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INFLUENCE OF THE CERAMIC MOULDS INSULATION ON THE QUALITY OF GAS TURBINE BLADES MADE FROM THE INCONEL 713C – NICKEL-BASED SUPERALLOY

WPŁYW OCIEPLANIA FORM CERAMICZNYCH NA JAKOŚĆ ODLEWÓW ŁOPATEK TURBINY Z NADSTOPU INCONEL 713C

The influence of mould insulation on the microstructure of the nickel-based superalloy – Inconel 713 C, used in gas turbine blades, was investigated. Turbine blade castings were made in industrial conditions. Three varieties of moulds insulation were used. Based on macroscope, fluorescence (surface defects) and radiographic investigations (internal defects) the quality of the castings was estimated. For selected castings light microscopy observations of cross sections of blades were carried out, as well. The average size and morphology of grains were estimated. It has been found, that the kind of the mould insulation influences the quality of castings and should be adjusted to the type of blade.
Keywords: turbine blade; ceramic mould; mould insulation; Inconel 713C; microstructure

W pracy ustalono wpływ ocieplenia formy na mikrostrukturę odlewów łopatek turbiny ze stopu Inconel 713C. Wykonano w warunkach przemysłowych odlewy łopatek o szerokości pióra 22 i 30 mm oraz jego długości 50 mm. Stosowano trzy rodzaje ocieplenia form ceramicznych. Jakość odlewów określono na podstawie badań makroskopowych, fluorescencyjnych (wady powierzchniowe) i rentgenowskich (wady wewnętrzne). Dla wybranego odlewu łopatki wykonano badania mikroskopowe. Określono średnią średnicę ziaren i ich rozmieszczenie na przekroju odlewu łopatki. Stwierdzono wpływ sposobu ocieplenia formy na mikrostrukturę pióra łopatek wykonanych ze stopu Inconel 713C. Wyniki badań stanowią podstawę dla dalszych prac dotyczących wpływu ocieplenia form na jakość odlewów łopatek turbin.

1. Introduction

Since their invention, over 50 years back, heat – and high temperature creep resisting Ni and Co – based superalloys γ' – strengthened, underwent numerous stages of evolution. This applies to chemical composition, casting technology, properties, as well as, a range of applications, which exceeds hot parts of gas turbine production [1].

Castings for hot part of gas turbine need extremely precise running of the technological process, a choice of process parameters and quality control of final castings. As for its technological factors - chemical composition, time and temperature of overheating and pouring of melt, as well as, shape and material of mould all influence crystallization kinetics. Crystallization kinetics is characterized by: number of forming grains (nucleation) and velocity of their growth. Control of technological factors makes it possible to predict the casting microstructure, as well as, mechanical and physical properties and lower casting defects (non metallic inclusions, cracks, porosity and misruns) [2, 4, 5, 6].

2. Methods of study

- The bars of commercial alloy Inconel 713C were studied. Their nominal composition was: Ni – 72, Cr – 14, Co – 0,4, Mo – 4,2, W – 0,2, Ta – 0,02, Al – 6,2, Ti – 0,6, Fe – 0,02, Mn – 0,001, Si – 0,001, C – 0,15, B – 0,012, Zr – 0,1, Nb – 2, Cu – 0,001, V – 0,002, Pt – 0,003 [wt%].

The model set consisted of : pouring gate, crossgate, three vents, six turbine blades wax models (22 and 30 mm blade width). The model sets were manually covered with 9 ceramic layers. The first and the second layers

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were made of "Alundum Elektrokorund 100" with silica bond. Layer 3 and 4 were composed of "Molochite 30/80" with ethyl sillicate as bond for layer 3 and silica for layer 4. "Molochite 16/30" was used for layers 5 to 8 (silica bond – layers 5 and 7; ethyl silicate for layers 6 and 8). Drying time for layers with silica bond and ethyl silicate was 3 h and 7 h respectively. The ninth layer was silicate only, and after spreading the mould was dryed for 50 h.

Ceramic moulds, after wax-losing in an autoclave and drying, were placed in a gas chamber furnace for pre – annealling at the temperature of 1150°C for 0.5 h.

Moulds were insulated with a monolayer of "Fiberfrax" (Tab.1).

TABLE 1

Properties of insulate material

Material	Thickness, mm	Density, kg/m^3	Maximum work temperature, °C
FIBERFRAX	13	64	1250

Three varieties of moulds were made:

– with gate system (pouring gate and crossgate) and mould drag insulated (Fig. 1-1),
– with only gating system insulated (Fig. 1-2),
– without insulation (Fig. 1-3).

Insulating gating system lowers the rate of heat transfer, and by that, mould feeding with molten metal is improved. Insulation of mould drag increases crystallization time in the bottom of the casting.

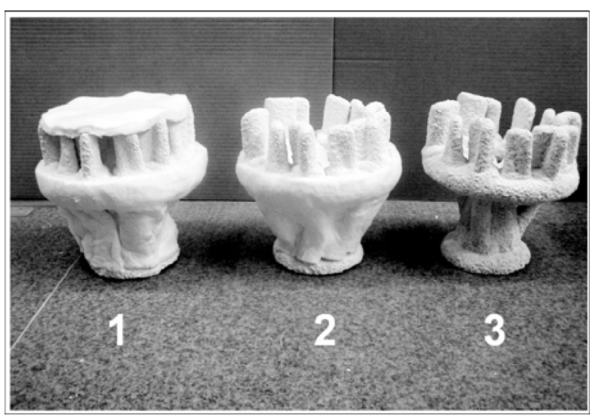

Fig. 1. Ceramic moulds

Insulated mould was annealled in a tunel -gas furnace CGE - VSM02 (Tab. 2).

TABLE 2

Coditions of annealing of ceramic moulds

	Loading zone	Soak zone	Unloading zone
Temperature, °C	400	700	400
Time, min	30	90	30

After annealling, moulds were placed in rows in an insulated box preheated to 600°C. Casting was conducted in a vacuum furnace. The pressure in the vacuum chamber was 2 Pa. Molten super-alloy was brought to the temperature of 1470°C and hold at this temperature for 2.5 mins. The moulds were filled within 2s and taken out after 10 mins. The pouring gate was insulated with "Fiberfrax". Air-cooling time was 6.5 h.

Cooled castings were taken out of the moulds, and subsequently cut and sand-blasted. Castings were heat-treated in a SECO-WARWICK furnace (Tab.3).

TABLE 3

Conditions of heat treatment

Stage	Pressure, Pa	Temperature, °C	Heating time, min
1	0,12	–	10
2	0,12	650	10
3	0,12	720	10
4	78	980	10
5	78	1080	31
6	78	50	Cooling with furnace down to 50°C
7	49996	50	3

Macroscopic, fluorescence and roentgen investigations were made on the turbine blades castings.
Specimens for microscopy were prepared using standard methods. The samples were etched with reagent 100g Fe_2B + 600 cm^3 HCl + 500 cm^3 + distilled H_2O.
Microscopic examination was performed on light microscope Zeiss.
Average number of grains per length unit was calculated by Ryś method [3]:

$$N_L = \frac{N}{L_T} \tag{1}$$

where: N_L – average number of grains per length unit, N – number of grains cut by the measuring length, L – length of the measuring segment
Average diameter of flat grain d was based on following formula [3]:

$$d = \frac{d_1 + d_2}{2} \tag{2}$$

where: d_1 – longest segment on grain cut, d_2 – shortest segment on grain cut.
For every measuring length the average diameter of grain (arithmetical mean) D was calculated. Grains slenderness is defined by coefficient f, calculated as follows [7]:

$$f = \frac{a}{b} \tag{3}$$

where : a – length, b – width of grain
All measurements (N_L, d, D, f) were carried out for various thickness of the blade sections (tab.4, fig.2).

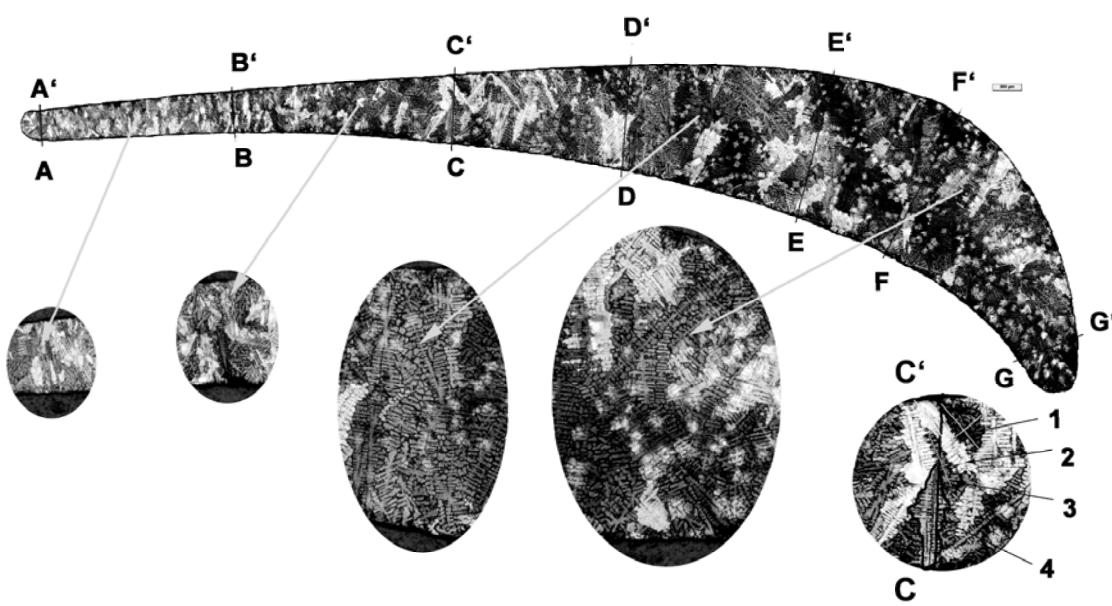

Fig. 2. Microstructure of the Inconel 713C and example of grain counts on the 22 mm width turbine blade

TABLE 4

Turbine blades wall thickness on the cuts

Width 22 mm		Width 30 mm	
Cut	Wall thickness, mm	Cut	Wall thickness, mm
A – A’	0.5	A – A’	0.9
B – B’	0.7	B – B’	1.8
C – C’	1.2	C – C’	2.7
D – D’	1.8	D – D’	2.8
E – E’	2.6	E – E’	2.3
F – F’	2.8	F – F’	1.8
G – G’	1.0	G – G’	1.2
		H – H’	0.8

3. Results and discussion

In turbine blades castings 22 mm of width, as a result of increase of the crystallization time (insulation) a reduction in the number of misruns was observed. Mould insulation had no effect on non-metalic inclusions content. These can come from the ceramic mould, especially from the layer, which interacts with molten metal. Careless cleaning of mould prior to pouring, or impurities of molten metal can also be the causes. Determination of the origin of each inclusion require detailed analysis. Cracking is caused by mechanical damage or tension (contraction of alloy, temperature difference between mould and molten metal or wall thickness differences). No change in the number of cracks was observed (tab. 5). It has been established that the cause of misruns is high crystallization rate in small section areas, but this need to be confirmed by the rapid solidification method [8,9]. In the case of turbine blades the trailing edge is most endangered .

TABLE 5

Defects in turbine blades castings

Mould	Defect	Number of the defected castings	
		Turbine blade width, mm	
		22	30
Without insulation	Misruns	4	–
	Nonmetallic inclusions	–	1
With only gating system insulated	Misruns	3	–
	Cracks	1	–
	Nonmetallic inclusions	1	2
With gate system and mould drag insulated	Misruns	1	2

The dendritic structure of alloy was confirmed by microscopic investigation (Fig 2). An influence of cooling rate on the morphology and the size of dendrites in turbine blades casts was observed (Fig.3, 4) [10].

Based on the microscopy a decrease in size and grade of the branches in the mould with insulated gating system was confirmed. The difference between grains along the casting section was also observed - smaller ones are characteristic of the top layers of the casting. Size reduction of the grains is caused by faster heat transfer and the influence of modification (cobalt aluminate in the first mould layer). The way the heat is transfered influences also the microstructure morphology – in the thinner parts of the section columnar grains were found, while in the thicker parts of the section equiaxed grains were observed. Heat transfer is the slowest in the upper part of the mould (under the crossgate). The dendrites in upper parts of the blades are highly branched. The results of the evaluation of the dendritic structure are shown in other work [11].

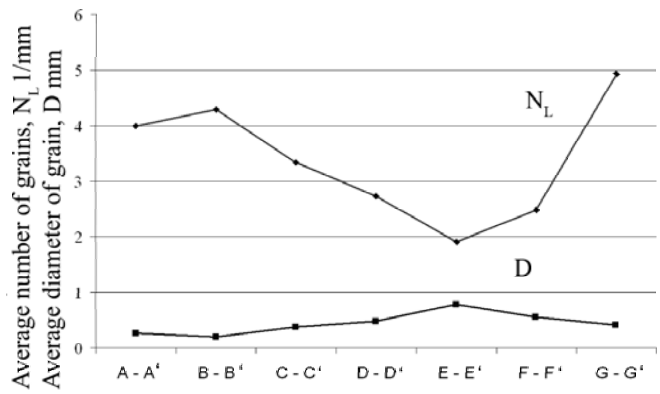

Fig. 3. Influence of thickness and zone of the blade casting, 22 mm wide, on average number and diameter of the grains

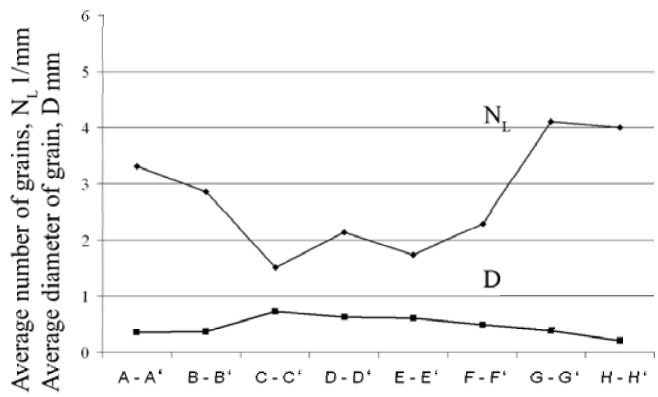

Fig. 4. Influence of thickness and zone of the blade casting, 30 mm wide, on average number and diameter of the grains

In the 22 mm wide turbine blades castings a great diversity of the slenderness coefficient f was observed (the larger the cut, the greater diversity of the grain slenderness) (Fig. 5).

The slenderness of the dendrites in the turbine blade castings, 30mm wide, in the middle parts of the section (the broadest) is highly diversified. The grains in this part of the cut are equiaxed (Fig.6).

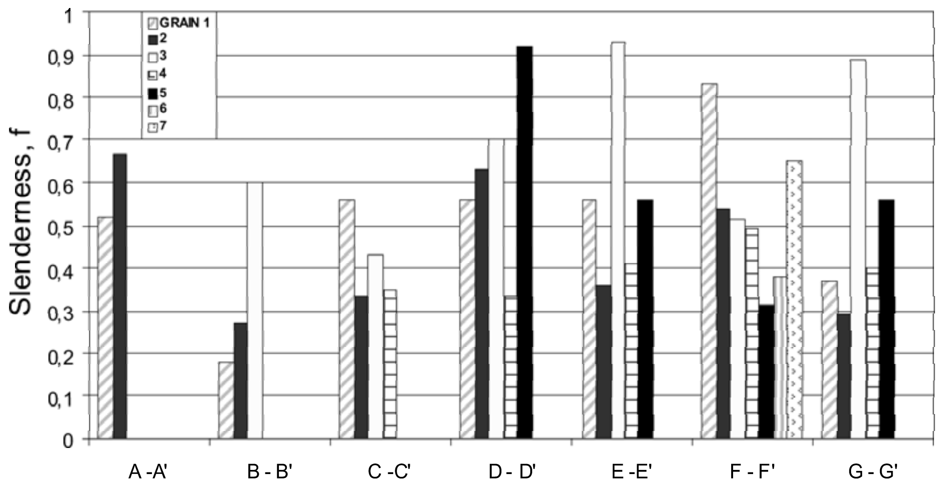

Fig. 5. Influence of thickness and zone of the blade casting, 22 mm wide, on grain shape coefficient

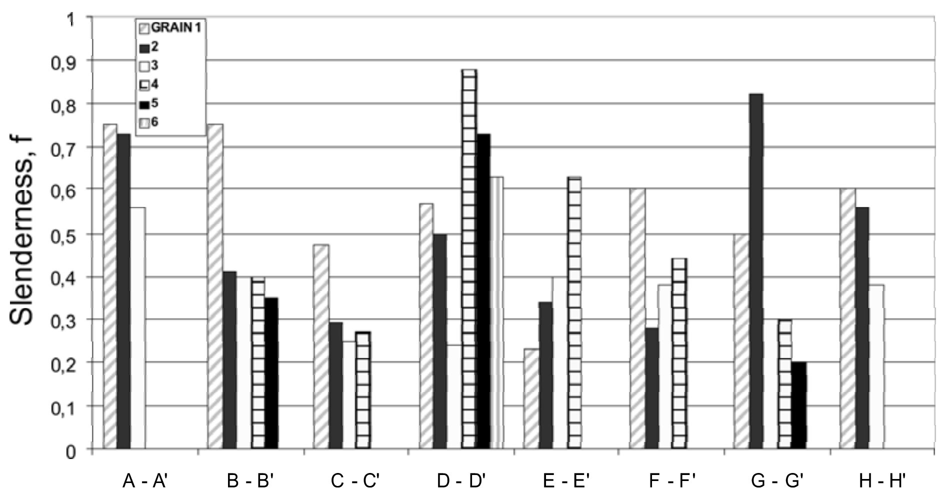

Fig. 6. Influence of thickness and zone of the blade casting, 30 mm wide, on grain shape coefficient

4. Summary

Both the method and the material of insulating ceramic mould has an influence on the occurrence of misruns in turbine blades castings of approx. size of 22x50 mm. The use of the insulation is the cause of a significant decrease in the number of defects – misruns. This is due to the longer crystallization time of the castings. In the course of the experiments, it has been determined that insulating only the pouring gate is insufficient. It was observed, that the insulation of the trailing edge (approx. 1mm wide) results in just a minimal reduction in the number of misruns. Due to the small variance of the cut width, there were no contraction type defects in turbine blades castings of approx. size of 30x50mm.

The wall thickness influences the morphology of the dendritic grains. The experiments showed, that a decrease in the wall thickness is proportional to an increase in the number of columnar grains. In turn, in the wider parts of the cut an appearance of equiaxed grains can be observed, which is characteristic of equiaxed growth. The results of the dendrites arms spacing measurements are shown in the work [11].

REFERENCES

[1] A. H e r n a s, Żarowytrzymałość stali i stopów. Wydawnictwo Politechniki Śląskiej, Gliwice 2000.

[2] E. F r a ś, Krystalizacja metali. Wydawnictwa Naukowo-Techniczne, Warszawa 2003.

[3] J. R y ś, Stereologia materiałów. Fotobit – Design, Kraków 2005.

[4] C. T. S i m s, N. S. S t o l o f f, W. C. H a g e l, Superalloys II. John Wiley & Sons, Inc., New York 1987.

[5] J. Z y c h, Analiza wad odlewów. Wydawnictwa Naukowo-Techniczne, Kraków 2004.

[6] Cz. A d a m s k i, A. G ó r s k i, S. K o b y l i ń s k i, Systematyka wad odlewów metali nieżelaznych. Warszawa, PWT 1956.

[7] L. W o j n a r, K. J. K u r z y d ł o w s k i, J. S z a l a, Praktyka analizy obrazu. Polskie Towarzystwo Stereologiczne, Kraków 2002.

[8] N. B o u t a r e k, D. S a i d i, M. A. A c h e h e b, M. I g g u i, S. B o u t e r f a i a, Materials Characterization **59**, 951-956 (2008).

[9] H. F a r h a n g i, S. N o r o u z i, M. N i l i - A h m a d - a b a d i, Journal of Materials Processing Technology **153-154**, 209-212 (2004).

[10] T. A n t o n s s o n, H. F r e d r i k s s o n, Metallurgical and Materials Transactions B **36B**, 86-95 (2005).

[11] D. P i e c z b a, A. soJach, Ocena mikrostruktury dendrytycznej odlewów łopatek turbin z nadstopu Inconel 713C, Materiały konferencyjne XXVII Szkoły Inżynierii Materiałowej, Kraków-Krynica 2009.

[12] A. J a c h, Wpływ warunków odlewania na strukturę pióra łopatki o szerokości 22 mm, praca dyplomowa, AGH Kraków 2008.

[13] D. P i e c z a b a, Wpływ warunków odlewania na strukturę pióra łopatki o szerokości 30 mm, praca dyplomowa, AGH Kraków 2008

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