ARCHIVES
of
FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 15
Special Issue
3/2015

77 – 82

15/3

The Microstructure of Thin-walled GX2CrNiMoN25-6-3 Cast Steel Made by Centrifugal Casting

G. Stradomski[a]*, M. Nadolski[b], Z. Stradomski[c]
[a]Institute Metal Forming and Safety Engineering,
[b]Department of Foundry,
[c]Institute of Materials Engineering, Faculty of Production Engineering and Materials Technology,
Technical University of Częstochowa, Poland.
*Corresponding author. E-mail address: gstradomski@wip.pcz.pl

Received 11.06.2015; accepted in revised form 20.07.2015

Abstract

The paper presents the results of investigation into the technological possibility of making light-section castings of GX2CrNiMoN25-6-3 cast steel. Due the fact that the GX2CrNiMoN25-6-3 duplex cast steel has a complex microstructure authors of this paper took on its analysis. For making castings with a wall thickness in the thinnest place as small as below 1 mm, the centrifugal casting technology, as it was presented in the paper [1], is one of the most effective technology. In the paper was made the analysis of four different parameters of the casting process and different parameters of heat treatment.

Keywords: Duplex cast steel, Centrifugal casting technology

1. Introduction

The main area of application of ferritic-austenitic steels and cast steels, also called duplex cast steels, are structures and elements subjected to high loads and exposed to environments favouring stress, pitting or crevice corrosion. Under such conditions, ferritic-austenitic steels and cast steels with a comparable fraction of their basic phases, i.e. ferrite and austenite, exhibit a better set of mechanical properties, compared to traditionally used ferritic or austenitic steels. Their higher mechanical properties compared to austenitic cast steels and good resistance to general and pitting corrosion have caused steels and casting steels of the duplex family to become today irreplaceable in the chemical industry for the construction of, e.g., the stores and tanks of ships transporting products with high chemical activity, such as phosphoric acid, concentrated sulphuric acid or strongly alkaline media, or for equipment to be used in the petrochemical, power and pulp and paper industries [1-7]. Owing to their high yield strength, they are used for the construction of heat exchangers (thin walls plus good thermal conductivity), heaters, coolers, condensers; or desalination, desulphurization and purification installations (e.g. in waste treatment plants). Their good resistance to fatigue corrosion makes them suitable for the construction of centrifuges, rotary vane driers and other dynamically loaded devices.

The centrifugal casting technology is most often used for producing castings in the form of bodies of revolution without coremaking. The mould is set in rotating motion around the vertical, horizontal and inclined axes. It is also able to rotate simultaneously around mutually perpendicular axes, e.g. the vertical and horizontal ones [8-12]. Shape castings, on the other hand, are made in a mould or moulds arranged on the edges of the disc of the centrifugal pourer with a vertical axis of rotation.

Due to its chemical composition, low carbon content and high chromium content (above 21%), nickel content normally not less than 3-6%, and an addition of elements, such as molybdenum and nitrogen, the alloy under investigation is characterized by poor casting properties. While for casting with a considerable wall thickness this does not pose any problem, in the case of light-section castings this makes a great obstacle. Basic drawbacks in those cases in the incorrect reproduction of the mould and casting contraction defects. A remedy for these problems can be increasing the casting module above the recommended 30% or producing an adequate metallostatic pressure inside the mould. Using an enlarged riser head will result in a very substantial waste of even up to 2/3 of the finished product. An alternative seems to be to employ the centrifugal casting technology; while, it is expected that by appropriately selecting the parameters it will be possible to obtain not only a higher efficiency, but also a good or even better surface with the simultaneous possibility of reproducing the wall with a thickness of up to 1 mm.

It should be noted that castings made in the technology of centrifugal casting are characterized by a specific microstructure that why authors of this work present results of microstructure changes in raw condition as well as three heat treatments.

2. Research material and methodology

The subject of the research was cast steel in the GX2CrNiMoCuN25-6-3 grades according to PN-EN 10283:2002. Chemical composition of the cast steel is summarized in Table 1.

Table 1.
Chemical composition of the examined cast steel grade

No.	C	Cr	Ni	Cu	Mo	Mn	Si	S	P	N
1	0.025	26.80	6.48	0.03	3.00	1.19	1,04	0.011	0.008	0.25

The aim of the investigation was to assess the possibility of using the centrifugal casting technology as an alternative to other casting techniques for duplex cast steels in order to produce light-section shape castings.

The study endeavoured to demonstrate that the change in technology would not have a negative effect on the quality of the casting. Tests were carried out on a casting representing a pump rotor produced on a commercial scale by a domestic manufacturer. A rotor model (Fig. 1) adapted to the centrifugal casting technology was produced by 3D printing.

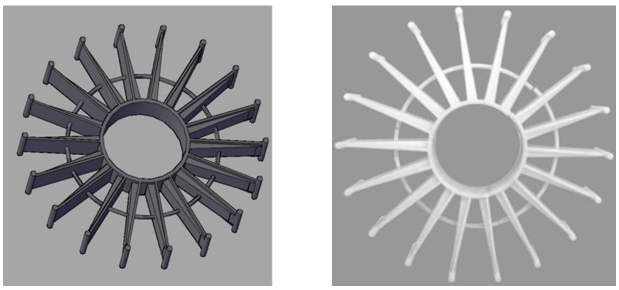


Fig. 1. Pump rotor a) CAD 3D model, b) 3D print

On the basis of the 3D print, thin-walled ceramic mould were made according to the investment pattern technology in the solution with a support layer. So prepared mould, after the pattern fusing and baking process, was cooled down to a temperature of about 500°C. At this temperature, the mould was mounted on the vertical rotation axis centrifugal pouring stand. To establish the preliminary pouring process parameters, three series of castings were made with basic process parameters, as shown in Table 2.

Tabela 2.
The parameters of the casting process for cast steel GX2CrNiMoN25-6-3

Designation	Pouring temperature, °C	Rotation speed, r / min	Pouring method
Series 1	1550	250	rotating mould
Series 2	1550	200	rotating mould
Series 3	1550	0	fixed mould

The "fixed mould" pouring method is understood here as the one, where as soon as the mould has been filled with the alloy, it is set in rotary motion at preset rotational speed. In contrast, the term "rotating mould" is used where the mould is filled with the alloy as it rotates. The rotation duration of castings during solidification was 2 minutes, and after about 5 minutes the castings were knocked out to allow them to solidify freely.

For the microstructure analysis were taken samples from rotor's blades. The structural examinations were performed with a Nikon Eclipse MA-200 optical microscope on specimens etched with the Mi21Fe reagent.

3. Research results and their discussion

The microstructure analysis was made for the raw condition for series 1-3 materials. For centrifugal castings were made three type supersaturation heat treatment. From castings were cut out rotor's blades which were treated according with parameters presented in table 3.

Table 3.
The parameters of the heat treatment

Series	1	2	3
Supersaturation 1	1050°C for 90 min		
Supersaturation 2	1100°C for 120 min		
Supersaturation 3	1100°C for 240 min		

The analysis were made for three part of sample the end, the central part and the axis as it is presented on fig 2. In the paper due lack of space on figures 3 and 6-8 will be presented microstructure from the central part.

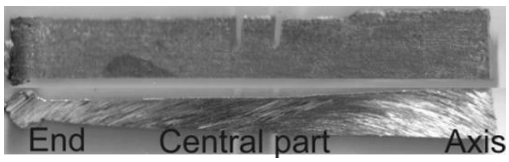
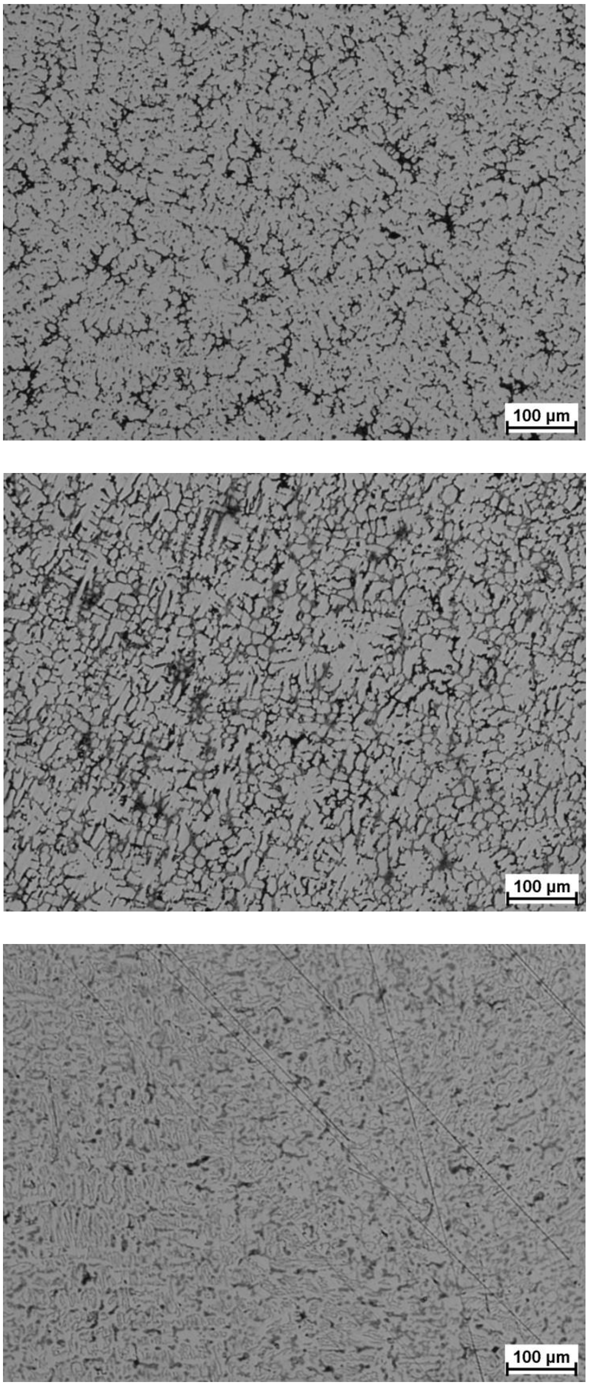


Fig. 2. Cut out rotor blade with marked area of microstructure analysis



a) b) c)

Fig. 4. The microstructure GX2CrNiMoCuN25-6-3 for the raw condition; a) series 1, b) series 2, c) series 3 - magn.100x

The results for Series 1 & 2 were characterized by a similar microstructure in terms of the grain size and the percentage fraction of basic phases (54 and 58%). In the table 3 are presented result of basic phases fraction percentage obtained with use of the Nis-Elements D software. At the same time, small precipitations of the sigma phase, distributed uniformly within the entire volume, were observed. Such distribution [13] of this phase increases the erosion resistance, which is particularly important for parts exposed to aggressive working medium. For Series 1 & 2, the directional character of the structure is additionally observed, whose effect for the alloy under investigation would need to be determined in a separate study.

The comparison of the gravity cast structure has revealed that the casting of Series 3 exhibits an increased fraction of the sigma phase [14]. The cause of the increased sigma phase fraction is seen in the slower heat removal from the solidifying casting, in spite of the lower pouring temperature.

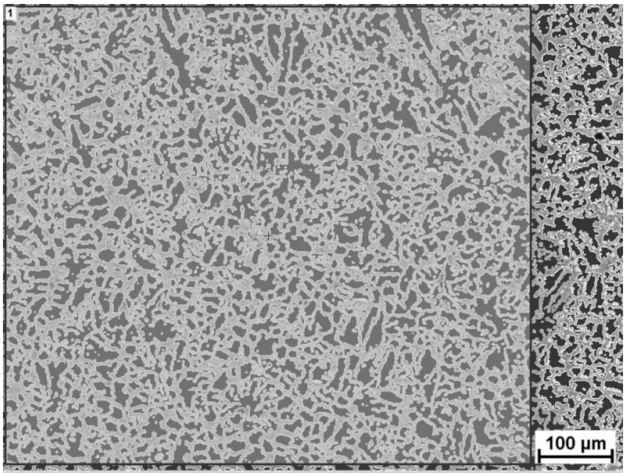
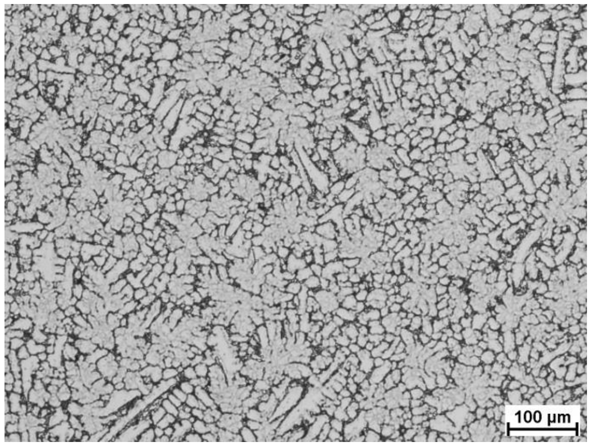
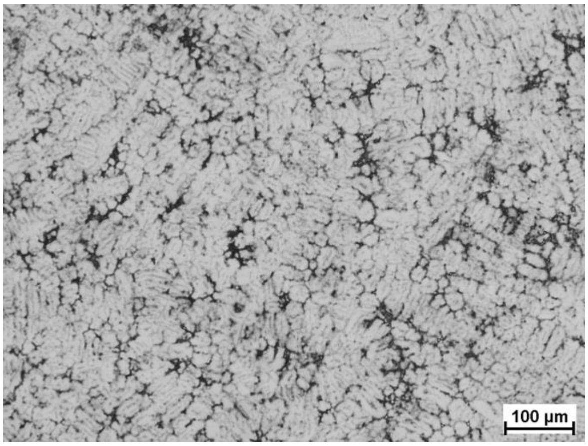


Fig. 5. The example of microstructure with marked threshold use during phases fraction percentage analysis.

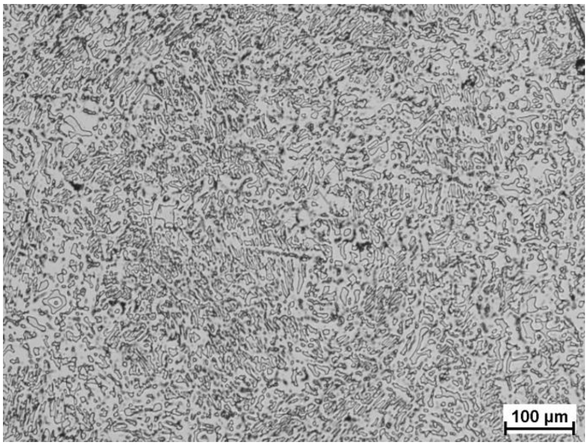
Figures 6-8 presents microstructure for different supersaturation according to the table 3.



a)

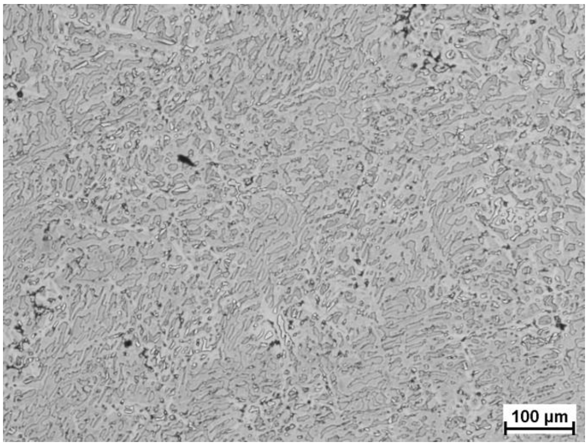


b)



c)

Fig. 6. The microstructure GX2CrNiMoCuN25-6-3 after supersaturation 1; a) series 1, b) series 2, c) series 3. - magn.100x



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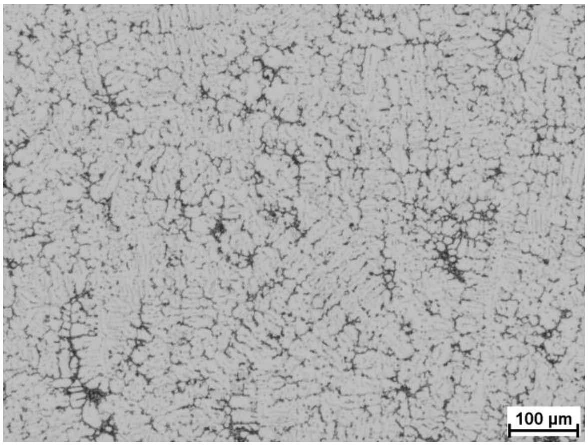
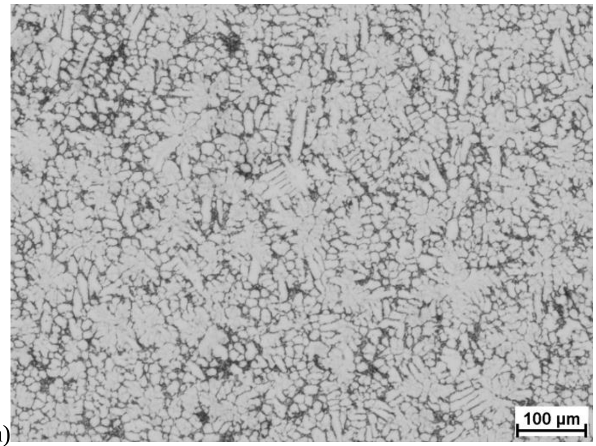
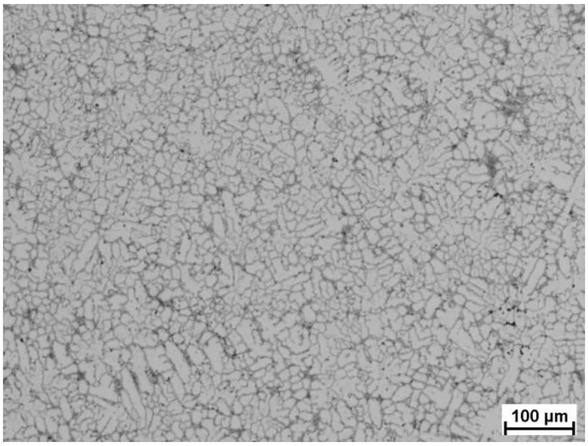


c)

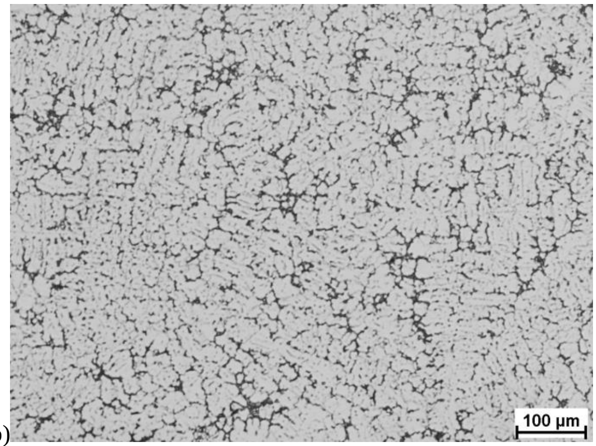
Fig. 7. The microstructure GX2CrNiMoCuN25-6-3 after supersaturation 2; a) series 1, b) series 2, c) series 3. - magn.100x



a)



a)

b) 

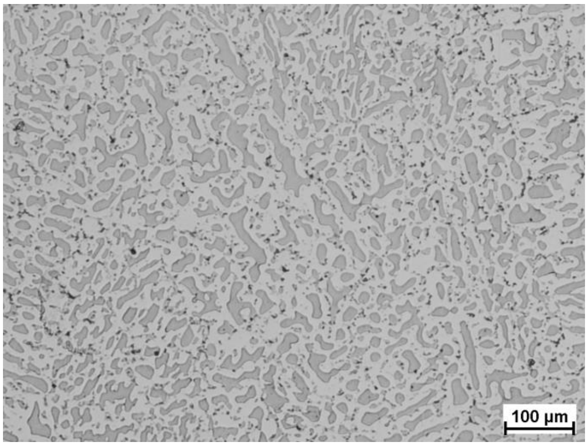
c) 

Fig. 8. The microstructure GX2CrNiMoCuN25-6-3 after supersaturation 3; a) series 1, b) series 2, c) series 3. - magn.100x

The cast steel microstructure analysis after heat treatment showed that there is a large convergence for castings designated as Series 1 and 2. The literature [2, 13] determine that the correct volume fraction of primary phase should be about 50%. Due to the erosion resistance the fraction volume should not be less than 30 to 70% [15]. In the table 4 are presented result of basic phases fraction percentage obtained with use of the Nis-Elements D software.

Table 4.
Results of basic phases fraction percentage obtained with use of the Nis-Elements

Designation	Percentage of ferrite			
	Raw condition	Supersaturation 1	Supersaturation 2	Supersaturation 3
Series 1	54%	53%	50%	55%
Series 2	58%	56%	55%	53%
Series 3	36%	47%	52%	54%

An important issue from the point of view of both corrosion resistance and mechanical properties is the presence in the microstructure of sigma phase. Therefore, in the element highly exposed to dynamic loads, working in aggressive environments is allowed only very specific layout of this phase, in the form of small precipitates within the ferrite grains and definitely it is unacceptable to the precipitation of the ferrite austenite boundaries. Because in the raw condition for both Series 1 and 2 sigma phase precipitations were observed with similar morphology and a similar volume were used different variants of supersaturation. Supersaturation from the temperature of 1050°C for 90 min did not result in complete dissolution of sigma phase for any of the three variants (series). For the Series 1 after supersaturation from the temperature of 1100°C for 120 minutes, all precipitation has been dissolved, but for Series 2 and 3 the time was insufficient. After the time 240 min at 1100°C for the series 2 were not observed sigma phase precipitates. The series 3 after this period was characterized by a certain volume of this phase as fine precipitates. However, that Series can only be regarded as a reference.

Observed in the raw condition strong directionality of the grains, particularly visible for the Series 1 has been maintained after heat treatment. Such an arrangement of small grains should guarantee good operational properties of casting..

Worth to highlight is the fact of obtaining almost uniform participation of both phases already-cast for Series 1 and 2. After the treatment by which the sigma phase was eliminated this state was preserved (Table 3).

4. Summary

The studies of the microstructure changes revealed a high similarity for cast designated as Series 1 and 2 for both raw condition and after supersaturation. The use of centrifugal casting for duplex steel caused the emergence of a strong directionality of the grains, particularly visible for Series 1. The directionality was also retained for the state after heat treatment. In all series of castings it was observed the presence of sigma phase in the raw condition. Depending on the casting Series after 120 or 240 minutes was observed the sigma phase annihilation.

The performed investigation confirm that centrifugal casting technology can be used to produce light-section shape castings of duplex cast steel.

Moreover, in conformance with the literature reports describing the method of centrifugal casting of metals and alloys, it has been demonstrated that it is possible to produce light-section shape castings of duplex cast steel with an increased output and a reduced pouring temperature.

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