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

F. Binezyk a, *, J. Cwajna b, P. Gradoń a

*Institute of Metals Technology
b Institute of Materials Science
Silesian University of Technology, Krasinskiego 8, 40-019 Katowice, Poland
*Corresponding author. E-mail address: franciszek.binczyk@polsl.pl

Received 31.03.2017; accepted in revised form 10.07.2017

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 CoAl₂O₄ 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 CoAl₂O₄ in addition to zirconium(IV) silicate ZrSiO₄ and colloidal silica. Cores prepared for drying are presented in Fig. 1.

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 % CoAl₂O₄. 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.

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.

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 % CoAl₂O₄).

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.
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.

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 shows 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](image)

**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**

Project co-financed by the European Regional Development Fund under the Operational Programme Innovative Economy and the National Centre for Research and Development Poland(NCBR) Grant No. INNOLOT/I/8/NCBR/2013 (2013-2018) - INNOCAST.

**References**

[1] Fang Jian, Yu Bin, (1982). Investigation of the Surface Grain Refinement for Superalloys Castings. In R. Brunetaud, D. Coutouradis et al. (Eds.), *High Temperature Alloys for Gas Turbines* (pp. 987-997). Brussels: Springer Netherlands.
[2] Reed, R.C. (2006). *The Superalloys – Fundamentals and Applications.* New York: Cambridge University Press.
[3] Campbell, J. (2011). *Complete Casting Handbook.* Oxford, Butterworth-Heinemann.
[4] Zielnińska, M., Sieniawski, J. & Poręba, M. (2007). Microstructure and mechanical properties of high temperature creep resisting superalloy Ren’e 77 modified CoAl2O4. *Archives of Materials Science and Engineering.* 28(10), 633-636.
[5] Zielnińska, M., Sieniawski, J. & Wierzbnińska, M. (2008). Effect of modification on microstructure and mechanical properties of cobalt casting superalloy. *Archives of Metallurgy and Materials.* 53(3), 887-893.
[6] Yuhua Xiong, Xiu Ying Wei, Jun Du, Aimin Yang, Lin Liu, & Daben Zeng. (2004). Grain refinement of Superalloy IN718C by the addition of Inoculants. *Metallurgical and Materials Transactions.* A 35(7), 2111-2114.
[7] Wenzhong Jin, Fudong Bai, Tingju Li, Guomao Yin, (2008). Grain refinement of superalloy IN100 under the action of rotary magnetic fields and inoculants. *Materials Letters.* 62, 1585-1588.
[8] Matysiak, H., Zagórska, M., Balkowiec, A., Adamczyk-Ciesiak B., Dobkowski K., Koralnik M., Cygan R., Nawrocki J., Cwajna J. & Kurzydłowski K.J. (2016). The Influence of the Melt-Pouring Temperature and Inoculant Content on the Macro and Microstructure of the IN713C Ni-Based Superalloy. *JOM.* 68(1), 185-197.
[9] Lin Liu, Taiwen Huanga, Yuhua Xiongb, Aimin Yangc, Zhilong Zhaoa, Rong Zhangb & Jinshan Lia. (2005). Grain refinement of superalloy K4169 by addition of refiners: cast structure and refinement mechanisms. *Materials Science and Engineering.* A 394, 1-8.
[10] Binczyk, F. & Sleziona, J. (2010). Effect of modification on the mechanical properties of IN-713C alloy. *Archives of Foundry Engineering.* 10(1), 195-198.
[11] Binczyk, F., Sleziona, J. & Gradon, P. (2011). Modification of the macrostructure of nickel superalloys with cobalt nanoparticles. *Composites.* 1, 49-55.
[12] Whateley P.N. (1999). U.S. Patent No. 5,983,983. Washington, D.C.: U.S. Patent and Trademark Office.
[13] Binczyk, F., Cwajna, J., Gradon, P., Matika, M. & Findziński, R. (2015). Surface modification of cored thin walled castings of nickel superalloy IN-713C. *Archives of Foundry Engineering.* 15(3), 17-20.
[14] Szała, J. (2001) Application of computer image analysis to quantify the structure of materials. Silesian University of technology Press. Gliwice. (in Polish).