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Evaluation of Casting Shrinkage and Liquid Metal Fluidity of IN-713C Alloy

F. Binczyk *, M. Cieśla, P. Gradoń, R. Findziński
Department of Materials Technology
Silesian University of Technology, Krasińskiego Str. 8, 40-019 Katowice, Poland
*Corresponding author. E-mail address: franciszek.binczyk@polsl.pl

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Abstract

This paper presents the results of measurements of liquid metal fluidity and linear shrinkage of nickel alloy IN-713C in vacuum induction melting furnace Balzers VSG-2. Because of limited volume of the furnace chamber special models for technological trials were designed and constructed to fit in the mould of dimensions 170x95x100mm. Two different designs of test models were proposed: horizontal round rods and modified spiral. Preliminary studies were carried out for alloys Al-Si. Horizontal round rods test was useful for evaluation of fluidity of hypoeutectic silumin, however in case of nickel superalloy the mould cavity was completely filled in each test because of high required pouring temperature. Positive results were obtained from the modified spiral test for all alloys used in the research. Relationship between the linear shrinkage for the test rod and a specific indicator of contraction defined on a spiral was observed.

Keywords: Linear shrinkage, Fluidity, Castability, Spiral test, Round rod test, Pouring temperature, IN-713C, Superalloy, Silumin

1. Introduction

High temperature nickel alloys (aka superalloys) are the primary material used for casting components of aircraft engines, both the static and rotating parts operating at very high temperature under the mechanical stress. Castings of these parts require very high quality surface finish and dimensional accuracy. Hence in their production the precision los wax method is used [1,2].

Design and creation of wax models requires, among other things, knowledge of linear shrinkage value of used alloy and its ability to reproduce the shape of the mould cavity. Turbine blades typically have a very complicated shape, thin walls and, in many cases, internal cooling channels. Precise reproduction of such complicated shape demands high fluidity of an alloy. Fluidity increases with the pouring temperature, however too strong overheating of the alloy leads to the formation of casting defects.

2. Research problem

Casting parameters and chemical composition have the biggest impact on the fluidity. The chemical composition influences the beginning and the end of solidification, thermal conductivity, specific heat, the surface tension and heat capacity. All of these properties have a huge impact on the liquid metal flow in the gating system and on the degree of wetting of the mould. The most important factor determining the fluidity is the casting temperature and the resulting value of the degree of overheating, i.e. the difference between the pouring temperature and the temperature of the beginning of solidification. Another important factor is the velocity of liquid metal flow in channels of gating system [3, 4].

The mould temperature is also important factor determining the fluidity. In case of superalloy casting the moulds are heated to a temperature of about 1100°C, which allows to reduce casting temperature [5-7].

As of today, there is little information in the published literature about casting shrinkage and fluidity of nickel superalloys. Especially as a function of the casting temperature.

3. Materials and methods of investigation

The aim of the study was to develop a comprehensive test for determining fluidity, reproducibility and linear shrinkage for alloys used in casting, in particular for nickel superalloys melted in Balzers VSG-2 VIM furnace. The furnace chamber, due to its small size, does not allow standard fluidity and shrinkage test methods to be used. A view of the chamber with the casting mold is shown in Figure 1.

Fig. 1. Balzers VSG-2 VIM furnace chamber

The workspace of furnace allows placing of the casting mould of maximum dimensions 170x100x120mm. This in turn has imposed the test models dimensions: maximum length of 150 mm and width of 95mm, main sprue height of about 75mm.

Moulding boxes were made from 3.5 mm thick steel sheet by welding. Guide rails and clamps were added to allow precise assembly during the moulding process. Image of such moulding box (assembled) is shown in Figure 2.

Fig. 2. Moulding box

Two models were designed and manufactured:

1. Horizontal round rods.
2. Spiral of length about 82cm.

Spiral model was made after the preliminary test with round rods model for evaluation of fluidity of IN-713C and hypereutectic silumin. Fluidity of these alloys was high enough to fill all the rods in the test completely. In case of IN-713C alloy high required overheat was enough to rise fluidity above the test length, in hypereutectic silumin same effect was caused by specific properties of this alloy, even below the T_{liq} temperature. Model for horizontal rods test is shown in Figure 3.

Fig. 3. Horizontal round rod fluidity and shrinkage test with the "parent" mould

The individual rods have the following dimensions:

- rod for measuring shrinkage - 12mm diameter and 150mm length,
- rods for measuring fluidity - diameters of 10, 8, 6, 5 and 4 mm and the same length of 100mm,
- triangular elements to assess the reproducibility, height of 15mm, thickness of 1.5 mm and a variable width, which is the result of different apex angles that were respectively 90°, 45° and 30°.

Spiral model was made using a cable with a diameter of 6mm, which was, due to the lack of the parting plane, moulded by peeling and then cast using hypoeutectic silumin from the temperature of about 900°C. The diameter of the base channel is 6 mm with the length (unrolled) of about 820mm. Metrics placed every 50mm were installed on the upper part of the spiral. Spiral test model is shown in Figure 4.

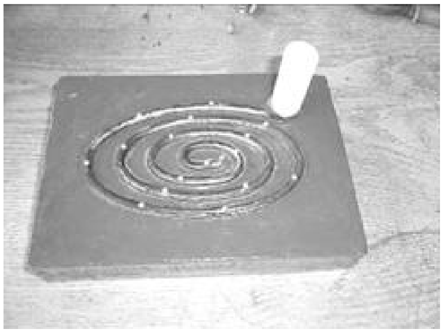

Fig. 4. Modified spiral fluidity test with the "parent" mould

The study was conducted for nickel alloy IN-713C, which contains on average: 0.03% Co, 13.26% Cr, 5.85% Al, 4.10% Mo, 0.85% Ti, 2.27% (Nb + Ta). Alloy was were melted in an VIM furnace Balzers VSG-02 using an Al_2O_3 crucible. Batch weight was about 1,2 kg. Melting was carried out in a vacuum of about 10^{-3}. Prior to pouring, the volume of the furnace was filled with argon. Pouring was conducted under an argon atmosphere at the pressure of about 900 hPa.

4. The results of investigations and discussion of results

Studied IN-713C alloy was poured at temperatures 1420°C, 1460°C, 1500°C and 1600°C. In case of the rod test, rods were filled completely in every temperature. Pouring below 1420°C is not recommended. T_{liq} temperature for this alloy is about 1325°C to 1340°C, depending on the carbon content [8, 9]. Image of the sample casting is shown in Figure 5.

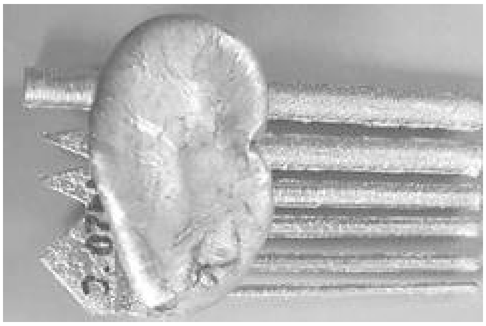

Fig. 5. Sample rod test casting.

In case of complete fill of the mould only shrinkage measurements were made on the φ12x150mm rod. Results are shown on Figure 6.

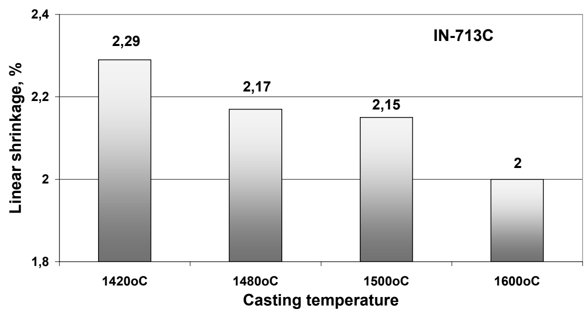

Fig. 6. Linear shrinkage as a function of the casting temperature

Castings made in modified spiral fluidity test are shown in Figures 7 to 10.

Fig. 7. Spiral test at 1420°C

Fig. 8. Spiral test at 1460°C

Fig. 9. Spiral test at 1500°C

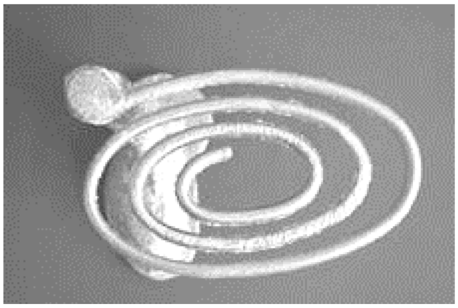

Fig. 10. Spiral test at 1600°C

Results of fluidity measurements in modified spiral test are shown in Figure 11.

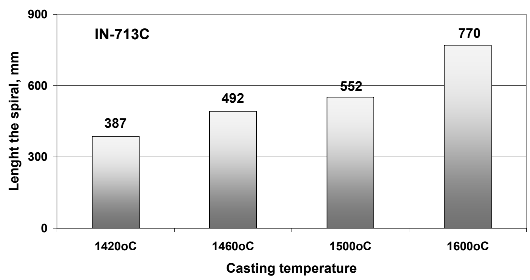

Fig. 11. Spiral as a function of the casting temperature

Proposed rod test does not allow direct determination of fluidity, due to the complete filling of even the thinnest rods. Therefore, while useful to measure the shrinkage, does not give fully satisfactory results. On the other hand spiral fluidity test gives good and comparative test results.

Thus, the possibility to evaluate linear shrinkage using the spiral casting was considered. Two most distant from one another metrics (markers) on the spiral model were selected as an initial dimension to evaluate shrinkage, as shown in Figure 12.

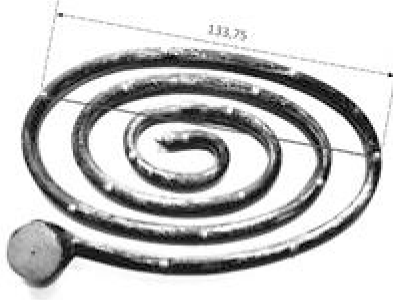

Fig. 12. Method of shrinkage measurement in the casting of fluidity spiral

Results of shrinkage measurements on fluidity spiral were shown in Figure 13.

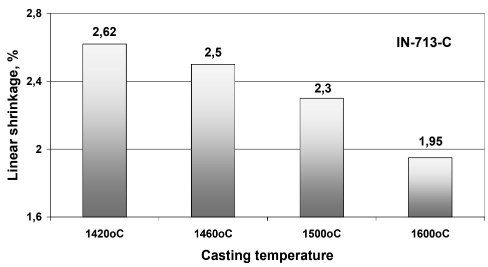

Fig. 13. Shrinkage between markers of fluidity spiral as a function of the casting temperature

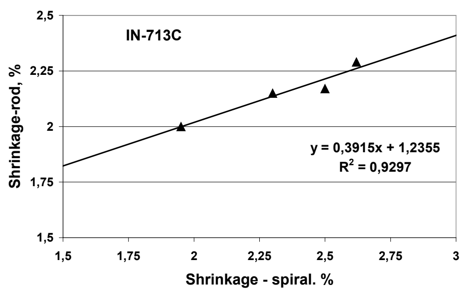

Fig. 14. Comparison of the values of shrinkage obtained in spiral and rod tests

The results of measurements of shrinkage based on the variation of the distance between the extreme markers of fluidity spiral were compared to values obtained in the rod test as shown in Figure 14. The coefficient of determination R^2 for comparison of the results for nickel alloy shows a fairly good correlation between the values of x and y means that 93% of the results should be regarded as reliable.

5. Conclusions

Designed horizontal round rod test does not allow to determine the fluidity of nickel alloys, due to the necessity of pouring at a temperature well above T_{liq}, which for the alloy IN-713C is from 1325°C to 1340°C (depending on carbon content). Balzers VSG-2 VIM furnace does not allow using mould longer then 170mm. This in turn imposes a 100mm length rods which were being completely filled in each case (even at minimum temperature of 1420°C). Linear shrinkage of nickel alloy IN-713C is about 2.3% and decreases with increasing pouring temperature.

It has been shown that for nickel alloy IN-713C there is a good correlation (coefficient of determination $R^2 = 0.93$) between the shrinkage measured in the rod tests and in spiral tests (distance between the extreme markers on the spiral). The relationship is linear and can be expressed as: $y = 0.1441*x + 0.9873$.

Fluidity of IN-713C alloy increases with increasing temperature which is the result of increase of the degree of overheating.

Acknowledgements

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