ARCHIVES of FOUNDRY ENGINEERING

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

ISSN (1897-3310)
Volume 7
Issue 4/2007

63 – 68

13/4

Structural gradient in a thin wall casting of ductile iron

E. Fraś*, M. Górny
AGH - University of Science and Technology, Reymonta 23, 30-059 Cracow, Poland
*Corresponding author. E-mail address: edfras@agh.edu.plT

Received 29.06.2007; accepted in revised form 06.07.2007

Abstract

In this paper a experimental and theoretical structural analysis of thin walled casting made of ductile iron is presented. The work shows that these castings posses a non-homogenous gradient structure associated with (i) the graphite nodule densities and (ii) the ferrite and cementite volume fractions. The microstructural inhomogeneities are attributed to sharp variations in the cooling rates along the length of the casting. The experimental investigations were made using of the castings with a 1.6 mm wall thickness, where the graphite nodule count, N_F and de fractions of ferrite, f_f and cementite eutectic, f_c were determined as a function of distance from the runner. It was found that the theoretical predictions were in good agreement with the experimental outcome. In particular, this work shows that it is possible to produce thin wall plate shaped castings made of nodular cast iron with wall thicknesses of 1.6 mm (without chills, cold laps, or misruns).

Keywords: Thin wall ductile iron, Structure, Gradient

1. Introduction

Recent trends in the design of vehicle components have been focused in the production of thin-wall ductile iron castings (TWDI) in order to save materials and energy. In general, there has been an increasing demand for thin-wall ductile iron castings with a wall thickness below 3 mm and with a high strength to weight ratios [1,2]. In literature there are very little information on technology of TWDI. Accordingly, the aim of this work is to establish the effect of the casting length and of riser-gating systems on the exhibited TWDI microstructure.

Ductile iron can be credited which characterize high sensitivity on cooling rate what in consequence leads to structural gradients G_x that is continuous changes of structural features of cast iron and (properties accordingly) along one of it direction.

2. Methodology

The aim of this article is to investigate structural changes of plate shaped castings along a casting length with and without risers and with various gating systems. Melts were produced using an electric induction furnace. The raw materials were Sorelmetal and steel scrap as well as commercially pure silicon. After melting of the charge and preheating to 1500°C the bath was poured into the mold into plate shaped mold cavities with a wall thickness, s = 1.6 mm without (Fig.1a) and with a riser (Fig.1b) as well as with 3 back gates without riser (Fig.1c). The molds were made of chemically bonded 75-mesh silica sand. A Pt-PtRh10 thermocouples was inserted in the runner of plates and an Agilent 34970A electronic module was employed for numerical temperature recording. Metallographic determinations of nodule count, as well as cementite and ferrite fractions were then made on samples cut from these plates.

3. Results and discussion

Samples without a riser

Structure
In samples without a riser the solidified length of casting obtained was 175 mm, which is shorter than the mold cavity length 200 mm (see Fig.1a). The experimental results (points in Fig. 2) were approximated using the following equations:

Graphite nodule count, N_F (R = 0.97)

For $1\,\text{mm} \le x \le 162\,\text{mm}$

$$N_F = 2451 + 4.75\exp(0.036x) \qquad (1)$$

Gradient of the graphite nodule count, G_{N_F}

$$G_{N_F} = \frac{dN_F}{dx} = 1.71\exp(0.36\,x) \qquad (2)$$

Ferrite fraction, f_f *(* R = 0.98)

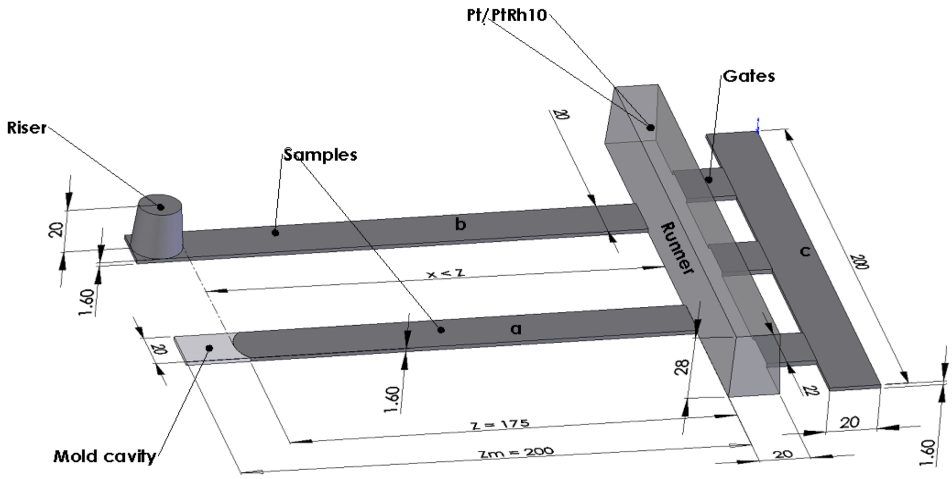


Fig. 1. Size (mm) and shape of the thin-walled samples and mold cavity (a) without and (b) with a riser and with three gates (c)

for $1\ \text{mm} \le x \le 155\,\text{mm}$

$$f_f = 14.95 + 85.08\,x^{-1} - 7.52\,10^{-7}\,x^3 \qquad (3)$$

Gradient of the ferrite fraction, G_{f_f}

$$G_{f_f} = \frac{df_f}{dx} = -2.98 + 0.62\ x - 0.03\ x^2 \qquad (4)$$

Cementite fraction, f_c (R = 0.98)

for $163\,\text{mm} \le x \le 170\,\text{mm}$

$$f_c = 2.13\,x - 345.35\,, \qquad (5)$$

Gradient of the cementite fraction G_{f_c}

$$G_{f_c} = \frac{df_c}{dx} = 21.08 \qquad (6)$$

where x is the distance from the runner in mm.

In particular, notice (Fig. 2 and 3) that there are marked differences in nodule count and ferrite fraction along the length of casting.. Moreover, from the experimental outcome (Fig. 3c), it is evident that there is a critical casting length, x_{cr} (between 162 and 163 mm) for the grey to mottled structure transition. In the mottled zone, as x increases, the cementite fraction also increases, while in the grey zone, N_F increases and f_f decreases with increasing x (fig. 3). Hence, a measure of the structural inhomogenity within the grey zone of the castings can be given by the differences in nodule count and in ferrite volume fractions between the initial and the final casting distances.
The differences in nodule count, ΔN_F and ferrite fraction Δf measured at distance x =1 mm and x =162 mm from the runner are:

$$\Delta N_F = 3966 - 2373 = 1593\ \ \text{mm}^{-2} \qquad (7)$$

$$\Delta f = 100 - 13 = 87\ \% \qquad (8)$$

It can be observe that Δf is relatively large. Apparently, appreciable heating of the mold material in the vicinity of the runner after eutectic solidification diminishes the cooling rate during the eutectoid transformation favoring the formation of ferrite.

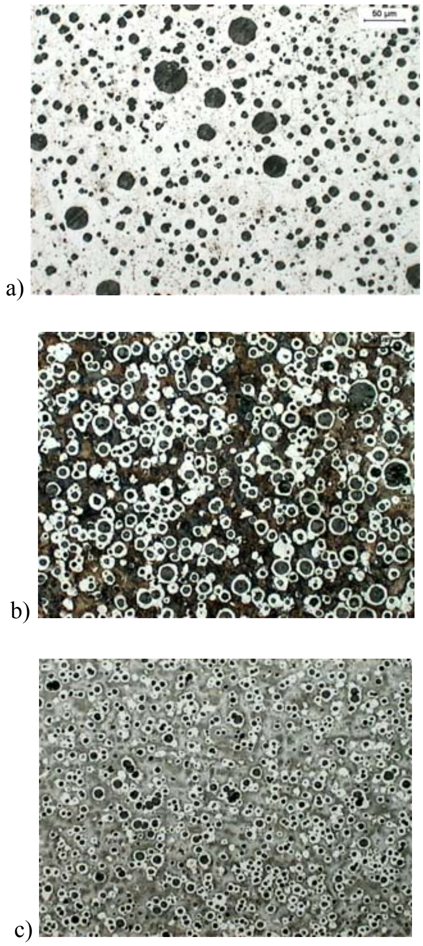


Fig. 2. Exhibited microstructures of samples taken at (a) 1.0 mm, (b) 14 mm and (c) 161 mm from the runner. Sample etched using Nital

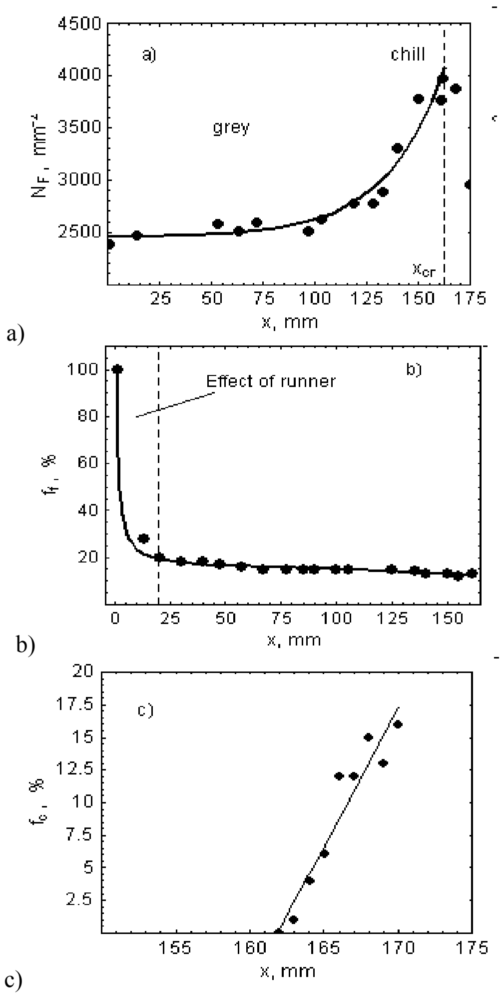


Fig. 3. Influence of distance x from the runner on (a) nodule count, (b) ferrite fraction and (c) cementite fraction

Melt temperature drop in the mould channel

As a result of heat transfer between the flowing liquid stream and the surrounding mold walls, the melt temperature of liquid metal, T_i in channel continually drops. According to work [4] the temperature of liquid metal, T_i decreases with the distance x from the entrance of the channel as it is presented in Fig 4. The cooling rate Q, of liquid cast iron at the equilibrium temperature, T_s for the graphite eutectic is given by [5-9]:

$$Q = \frac{8 T_s a^2}{\pi c^2 s^2 \ln \frac{T_i}{T_s}} \qquad (9)$$

where a-is material mold ability to absorb heat, T_s is equilibrium temperature of graphite eutectic, c is specific heat of cast iron, s is wall thickness of casting.

Figure 4a shows that the liquid metal temperature, T_i decreases as the distance, x from the runner increases. Using temperature T_i from Fig.4a and equation (9) a function Q = f(x) can be schematically plotted (Fig.4b). Thus, the cooing rate Q, increases along the x < Z length, particularly at the tip of the samples (Fig 4b). It is well known that as Q along the distance x increases the nodule count also increases in agreement with the experimental outcome (Fig. 3a).

At a critical distance x_{cr} (Fig 3-5), the cooling rate is high enough to reach the condition $\Delta T_m = T_s - T_m = \Delta T_{sc}$

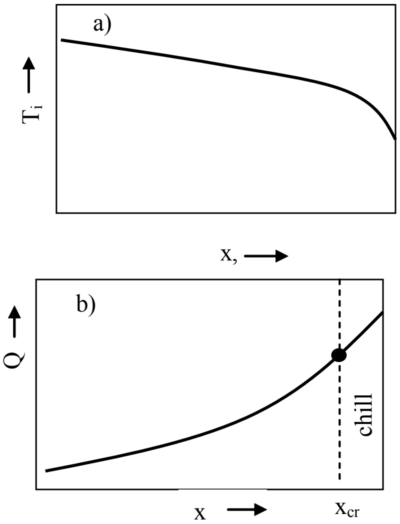


Fig.4. Influence of distance from the runner, x on (a) temperature T_i and (b) cooling rate Q

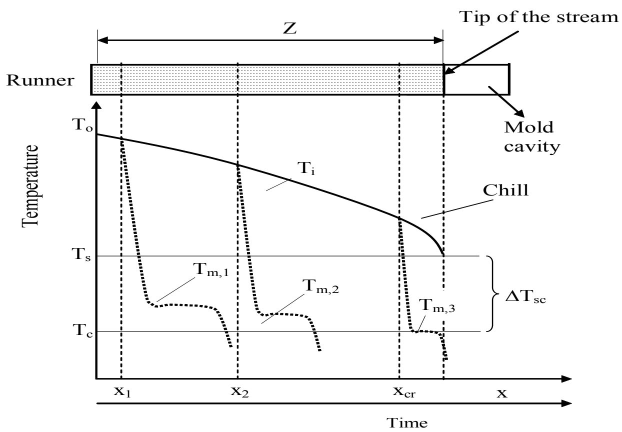


Fig. 5. Temperature changes in liquid cast iron, T_i, and cooling curves (discontinuous lines) at various lengths, x. ΔT_{sc} is the range between the equilibrium temperature, T_s for graphite eutectic and cementite eutectic, T_c , T_m is the temperature for eutectic solidification

Samples with a riser

When the riser is placed at a lenght of 175 mm the metal flowing into the riser causes an increase of the time flowing of liquid metal through the mold channel. Large size risers lead to long filling times and increasing heating of the surface of the mold cavity channel. Thus, the liquid cast iron is cooled relatively slow resulting in lower temperature drops. For example if the temperature drop of the metal in the channel without riser is $T_o - T_Z$, the temperature drop in the channel with a riser is $T_o - T_r$. (Fig. 6).

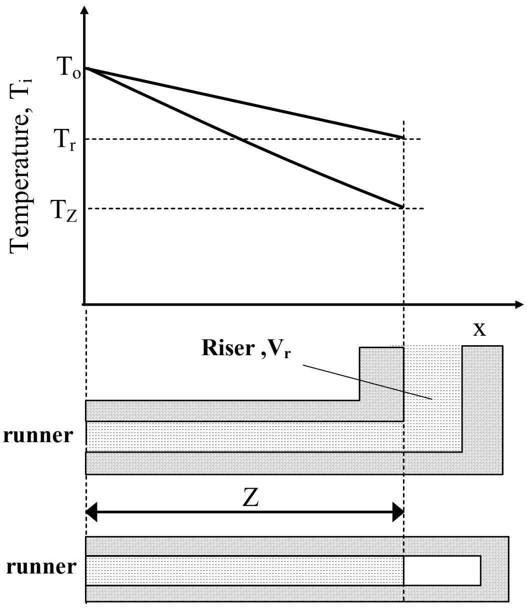


Fig.6. Temperature drop in castings with and without riser

Apparently, the temperature distribution becomes more uniform and the differences in cooling rates diminish leading to lower structural differences (structural gradients).
The results of metallographic evaluations for plate shaped castings with risers are given in Figs.10 and 11. The experimental outcome was approximated by the following equations:

Graphite nodule count, N_F (correlation coefficient R = 0.95)

for $20\,mm \le x \le 170\,mm$

$$N_F = 2625.9 + 0.00171 \ \exp\left(\sqrt{x}\right) \tag{10}$$

Ferrite fraction, f_f *(*correlation coefficient R = 0.84)

for $20\,mm \le x \le 156\,mm$

$$f_f = 19.911 - 0.050\,x \tag{11}$$

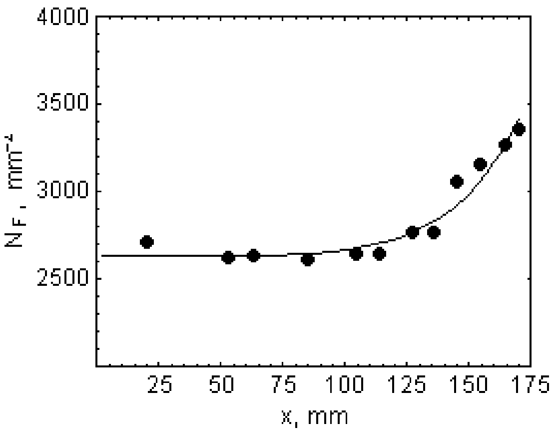
The difference in nodule count (fig.7) measured at x = 20 mm and x = 170 mm the initial and final locations is

$$\Delta N_F = 3355\text{-}2705 = 650\ ,\ mm^{-2} \tag{12}$$

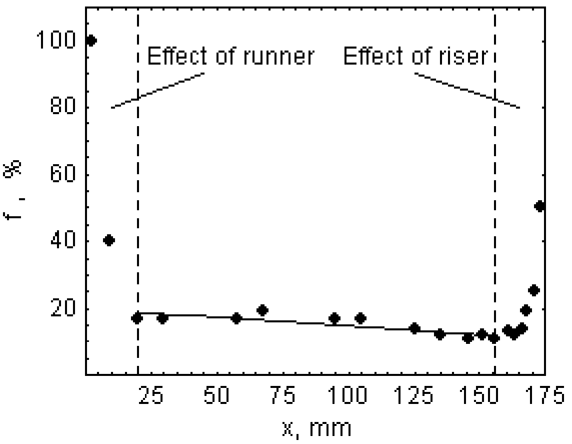
and the difference in ferrite fraction (fig.7) measured at x = 20 mm and x = 155 mm (that is, without taking into account the influence of the runner and riser) is

$$\Delta f = f_{,f,b} - f_{,f,e} = 17\text{-}13 = 4,\ \% \tag{13}$$

Comparing the results of castings with and without risers (Figs. 3 and 7) it is worth pointing out that the use of risers eliminates the formation of chills and the differences in nodule counts at the beginning and the end of the casting length are significantly reduced (i e from ΔN_F =1593 mm^{-2} to ΔN_F =650 mm^{-2}). Hence, risers favor the development of more uniform casting structure during the eutectic transformation. Once the eutectic transformation is completed, mold regions of in the neighborhood of the large runners and risers are heated up and cause a slow cooling of the cast iron during the eutectoid transformation.



a)



b)

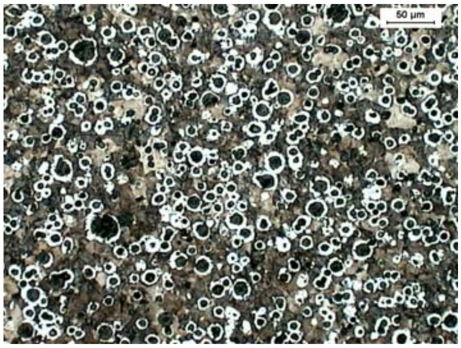
Fig. 7. Influence of distance from the runner, x on (a) nodule count and (b) ferrite fraction

In turn, these regions develop relatively large ferrite fractions compared with other locations (Figs. 7 and 8a,d).

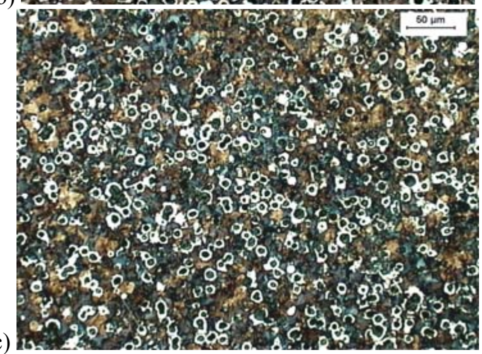
Samples with 3 back gates

In this case, of the 3 back gates were incorporated to the thin mould sections (Fig.1c). This in order to promote metal flow and heating of the mold materials in the various thin sections and to obtain more homogeneous of the cooling and solidification rates of the metal. Results these investigations are shown in Fig. 9 and 10. The nodule count are in 2240 do 2374 mm^{-2} range and the ferrite fraction in 30 to 0 37 % range (Fig 14). For casting with gate at one end these differences are much large (2373 to 3966 mm^{-2} and 12 to 100%). Moreover, at the end of plates the chill occurs (Fig..3 c). Thus, it can be stated that using a lot of back gates leads to more homogeneous structure. and in consequence to more homogeneous properties of thin wall ductile iron castings.

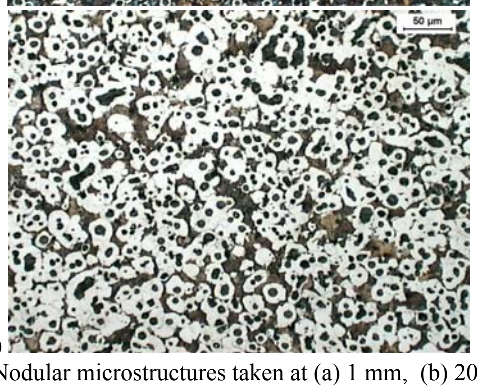
a)



b)



c)



d)

Fig. 8. Nodular microstructures taken at (a) 1 mm, (b) 20 mm, (c) 155 mm and (d) 175 mm (d) from the runner. Sample etched using Nital

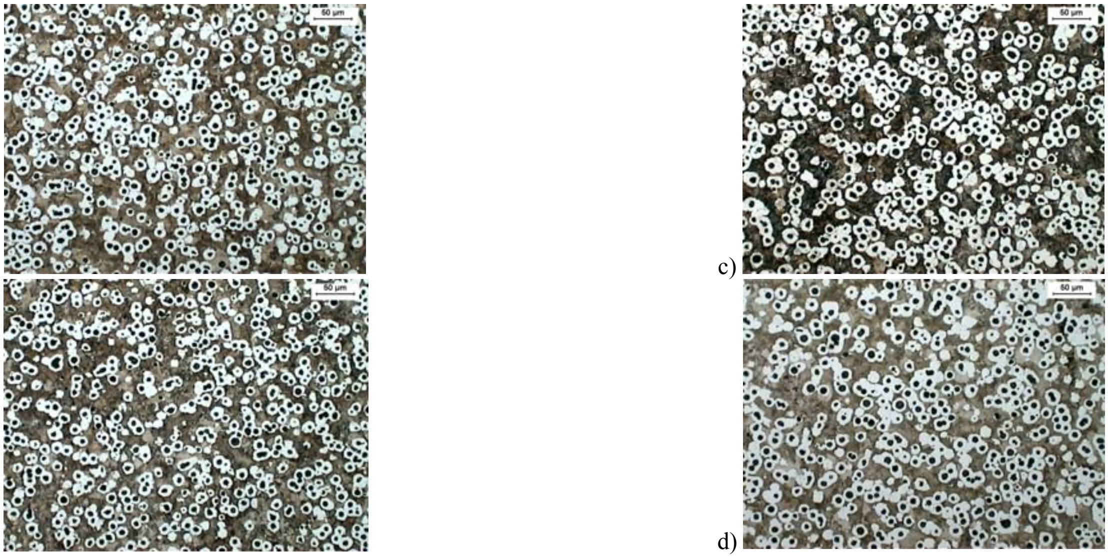


Fig. 9. Nodular microstructures taken along the length of plate at (a) - 1 mm, (b) - 20 mm, (c) - 155 mm and (d) -175 mm (d) from the runner. Sample etched using Nital

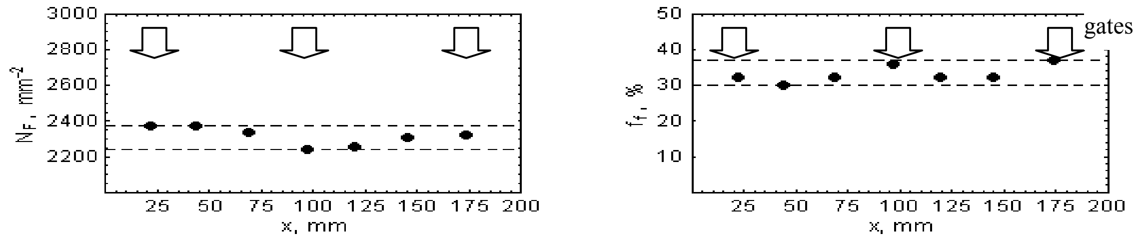


Fig. 10. Nodule count N_F and ferrite fraction f_f along the length of plates

4. Concluding remarks

1. It is possible to produce thin wall plate shaped castings made of nodular cast iron with wall thicknesses of 1.6 mm (without chills, cold laps, or misruns).
2. It has been shown that despite of the constant wall thickness, the microstructural features of ductile iron can be inhomogeneous (nodule count, chill, ferrite fraction) along its length as a result of changes in the cooling rate.
3. In order to fabrication of thin wall castings with hommogeneus structure made of nodular cast iron using rather a few gates is recommended instead risers.

Acknowledgments

This work was supported by Grant PBZ/KBN Poland – No 3T08B04230

References

[1] Labrecque, C., Gagne, M., Production of thin-wall iron castings , Int. J. Cast Metals Research, vol. 16, 313 318, (2003).

[2] Cuttino, J. F., Andrews, J. R., Piwonka, T.S., Development in thin-wall iron casting technology, AFS Transactions, vol. 107, 363-372, (1999).

[3] Ryś J : Stereology of materials, Fotobit, Cracov, 1995.

[4] Fraś E., Wiencek, Górny M, Thin wall ductille castings as a gradient Material, Archives of Metallurgy and Materials, 2006, vol. 50\1, nr.3, 423-431.

[5] Fraś E., Górny M., Lopez H.F, Eutectic Cell and Nodule Count in Cast Iron. International Steel and Iron Japan Institue., ISIJ Int., vol. 47 (2007) No. 2, 259-268.

[6] Fraś E., Górny M., Lopez H.F, Eutectic Cell and Nodule Count in Cast Iron- Experimental Verification. International Steel and Iron Japan Institue., ISIJ Int., vol. 47 (2007) No. 2, 269-276.

[7] Fraś E, M. Górny, H.F. Lopez, Chilling tendency and nodule count in ductile cast iron Part I theoretical Backgound, Transactions of the American Foundryman Society, vol.114, 575-594, 2006.

[8] Fraś E, M. Górny, H.F. Lopez, Chilling tendency and nodule count in ductile cast iron Part II Exparimental verification, Transactions of the American Foundryman Society, vol.114, 595-603, 2006.

[9] Fraś E, M. Górny, H.F. Lopez, Chilling tendency and nodule count in ductile cast iron Part III Thermal Analysis, Transactions of the American Foundryman Society, vol.114, 595-603, 2006