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Mechanical Properties And Creep Resistance Of Nickel Alloys After Complex Modification And Double Filtration

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Abstract

The paper presents the results of studies to determine the effect of complex surface and bulk modification and double filtration during mould pouring on the stereological parameters of macrostructure and mechanical properties of castings made from the post-production waste IN-713C and the MAR-247 nickel alloys. The evaluation covered the number of grains per 1mm^2 of the sample surface area, the average area of grains and the shape index, hardness HB, tensile strength and resistance to high temperature creep. The results indicate the possibility of controlling the stereological parameters of macrostructure through application of several variants of the modification, controlling in this way also different low- and high-temperature properties. The positive effect of double filtration of the alloy during mould pouring on the metallurgical quality and mechanical properties of castings has also been emphasized.

Keywords: Nickel Superalloys, Macrostructure, Modification, Filtration, Hardness, Creep Behaviour

1. Introduction

Precision castings of aircraft engine components (turbine discs, compressor blades, high pressure turbine blades) should be characterised by high stability of mechanical properties, corrosion resistance and creep resistance at high temperatures [1, 2]. Additionally, these castings are required to have very narrow dimensional tolerances, excellent surface finish in as-cast state and after heat treatment, and minimum level of the gas and shrinkage porosity defects. Therefore attempts are made to produce the structure of equiaxed grains within the entire volume of the casting. The fundamental technological problem in casting of these alloys is the ability to control the type and size of grains and adjust them to the specific operating conditions of individual aircraft engine components. The enlargement of grain size increases the creep resistance at normal and high temperatures, and for this reason structure of this type is recommended for the rotating components (combustion chamber). Castings with fine-grained structure show higher mechanical properties at low temperatures and improved thermal fatigue resistance, and therefore they are successfully applied for fixed elements operating at low temperatures. The reference literature, both national and international, offers abundant information on the process of microstructure refining in nickel superalloys by modification with nanoparticle inoculants [3-6]. The effect of $CoAl_2O_4$ modifier content in the modifying coating on the size of grains, and hence on the microstructure and, further, on the mechanical properties of the creep resistant MAR M 509 cobalt superalloy and RENE-77 alloy is described in [7]. The authors of this study were also conducting successful research on the structure refinement and properties of alloys such as IN-713C, IN-100 and MAR-247, using a combined treatment of surface and bulk modification [8-12].

2. Research problem

Nickel alloys are not produced in Poland, neither are the recovery remelting processes carried out. Therefore, an important issue is the management of production waste (rejects, components of gating systems, etc.). It was found that repeated melting of the charge composed of ingots made from nickel alloys does not lead to significant changes in the chemical composition, going beyond the established boundaries [13]. The problem in the process of nickel alloys melting and casting is how to maintain a good metallurgical quality of ingots used as a charge material. It has been found that the metallurgical quality of these ingots is often poor (oxide-coated shrinkage porosity and cavities), which significantly reduces the quality of castings [14]. Therefore, so important is filtering of metal, removing the impurities during casting.

In terms of the performance characteristics of the creep resistant alloys based on nickel, it is highly recommended to provide an optimum combination of satisfactory mechanical properties at elevated and high temperatures (tensile strength, yield strength, elongation) and resistance to high temperature creep. The preferred complex of properties can be obtained, among others, by appropriate selection of the grain size, orientation, and homogeneity. Grain size can affect the mechanical properties, plastic properties and creep resistance. In practice, the grain size is adjusted to the operating conditions of the alloy. Fine-grained equiaxed structure is suitable for operation at low temperatures (up to 700°C), where high fatigue resistance and tensile strength are required.

At the operating temperature of the rotating blades (about 1100°C) it is the creep behaviour that plays the decisive role. In such cases, the prevailing tendency is to have large grains and monocrystalline structure in final products.

Therefore, a very important problem is to have the possibility of influencing the formation of macrostructure as a result of different variants of the modifying and refining treatment applied to nickel alloys.

3. Research materials and methods

The aim of the conducted studies was to examine what impact the modification technique (bulk modification alone or combined surface and bulk modification) will have on the formation of microstructure and mechanical properties in pilot castings.

The combined surface and bulk treatment requires the presence of an additional filter placed in the pouring basin. The filter contains cobalt aluminate and additives of active elements (Al or Hf powder). An additional effect of this solution is the double filtration of alloy.

Studies were conducted on an IN-713C nickel alloy and MAR-247 superalloy (post-production waste: rejects, parts of the gating system, etc.). Melting was carried out in a vacuum induction furnace, model IS 5/III, made by Leybold – Heraeus, using argon as a protective gas atmosphere.

The location of filter is shown in Figure 1. A view of the blue mould and white mould with a modifying filter is shown in Figure 2. Moulds with wool insulation as shown in Figure 3 were preheated in an electric resistance furnace to 1000°C before placing them in the furnace chamber. The pouring temperature was 1500^{o}C.

Four experiments were carried out:

1. Melt IN-713C (B), (blue mould, blue filter)
2. Melt IN-713C (W), (white mould, blue filter)
3. Melt MAR-247 (B), (blue mould, blue filter)
4. Melt MAR-247 (W), (white mould, blue filter)

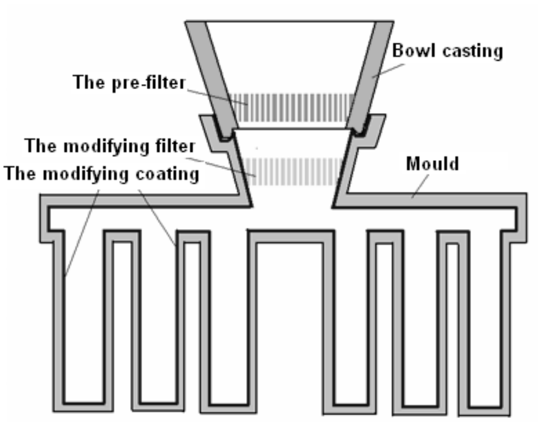

Fig. 1. Schematic diagram of the ceramic mould –filters location

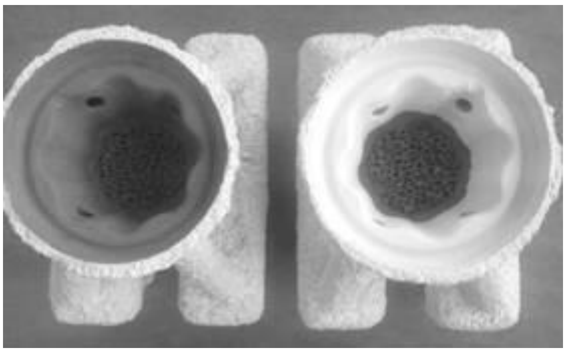
Fig. 2. Moulds blue and white before insulation

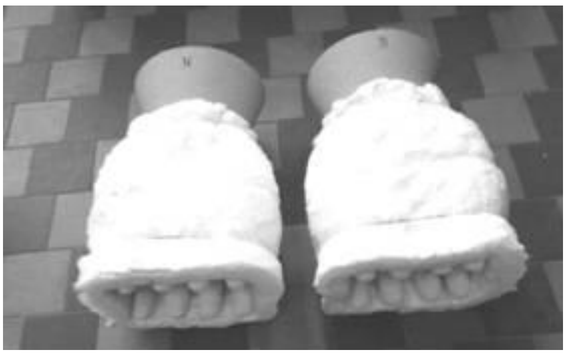
Fig. 3. Moulds with insulation ready for tests

4. Results and discussion

Samples for macrostructural examinations were etched with Marble reagent. The results of these observations are shown in Figure 4.

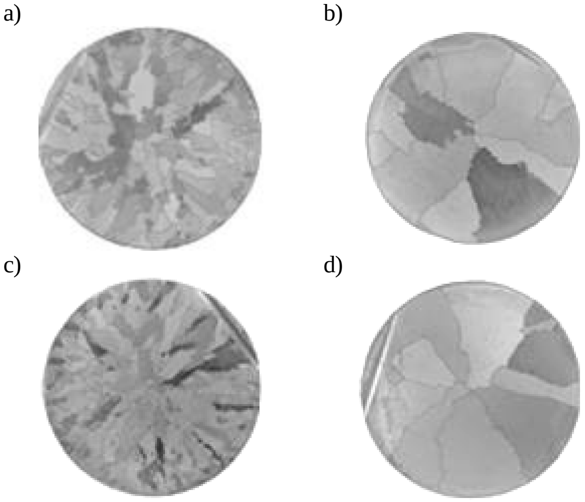

Fig. 4. Macrostructure on cross-sections of castings: a) IN-713C (B), b) IN-713C (W), c) MAR-247 (B), d) MAR-247 (W)

The basic parameters of the macrostructure were evaluated by Met-Ilo programme. The results of calculations for the number of grains, average surface area and shape index values are shown in Figures 5÷7.

The study shows that the bulk modification alone favours the formation of coarse-grained structure, while the simultaneous (complex) bulk and surface modification has a beneficial effect on the formation of fine-grained structure. A significant influence of pouring temperature on the formation of stereological characteristics of the macrostructure has been observed. The lower is the temperature of pouring, the more the modifying effect tends towards stronger refinement of the granular structure.

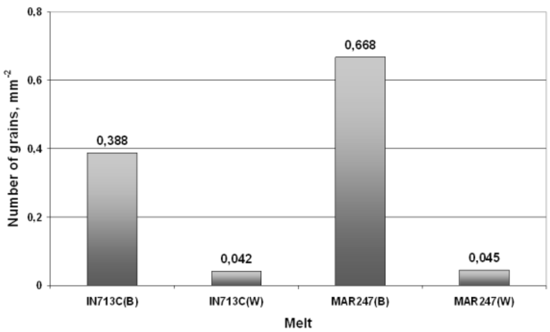

Fig. 5. Number of grains per 1mm^2 vs surface area

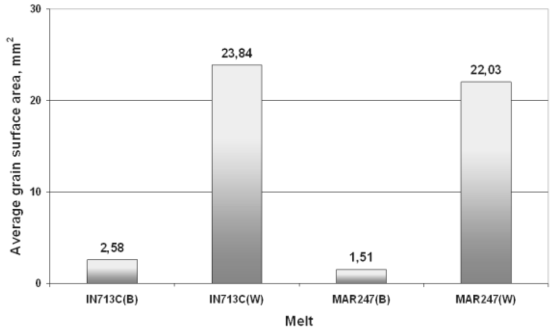

Fig. 6. A comparison of the average grain surface areas

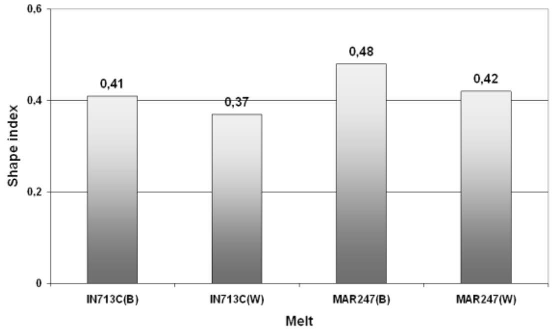

Fig. 7. A comparison of the grain shape index

From the obtained castings, samples were prepared for mechanical tests at room temperature and for high-temperature creep resistance studies. The results are shown in Figures 8 and 9 for the tensile strength and yield strength (R_m and R_{02}), respectively, and in Figures 10 and 11 for the high-temperature creep rupture strength, e.g. MAR-247 alloy (982^{o}C, the stress of 157.1 MPa).

The consequence of modification is an obvious increase of mechanical properties, especially of the yield and tensile strengths. Compared with unmodified melt, these properties increase by about 10 to 15% as a result of the combined modification. Yet, it has turned out that too strong effect of modification deteriorates the high-temperature creep resistance.

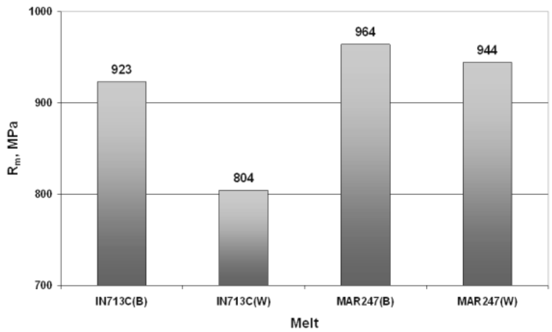

Fig. 8. The tensile strength R_m

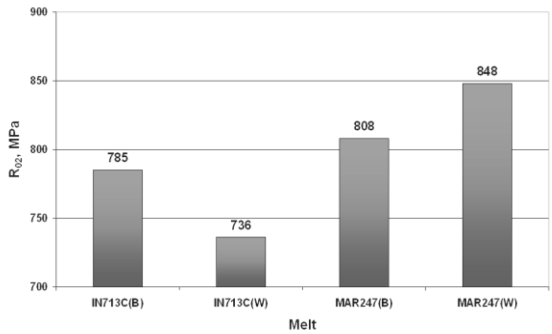

Fig. 9. The yield strength R_{02}

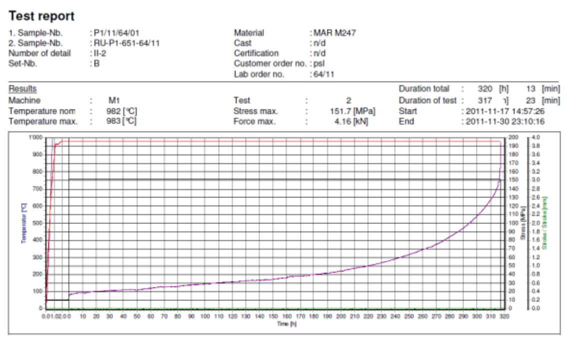

Fig. 10. Plotted results of creep test for MAR-247 (W) (white mould, blue filter) – time-related creep rupture strength (317 h 23 min.)

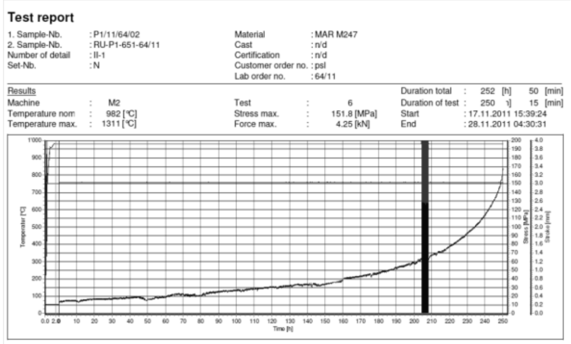

Fig. 11. Plotted results of creep test for MAR-247 (B) (blue mould, blue filter) – time-related creep rupture strength (250 h 15 min.)

Samples with fine-grained structure (combined surface and bulk modification) are characterised by shorter time to failure, i.e. below an acceptable level. Compared to previous results [8-10], a favourable effect of double filtration on the mechanical and plastic properties, and on the creep resistance has been observed.

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