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The Effect of Temperature on the Result of Complex Modification of IN-713C Superalloy Castings

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Abstract

The paper presents the results of research on the determination of the effect of pouring temperature on the macrostructure of the castings subjected to complex (surface and volume) modification and double filtration. Tested castings were made of post-production scrap (gating system parts) of IN-713C superalloy. Tests included the evaluation of the number of grains per 1 mm^2 , mean grain surface area, shape factor and tensile strength. Casting temperature below $1470 \text{ }^\circ\text{C}$ positively influenced the modification effect. The grains were finer and the mechanical properties increased, especially for castings with thicker walls. On the other hand, manufacture of thin walled castings of high quality require pouring temperature above $1480 \text{ }^\circ\text{C}$.

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

1. Introduction

Nickel superalloy used for aircraft engine components are not as yet produced in Poland. Domestic industry is based on import and the nickel superalloys castings are manufactured in only a few foundries. What is particularly important is that the remelting and refining of post processing scrap is not realised at all in domestic foundries. Scraps is probably sent back to the alloy manufacturer abroad.

An important technological and economic problem is the management of industrial scrap (failed castings, gating system parts and such). Reusing of alloys may require supplementing the alloying additions (especially the chemically active ones) and the application of modification process to refine the alloy. In fact, almost all of the cast jet engine components require modification

in the mould to achieve the equiaxed grain structure and grain refinement.

Observations of surface and cross-section macrostructure has shown that the surface modification process used to date does not offer fully satisfactory results. The modification effect is present only in the surface layer of the casting to a depth of circa 1 mm. Deeper, in the internal areas of the casting the grains take the unfavourable columnar form. The results of such investigations are presented in papers [1-3].

Previous research has shown that the pouring temperature has a significant influence on the morphology of primary structure (macrostructure). This is important because the pouring temperature influences the liquid metal fluidity and thus the ability to reproduce the mould details and thin walls.

2. Materials and methods of investigation

The samples for testing were taken from “carrot” (cone shaped) type test casting. The large test moulds provided by WSK Rzeszow were cut to fit the furnace chamber. The resulting mould had two truncated cone shaped cavities: one unmodified (white) and one surface modified (blue). The patented [4] ceramic modifying filter was installed in the pouring basin. The type S Pt-PtRh10 thermocouple encased in quartz glass tube was installed in unmodified cavity. The schematic of the test mould and its preparation for pouring are shown on Figs. 1 and 2.

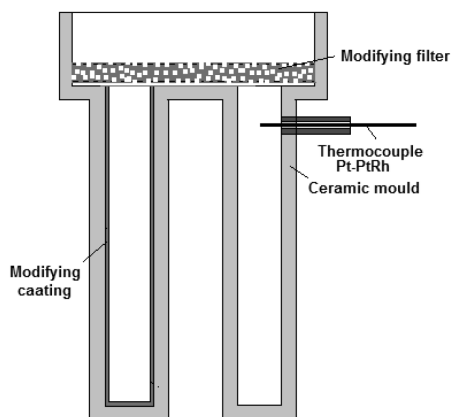


Fig. 1. Schematic of the ceramic mould

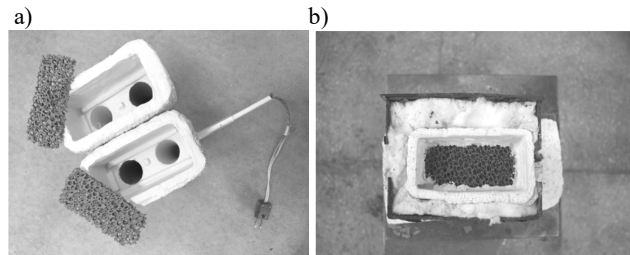


Fig. 2. Ceramic moulds with visible „blue” and “white” cavities (a) and with installed filter in insulated casing (b)

The experiments were carried out according to the plan presented below.

Melt	Casting temperature	Mould	Filters
1	1480 °C	Blue mould – modifying	Blue filter
	1480 °C	White mould – unmodified	Blue filter
2	1570 °C	Blue mould – modifying	Blue filter
	1570 °C	White mould – unmodified	Blue filter

Moulds were insulated using wool insulation and heated to 1000 °C before pouring. Tested charges consisted of post-

production scrap (gating system parts) of IN-713C. Melting and pouring was carried out in Balzers VSG-02 vacuum induction furnace using Al₂O₃ crucible. The charge weight was about 1200 g and the casting weight was about 800 g. The vacuum of 10⁻³ T was maintained during melting. Before pouring, the furnace chamber was filled with argon. The pouring was carried out in the argon atmosphere at a pressure of 900 hPa. The temperature of liquid metal was controlled using type S Pt-PtRh10 thermocouple immersed in the crucible.

The solidification parameters of all cast samples were determined by the ATD analysis using the thermocouple installed in the mould. Each cast was also subjected to the chemical composition test using optical emission spectrometer Oxford Instruments FOUNDRY-MASTER. The finished castings are shown on Fig. 3 and the results of chemical composition analysis are presented in Table 1.

Table 1.
The results of chemical analysis

Melt	C	Cr	Al	Ti	Ni
1	0,147	13,7	6,08	0,915	rest
	Mo	Nb	Ta	Co	
	4,28	2,22	0,05	0,261	
2	C	Cr	Al	Ti	rest
	0,133	13,6	6,21	0,948	
	Mo	Nb	Ta	Co	
	4,32	2,23	0,05	0,273	



Fig. 3. Finished castings

3. The results of investigations and discussion of results

The results of ATD analysis of cooling and solidification process are shown on Fig. 4 and Fig. 5.

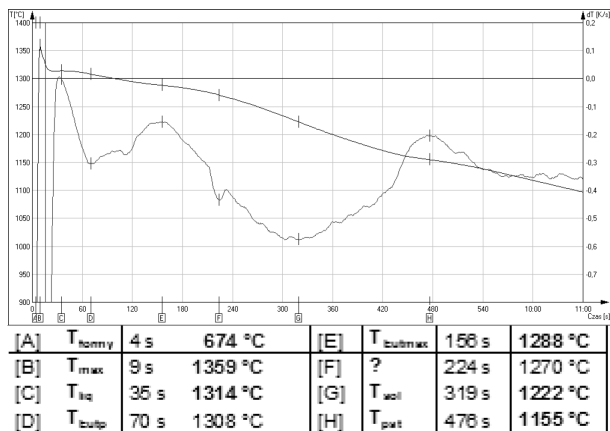


Fig. 4. Results of thermal analysis ATD - Melt 1 (casting temperature 1480 °C)

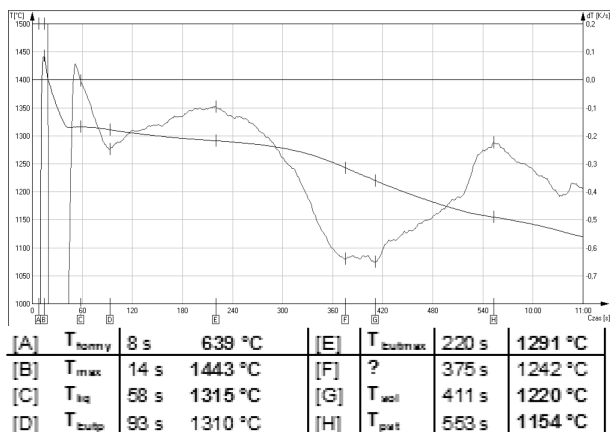


Fig. 5. Results of thermal analysis ATD - Melt 2 (casting temperature 1570 °C)

ATD results show that the pouring temperature does not have a significant influence on solidification parameters (in the studied range). T_{liq} temperature for the melt 1 was 1314 °C and for the melt 2 1315 °C. Similar convergence occurred in the case of the eutectic temperature T_{Emax} (1288 and 1291 °C) and the solidification end temperature T_{sol} (1222 and 1220 °C). Higher pouring temperature lengthens the individual solidification phases, for example the time to T_{sol} for melt 1 was 319 s and for melt 2 was 411 s. This undoubtedly has impact on on macrostructure. The ATD graphs, especially the last stages of solidification, suggest that the metallurgical quality of the charge material was good [5,6].

The evaluation of macrostructure was carried out on etched cross-sections and side surfaces of the castings using digital image analysis program Met-Ilo [7]. The samples after etching are shown on Figs. 6 to 9.



Fig. 6. Macrostructure of side surface and cross-section of test casting (1480°C, white mould, blue filter)

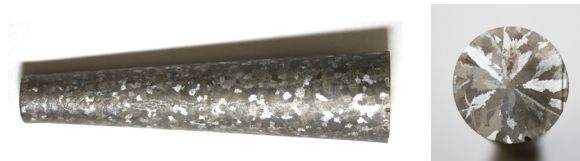


Fig. 7. Macrostructure of side surface and cross-section of test casting (1480°C, blue mould, blue filter)



Fig. 8. Macrostructure of side surface and cross-section of test casting (1570°C, white mould, blue filter)

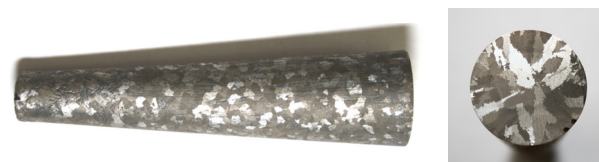


Fig. 9. Macrostructure of side surface and cross-section of test casting (1570°C, blue mould, blue filter)

Following parameters were used for the macrostructure evaluation:

- number of grains per 1 mm²,
- mean grain surface area,
- mean grain shape factor.

The results of evaluation are presented on Figs. 10 to 12.

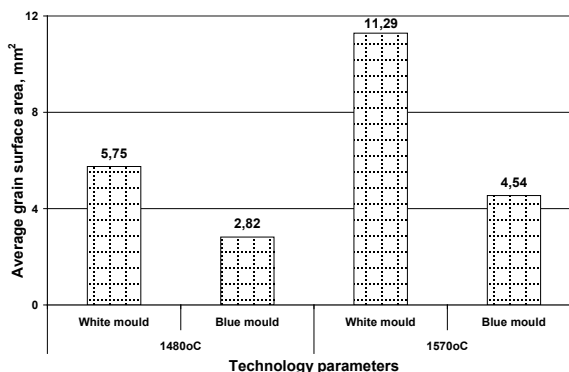


Fig. 10. A comparison of the average grain surface areas

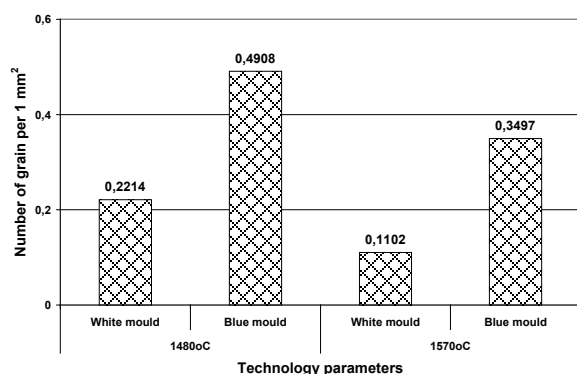
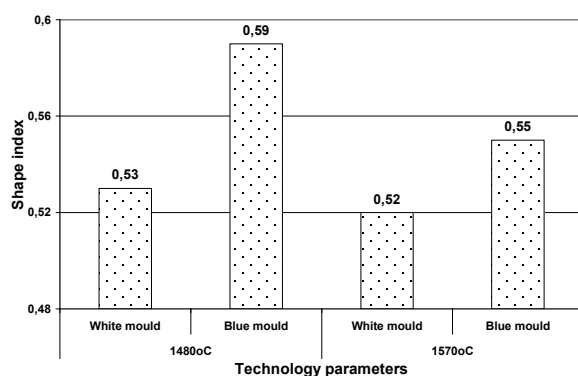
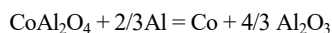
Fig. 11. A comparison of the number of grains per 1 mm²

Fig. 12. A comparison of the shape factor

Performed studies show that the volume only modification favours the creation of coarse grained structure while the complex surface and volume modification favours more beneficial fine grained structure. Significant influence of pouring temperature on resulting macrostructure was observed. Lower pouring temperatures strengthen the modification effect which lead to stronger refinement of grains. The benefit of volume modification (white mould, blue filter) become apparent with lower pouring temperature and the fine and equiaxed grains are formed. The number of grains per mm² was almost doubled in 1470 °C. The modification changes not only the size of a grain, but also changes the shape of the grains (Fig. 12).

Mechanism of modification using cobalt inoculants (CoAl₂O₄), especially the effect of temperature on the liquid metal – mould boundary, is not yet fully understood. Papers [8,9] suggest that the exchange reaction between the inoculant and the active alloying elements (like Al or Cr) occurs after the metal has been poured to the coated mould cavity:



Among the products of this reaction there are active Co particles which can initiate the crystallization of the alloy. This reaction

may occur on mould surface or on filter surface. Authors of [1,2] have hypothesized that the Co particles may have the borderline stability in liquid phase. This was called the dissolution temperature and presumed to be at around 1440 °C.

The Co particles (clusters) can be the crystallization seeds only to the point of dissolution in liquid alloy. When the pouring temperature is low so is the initial temperature on the mould – metal interface. In this case the time of contact between the liquid and the mould surface is shorter and so fewer Co particles are dissolved. This can be observed in thin walled castings where the number of seeds that are not dissolved is greater and so the effect of surface modification is more pronounced.

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