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Effect of modification on the mechanical properties of IN-713C alloy

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Abstract

The results of studies on the effect of modification on macrostructure and mechanical properties (hardness, R_{02}, R_m, elongation A_5 and reduction of area Z) of IN-713C nickel alloy, examined on "carrot"- type specimens[(1)] were presented. One surface-volume modified melt and two volume-modified melts were made. As a reference, the results obtained on non-modified castings were used. A very beneficial effect of the combined surface-volume modification on alloy macrostructure (equiaxial crystals) and mechanical properties was reported. Volume modification produces mixed structure of columnar and equiaxial crystals. The efficiency of modification was additionally enhanced by application of filters made according to the authors' genuine design. The inoculant used in these filters was cobalt aluminate $CoAl_2O_4$.

Keywords: IN-713C nickel alloy, structure modification, structure, tensile strength R_m, yield strength R_{02}, elongation, hardness

1. Introduction

The structural „hot parts" of aircraft engines are subject to quite exceptional requirements as regards the manufacturing process and quality parameters. At present, 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 sensitive to crack formation and propagation, resulting in fatal failure of the aircraft engines [3, 4]. Therefore, every attempt should be made to obtain the structure of equiaxial grains within the whole casting volume.

One of the means to obtain this goal is surface modification with inoculant placed in the coating layer directly contacting casting surface [5].

Unfortunately, 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. Farther, in the central part of casting, the undesired structure of columnar crystals remains unchanged [7-10].

The authors of this study were investigating the solidification process [7] and the effect of volume modification of IN-713C nickel superalloy on the stereological parameters of alloy macrostructure [8, 9]. 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 [10].

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 macrostructure, microstructure and mechanical properties of test castings. The results of mechanical tests (tensile strength R_m, yield strength R_{02}, elongation A_5), Brinell hardness measurements (HB) and casting cooling rate studies were examined in detail to state their possible effect on macro- and microhardness of individual phase constituents present in the IN-713C nickel alloys.

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. For melting, vacuum 10^{-2}Tr high was applied. 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 about 1500°C.
The crucible temperature was measured with a Pt-PtRh10 immersion thermocouple, and additionally with laser pyrometer. The temperature on pouring was 1460°C.
"Carrot"-type specimens were cast. The 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 additionally 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 applied on 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°C, the filter was placed in the mould pouring basin. To reduce the heat transfer rate, the ceramic mould was wrapped with an insulating material. Moulds ready for pouring are shown in Fig. 1.

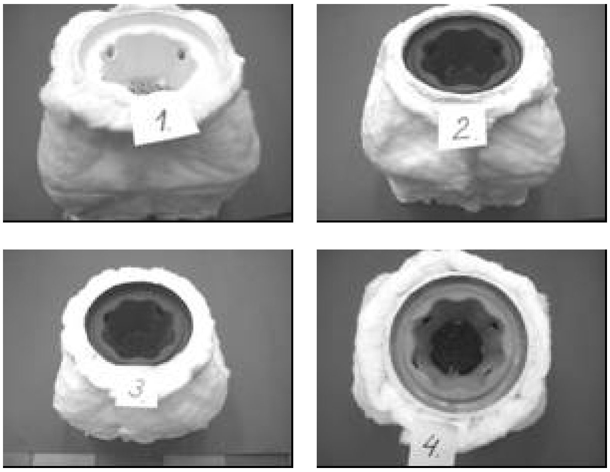

Fig. 1. Moulds ready for pouring

Moulds, before transfer to the casting chamber of induction furnace, were preheated to 1100°C in an electric chamber furnace. It has been proved by experiments that during the time of about 6.5 minutes which must elapse before pouring starts (mould taken out from the chamber of preheating furnace, transfer to casting chamber and pressure equalisation), the temperature of mould drops by nearly 800°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 1470°C. A view of the mould placed in the chamber of induction furnace is shown in Fig. 2, while Figure 3 shows a general view of crucible and mould poured with alloy (as seen through a peep-hole).

Fig. 2. Preheated mould in the chamber of induction furnace made by Leybold

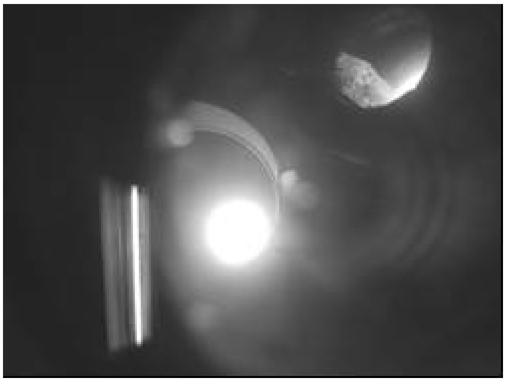

Fig. 3. Furnace interior after mould pouring

3. The results of investigations and discussion of results

"Carrot"-type test castings produced for individual experiments are shown in Fig. 4. 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. 5.

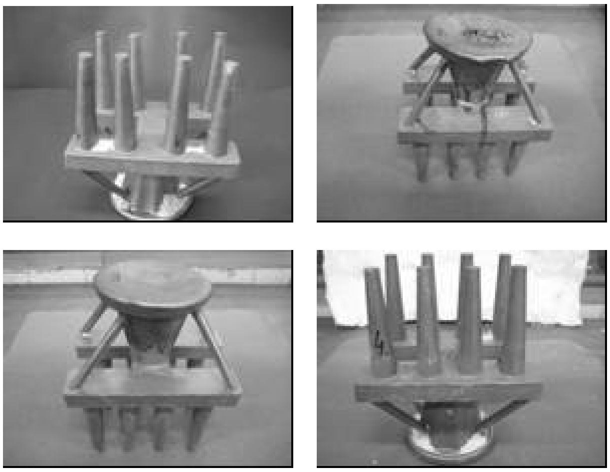

Fig. 4. Castings ready for experiments

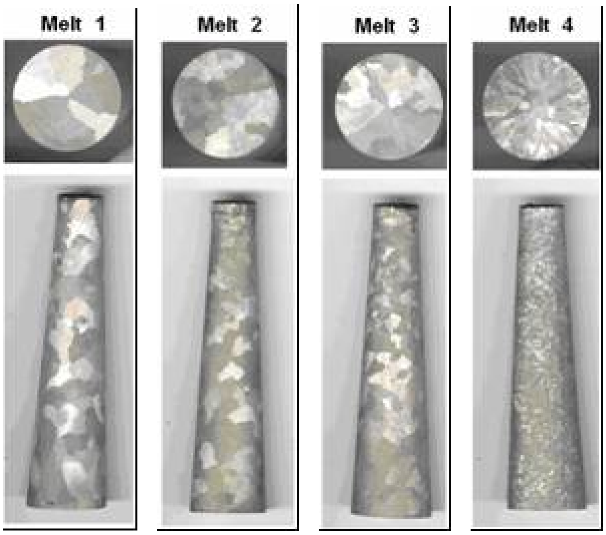

Fig. 5. The results of macrostructural examinations

As might be expected, the macrostructure of castings poured from non-modified alloy is composed of large columnar grains. Modification refined alloy macrostructure and resulted in the formation of equiaxial grains.

Figure 5 shows that 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 more efficient modification with the authors' genuine filter.

Vickers hardness was measured with ZWICK /ZHV50 hardness tester at a loading of 98,1N. Five measurements were taken on each specimen. The results converted to Brinell scale are compared in Table 1, while averaged values are plotted in Fig. 6.

Table 1. The results of Vickers and Brinell hardness measurements.

Result	Melt 1		Melt 2		Melt 3		Melt 4	
	HV	HB	HV	HB	HV	HB	HV	HB
1	333	313	346	327	354	334	374	353
2	358	338	349	328	357	337	370	350
3	344	324	362	342	356	336	368	348
4	333	314	346	326	354	334	359	339
5	347	327	345	325	362	341	362	342
medium	343	323	350	330	357	336	367	346

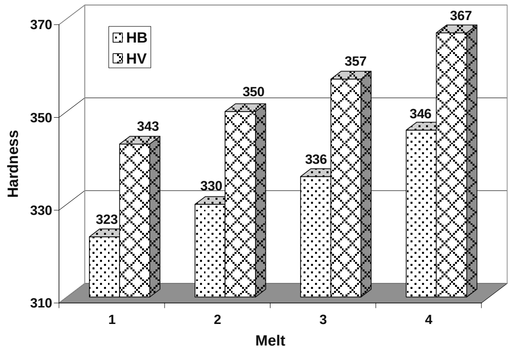

Fig. 6. A comparison of hardness values in the examined specimens

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 7. On the other hand, averaged results of the measurements of R_m, R_{02} A_5 and Z are plotted in Figs. 8 to 11.

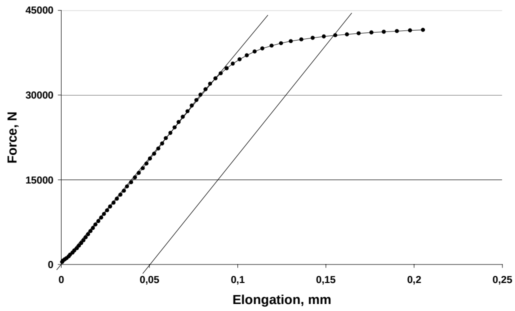

Fig. 7. The example of tensile curve plotted for specimen from melt 4

From the conducted tests and investigations it follows that the combined method of surface and volume modification (modification coating applied on the internal mould surface and modifier as a filter constituent, respectively) 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.

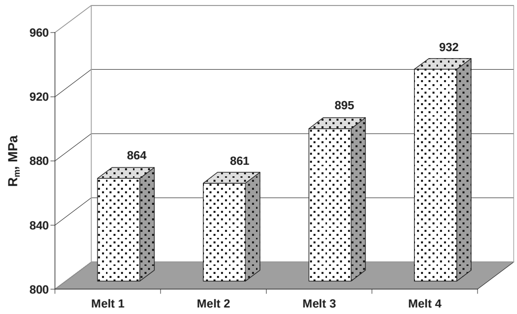

Fig. 8. A comparison of the tensile strength R_m

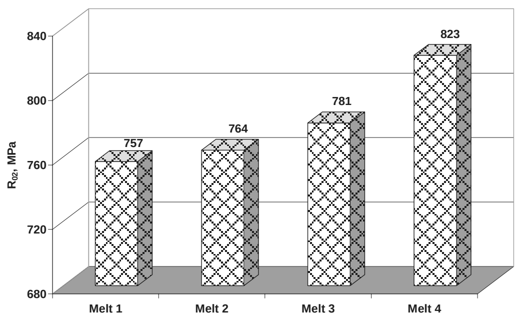

Fig. 9. A comparison of the yield strength R_{02}

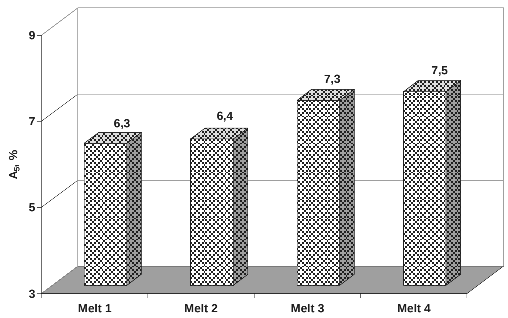

Fig. 10. A comparison of the elongation A_5

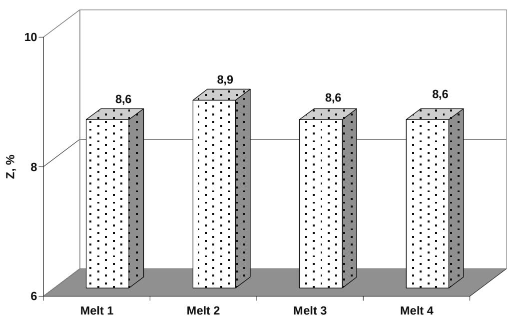

Fig. 11. A comparison of the reduction of area Z

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% .

(1)specimens shaped like a frustum of cone – “carrot” is a genuine name given by the authors of the present study to these specimens made by investment casting process

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