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Analysis of Solidification Parameters and Macrostructure of IN-713C Castings after Complex Modification

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Abstract

The paper presents a research results concerning impact of volume modification (ceramic filter containning cobalt aluminate and hafnium powder) and simultaneous surface and volume modification on solidification and stereological parameters of macrostructure of castings made from post-production scrap of nickel superalloy IN-713C. Research included investigation of the influence of chemical composition on the temperature T_{liq} i T_{sol} and evaluation of following macrostructure parameters: the number of grains per mm^2, average grain area and shape coefficient. Results indicate high influence of carbon content on T_{liq}. Macrostructure of sample castings indicate positive effect of surface and volume modification, however impact of surface modification is more pronounced.

Keywords: Nickel alloys, Superalloys, Modification, Inoculation, Solidification, Thermal analysis, Macrostructure

1. Introduction

Precise castings of aircraft engine parts should have high stability of mechanical properties, high-temperature corrosion resistance and creep resistance [1, 2]. In addition to the above, efforts are made to obtain macrostructure composed of equiaxial grains in whole volume of the casting and minimal gas and shrinkage porosity. Main problem of superalloy casting technology for aircraft engine components is the ability to influence the shape and size of the grain to create parts well-tailored to different conditions inside the gas turbine. Creep resistance and other high temperature mechanical properties increases with grain size, so this type of structure is preferred for turbine blades. Fine grained castings exhibit better mechanical properties in lower temperatures and higher resistance to the thermal fatigue therefore are used successfully for stationary elements, and parts working in lower temperature. Much information is available in scientific literature on methods of macrostructure refinement by nanoparticle inoculants in nickel superalloys [3-6]. Influence of cobalt aluminate addition in modifying mould coating on grain size, microstructure and mechanical properties of castings made from cobalt superalloy was investigated in paper [7]. Authors of present study also conducted successful research on the structure refinement of nickel superalloys (IN713C, IN-100 and MAR-247) by surface and volume modification [8-12].

2. Research problem

Ability to re-use post production scrap (defective castings, gating system parts etc.) is importat aspect of casting technology of nickel superalloys for aircraft engine parts. It has been proved that the re-melting of nickel superalloy scrap does not result in significant changes to chemical composition [13]. It was also found that in many cases the quality of master-heat ingots was poor because of oxide impurities in shrinkage cavities and microporosities. These defects were not found in castings made from re-melted scrap [14]. For best functional properties, castings made from heat-resistant nickel superalloys should have optimal combination of mechanical properties (tensile strength, yield strength, elongation, creep resistance) in elevated and high temperature. Best combination of properties can be obtained by influencing size, orientation and homogeneity of grains. Castings with macrostructure composed of fine, equiaxial grains are used for parts working in lower temperatures (below 700°C). In case of high temperature components like turbine blades (about 1100°C) decisive factor is creep. Creep resistance increases with grain size, so for turbine blades is best to obtain large grain or monocrystal.

Because of the macrostructure – mechanical properties relationship the ability of influencing grain size and shape by different methods is very important part of nickel superalloy casting technology.

3. Materials and methods of investigation

Aim of the research was to evaluate the influence of modification technique (only volume or complex, volume and surface) on solidification process and stereological parameters of macrostructure in sample castings.

Complex modification technique involves installation of the ceramic filter, coated with cobalt aluminate and hafnium powder, into the pouring cup of the ceramic mould. Ceramic filters were manufactured according to the method described in paper [11].

Four types of modification coatings for filters were used:
- melt 1: zirconium silicate + 10% cobalt aluminate,
- melt 2: zirconium silicate + 20% cobalt aluminate,
- melt 3: zirconium silicate + 10% cobalt aluminate + 5% Hf,
- melt 4: zirconium silicate + 20% cobalt aluminate + 5% Hf.

Material used for research was post-production scrap of nickel superalloy IN-713C. Melting was carried out in induction furnace Balzers VSG-02 in Al_2O_3 crucible and with a protective atmosphere of argon. Sample moulds made by WSK Rzeszów in investment casting process were altered to fit the furnace. Ceramic mould consist of two conical canals and a pouring cup with installed filter. Inside surface of one of the canals (so called “blue”) is coated with modifying layer of zirconium silicate and 20% cobalt aluminate while second canal was not coated (“white”). In this manner 8 combinations of modifying conditions were obtained. Type S thermocouple for thermal analysis (ATD) was installed in “white” canal in protective quartz tube.

Moulds were heated before placing in the furnace. Temperature of the mould and of the molten metal was controlled with type S thermocouple mounted in the furnace. Mould temperature at the time of pouring was 750°C. Metal was poured from about 1460°C.

Moulds before installation of modifying, ceramic filter and with visible opening for thermocouple instalation are shown on Fig. 1. Mould with installed filter inside protective steel casing with wool insulation is shown on Fig. 2.

Fig. 1. Ceramic moulds with visible „blue” and “white” canals

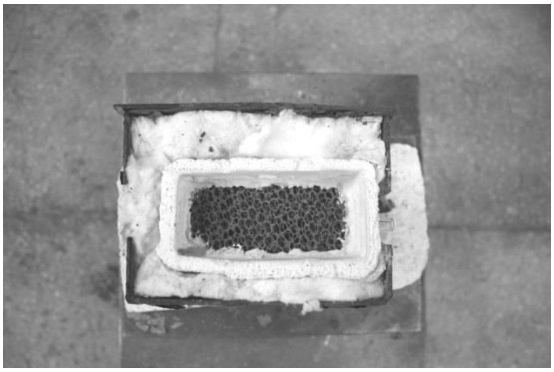

Fig. 2. Ceramic mould with installed filter in insulated casing

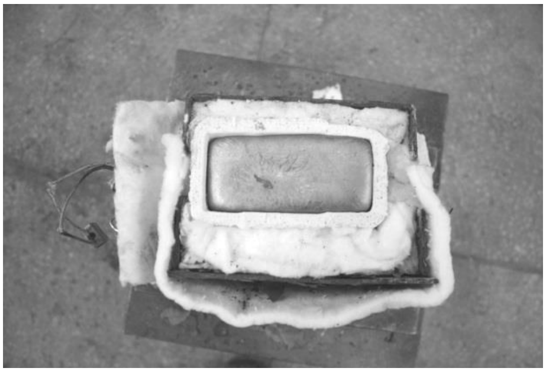

Fig. 3. Sample casting after solidification

4. The results of investigations and discussion of results

Samples for macrostructure evaluation were cut from castings below the point of temperature measurement for thermal analysis (TDA). Macrostructure was revealed using Marble etching. Images for macrostructure analysis were obtained on Nicon Epiphot 200 stereoscopic, optical microscope. Computer analysis of recorded microscopic images was performed using MetIlo image processing program [15]. Results of the analysis were shown on Fig. 4. For the description of size and shape of grains following parameters were used:

- number of grains on the sample surface,
- average grain surface,
- shape coefficient.

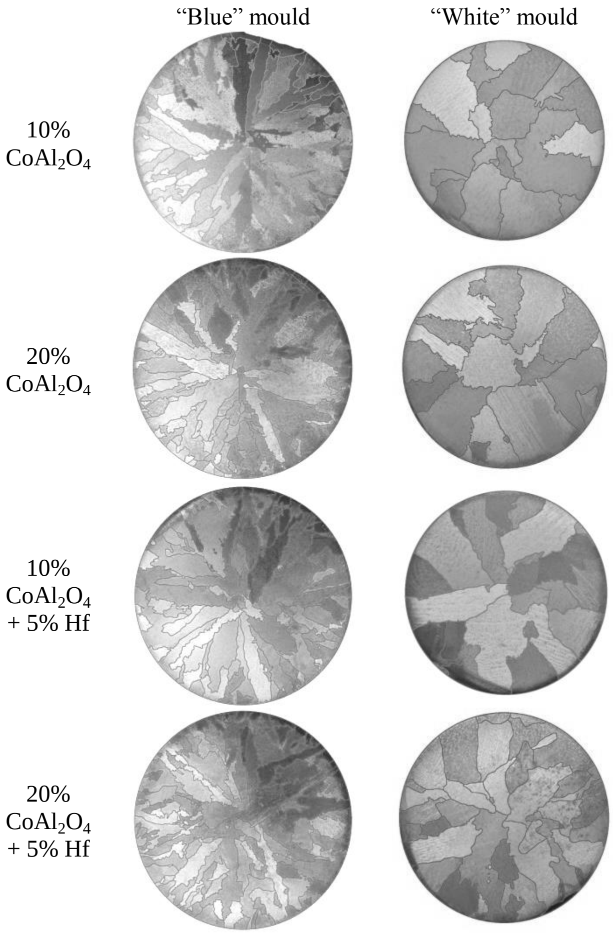

Fig. 4. Macrostructure on cross-sections of castings

Measurement results of the number of grains, average grain surface and shape coefficient are shown on Fig. 5 and Fig. 6.

Results of the study show that volume-only modification promotes the formation of coarse grains. On the other hand, complex (volume and surface) modification creates fine macrostructure. Significant influence of hafnium powder addition to filter modifying coating was also found. This effect is most evident in “white” parts of castings 3 and 4. Average grain surface is lower in comparison to castings without hafnium powder addition.

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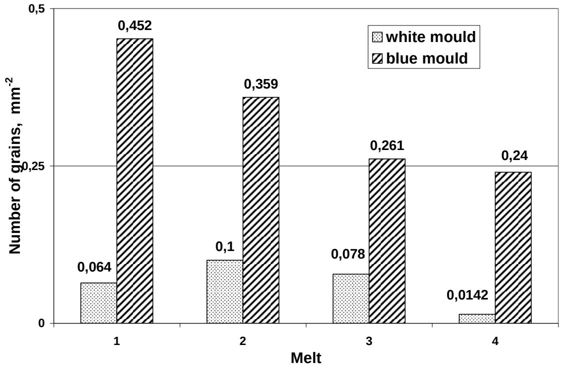


Fig. 5. Number of grains per 1mm^2 vs. surface area

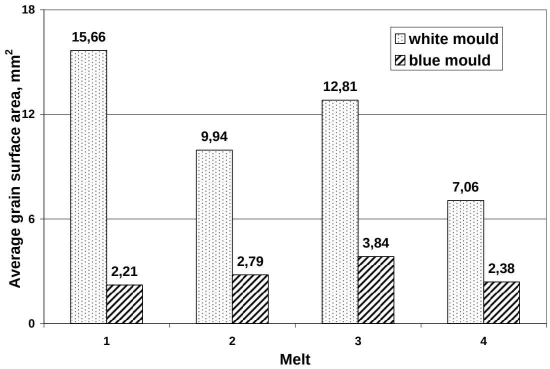


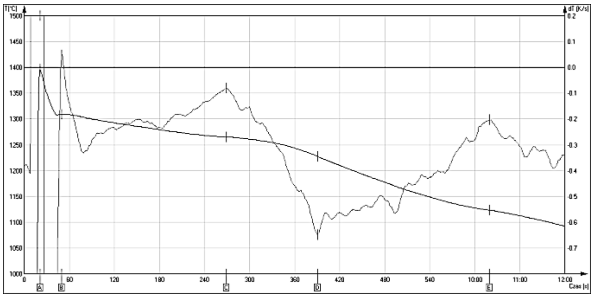
Fig. 6. A comparison of the average grain surface areas

Very significant influence of pouring temperature on stereological parameters of macrostructure was found. For every casting pouring temperature was similar, however maximum temperature registered in course of thermal analysis was as follows:

- melt 1 - 1396°C,
- melt 2 - 1411°C,
- melt 3 - 1425°C,
- melt 4 - 1400°C.

Magnitude of modification effect was greater in lower temperatures. In case of melt 3 maximum registered temperature of 1425°C undoubtedly weakened the effect of volume modification.

Example of ATD graph was shown on Fig. 7. Similar graphs for every melt were used to determine solidification parameters T_{liq}, T_{Eut} i T_{sol}. Based upon obtained T_{liq} values, results of chemical composition analysis and results of previous experiments [8-14], relation of T_{liq} and carbon content was plotted on Fig. 8.



T_{max}	A	2 s	1396°C
T_{liq}	B	5 s	1309°C
T_{Eut}	C	270 s	1265°C
T_{sol}	D	391 s	1228°C
T_{pst}	E	620 s	1123°C

Fig. 7. ATD graph for melt 1

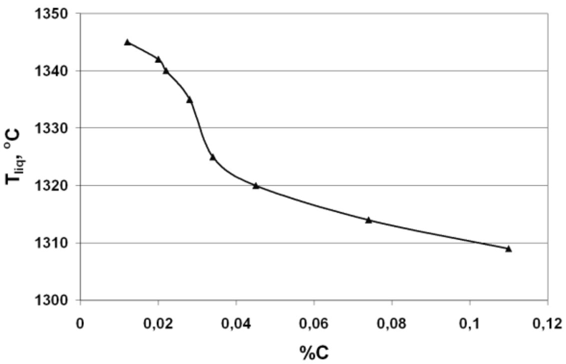


Fig. 8. Relation between carbon content and T_{liq} based upon experimental data

These results show that carbon content in examined superalloys has significant influence on solidification parameters (similar to iron alloys). It should be noted that carbon is very susceptible to loss due to re-melting. Content of other alloying elements (mainly Cr, Al, Ti, Mo and Nb) stay in the norm between re-melts. Thus by lowering carbon content it is possible to lower superheating in constant pouring temperature to obtain better fluidity and castability.

Acknowledgements

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