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Research Article

Dimensional Stability Investigation on a Gas Turbine Blade in Investment Casting

Y. Miladi[1], M.R. Alizadeh[2]*, A. Khedmati[3]

[1,2,3]MavadKaran Engineering Company, MAPNA Group, Tehran, Iran

**Corresponding Author: mra.alizadeh64@gmail.com*.

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Abstract— In General, casting process with high dimensional accuracy has been always very challenging. In effect, in these casting processes, dimensional deviations usually are initiated from wax injection into a die. In this research, the blade that was studied had a shroud and its airfoil's length was very long, thus, the most deviation in the dimension of the blade was observed in the shroud of the blade. In other words, the dimension of the blade was studied in its shroud specifically. Therefore, casting the blade with an appropriate degree of accuracy and stability was very difficult and significant. In this study, one proposed solution that suggested preventing the deviation was controlling the dimension of the shroud to assure its geometry assurance. The proposed solution was to attach a wax rod from the platform area to shroud to prevent further deflection of the blade tip. Then, to evaluate the deviation amount, dimension was measured by coordinate measuring machine (CMM) tool and also by geometry optical measuring (GOM) method. The results show that using wax rods improved the dimensional deviations. In fact, the statistical measurements show that the amount of deviation in the critical points of the blades with rod is more compatible with the base model compared to the blades without rod.

Keywords— Dimensional Stability; Dimensional Deviation; Investment Casing, Investment casting, Wax, Shroud.

1. Introduction

Generally, in investment casting process, wax stability has always plays a crucial role in final dimensions of the product. In this regard, important issues such as type of wax, geometrical shape of wax model and injection parameters should be considered. It has been observed that amongst injection parameter, injection time is the most significant parameter. In essence; This process is usually suitable for producing parts having intricate dimensions and shapes. In fact, the airfoils of blades which involve complicated shape can be achievable by this significant process [1].

Moreover, the thin sections in the blades can be produced by investment casting process. As a result, this process can assure dimensional accuracy which is so crucial in gas turbines. However, investment casting process involves multiple nonlinear physical processes, which require consideration of geometry, material properties, boundary conditions, as well as several complicated boundary conditions, several complicated phenomena such as wax deviations, high-temperature sintering of ceramics, directional solidification of super alloys, and coupling characteristics of complex structure and materials. Accordingly, there is a constant need for methods that can be used to predict the final cast shape and control the cast dimensions with an appropriate degree of accuracy [2].

In addition, injection die plays the first role to reach a high dimensional stability. Many efforts and studies have been performed about the dimension's accuracy of in this field. For instance, in a previous study, in order to conform the dimensional tolerances, an efficient numerical method by finite element methodology (FEM) was presented for the wax pattern die and design profile of turbine blades [3].

In other study, one of the reasons for inaccuracy of dimensions is related to uncertainties about tolerances for the casting contraction. This is due to the not taken into account the "net" contraction values for the specific alloy. So, the contraction accuracy can directly affect the fine dimensional accuracy [4].

Therefore, the type of the material which can be Cobalt or Nickel based and their inherent contraction during solidification step has positively or negatively effect in their deformation in the blades' final dimension. In fact, due to the temperature difference in each stage in the turbines, their material should be selected based on their stability. In other words, the stability in their dimensions is also related to the base of material to obtain tight casting tolerances [5, 6].

As a result, the dimensional change occurs mostly in wax injection phase and continues in casting, solidification and cooling phases. In effect, the contraction amount depends on a large extent on the chemical composition and pouring temperature and cannot be controlled thoroughly throughout investment casting process [7].

Experimentally, in one of the previous related study production of precise castings by investment casting was investigated meticulously by A. Hermen and his colleagues. According to this study, it was concluded that to remove the wax deviations, preserving the wax model after removing it from the die is very significant process. As a matter of fact, using fixative preparation and controlling of the wax model is directly affect the final dimension of the blade. Some solutions like exploiting the wax model in the water tank were investigated. Figurer 1 shows the fixative tool in the water tank in their work [8].

Figure.1 Temporary water tank to hold the complicated shape of airfoil [8].

In other research, it showed that the cooling effect of the cooling bath with using a reformer simultaneously can control the temperature fluctuations of the wax which directly control its deviation. In this research, it was revealed that dimensional imbalances of the blade not only related to the casting process but also on the wax injection parameter. Figureure 2 illustrates the studied blade in the mentioned research and figureure 3 displays the deviation profile in one of the sections [9].

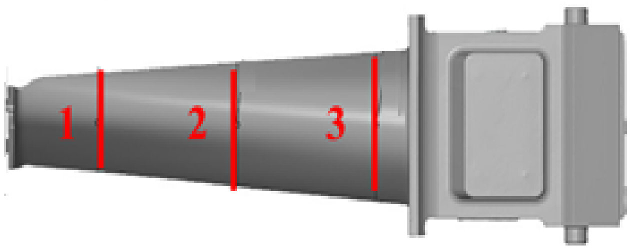

Figure.2 Illustration of the location of the evaluated cuts on the blade [9].

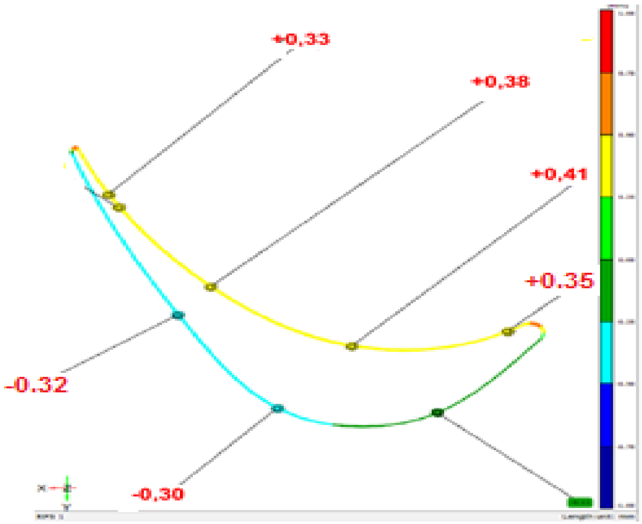

Figure.3 Section 2 from figure. 2. (All dimensions are in mm) [9].

Therefore, the wax's thermo-physical condition, its thermo-mechanical properties, the metal die features, and the process parameters affect the dimensions of the wax pattern. Significant process parameters embrace the injection temperature; die temperature, and holding time in fixative preparation [10].

The accuracy of the wax patterns, on the other hand, used in the investment casting process has a direct effect on the accuracy achievable in the final cast part. It is essential to comprehend the proper parameters of wax. Shrinkage allowance is the main factor occurring in the dimensions of wax patterns [11].

2. Experimental Method

In this research, one scientific and industrial solution has been proposed to preserve wax models dimensions. In fact, due to the long length of the blade which studied in this paper, the wax model was very susceptible to deviation. So, since the most deviations occur in wax injection process, this process supervised privately. Wax model is created by injection wax into a metallic mould cavity, to produce a model with strict dimensional tolerances. The metallic mould also has to allow for shrinkage of the material to be cast. The schematic figureure 4 shows Schematic of studied blade. Table 1 shows the injection parameters which was identical in all the injections.

Figure.4 Schematic of studied blade.

Table 1. Injection parameters

Parameter	Condition
Wax temperature	70 ˚C
Injection time	60 s
Holding the wax model in the die	240 s
Cooling time in water bath in fixative preparation tool	1800 s

After wax injection, the wax models are placed in a secondary fixture (Figureure 5) and the assembly is immersed in a tank of ambient temperature water (Figureure 6).

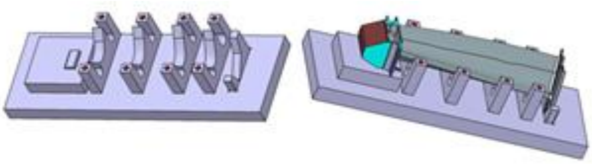

Figure.5 Images of secondary fixture.

Figure.6 Image of wax model and secondary fixture a tank of ambient temperature water.

After the blades were removed from the tank, they stand in a frame (Figureure 7). Then, they were checked with the setter according to the figureure 8 and prepared for assembling step. Finally, four blades assembled into a wax cluster as figureure 9.

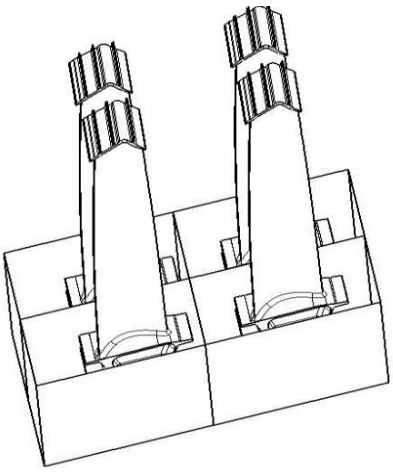

Figure.7 Standing wax models after leaving from the water tank.

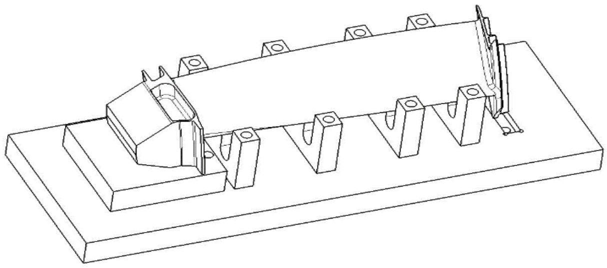

Figure.8 Controlling the blade in the setter.

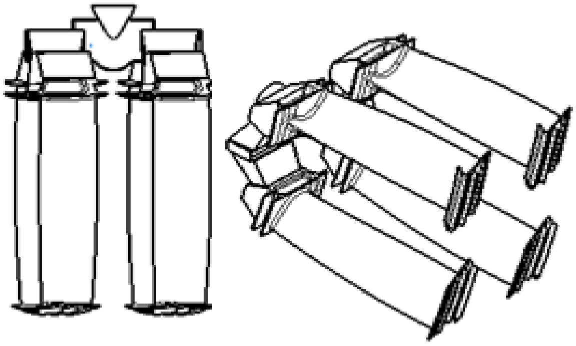

Figure. 9 The schematic of assembled wax cluster of blade without wax rod.

In the next step, wax cluster is dipped into a silica slurry bath and a ceramic shell was produced through ceramic coating layers. Figureure 10, shows the ceramic shell image. The shell is then heated to dewax the mold, followed by firing and preheating before the molten metal is poured into the dewaxed cavity. Afterward, the molten metal was poured into the ceramic shell in the vacuum furnace. The alloy was Nickel base superalloy IN738LC, and its chemical composition is shown in table 2. Casting technical details have been published previously by the author [12].

Figure.10 Image of Ceramic shell.

Table2. Chemical composition of IN738LC (wt%).

C	Si	Mn	P	S	Cr	Mo	W	Co
0.12	<0.05	<0.005	0.0003	0.0003	15.7	1.7	2.5	8.4
Nb	**Fe**	**Ti**	**Al**	**Al+Ti**	**B**	**Ta**	Zr	**Ni**
0.9	0.08	3.4	3.5	6.9	0.01	1.7	0.02	Bal.

Finally, after fettling and cutting in the knock out process the dimension of the blades was studied by coordinate measuring machine (CMM) tools and geometry optical measuring (GOM) method.

In the other wax cluster, since the most deviation of this blade was related to its shroud, according to figureure 11 a wax rod was attached from shroud to its platform. Figureure 12 also shows the assembly schematic of wax models of blades with wax rods.

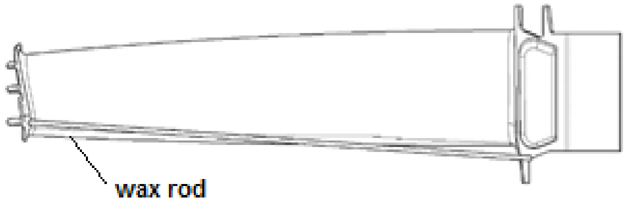

Figure.11 The wax models with wax rod.

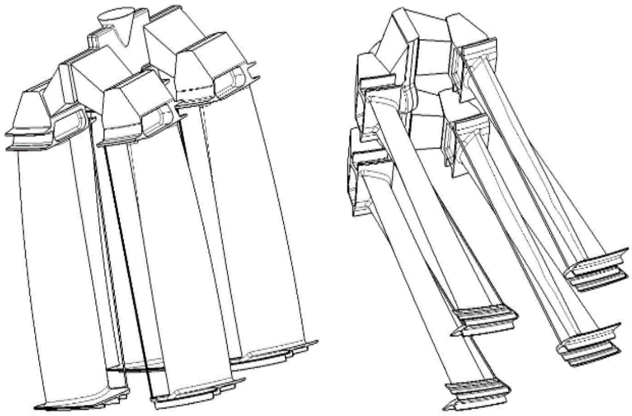

Figure.12 the assembly schematic of wax models of blades with wax rods.

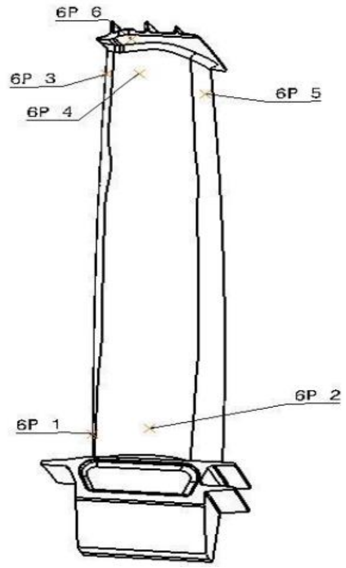

Figure.13 The blade's 6 points locations.

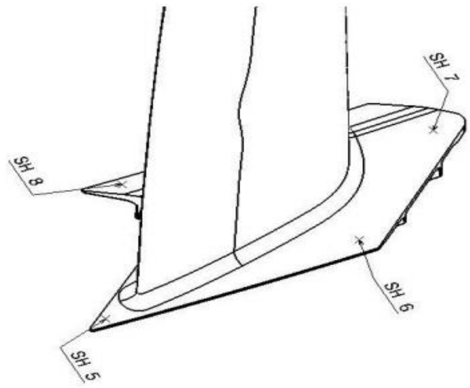

Figure.14 The blade's critical points in the shroud.

3. Results and discussion

In this research, dimensional stability of a gas turbine blade was studied. As a general, the most consideration in producing of such a blade with a long length is its conformity in dimension with the computer model. Since the length of the blade was long and about 300mm, the most difficulty in producing of it was preventing it from being deviated. As a matter of fact, the wax is largely susceptible to twist in some specific direction, and preventing it from being deviated is the most challenging step in investment casting process. according to CMM result, this twist and deformation was observed mostly in the shroud of the blade.

That is to say, in investigation of geometrical assurance by using CMM, it was cleared that the shroud had a deviation from CAD model. Figureure 13 displays a schematic of the blade and its 6 points locations. Figureure 14 shows two critical points in the shroud (SH5 and SH8) where the dimensions observed.

Moreover, the deviations in the shroud were also observed by GOM evaluation. Figureure 15 shows comparison of the blade GOM output with CAD model. Figureure 16 displays these deviations points in SH5 and SH8.

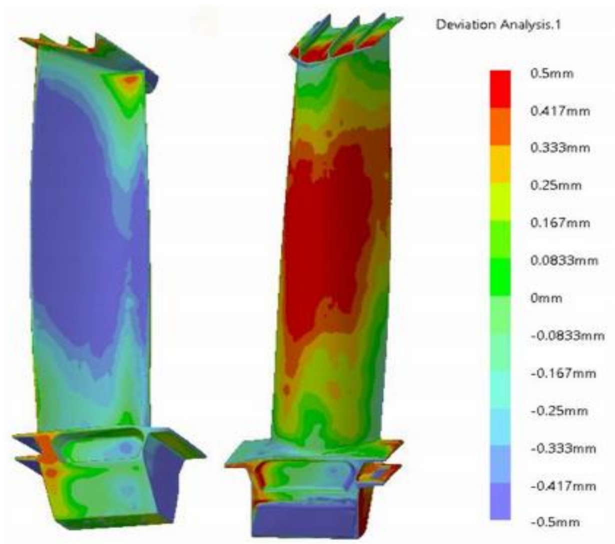

Figure.15. GOM output in a non-used bar blade.

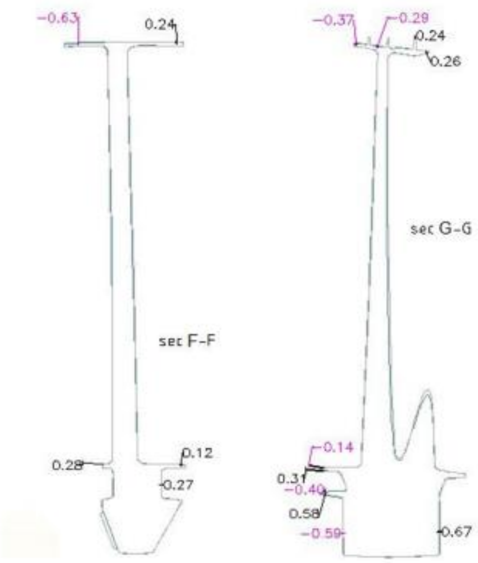

Figure.16. The deviations observed by GOM method.

According to this paper, CMM measures were performed for both used and non-used rod blades. According to the careful study, it was cleared that when the rod wax not used, the deviations of points SH5 and SH8 was about 0.6mm while when the rod was used this amount was decreased to 0.1mm. In consequence, the results proved that in the blades which produced without controlling rod, the deviation in critical point in the shroud was about 0.5mm more than the used-rod blades. This dimensional improvement will further enhance the blades' performances.

4. Conclusion

In summary, the investigation of wax dimension in two different wax assembling system was studied and compared to each other. Since, the wax dimensional accuracy is directly affecting the metal blade's accuracy, in this study the wax's deviation studied meticulously. According to this study, it was cleared that the shroud of the blade is very susceptible to deviation due to its long length. As a result, in one of the wax clusters, a wax rod attached to each blade and from the shroud to its platform in root. In the other, wax rod was not used.

All in all, the blades with and without rod were compared dimensionally by coordinate measuring machine (CMM), and from the comparison of the measures, it was understood that using the rod was enabled to prevent critical point in the shroud from being deviated. That is, when the blade produced without rod the deviation in point SH5 and SH8 which are critical dimensional points, it showed about 0.6mm deviation from CAD model, while by using the rod, this deviation is decreased to 0.1mm. In addition, one blade did not possess any dimensional devotion and the final measurement was completely in the tolerances range. As a result, blades which produced without controlling rod, the deviation in critical point in the shroud was about 0.5mm more than the used-rod blades. So, they can interfere the production negatively.

Ultimately, it is suggested that, the investigation on the dimensional control has to be studied carefully and some other technical and scientific solutions might be tested. Therefore, the deviations can be reduced more than the current result, so, in the next study from these authors, some other considerations like changing the wax chill dimensions and increasing the time of preserving the wax blade in the fixative preparation tool will be studied. In other word, preserving time of the setter and using a modified shape of wax chill can improve the results increasingly.

Data Availability: None.

Conflict of Interest

All authors are requested to disclose any actual or potential conflict of interest including any financial, personal or other relationships with other people or organizations that could inappropriately influence, or be perceived to influence, their work. Otherwise, Authors declare that they do not have any conflict of interest.

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Author's Contribution

Author 1- researched literature and conceived the study. Also designed of experimental and wrote the first draft of the manuscript. All authors reviewed and edited the manuscript and approved the final version of the manuscript.

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Author 3- Evaluated the dimension results.

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