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Mechanical properties and creep resistance behaviour of IN-713C alloy castings

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Abstract

The paper presents the results of investigations on the effect of modification process on mechanical properties and high-temperature creep resistance behaviour of IN-713C alloy specimens. Two melts modified in volume were made and one melt modified by combined surface-volume technique. A beneficial modifying effect of filters designed according to the authors' genuine concept has been proved. As a reference, the results obtained on non-modified castings were used. A very beneficial effect of combined modification on the degree of equiaxial grain refinement and increase of R_m and R_{02} has been reported. Unfortunately, refining of macrostructure obviously deteriorates the alloy high-temperature creep resistance behaviour.

Keywords: IN-713C nickel alloy, Modification, Macrostructure, Tensile strength, Creep

1. Introduction

Structural „hot" elements of the aircraft engines are subject to special requirements of production and quality. Currently, the near-net-shape castings of the aircraft engine parts are made from modern grades of nickel and cobalt alloys, like RENE-77, IN-100, IN-713C [1, 2]. On solidification, these alloys produce a specific type of macrostructure, composed of frozen and columnar grains. Structure of this type is prone to crack formation and propagation, resulting in fatal failure of the aircraft engines Therefore, every attempt should be made to obtain the structure of equiaxial grains within the whole casting volume.

One of the solutions leading to this goal is surface modification with inoculant placed in a layer directly reproducing the casting surface [3].

However, surface modification of castings cannot solve the design problems. It has been proved that the macrostructure of IN-713C alloy castings poured in moulds with a modifying coating undergoes modification only on the casting surface or in sub-surface layers. Moving towards the central part of casting, the undesired structure of columnar crystals remains unchanged.

The authors of this study were investigating the solidification process [4] and the effect of volume modification of IN-713C nickel superalloy on the stereological parameters of alloy macrostructure [5, 6]. The results presented in the study are a good example of the beneficial effect of volume modification on the crystallisation and refinement of equiaxial grains. Promising results were obtained when the modification process was carried out with a mixture of cobalt aluminate, aluminium powder and colloidal silica used as a binder. The modifying effect of cobalt particles was confirmed [7].

In this study, an attempt has been made to determine what effect the type of modification (volume modification or combined surface-volume modification) can have on the refinement of macrostructure (equiaxial grains), mechanical properties and high temperature creep resistance behaviour of specimens cast from IN-713C alloy.

2. Materials and methods of investigation

Studies were conducted on an IN-713C nickel superalloy which, besides nickel, also contained: 0,03% Co, 13,26% Cr, 5,85% Al, 4,10% Mo, 0,85% Ti, 2,27% (Nb + Ta) and 0,12%C.
Melting was carried out in a vacuum induction furnace, model IS 5/III, made by Leybold – Heraeus. The crucible made from rammed MPi refractory material based on MgO was used. Melting was carried out in vacuum 10^{-2}Tr high. Before pouring, argon at a pressure of about 400 Tr was introduced to the furnace chamber. The charge weight was 8,5 kg. Before pouring, the alloy was overheated to a temperature of 1500^{o}C.
The temperature of the melt in crucible was measured with a Pt=PtRh10 immersion thermocouple, and additionally with laser pyrometer. The temperature on pouring was 1460^{o}C.
Ceramic moulds were made by investment process at the WSK-PZL Rzeszów.
The following four experiments were carried out:
1. White mould (without modifying coating) with common-type ceramic filter.
2. White mould (without modifying coating) with common-type ceramic filter coated with inoculating agent.
3. White mould (without modifying coating) with ceramic filter of the authors' genuine design.
4. Blue mould (with modifying coating) with ceramic filter of the authors' genuine design.

So, in experiments 2 and 3, the modification was of a volume type, while in experiment 4 it was of a surface-volume type. The modifying coatings for moulds and the ceramic filters contained zirconium silicate, cobalt aluminate (about 10%) and colloidal silica as a binder. Filters designed by the authors were made from polyurethane foam, zirconia flour, cobalt aluminate and colloidal silica. After "melting out" of the polyurethane foam at a temperature of 600^{o}C, the filter was placed in a mould pouring basin. To reduce the heat transfer rate, ceramic moulds were wrapped with an insulating material. Moulds ready for pouring are shown in Fig. 1.

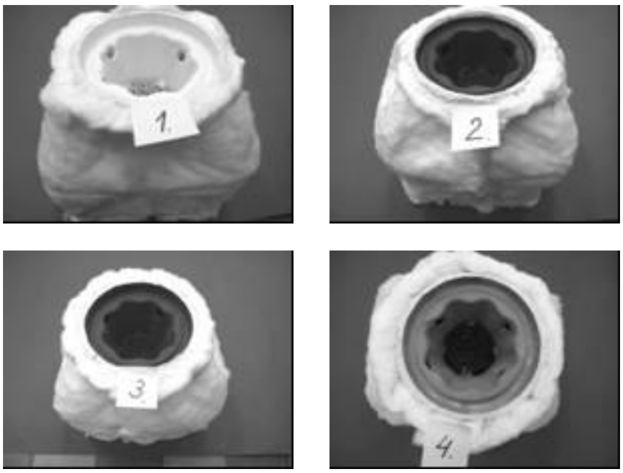


Fig. 1. Moulds ready for pouring

Moulds, before transfer to the casting chamber of induction furnace, were preheated to 1100^{o}C in an electric chamber furnace. It has been proved that since the moment of taking the mould out from the chamber furnace, placing it in transfer chamber, pressure equalisation and start of pouring (total time of about 5 minutes), the temperature of mould drops by nearly 750^{o}C. The temperature of both molten metal and ceramic mould was controlled with a Pt-PtRh10 immersion thermocouple. Alloy was poured into a mould at a temperature of about 1465^{o}C. Figure 3 shows castings after breaking of the ceramic mould.

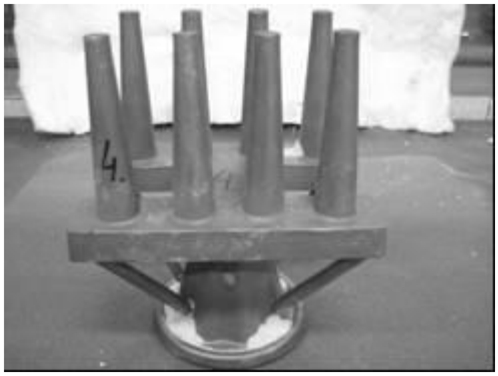


Fig. 2. Casting with specimens made according to experiment 4

3. The results of investigations and discussion of results

From castings, the specimens for macroscopic examinations were prepared. The specimens were etched with Marble's reagent. The results of examinations are shown in Fig. 3.

As might be expected, the macrostructure of castings poured from non-modified alloy is composed of large equiaxial grains. Modification refined alloy macrostructure and resulted in the formation of equiaxial grains.
As follows from Fig. 3, the highest degree of grain refinement was obtained in experiment 4, which consisted in simultaneous surface modification (the coating applied on an internal mould surface) and volume modification (the use of a filter of the authors' own design). A comparison of macrostructures observed in specimens from melts 2 and 3 indicates better modification effect using filter made by the new technology.

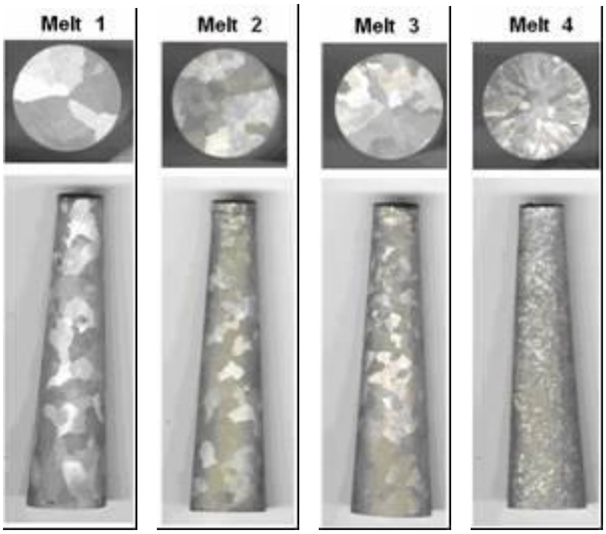


Fig. 3. The results of macrostructure examinations

The mechanical properties (R_m and R_{02}) and elongation A_5 as well as the reduction of area were determined on a fivefold specimen (ϕ8x40) with threaded ends (M12 thread).
The tensile test was carried out on a MTS-810 machine of 250kN maximum force with TESTSTAR control system. Elongation was measured with strain gauge of 25 mm measurement base.

The tensile test curve plotted for a specimen from melt 4 and the method for yield strength determination are shown in Fig 4. On the other hand, averaged results of the measurements of Rm, R_{02} A_5 and Z are plotted in Figs. 5 to 8.

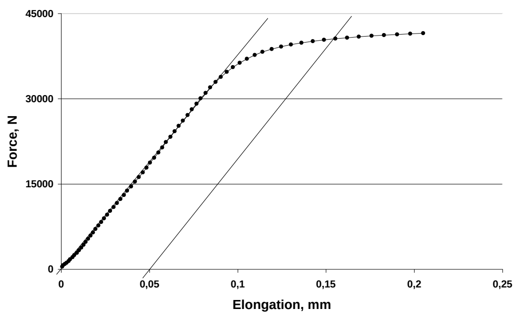


Fig. 4. The example of tensile curve plotted for specimen from melt 4

The creep test was carried out on a „waibag" type creep testing machine (the laboratory at Rzeszów University of Technology has got NADCAP accreditation). Specimens were heated in furnace up to a temperature of 982°C and loaded with axial force of a constant value causing in their cross-sections the preset tensile stresses of 151,7MPa. Specimen temperature was controlled with a Pt-Rh/Pt thermocouple.

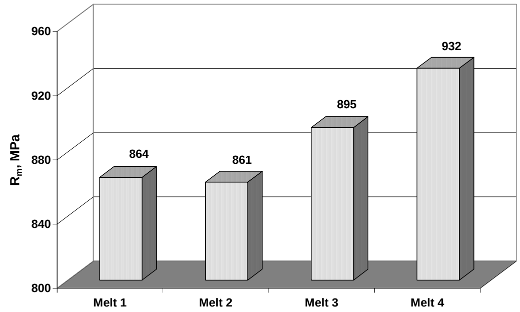


Fig. 5. A comparison of the tensile strength R_m

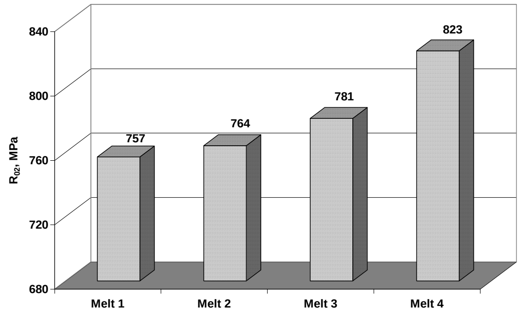


Fig. 6. A comparison of the yield strength R_{02}

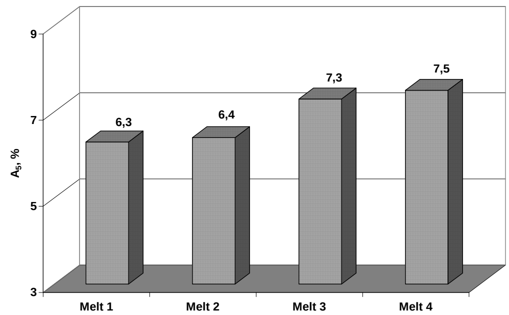


Fig. 7. A comparison of the elongation A_5

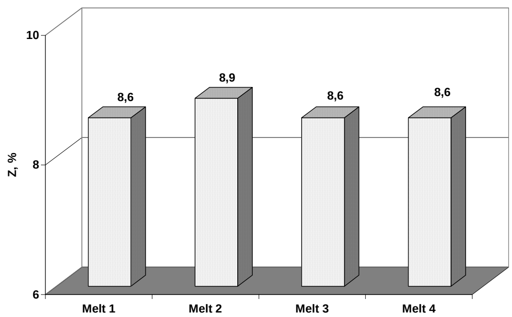
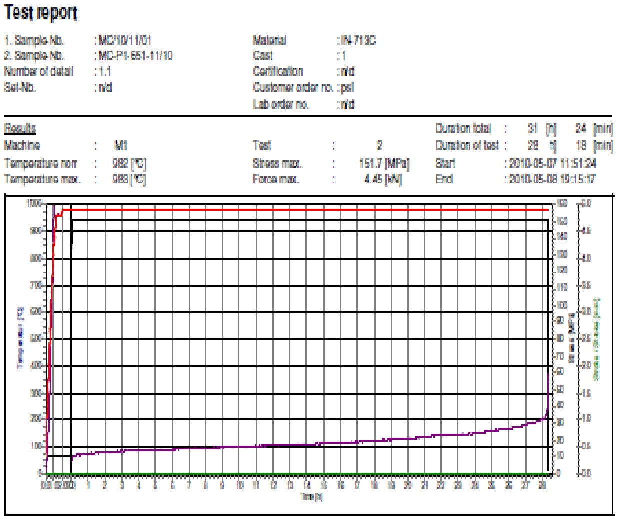
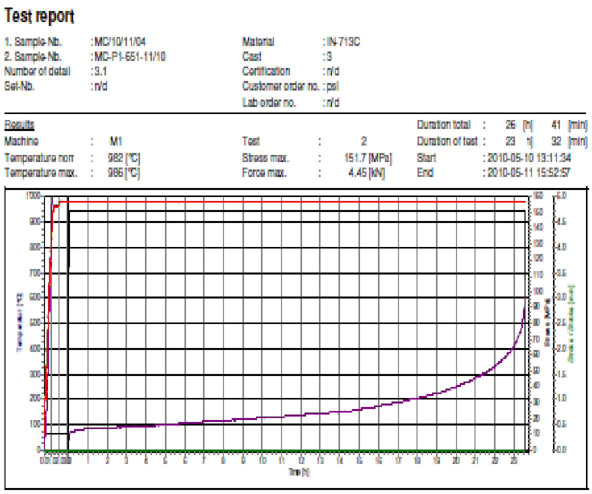


Fig. 8. A comparison of the reduction of area Z

The high-temperature creep resistance evaluation was based on the time lapse until specimen failure and on the value of elongation. Measurements were taken on 2 specimens. A sample of resultant documentation for the creep test carried out on specimens from experiments 1 and 3 is given below.





As assumed previously, the time until failure of IN-713C alloy specimen should be 23 hours minimum.

Mean time values (test duration) until specimen failure and values of elongation from individual experiments were:

Melt 1: time t_C - 29h 45 min., elongation A5 – 8,5%.
Melt 2: time t_C - 27h 20 min., elongation A5 – 10,0%.
Melt 3: time t_C - 23h 35 min., elongation A5 – 7,5%.
Melt 4: time t_C - 21h 26 min., elongation A5 – 8,0%.

4. Conclusions

From the conducted tests it follows that the combined method of surface modification (modifying coating on the internal mould surface) and volume modification (modifier as a constituent of the filter) produces the structure of equiaxial crystals within the entire casting volume. Volume modification alone results in the formation of mixed structure of both columnar and equiaxial grains. A consequence of the modification process is the well visible increase of mechanical properties, yield strength and tensile strength in particular. Compared with non-modified melt, the combined modification has improved these properties by approximately 10 to 15%. Unfortunately, it has also been noticed that too strong modification has unfavourable effect on the alloy high-temperature creep resistance behaviour. Specimens characterised by fine-grain structure (the combined process of surface and volume modification) are also characterised by the shortest time to failure, definitely beyond the admissible level.

Acknowledgements

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