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THE METHOD OF PRODUCTION OF THIN-WALLED CASTINGS MADE OF GX2CrNiMoN25-6-3 CAST STEEL

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Abstract

The possibility of production of thin-walled castings made of GX2CrNiMoN25-6-3 cast steel was assessed for the exemplary final casting with variable wall thickness. The assessment both of the solidification process of GX2CrNiMoN25-6-3 alloy and of the final degree of mould cavity filling was done by means of the NovaFlow&Solid program. The body of the casting with its variable wall thickness, including sections thinner than 1 mm, demanded for the appropriate production technology. The paper presents the results of technological tests with respect to the application of the centrifugal casting, which confirm the adopted technology of pattern and mould production. The analyzed technology makes it possible to produce castings of high surface quality, with simultaneously increased yield, and to lower the unit cost of production as compared with the production method used so far.

Key words: numerical modeling, centrifugal casting, duplex cast steel

1. INTRODUCTION

The centrifugal casting technology is usually, but not exclusively, applied for the production of the coreless castings exhibiting the solid of revolution geometry. The centrifugal casting process relies on taking the advantage of the centrifugal force while filling the mould cavity with molten metal or alloy. In general, three ways of introducing the liquid alloy into the mould cavity are discerned (Stradomski et al., 2010; Pilarska & Nadolski, 2015; Stradomski et al., 2015a; 2015b; Górny, 1966; Nadolski et al., 2015):

- the true centrifugal casting – the axis of the casting coincides with the axis of rotation; external surface of the casting reproduces the shape of the mould cavity, while the internal surface is formed due to the action of the centrifugal force,
- the semi-centrifugal casting – in this case the internal surface is shaped by the applied cores, but the axis of rotation still coincides with the axis of the casting,
- the pressure centrifugal casting – here the main sprue is placed along the vertical rotational axis, and the cast alloy fills the mould cavity due to the action of the centrifugal force applied already during its introduction into the sprue and gating system.

The mould can be rotated around the vertical, horizontal, or inclined axis. It can also be simultaneously turned around two axes perpendicular to each other, e.g. vertical and horizontal ones (Górny, 1966; Pilarska & Nadolski, 2015; Stradomski et al., 2010; Stradomski et al., 2015a; 2015b). The shaped castings are produced in a mould or moulds arranged along the perimeter of the centrifugal pouring machine disc with the vertical axis of rotation. The technology of centrifugal casting is applied for castings ranging in mass from several grams (microcastings) to several tons. Gołowin (1963) gives an

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example of the centrifugally cast 45-tonnes ingot, the vertical axis of rotation being applied. As far as the machines of horizontal axis of rotation are concerned, they are used to produce thin-walled castings of the size restricted to the maximum diameter of 700 mm and the maximum mass of about one metric ton (Górny, 1966).

The main area of application of the ferritic-austenitic (or: duplex) steels and cast steels are the structures and elements subjected to high loads and to the environments fostering the stress, pitting, or crevice corrosion. Under such conditions, ferritic-austenitic steels and cast steels exhibit better set of properties than the traditionally used ferritic or austenitic steels of comparable fractions of the basic phases, i.e. of ferrite and austenite. Good mechanical properties and high resistance to corrosion in general, and especially to the pitting corrosion, significantly exceeding those of the austenite cast steels, cause that the steels and cast steels of the duplex family are today simply irreplaceable in chemical industry, e.g. for the structural elements of holds and tanks of ships transporting chemically active products – phosphoric acid, dipping acid, highly alkaline media etc., as well as for devices used in oil industry, power industry, gulp and paper industry, or food industry (Cassagne & Busschaert, 2007; Dyja et al., 2012; Dyja & Stradomski, 2006; Nowacki, 2013; Olsson & Malin, 2007; Stradomski, 2010; Stradomski et al., 2010, Stradomski, 2014; Stradomski et al., 2012; Stradomski et al., 2015a; 2015b). Due to their high yield strength, they are used in such constructions as heat exchangers (thin walls and good thermal conductivity), heaters, coolers, condensers, desalting or sulphur removing devices, cleaning plants (e.g. sewage-treatment plants). At the same time their good resistance to the fatigue corrosion fosters their application in centrifuges, blade dryers, and other dynamically loaded devices.

The assessed GX2CrNiMoN25-6-3 cast steel exhibits low casting properties because of its chemical composition: the low carbon content and high chromium content (over 21%), nickel being as a rule at the level of 3-6%, and the addition of such elements as molybdenum or nitrogen (Stradomski, 2014; Stradomski et al., 2015a; 2015b). While it is of no significance in the case of massive castings with thick walls, it is a great obstacle in production of thin-walled castings. Main defects occurring in the latter case are the incorrect reproduction of the mould cavity and the shrinkage defects. The solution of the problems can be found by either increasing the sinkhead, or applying the sufficient metal pressure inside the cavity. The application of increased sinkhead, however technologically effective, is economically unreasonable and results in excessive scrap, reaching up to even 2/3 of the final casting mass (Stradomski et al., 2015a; 2015b). The technology of centrifugal casting seems to be an alternative, and provided the parameters are properly selected, it is assumed to enable getting not only the higher efficiency, but also good or better surface quality with simultaneous advantage of reproducing walls as thin as 1 mm.

2. METHODOLOGY OF INVESTIGATION

The purpose of investigation was the assessment of application of the centrifugal casting technology as an alternative to the gravity casting of duplex cast steel. An experimental melt was performed in order to obtain the thin-walled shaped casting, the numerical model of which is presented in figure 1, juxtaposed with the cross-section of the final casting showing the areas where microstructure and roughness were measured (figure 2). The charge was melted in Leybold-Heraeus induction furnace equipped with A6 crucible. The mould was prepared as supporting thin-walled one according to the investment casting method.

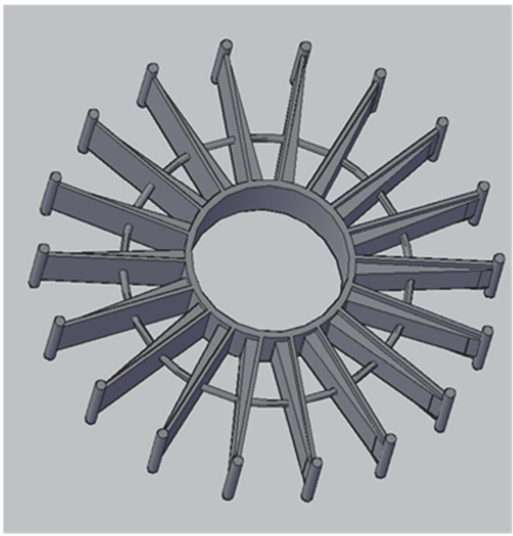

Fig. 1. *Pump rotor – the 3D model.*

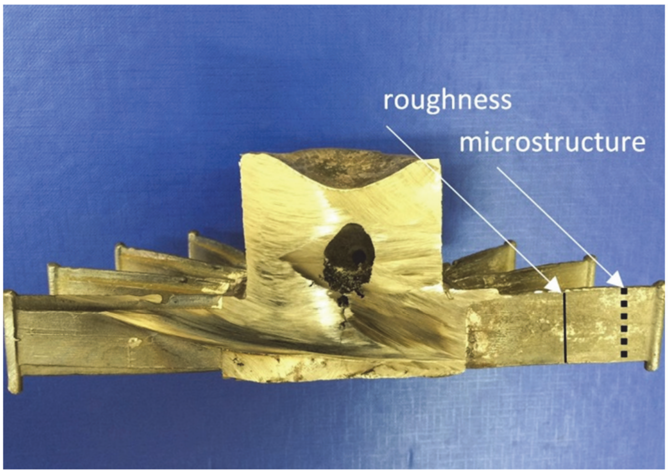

Fig. 2. *Cross section of the pump rotor.*

Table 1. *Chemical composition of the examined cast steel grade.*

C	Cr	Ni	Cu	Mo	Mn	Si	S	P	N
0.025	26.80	6.48	0.03	3.00	1.19	1,04	0.011	0.008	0.25

The investigated material was GX2CrNiMoCuN25-6-3 grade cast steel (PN-EN 10283:2004). Its chemical composition is summarized in table 1.

The assessment of the manufacturability of the casting structure was accomplished using the NovaFlow&Solid CV 4.3r8 program. The NovaFlow&Solid program is designed for numerical modelling of such phenomena as the liquid metal flow in the gating system and in the mould cavity, as well as solidification and cooling of a casting. Mass transport is described by the modified Navier-Stokes equation, while the thermal problem is solved on the basis of the Fourier-Kirchhoff equation. The model equations are solved by the coupled method of finite differences and elementary balances developed by NovaFlow&Solid. Numerical simulations of cooling and solidifying processes were performed for the casting without a gating system or sinkheads, placed in the mould according to the desired pouring position. It was assumed that the analysed casting would be produced in the sand mould with dimensions of 250×250×120 mm. The purpose of calculation was to identify the primary thermal centres within the casting and to find the shrinkage porosity distribution after complete solidification. The thermal problem was solved while mould pouring and filling stages were neglected. It was assumed that at the initial moment the mould is 100% filled with liquid metal, and the initial temperature in every point of the melt is equal to 1600°C.

For the assumed feeding applied in the axis of symmetry of the casting, the technological correctness of the solution was stated for gravity casting. According to this scheme, both gravity casting and the centrifugal one were produced. However, the mould rotational axis for the latter case coinciding with the axis of symmetry of the casting. The mould used for centrifugal casting was first gravity filled with metal, thus avoiding the gas entrapment and oxidation of the alloy, then the centrifugal force was applied affecting the solidification process. Parameters of the casting process are presented in table 2.

Microstructure examination was carried out by means of Nikon Eclipse MA-200 optical microscope on specimens etched with Mi21Fe etchant, and the exemplary microphotographs are presented in figure 6. Additionally, the obtained casting were qualitatively checked for their dimensional accuracy. Also their surface roughness was assessed. The roughness measurements were performed by means of DIAVITE DH-5 roughness meter, determining the R_a and R_z parameters.

Table 2. *Parameters of the casting process applied for GX2CrNiMoN25-6-3 cast steel.*

Designation	Pouring temperature [°C]	Rotation speed [rpm]	Casting method
Series 1	1550	0	Gravity filling, solidification in the stationary mould
Series 2	1550	200	Gravity filling, solidification in the rotating mould

3. RESULTS OF EXAMINATION

Identification of primary thermal centres within the casting volume was carried out on the basis of temperature field determined for the final stage of solidification, and by applying the criterion of the residual liquid. The results of numerical simulation are shown in figures 3 and 4. Bright fields on the temperature map and on the map of liquid phase fraction indicate the local thermal centres within the casting. Their presence results in high occurrence probability of shrinkage defects. The areas where shrinkage defects can probably occur are indicated on the porosity map (figure 5). The brightest areas mark the regions in which the fraction of liquid phase is equal to 100%, while the darkest ones correspond to the regions of possible occurrence of shrinkage defects.

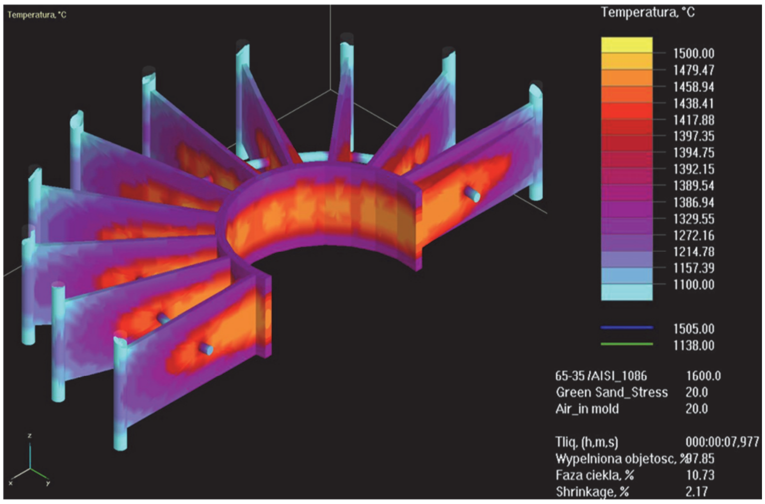

Fig. 3. Momentary temperature field in the final stage of solidification.

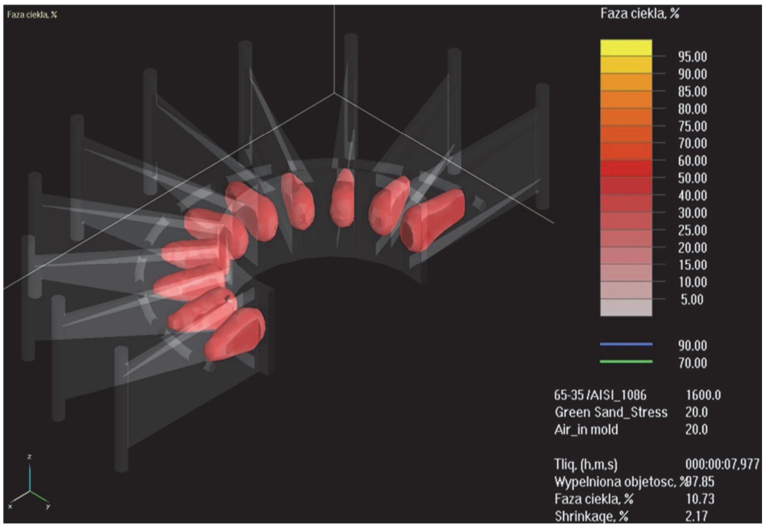

Fig. 4. Distribution of residual liquid within casting in the final stage of solidification (10% of liquid phase).

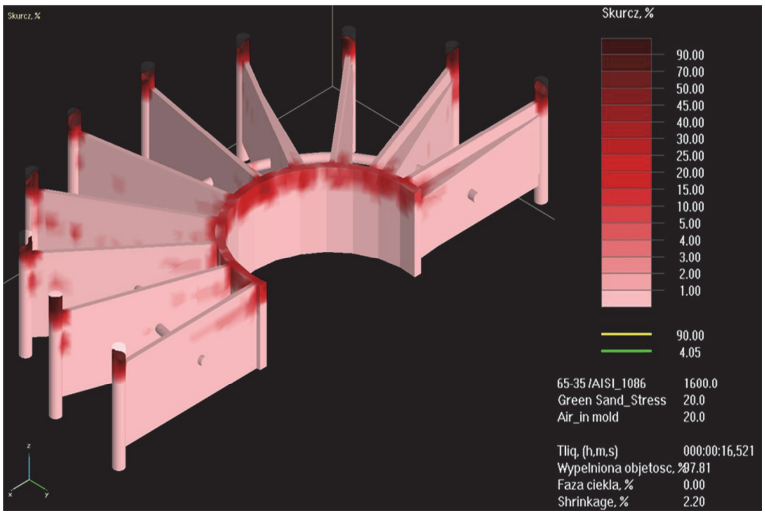

Fig. 5. Distribution of shrinkage porosity within the casting.

It was assumed that the presence of liquid phase in the final stage of simulated solidification (figure 4) should contribute to the better feeding of the casting, finally eliminating its slight porosity (figure 5). The performed examination of microstructure of produced experimental castings, both the gravity cast one and the one solidifying under the influence of centrifugal force, confirmed the correctness of the theoretical assumptions. The examinations were carried out at the middle section of the rotor blade working part, as an element most exposed to harmful influences during its work.

Comparison of microstructure of the gravity casting (figure 6a, 6b) and the casting solidified under the conditions of centrifugal casting (figure 6c, 6d) showed that both of them have the ferritic-austenitic microstructure. The precipitates of sigma phase in a form of tiny inclusions were also observed in both castings. The important feature of the examined microstructure is that the sigma phase, which – generally speaking – lowers the strength properties, is evenly distributed within the whole volume. Such a distribution of hard and brittle sigma phase within the working element (the rotor blade) leads to the increase of its erosion resistance, which seems particularly essential for elements exposed to aggressive environment (Charles, 2008; Marken, 2005; Shargay, 2005; Stradomski, 2010). Characteristic feature of centrifugal casting is distinct directionality of grains related to the rotational movement of the mould during solidification (figure 6c). For castings of both series, the grain size and the percentage of both main structural components are similar, but the casting coming from Series 1 exhibits somewhat greater fraction of sigma phase (figure 6a, 6b). The reason can be seen in the change of the solidification mechanism and in slower heat removal from the casting solidifying under the influence of gravity force only. The roughness measurements indicate the lower roughness for the centrifugally cast casting, which is characterised by R_z and R_a parameters lower nearly by half than the gravity cast one (table 3).

Table 3. *Surface roughness results.*

	R_a [µm]	R_z [µm]
Series 1	7,34	40,9
Series 2	4,39	20,0

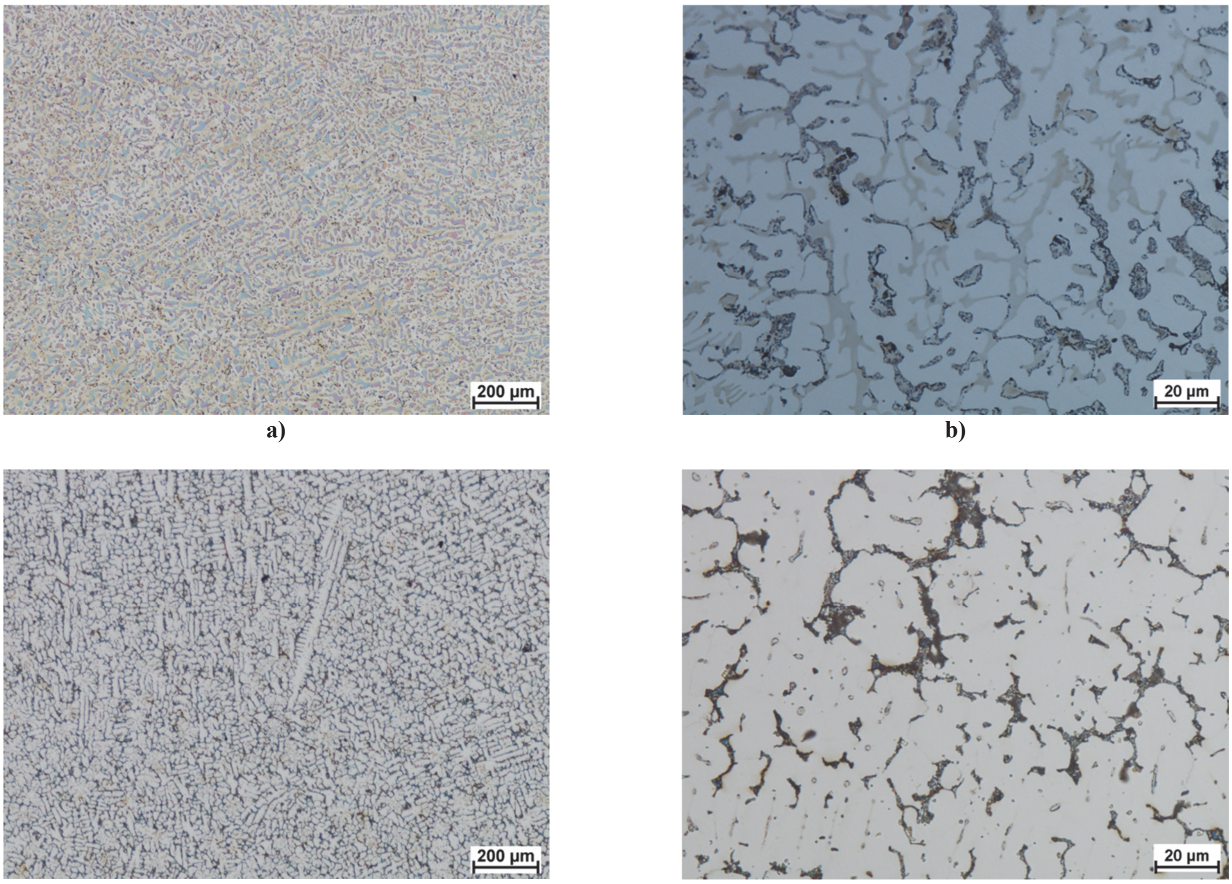

Fig. 6. *Microstructure of GX2CrNiMoCuN25-6-3: a, b) Series 1, mag. 50× and 500×; c, d) Series 2, mag. 50× and 500×.*

4. CONCLUSION

The assessment of solidification of a casting made of GX2CrNiMoN25-6-3 alloy and of the final degree of mould cavity filling, carried out on the basis of computer simulation performed by means of the NovaFlow&Solid program, was confirmed by experimental research. For the applied centrifugal casting (Series 2) the shrinkage cavity is located outside the demanded shape of the casting (figure 2). The casting itself, designed as the one of variable wall thickness, in some regions as thin as 1 mm or even thinner, was characterised by excellent surface reproduction and roughness lower than that of the casting produced in the Series 1. For the casting solidifying under the gravity forces only, the relocation of shrinkage cavity beyond the casting contour therefore the selection of centrifugal casting method would demand for a sinkhead which would increase the rough casting mass by about 50%. Both experimental castings under comparison exhibit economically justified. Both the compared experimental castings exhibit ferritic-austenitic microstructure with precipitates of the sigma phase in the form of tiny inclusions. Characteristic feature of the centrifugally cast casting is a distinct directionality of the grains related to rotational movement of the mould, with simultaneous decrease in the sigma phase fraction, caused probably by faster heat removal from the mould than it was in the case of comparative gravity casting.

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SPOSÓB WYKONYWANIA CIENKOŚCIENNYCH ODLEWÓW ZE STALIWA GX2CRNIMON25-6-3

Streszczenie

W pracy ocenie poddano możliwość wykonania cienkościennych odlewów ze staliwa GX2CrNiMoCuN25-6-3 na przykładzie docelowego odlewu o zmiennej grubości ścianki. Wykonano ocenę wypełniania i krzepnięcia stopu GX2CrNiMoN25-6-3 na podstawie symulacji komputerowej wykonanej przy użyciu programu NovaFlow&Solid. Bryła odlewu o zmiennej grubości ścianki, w tym nawet poniżej jednego 1 mm, wymogła zastosowanie odpowiedniej technologii wykonania. Przedstawiono wyniki prób technologicznych odlewania odśrodkowego, potwierdzające przyjętą technologię modelu i formy. W porównaniu do dotychczas stosowanej metody wykonania, analizowana technologia umożliwia wykonywanie odlewów o wysokiej jakości powierzchni przy jednoczesnym zwiększeniu uzysku i tym samym obniżając koszty wykonania jednostkowego odlewu.

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