packaging

The risk of affecting the resulting dimensions can be reduced by adhering to well-defined technology regulations.

3. Evaluation of blades by 3D scan

3D scans were performed to verify the accuracy of the measures used. Their evaluation is used to detect deformation blades.

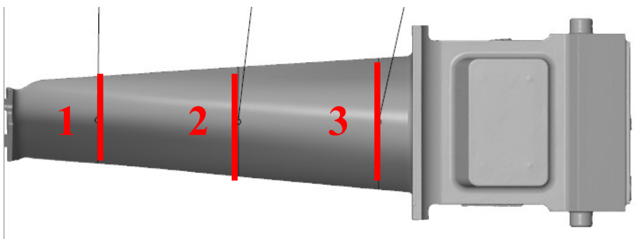

Fig. 11. Illustration of the location of the evaluated cuts on the blade

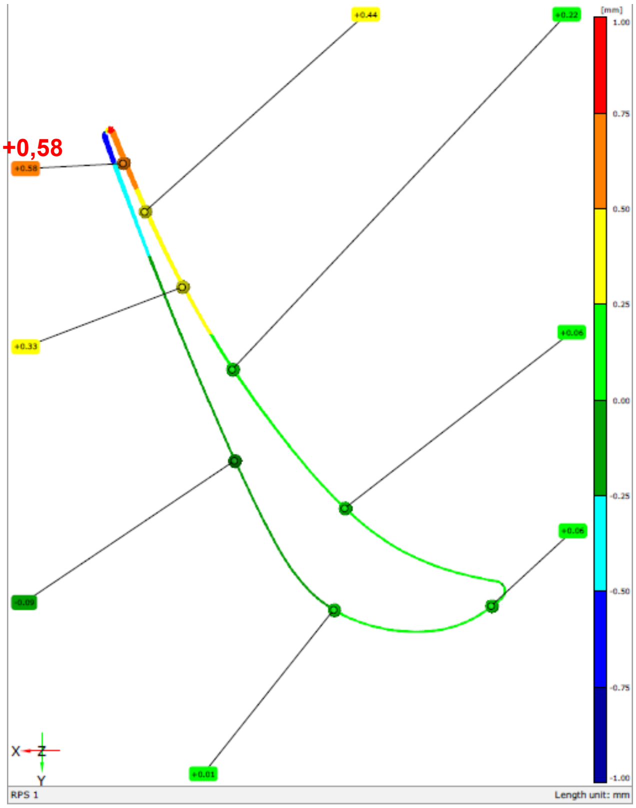

Fig.12. Cut 1

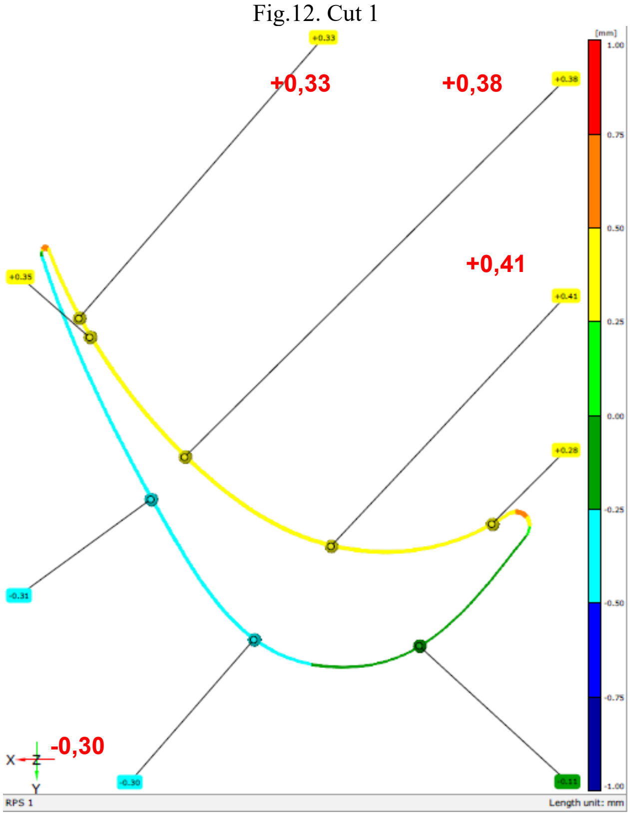

Fig. 13. Cut 2

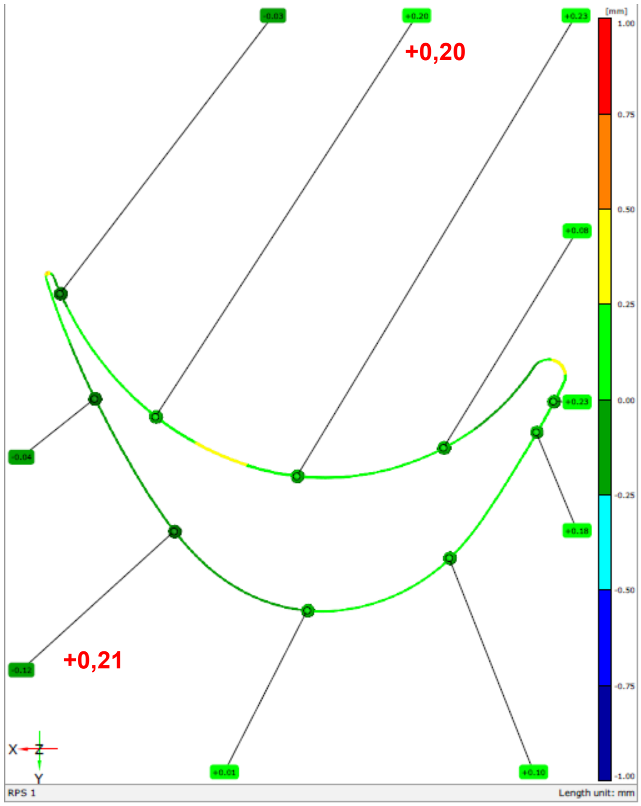

Fig. 14. Cut 3

On the outer side, the values of the plus, on the inside are minuscule. A possible solution would be to modify the form, but inappropriately. It would be necessary to incinerate the material so that the final dimension of the wax model would be shortened.

4. Conclusion

Below are the individual partial conclusions of the experiments.

Reformer

The Reformer is removed for 1 minute before the end of the wax blade model press cycle. Based on practical experience, it must be ensured that there is no confusion between reformers. This is possible, for example, by placing a marker or any object on the reformer to make it absolutely clear with the freshly pressed blade. This, of course, requires the operator to adhere to technological discipline. The bearing surfaces of the preparation are not provided with any insert - The bearing surface has a sharp edge and can damage the wax blade model. It would be advisable to provide these areas with a liner.

Evaluation of thermographic measurement

According to the initial results of the thermal camera, it is obvious that the metal preparation, which is to serve for the complete cooling of the wax blade model, rather heats the blades rather than to dissipate the heat. The same applies to the load that is laid on the blade due to deformation. It is clear from the images from the thermo-camera that the hinge is much more suited than the stowage agent for the heat of the blades. The wax blade model in the hanger cools more evenly.

Cooling bath

On the basis of the analysis of the results of the bath temperature results, it is crucial that the temperature of the reformer and the bath (water) itself are sufficient to ensure the thermal stability of the cooling. It is absolutely necessary to temper the bath at a suitable temperature - ie 10 ° C before starting the wax blade model pressing process. The cooling effect of the cooling bath and the reformer has a significant influence on the fluctuation of this temperature.

In order to maintain the temperature, a metal bath with insulation, possibly with a cover (eg polystyrene insulation) would be more suitable. However, for the experimental series of blade presses, the plastic bathtub was sufficient. For the industrial use of the bath it is then necessary to consider its ergonomics. The wax blade model storage device has a considerable weight, so it is necessary for the operator to have this bath at ergonomic height.

The reformer has a great effect on the temperature fluctuations of the bath. However, after tempering, the temperature stabilizes and, on the contrary, this reformer helps maintain the temperature. To speed up the bath tempering process, before starting the stamping cycle, it would be advisable to place the reformer in the refrigerator in order to avoid as much as possible the subsequent heat loss.

From the figures, it is clear that the reformer was not completely immersed in the bath. However, this is due to experimental conditions. For self-production it is necessary to ensure complete immersion of the reformer.

Mould for wax patterns

After pressing, the wax blade model remains random in one or the other half of the mold. It is not possible to influence the operator in which half of the blade remains. From the right half of the mold, the wax blade model can only be removed with difficulty, while it can be removed very easily from the left half. It is necessary to adjust the shape and thus facilitate the removal of the blade. Otherwise, the operator is forced to release the wax blade model, which leads to an undesirable extension of the cycle time between the wax blade model removal and the bathing, and in particular this can cause subsequent undesired deformation of the blade.

Gluing and moulding process

Thermographic results indicate that thermal influences during the bonding process should not have a more serious impact on wax model dimensions. In the case of bonding, it turned out to be an inappropriate manipulation where the blades lay unnecessarily on the table instead of being hanged in the preparation until the last moment. These potential causes of dimensional instability need to be eradicated throughout the production range.

Packaging proceeded without difficulty and without apparent potential causes of dimensional imbalances. The only significant problem was the placement of the product on the hanging of the tree after the second pack, when the tree was near the engine and there was a slight heating. This deficiency is simply solved by more convenient placement of the workplace according to the needs of the operator.

The main conclusions that can be made on the basis of the conducted experiments are as follows:

– The removal of the wax blade models from the injection molding should be stabilized.
– The 3D scans of the two selected blades clearly showed the problem of removing the wax blade models from the mold
– 3D scans have shown a problem with the blade length
– It is necessary to modify the injection molding - addition to the ejector plate (a very important problem!)
– Recommended watering device for water temperature around 10 ° C - not designed (was replaced by washbasin and ice)
– There is no significant thermal influence during wax blade model bonding, model manipulation is problematic
– Packaging in ceramic slurries and overburden has no significant effect on the resulting dimensions
– Placement of the product on the hanging of the tree after the second packing has to be solved within the workplace

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References

[1] Kubelkova, I., Herman, A. & Vratny, O. (2017). Evaluation of Critical Places on Wax Patterns of Blades. Proceedings of the 28th DAAAM International Symposium (pp.1126-1135), B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-11-2, ISSN 1726-9679, Vienna, Austria. DOI: 10.2507/28th.daaam.proceedings.157.

[2] Dong, Y.W., Zhao, Q., Li, X.I., Li, X.J. & Yang, J. (2017). Methodology to develop geometric modeling of accurate drilled cooling holes on turbine blades, proceedings of the ASME Turbo Expo: Turbine Technical Conference and Exposition, AMER Soc Mechanical Engineers, Three Park Avenue, New York, NY 10016-5990 USA. ISBN:978-0-7918-5091-6.

[3] Wang, D., He, B., Liu, S. et al. (2016). Dimensional shrinkage prediction based on displacement field in investment casting. *The International Journal of Advanced Manufacturing Technology*. 85(1-4), 201-208. https://doi.org/10.1007/s00170-015-7836-1.

[4] Herman, A., Vrátný, O., Kubelková, I. (2016). *Assessment of critical sites on wax models of blades.* Velká Bíteš: PBS Velká Bíteš. (in Czech).

[5] Teena, M., Manickavasagan, A. (2014). *Thermal Infrared Imaging*. Imaging with Electromagnetic Spectrum, pp 147-173.