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Application of Modified Cores for Grain Refinement in Castings of Aircraft Turbine Blades

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Abstract

Paper presents the results of research on modified surface grain refinement method used in investment casting of hollow, thin-walled parts made of nickel based superalloys. In the current technology, the refining inoculant is applied to the surface of the wax pattern and then, it is transferred to the ceramic mould surface during dewaxing. Because of its chemical activity the inoculant may react with the liquid metal which can cause defects on the external surface of the cast part. The method proposed in the paper aims to reduce the risk of external surface defects by applying the grain refiner only to the ceramic core which shapes the internal surface of the hollow casting. In case of thin-walled parts the grain refinement effect is visible throughout the thickness of the walls. The method is meant to be used when internal surface finish is less important, like for example, aircraft engine turbine blades, where the hollowing of the cast is mainly used to lower the weight and aid in cooling during operation.

Keywords: Innovative casting materials and technologies, Nickel alloy IN-713C, Surface modification, Turbine blades, Macrostructure

1. Introduction

Investment casting of nickel superalloys favours the formation of coarse grain. Therefore, inoculation grain refinement treatment is needed to refine the structure. Currently, the inoculant is applied on the wax pattern and then is transferred to the inner surface of the investment mould during the dewaxing. Such process is called surface modification [1-8]. This grain refinement method is effective only in the thin layer near the outer surface of the casting.

The inoculation mechanism, as described in the following works [9-11], is based on the nucleating effect of cobalt particulates which are reduced from cobalt(II) aluminate $CoAl_2O_4$ in reactions with chemically active alloying elements (such as Al, Cr, Nb, Hf) on the mould – liquid metal interface. Chemical reactions between the inoculant and alloying elements can lead to degradation of the casting surface. In superalloy castings for the aerospace industry, especially turbine blades, the outer surface quality of the casting is very important. Turbine blades are often hollow to reduce the weight and aid in cooling – because of that use of ceramic cores is needed during the investment casting process. To reduce the outer surface degradation during inoculation it is proposed to apply the inoculating layer on the surface of the core only, as opposed to the traditional mould surface modification, as suggested by [12]. Because the walls of the hollow blades are often thinner than 1.5 mm the inoculation should work throughout them, creating the reverse surface modification effect. The results of preliminary experiments show that this technique could be effective [13].

2. Materials and methodology

Paper presents the results of internal surface modification in thin-walled hollow castings of blades for low-pressure turbine rotor manufactured using investment casting of IN-713C nickel superalloy. The experiments were carried out in the precision foundry of Pratt and Whitney Rzeszow.

Moulds and cores were prepared according to standard practice of investment casting for nickel based superalloys. Ceramic cores were coated by inoculating layer containing respectively 5 and 10 % of cobalt(II) aluminate $CoAl_2O_4$ in addition to zirconium(IV) silicate $ZrSiO_4$ and colloidal silica. Cores prepared for drying are presented in Fig. 1.

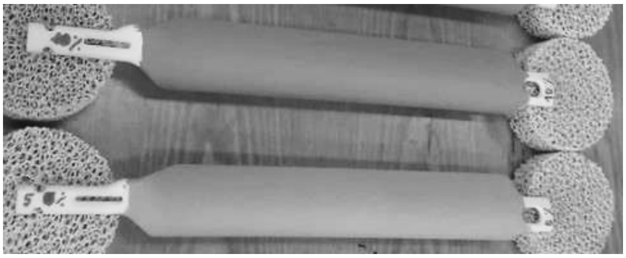

Fig 1. Cores after coating with 5 and 10 % mixture of $CoAl_2O_4$

Two large ceramic moulds were prepared. Wax pattern assemblies were prepared in such a way that they contained four coated and four uncoated cores. One wax pattern was then coated with standard inoculating layer of 5 % $CoAl_2O_4$. The arrangement of one of the moulds is presented in Fig. 2. The experimental procedure allowed for six different types of samples to be obtained as shown in Table 1.

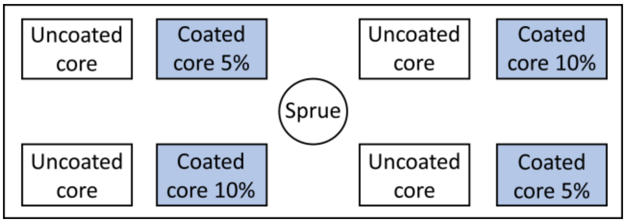

Fig. 2. Arrangement of experimental mould

Table. 1.
Samples obtained during the experimental procedure

Sample	Mould coating	Core coating
1	not present	not present
2	not present	5 % $CoAl_2O_4$
3	not present	10 % $CoAl_2O_4$
4	5 % $CoAl_2O_4$	not present
5	5 % $CoAl_2O_4$	5 % $CoAl_2O_4$
6	5 % $CoAl_2O_4$	10 % $CoAl_2O_4$

Specimens for the macrostructure analysis were cut from top and bottom of the sample castings. This allowed to investigate the influence of cooling rate on the macrostructure as cooling rate of the top part is lower because of the proximity to the gating system which is a most voluminous part of the casting. Prepared specimens are presented in Fig. 3 and 4.

Both inner and outer surfaces of cut specimens were etched to reveal the macrostructure. Image analysis by Met-Ilo software pack [14] was then used to characterise the macrostructure by following structural parameters:

- the number of grains per unit area
- average grain surface area.

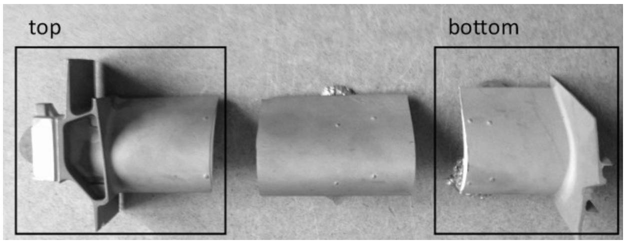

Fig. 3. Specimens cut from sample casting

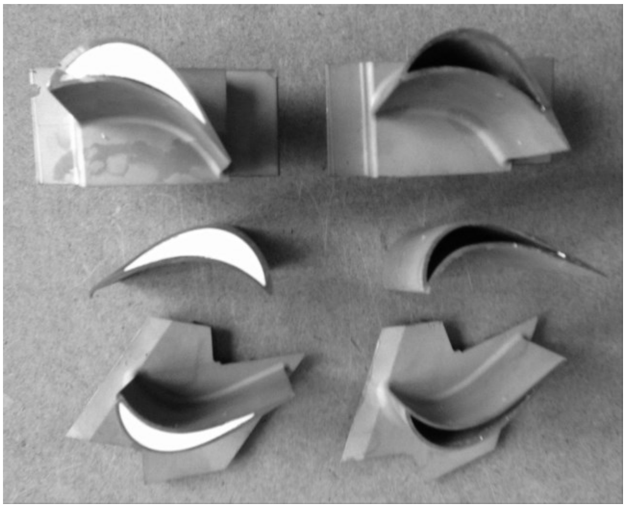

Fig. 4. Specimens before and after core removal

3. Results and discussion

Because of extensiveness of research material two most representative variants of interactions were chosen to be presented in this paper – the samples 1 and 2 (uncoated mould with uncoated core and with core coated in 5 % $CoAl_2O_4$).

The results for each of the specimens are comprised of the analysis of its inner and outer surface. The inner surface of the specimen was in contact with the ceramic core and the outer surface with the mould.

The macrostructure of specimens after etching and with grain boundaries marked in Met-Ilo image analysis software is presented in Figs. 5 and 6. The results of image analysis are shown in Figs. 7-10.

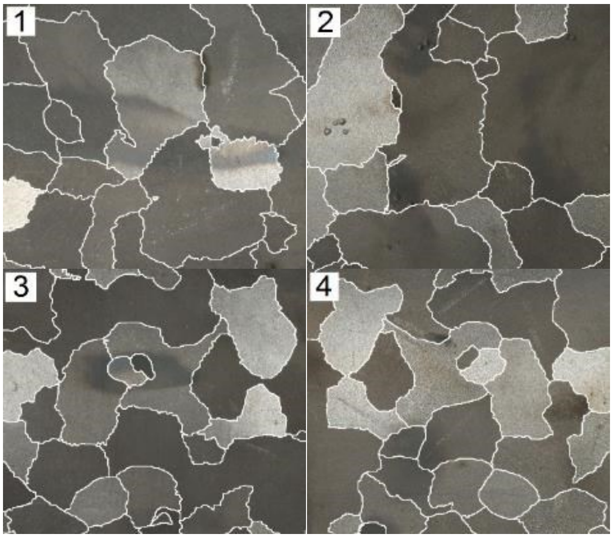

Fig. 5. Macrostructure comparison of specimens from sample 1: 1 – top inner (core), 2 – top outer (mould), 3 – bottom inner (core), 4 – bottom outer (mould)

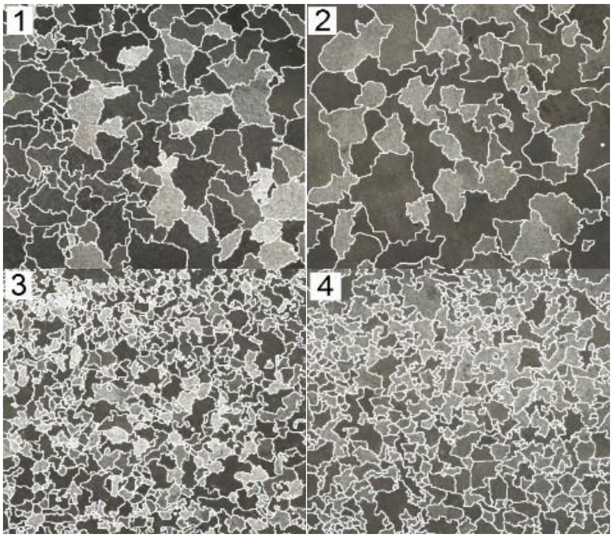

Fig. 6. Macrostructure comparison of specimens from sample 2: 1 – top inner (core), 2 – top outer (mould), 3 – bottom inner (core), 4 – bottom outer (mould)

Grain refinement effect of coating the core is clearly visible in specimens of sample 2 in comparison with uncoated sample 1. In addition to the refining of inner surface the fine structure can be observed also on the outer surface, which was not in contact with the coating. In addition to the refiner influence there is also some differences between top and bottom specimens. This is due to disparity in cooling rate caused by mould construction. The top parts of the mould are connected to the gating system which in case of typical turbine blade castings is comprised of large pouring basin, sprue and runners.

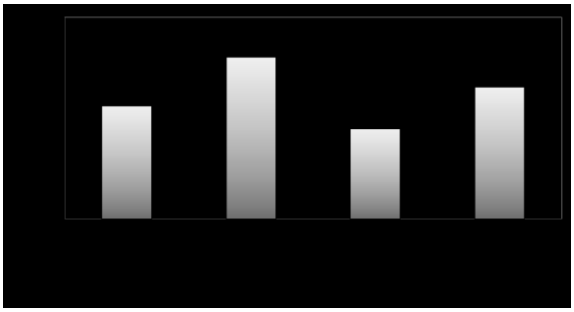
Fig. 7. Average grain surface area in specimens of sample 1

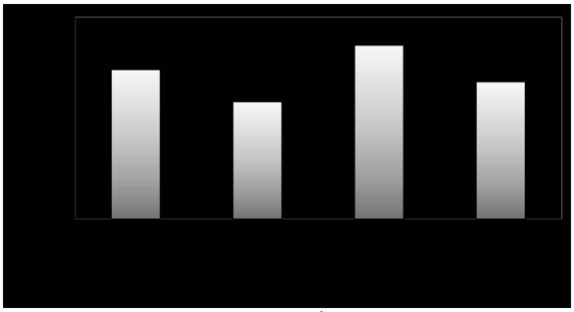
Fig. 8. Number of grains per mm^2 in specimens of sample 1

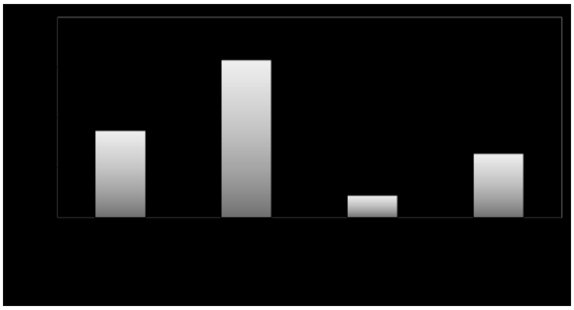
Fig. 9. Average grain surface area in specimens of sample 2

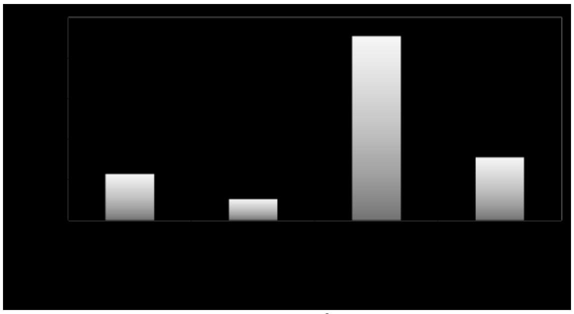
Fig. 10. Number of grains per mm^2 in specimens of sample 2

Data obtained during image analysis of macrostructure photographs show that due to the cooling rate disparity the top inner specimen of sample 2 are refined by about 15 times in comparison to the uncoated sample 1 and the bottom specimen about 50 times. Such large difference is associated with the refining mechanism characteristic for this method. Higher cooling rate favours the formation of crystallization nuclei – cobalt particles reduced from cobalt aluminate. The influence of supercooling degree on the nuclei formation (number and size) is presented in Fig. 11 [5,6].

Effect of grain refinement on the outer surface (facing the mould) of sample 2 is about 50 % lower than on the inner surface, especially in top specimens. Previous research show that this is sufficient for throughout grain refinement in turbine blades of this wall thickness [6].

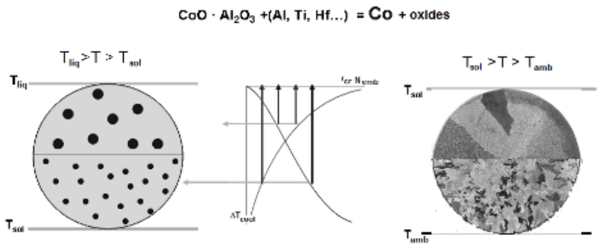

Fig. 11. Effect of supercooling on nucleation in casting of nickel based superalloys with refining coating

4. Conclusions

1. Results indicate positive and sufficient effect of surface modification of an aircraft turbine blade with a wall thickness of about 1 mm cast using core coated with grain refining layer.
2. Higher refining effect can be observed in the lower areas of castings which is caused by higher cooling rate.
3. The outer surface of castings, that has no contact with the refining layer, was in satisfactory condition, on the inner, grain refined surfaces a few small areas of light discoloration and unevenness were observed.

Acknowledgements

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