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Surface Modification of Cored, Thin Walled Castings of Nickel Superalloy IN-713C

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Abstract

In current casting technology of cored, thin walled castings, the modifying coating is applied on the surface of wax pattern and, after the removal of the wax, is transferred to inner mould surface. This way the modification leading to grain refinement occur on the surface of the casting. In thin walled castings the modification effect can also be seen on the other (external) side of the casting. Proper reproduction of details in thin walled castings require high pouring temperature which intensify the chemical reactions on the mould – molten metal interface. This may lead to degradation of the surface of the castings. The core modification process is thought to circumvent this problem. The modifying coating is applied to the surface of the core. The degradation of internal surface of the casting is less relevant. The most important factor in this technology is "trough" modification – obtaining fine grained structure on the surface opposite to the surface reproduced by the core.

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

1. Introduction

In recent years jet engine construction require the use of hollow turbine blades for better cooling capabilities and lower weight of the engine. In those blades the wall thickness is very low. To obtain the macrostructure refinement and equiaxed grains, the surface modification treatment is used. This consists of applying the modifying coating to the surface of the mould cavity. Modifying coating contains 5% cobalt aluminate. Because of very thin walls (about 1 mm) the pouring temperature must be respectively high. This can cause increased reaction between mould wall materials and molten alloy, which leads to lower surface quality of castings. Results of the investigations of this phenomena are presented in papers [1-4]. Recently the authors of this work undertake the research on the modification of the thin walled castings from the core surface. In this case the decreased surface quality is less relevant. The most important factor in this technology is the "trough" modification – obtaining the modification effect on the surface opposite to the surface reproduced by the core. During preliminary studies it was found that it is possible. Modification effect is particularly prominent in thin-walled castings.

2. Materials and methods of investigation

To construct the ceramic mould the core of turbine blade castings and parts of other ceramic moulds manufactured by the lost-wax process were used.

First the side walls of the mould were prepared. For this purpose about 10 layers of ceramic coating was applied to both (concave and convex) surfaces of the core (as in the lost-wax process). Then the coated core was cut in half to obtain the side (main) walls of the mould and two parts of the core. The core was then coated with the modifying layer on concave and convex sides. The mould cavity surface was not coated. Suitable mould wall inclination ensured the ability to obtain the samples of continuously varied thickness and shape determined by the core surface. Then the gating system elements (pouring basin and ceramic filter) was added. The stages of the mould preparation process are presented in Figure 1.

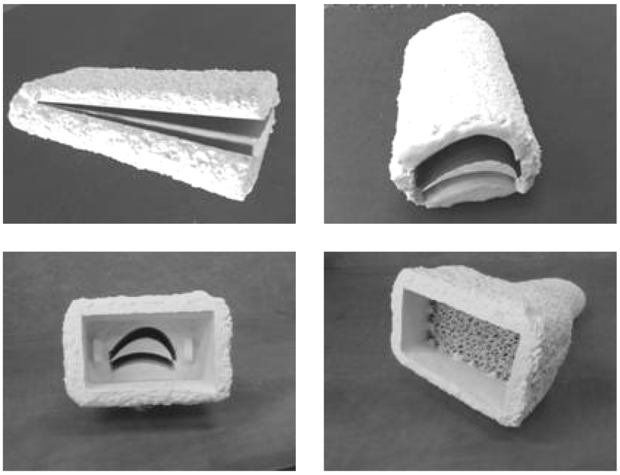

Fig. 1. Mould preparation process – the main stages

Mould was insulated with wool and heated in the chamber furnace to the temperature of about 900°C.

The IN-713C alloy (the post-production scrap) was melted in the induction furnace VSG-02 (manufactured by Balzers) using the Al_2O_3 crucible. The charge mass was about 1.2 kg. The melting was realised in vacuum of 10^{-3} T. Before pouring the furnace chamber was flooded with argon. During pouring the argon pressure was about 900 hPa. Pouring temperature was about 1500°C. The finished casting is presented in Figure 2.

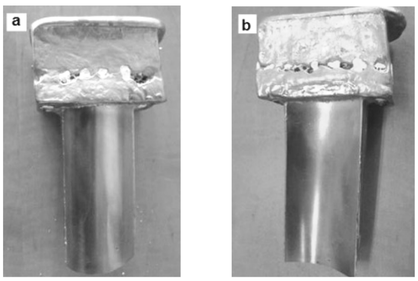

Fig. 2. Finished casting: a) convex surface, b) concave surface

3. The results of investigations and discussion of results

The gating system and the core were removed to obtain four surfaces for macrostructure investigation:

1. Convex U, from the unmodified mould wall,
2. Concave M, from the modified core,
3. Convex M, from the modified core,
4. Concave U, from the unmodified mould wall.

The sample was etched with the Marble solution. The concave and convex sides of the sample are presented in Figure 3.

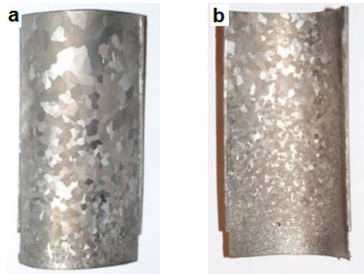

Fig. 3. Casting macrostructure: a) convex surface (1) – unmodified, b) concave surface (2) - modified

The macrostructure analysis was carried out in three distinct areas (up – U, center – C and down – D) which gave twelve sets of results for four surfaces of the casting. These areas were photographed after etching and analysed using the image processing software Met-Ilo [5]. The preparation of the images for analysis involved drawing the grain boundary lines by hand. The sample photos and grain boundary image layers are presented in Figures 4 and 5.

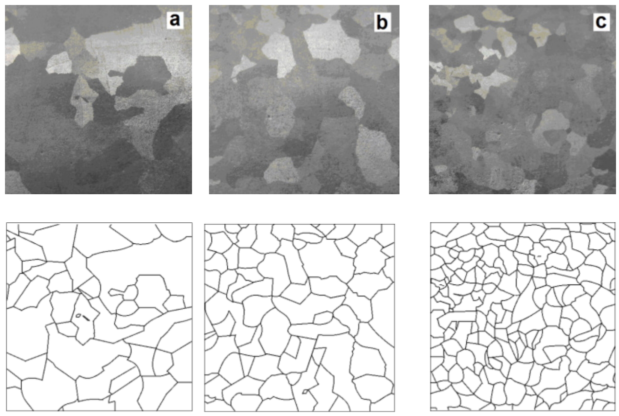

Fig. 4. Macrostructure analysis of Convex U (unmodified) surface a) up – U, b) center – C, c) down – D

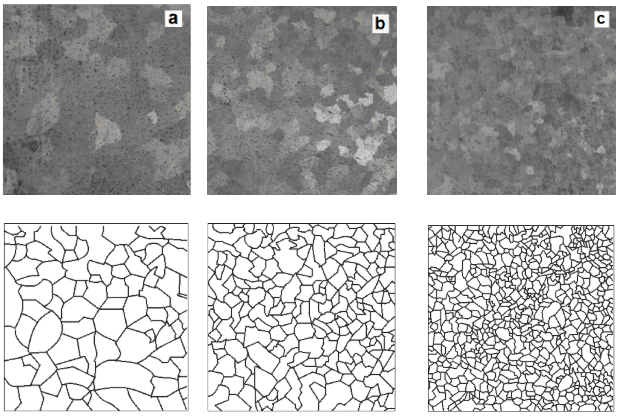

Fig. 5. Macrostructure analysis of Concave M (unmodified) surface a) up – U, b) center – C, c) down – D

The following characteristics of the macrostructure were investigated:

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

The results of this investigation are presented in Figures 6, 7 and 8.

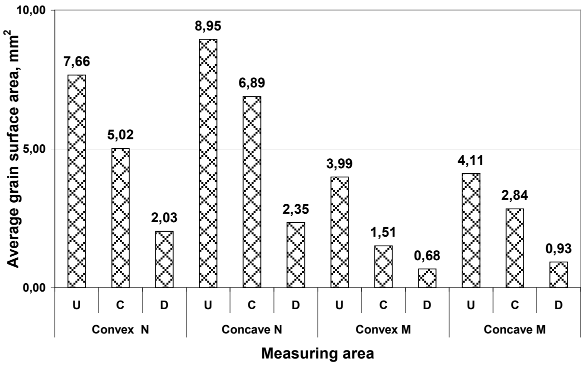

Fig. 6. Average grain surface area in dependence on the surface type and measuring area

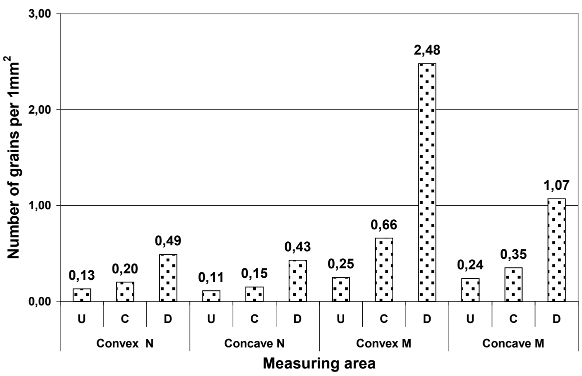

Fig. 7. Number of grains per 1 mm^2 in dependence on the surface type and measuring area

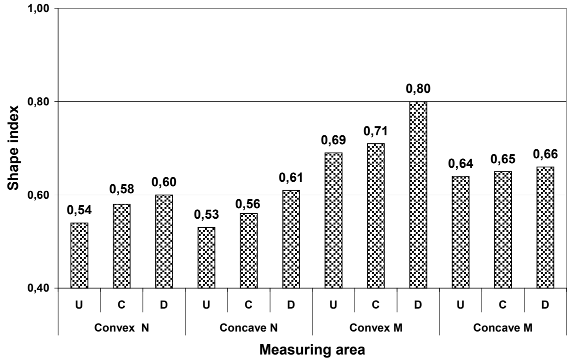

Fig. 8. Dimensionless grain shape factor in dependence on the surface type and measuring area

The results of this analysis show positive effect of modification from the core surface. It has been determined that this effect is more pronounced for samples with thinner walls, that is, for the samples cut from the lower part of the casting. The surface modification affects also the shape of the resulting grains leading to more equiaxed structure – higher values of the shape factor.

Comparison of the average grain surface area for two opposite sides of the sample (modified and unmodified) is presented in Figure 9.

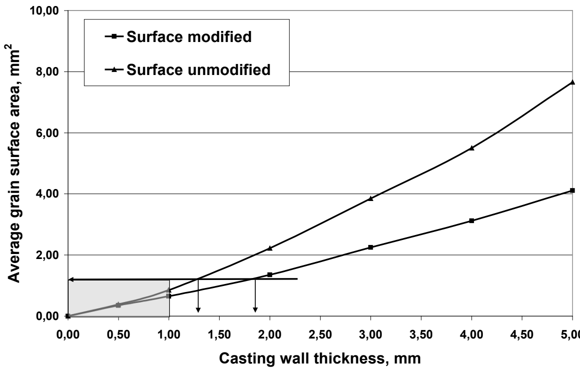

Fig. 9. Average grain surface area as a function of casting wall thickness for modified and unmodified sides

Fig. 9. shows that, for "preferred" average grain surface of about 2 mm^2 on the unmodified side, the modification effect from the core surface is present in walls up to 2 mm thick. The wall thickness of typical, cored turbine blade is about 1 mm, so it is in the range of the modification effect.

For comparison, the unpublished results from preliminary studies using only the mould surface modification process are presented in Figure 10.

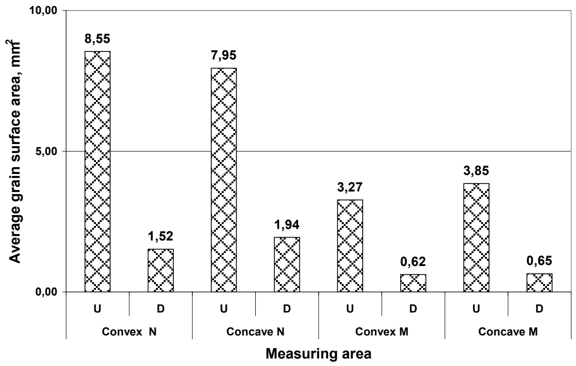

Fig. 10. Average grain surface area in dependence on the surface type and measuring area for samples modified from mould wall

As show in Fig. 10 the modification effect from the side of mould surface is stronger. This is due to the known effects of undercooling in the mould and the core on the number and critical radius of crystallization nuclei. Because the core is immersed in molten metal, the thermal conduction through the core is lower therefore the temperature on its surface is higher in comparison to the mould surface. This leads to lower undercooling. The effect of the degree of undercooling on the nucleation process (number and size of the nuclei) is presented in Figure 11 [6-8].

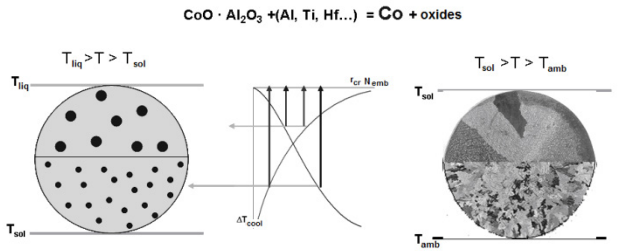

Fig. 11. The effect of undercooling on the nucleation process and macrostructure of the IN-713C alloy casting obtained using mould with modifying surface [7]

4. Conclusions

1. The experimental results show that the „through” modification from the core surface is possible in laboratory conditions. The effect of the modification is more pronounced in thin walled castings – the lower part of the sample.

2. The contiguous change of cooling rate on the length of the sample (from thinner to thicker walls) leads to continuous change in macrostructure. Because of this the accurate image analysis is difficult.

3. The intensity of modification effect from the side of the core is lower in comparison to modification from the side of the mould. This is due to lower heat conduction in the core which is immersed in molten alloy on both sides.

Acknowledgements

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