TURBINE WHEEL CASTING POURING PROCESS PARAMETERS IMPROVEMENT

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Abstract

Mechanical characteristics of the creep-resisting alloy IN 713 LC depends on its content and material purity, furthermore on the structure and structural non-homogeneities. Significant influence on the material properties, for its usage, has the way of crystallization, modification of the grain structure secured by technological setup of the casting tree and special directed insulation of the tree.

The aim was to realize the tests on the samples to achieve definition of casting process and sequential detail grain structure study of the directed solidified castings with higher mechanical properties at higher temperature. The samples were analyzed by RTG and FPI method and cut for additional testing. Interesting data were obtained in these areas: grain size and structure with dependence to the casting temperature, the shell annealing temperature and insulation by ceramic wool - Sibral, on the specified places defined with the insulation thickness to ensure surface controlled crystallization in the casting. Part of the study was aimed to cost reduction during process and definition of the necessary technological changes to reach profitability of the product.

Keywords: Turbine wheel, wax model, IN713LC, casting

1. INTRODUCTION

Thaw point is the temperature, when a crystalline solid passes from solid state to liquid one [1]. When the molten metal is melted, its heat energy starts to leak out through the mould that distributes it to its surroundings. The process continues till the moment, when the energy contained in the casting starts to approach the heat energy level in its surroundings. It starts by crystallization of the primary phase and get finished by complete solidification of the casting.

There grows the dendrites nucleuses of the metal matrix that continues growing. [2] The aim of this experiment is to achieve directionally solidified casting, especially in the area radial oriented grains on the blades to increase the mechanical resistance in the direction of rotation - max. centrifugal force.

The process is useful, with respect to technology, as the created crystals do not defend feeding of metal from risers. Materials with a wide interval of solidification do have a tendency to form in a thermal system microporosities in casting axis. [3]

For casting of the turbocharger wheels and components from heat resistant nickel alloys are also suitable Inconel 713LC studied by us, in which the melting and casting in a vacuum to eliminate the necessity of affine response elements (especially Al and Ti) to oxygen. In dilute vacuum atmosphere at a vacuum of about 5.10-4 mBar reactivity is almost zero elements and thereby achieves a good quality of pure alloy suitable for casting high - stressed parts cremation turbochargers operating at high temperatures during rotation. Due to the relatively high cost of the manufacture of castings with high added value, it is important to tune the process to avoid cost increases. The most commonly used materials for the production of thermally parts of castings turbochargers and turbine blades are the following alloys (See **Table 1**):

Table 1 Nominal chemical composition discussed alloys (wt. % Ni- base) (source: [4])

Alloy	C	Cr	Co	Mo	W	Nb	Ta	Ti	Al	Zr	B
IN 713 C	0.12	12.5	N/A	4.2	N/A	2.0	N/A	0.8	6.1	0.10	0.012
IN 713 LC	0.05	12.0	N/A	4.5	N/A	2.0	N/A	0.6	5.9	0.10	0.010
IN 738 LC	0.10	16.0	8.5	1.75	2.6	0.85	1.75	3.4	3.4	0.05	0.010
IN 792 5A	0.08	12.5	9.0	1.9	4.17	N/A	4.17	3.97	3.37	0.03	0.015

Fig. 1 Assembly of individual wax models into tree

Fig. 2 Trees dipping into a ceramic slurry

Fig. 3 Sending - making a final surface of layer

Fig. 4 Dewaxing procedure

To produce castings of superalloy is most commonly used method of investment casting. See **Fig. 1**-4 [4], where is quick visual description of the investment casting process - preparing of the ceramic shell, which is used for the casting as a mould.

2. DESCRIPTION OF THE ALLOYS

There was used the sample of turbine wheel made of alloy IN713LC for the experimental part of the project (see **Table 2**). It belongs among the first casted alloys of so called I. generation, where the vacuum metallurgy has been used for production. Reducing the carbon content in the alloy causes the solidus and liquids shift to higher temperatures and to improve certain material characteristics - plasticity. The alloy is ordinarily used in a raw cast form and from the point of precipitation of topologically closely organized phases through the operational exposition, is considered as structurally stabilized. IN713LC is creep-resisting Nickel based alloy, primarily determined for the method of lost wax process. The alloy is neither suitable for forming nor welding.

The alloy IN 738 and its modification IN 738 LC are compared to IN 713 LC between higher developmental materials called II. generation. Creep resistance frequently used version of IN 738 LC is comparable to IN 713 LC, but with higher content of Cr and other elements is more resistant to high - temperature corrosion.

In the case of alloy IN 738 LC is necessary, unlike the alloy IN 713C respectively. Optimum properties of the alloy achieve two-stage heat treatment, 1120 °C / 4h / solidification heat treatment and 760 °C / 16 h / hardening.

The experimental part of the project is focused on the practical investigation influence crystallization properties of the casting obtained, and controlling the temperature gradient of cooling of the shell form by selecting appropriate isolation at specified parts of the casting so that occurred in the maximum for controlled cooling, respectively the most intense heat away from where it is desirable formation directionally solidified grains on the blades of the turbine wheel.

3. EXPERIMENTAL PART

3.1. Technical part

During the development there were done several tests with different parameters. All tests, including technological parameters and partial conclusions are described below. During these tests have been repeatedly modified technological processes and manufacturing processes to ensure successful management of the project. IN 713 LC was used for the experimental purposes.

Table 2 Basic data (source: [4])

Casting name	Turbine wheel
Model number	816 998
Material	IN 713 LC

Table 3 Shell mould production technological parameters (source: [4])

Shell material	Molochite
Coats quantity	11 + 0,5
Shell thickness [mm]	cca 11 - 12
Dewaxing temperature [°C]	cca 185
Cup type	Ceramic cup with recessing for filter
Was assembly type	3 turbine wheels per tree

Ceramic shell and its composition give the possibility to influence the crystallization. Main parameters are defined in the **Table 3**. Ceramic wool Sibral is applied to control the cooling rate of the material portion of the casting (meridian). For the experiment there was used molochite shell and for its improved properties and high thermal shock resistance and greater dimensional stability compared to a quartz shell mould, which is also used alternative. The biggest benefit of this ceramic system is better temperature stability. Further, using a ceramic insulation, which retains heat well, thus taking the heat node upwards in cooperation with massive insulation allow a higher utilization of the material at the inlet, thereby reducing the economic demands on the cast.

Table 4 Casting Technological Parameters (source: [4])

Machinery	Vacuum oven VIM-IC 5E/II
Pouring Temperature [°C]	1476
Annealing Temperature [°C]	1080
Annealing Period [hours]	6
Vacuum [mBar]	$2.3*10^{-3}$
Batch Weight [kg]	32.4

Technological parameters of casting are described in the **Table 4.** Gating castings were after casting and sealing the opening of the door of the vacuum furnace is backfilled exothermic powder Pyromac 7G and left in an open oven for approximately 15 minutes. Then it was moved to the casting field where there was a gradual cooling in air to room temperature over about 8 hours.

Virgin wax Hyfill 478 is used as a model wax to maximum guarantee and stabilization the dimensional accuracy of the casting. Red wax which is visible on the wax model , see **Fig. 5** has the lowest melting point and is used to form expansion joints at the de-waxing in critical areas of the casting , which are the riser and the casting inlet part interconnected slots into the casting. Green (virgin) wax with a high temperature expands about 10 times more than ceramics was used to reduce cracking and damage of the shell.

The surface of the wax model provide excellent adhesion for coating degreased special agent that degreased cast down and partially etched so that the first layer contacted with the surface of the wax model. In terms of surface quality is less favorable to the production process, but in terms of cohesion and stability of the face layer is the best solution possible delamination of the layers apart. A clean surface is a prerequisite for good coating adhesion and slip. The most important aspects for dimensional and surface quality of the cast are the first two layers'.

Fig. 5 Wax model (source: [4])

Fig. 6 Shell (source: [4])

Fig. 8 The way of packing (source: [4])

Fig. 7a Macrostructure (source: [4])

Fig. 7b Macrostructure (source: [4])

The most important part of shell are first two layers' see **Fig. 6** determines the quality of the surface. This is reason, why was used fine stucco Molochite 50 - 80. This method can achieve the surface roughness Ra3.2. Then should be used further stucco, to reach higher thermal stability and indicates the strength of the shell.

The above parameters are used to reach control of the crystallization on the casting. This procedure formed on turbine wheel radial oriented grains to reach 30% higher strength than conventional castings. **Fig. 7a** and **Fig. 7b** show difference in the direction of the crystal grow, **Fig. 7a** is before heat transfer treatment, where wasn't reached proper crystallization, **Fig. 7b** is after treatment, where we achieve the proper quality of the grain orientation.

There was used the Sibral for the shell insulation. The feeder was insulated by double Sibral layer of 13 mm. Gating system was insulated by the layer of 13 mm. Wheel blades were left without insulation. The Top of the wheel was insulated by a layer of thickness of 13 mm. Insulation of the shell is on the **Fig. 8**.

3.2. Economic Evaluation

Profitability is a consequence of how well the process results satisfy needs and expectations of customers and with what financial efficiency they are provided. [5, 6]

Price of the most commonly used superalloys range from 300 CZK / kg to 500 CZK / kg (according to the ratio revert / virgin), we can say that focusing on the rationalization of this part of the production process, it would be possible to achieve significant economic savings. The most important requirement is to design suitable gating production system.

Model for a higher utilization of liquid metal can be found for example in the turbine wheel bearing TPS 44 from the Swiss company ABB.

In the common way of gating when casting 1pc in Inflow, during the last year there was used 15 kg per batch for 2 Inflows. At the same time, in the period from 1st January 2013 to 31st December 2013 there was casted in total 556 pieces of turbine wheels. As the casting material used IN 713LC 50 % / 50 % whose price is around 300 CZK / 1 kg. Material costs for casting 556 pieces of turbine wheels thus are: 7.5 kg x 556 pc x 300 CZK = CZK 1,251,000 CZK

The net weight of the turbine wheel is 2.62 kg. When using 7.5 kg per batch for production of one turbine wheel, the exploitability of liquid metal is 35 %.

Calculation [7] done for new possible Inflow system and casting 3 pieces in an Inflow, in which it is used in average 19.5 kg per batch. For casting a turbine wheel is therefore necessary to spend on average 6.5 kg per batch. Assuming that this way of gating there were cast 556 pieces of turbine wheels, as in 2013, the calculation of the material costs would be: 6.5 kg x 556 x 300 pc = CZK 1,084,200 CZK

Regarding material costs, the difference between the two ways of gating would theoretically be 166,800 CZK for the whole year. Saved would be approximately 560 kg of material IN 713 LC. Roughly speaking, 1 kg of superalloy IN 713 LC at a price of CZK 300 / kg would be saved for each turbine wheel casted using the new process.

As described above, the usefulness of the liquid metal is thus 40 %, assuming the use of a new gating method.

It is also necessary to take into account the increased production efficiency [8]. If it was decided to change the gating process the above described turbine wheels, should not only have positive effect on the saving of the used material, but also higher labor productivity in operations such as the manufacture of shells and mainly casting. The production capacity of vacuum furnaces is limited by their performance, and simply can say that the change of gating would therefore increase the production capacity of vacuum furnaces by approximately 15 - 20 %.

4. DISCUSSION

IN 713 LC alloy is low-tech, its heat resistance is at a good level and achieving the desired properties. It does not cause problems in attestation creep tests. When creep resistance comparable to IN 713 LC preference IN 738 LC increased resistance to high temperature corrosion, especially sulphurous environment. This is achieved by alloying complex, however, thereby increasing the density and cost alloys (vs. IN 713 LC is about half expensive). Solidification temperature interval compared to IN 713 LC roughly two and a half times the width of which should be taken into account when choosing risering castings to avoid microporosity. To achieve the desired utility properties of the alloy must be heat treated.

5. CONCLUSION

The experiment was realized on request of the customer to produce turbine wheels cast using the method of precision casting with large coarse columnar grains oriented in the radial direction. The coarse structure has a better creep resistance at higher temperatures than the fine-grained structure and the effect is enhanced if the number of columnar grains is minimized. Directional solidification may be used in our casting geometry achieved by influencing the thermal insulation properties of the mould. It directionally solidified achieved by influencing the temperature gradient in some parts of the mould. For this purpose we used insulating walls exothermic wrap, in our case Sibral. Thanks testing creep properties of the thus produced casting were able to document and can be demonstrated mechanical properties increase by about 7 % as regards the maximum of such a voltage. Ductility, commonly problematic achievable, is in such oriented grains achieved by a large margin.

Due to production increase, we are able to achieve competitive prices for developed casting technique of three wheels at the inlet, which is prepared for the production of specially crystallized castings with radial orientation of grains to achieve higher mechanical values than conventionally casted castings of similar shape.

This new technique will reduce mainly material costs and simultaneously increase the productivity of the manufacturing process. The cost analysis with data from last year assumed to reduce material costs up to 167 000 CZK. If the production will grow, which is assumed, the savings will be even higher.

The temperature of the metal and annealing temperature of the shell is very important and using metallographic setting parameters has been achieved serial deliveries with possibility to produce turbine wheels atypical way of casting and subsequent crystallization. Another raising or influencing the mechanical properties, as discussed above, is the use of alloys that will be investigated in other parts of the project. The most effect and applicability of higher generations alloys for manufacturing the turbine wheel which will have higher design parameters to increase the efficiency of the machine.

Upon closer examination of the structure there was showed the influence of gravity, resulting in deflection of the grain growth, thus totally negative influence, which was necessary to eliminate the change in position of castings at the inlet so as to achieve an even distribution of columnar grains symmetrical around the periphery of the casting. Further investigation will focus on eliminating the influence of temperature on the casting field cooling of castings, eliminating different cooling time and constant ensuring achievement of controllable macrostructure without using special equipment - crystallizer in a vacuum oven.

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