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Thin Wall Ductile Iron Castings: Technological Aspects

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Abstract

The paper discusses the reasons for the current trend of substituting ductile iron castings by aluminum alloys castings. However, it has been shown that ductile iron is superior to aluminum alloys in many applications. In particular it has been demonstrated that is possible to produce thin wall wheel rim made of ductile iron without the development of chills, cold laps or misruns. In addition it has been shown that thin wall wheel rim made of ductile iron can have the same weight, and better mechanical properties, than their substitutes made of aluminum alloys.

Keywords: Ductile iron, Thin wall, Wheel rim

1. Introduction

From marketing investigations [1] follow that within the last 15 years participation of aluminum alloys parts in Americans cars increase twofold while in European increase by 5 up to 20 %. From this, among other things reason lately it is observed decline of cast iron production [2], with the exception of ductile iron. However, systematically increases production of aluminum alloys castings. Producers of lightweights alloy castings; particularly on the basis on aluminum alloys enters the market, which was up to now reserved for cast iron. The advantages from replacements of cast iron castings into aluminum alloys castings results, among other things from lower density of aluminum, which is equal about 0.38 of cast iron density. Such difference lowers cars weight and in consequence fuel consumption. According to estimates [3] the reduction of the car weight by 100 kg enables to save 0.5 to 1 liters of fuel per 100 km Additional advantages of aluminum alloys are as follows:

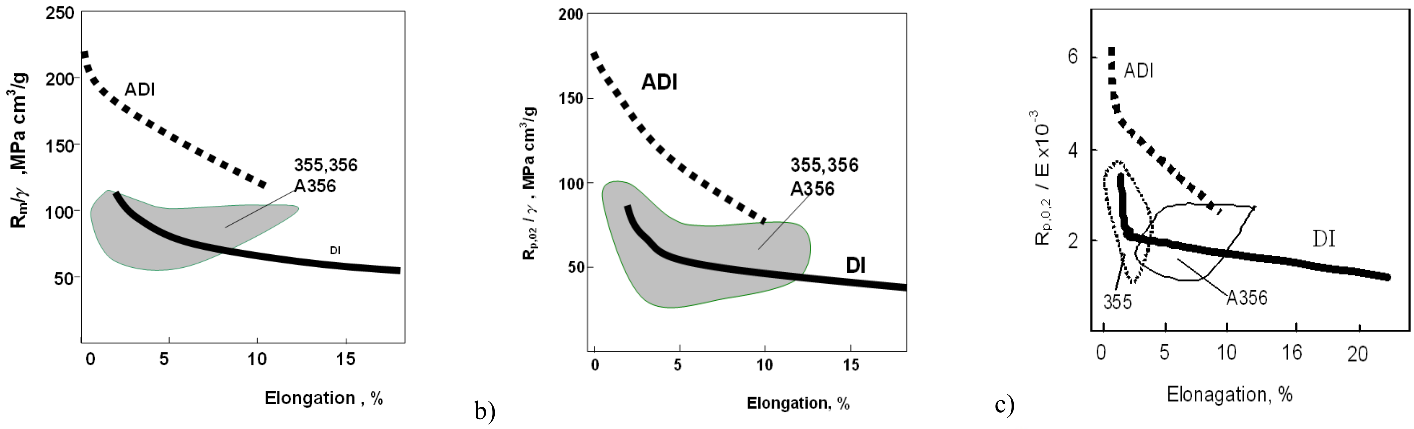
- low melting and pouring temperature, that is why loading heat of molds is relatively low, what enables to use conventional permanent-mold casting, which increase dimension accuracy and quality of castings surface (disadvantage of this method is problem with production castings without porosity, causes lower mechanical properties, especially fatigue resistance),
- non-magnetic character of aluminum, what facilitate scrap selection and its recycling,
- high thermal conduction, which facilitate better engine cooling,
- castings aesthetics.

The problem with replacement cast iron into aluminum seems less profitably when mechanical properties are taken into account, eg. strength, elongation, fatigue resistance, stiffness, etc. both groups of alloys and unique properties of cast iron connected with graphite presence (eg. high damping capacity, lubricate ability of graphite in diverse tribology pairs). From analysis of mechanical properties it can be state that for a given elongation, tensile

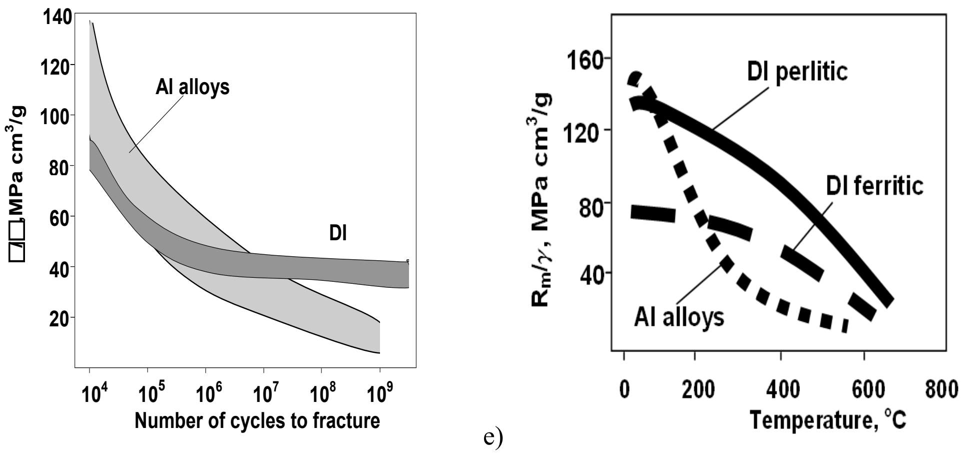
strength R_m, yield strength $R_{p0,2}$ and stiffness (assumed as ratio of yield strength $R_{p0,2}$ to Young modulus E) of typical grade of ductile iron are much more higher than for aluminum alloys.
Taking into account casting weight the strength indicators related to density γ of materials (indicator/γ) can be used. Then it is apparent that aluminum alloy and ductile iron ensure similar strength indicators (Fig.1a-c) [1]. An exception is austempered ductile iron (ADI), which has much better properties then remaining alloys.

Valuable advantage of cast iron is its ability to bear long-standing cyclic loading, which usually is shown as a stress – number of cycle dependency. From Fig. 1d follows that above 10^5 -10^7 cycles admissible stress for cast iron are higher than for aluminum alloys. Moreover, below a certain critical stress number of cyclic loads of cast iron tends practically to infinity without the presence of cracks. Such feature do not reveal aluminum alloys. It can be state that cast iron castings show much higher fatigue resistance and are safer in comparison to aluminum alloys. Taking into account strength indicators referenced to the materials density (indicator / γ), it appears that eg 1 kg of aluminum alloys and ductile iron, providing similar values of strength (Fig. 1). The exception is ADI, which considerably exceeds the other alloys. It follows that the ductile iron can be as light as aluminum alloy.

In some cases (eg. internal combustion engine, housing of catalyst) important is influence the temperature on mechanical properties. From Fig. 1e follows that exceed the 100 °C, relative strength of aluminum alloys radically decreases. Above 200 °C relative strength of ductile iron especially with pearlitic matrix considerably exceed relative strength of aluminum alloys. So for application at high temperature favorable is to use cast iron.



a) b) c)



d) e) f)

Material	Relative dumping capacity
Cast iron, thick graphite	100 - 500
Cast iron, fine graphite	20 -100
Ductile cast iron	5 -20
Steel	4
Aluminum	0.4

Fig. 1. Relative tensile strength (a,e) yield strength (b) and stiffness indicator (c) fatigue resistance (d) and relative dumping capacity (f); 355, 356, A356 – aluminum alloys. DI – ductile cast iron, ADI – austempered ductile cast iron according to ASTM

Next factors, which should be considered it is wear properties and dumping capacity. Cast iron possess ability for surface hardening, namely to generate hard and wear resistance surface layer and soft and plastic core (eg. timing gear). Significantly lower dumping capacity of aluminum alloys in comparison to cast iron (Fig.1f) generally leads to higher engine noisy. In general, from presented analysis it follows that cast iron castings characterize the same and in many essential cases – better mechanical and utilizable properties like alumnium alloys with the same weight. One of the essentials factor which should be also taken into account, when replacing castings made of cast iron into aluminum alloys is the factor of total consumption energy.

Generally it can state that production of cast iron castings is connected with energy savings and moreover contrary to aluminum and aluminum alloys, cast iron can be remelted many times without deterioration its quality.

Next and from the economics point of view the most important argument in aid of cast iron is much lower production costs of castings compared to aluminum alloys. Fig. 2 show individual costs of different materials essential for obtaining unit of $R_{p0,2}$.

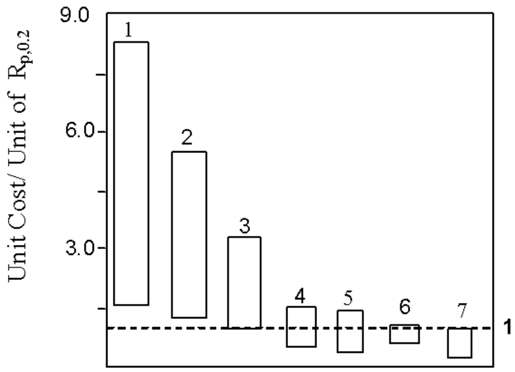


Fig. 2. Unit costs[1] of product essential for obtaining unit yield strength $R_{p0.2}$ normalized towards forget steel (up to 1); (1) - aluminum alloys castings, (2) – forged aluminum, (3) – cast steel, (4) – forged steel, (5) - heat treated steel, (6) – ductile iron, (7) – ADI [1]

The following conclusion follows that castings cost either ductile iron or ADI is much lower than aluminum alloys. Summing up the foregoing considerations the following conclusion come into being that decision of substitute cast iron castings with aluminum alloys is not always the rational and must be preceded by analysis of many factors like: production cost, mechanical properties at ambient and at elevated temperature, fatigue resistance, energy consumption, compatibility with parts made of different materials, noise and corrosion resistance. From the presented analysis follows that there exists potential possibility to produce lightweight and cheap cast iron castings. In foundry practice, usually it is adopted that in order to avoid castings defects (eg. chills, misrun castings, and cold shuts) they must be cooled down with relatively low rate and from this reason minimal wall thickness of cast iron castings should be above 3 mm. However, taking into account potential possibility of mechanical properties of cast iron such wall thickness often is redimensioned. It seems that technology of production of thin wall ductile iron castings (TWDI), where wall thickness is below 3 mm should be worked out at the beginning of expansion of development aluminum alloys castings.

Figure 3 shows the predicted cooling rates as a function of wall thickness for castings made with conventional molding sand, as well as a comparison with experimentally reported data. Problems with thin wall ductile iron castings technology are connected with "entering" into very high cooling rate range, which promotes chills and shortens the metal flow which results in the misrun, and cold shuts.

Accordingly, the aim of this work is to produce the real thin wall ductile iron castings which can be lighter than substitutes made of aluminum alloys, but with better mechanical properties and definitely better damping capacity and lower final cost.

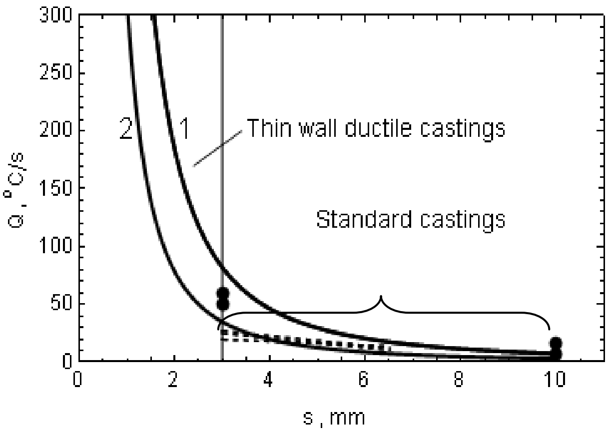


Fig. 3. Influence of wall thickness s and temperature T_i of liquid metal on the cooling rate of castings: line 1 – prediction for C=3.6%; Si = 2.7%; T_i = 1340 °C, c = 5.95 J/cm^{3}a = 0.11 J/(cm^2 s$^{1/2}$ °C), line 2 – prediction for C=3.6%; Si = 2.7%; c = 5.95 J/cm^3, T_i = 1450 °C, a = 0.09 J/(cm^2 s$^{1/2}$ °C) [4], points – experimental data [5], lines ------ experimental data [6]

2. Technological aspects

2.1. Chills

The method of obtaining thin-walled ductile iron with no chills, lies in the fact that the melted iron is chosen in such a way that its chemical composition and the type and amount of inoculant and spheroidizer to ensure in the casting with wall thickness s (expressed in millimeters) nodule count greater than obtained from the empirical formula [7]

$$N = \frac{1185200}{s^2 (23{,}34 - 4{,}07C + 18{,}8Si)^{4/3}} \quad (1)$$

The nodule count is influenced by the physical and chemical state of the liquid cast iron ie,: the chemical composition spheroidization and inoculation practice, type of inoculant and spheroidizing agent, quantity and granulation, Mg treatment and inoculation temperature and the bath superheat temperature and holding time as well as the time after of inoculation (fading of inoculation). Examples of the impact of technological factors on nodule count is shown in Figure 4 [8,9]. In general, the technological factors such as a high level of carbon and silicon, high inoculation intensities, low bath superheat temperatures and short holding times and short times after inoculation ensure a high nodule count and promote a decrease the chill of castings.

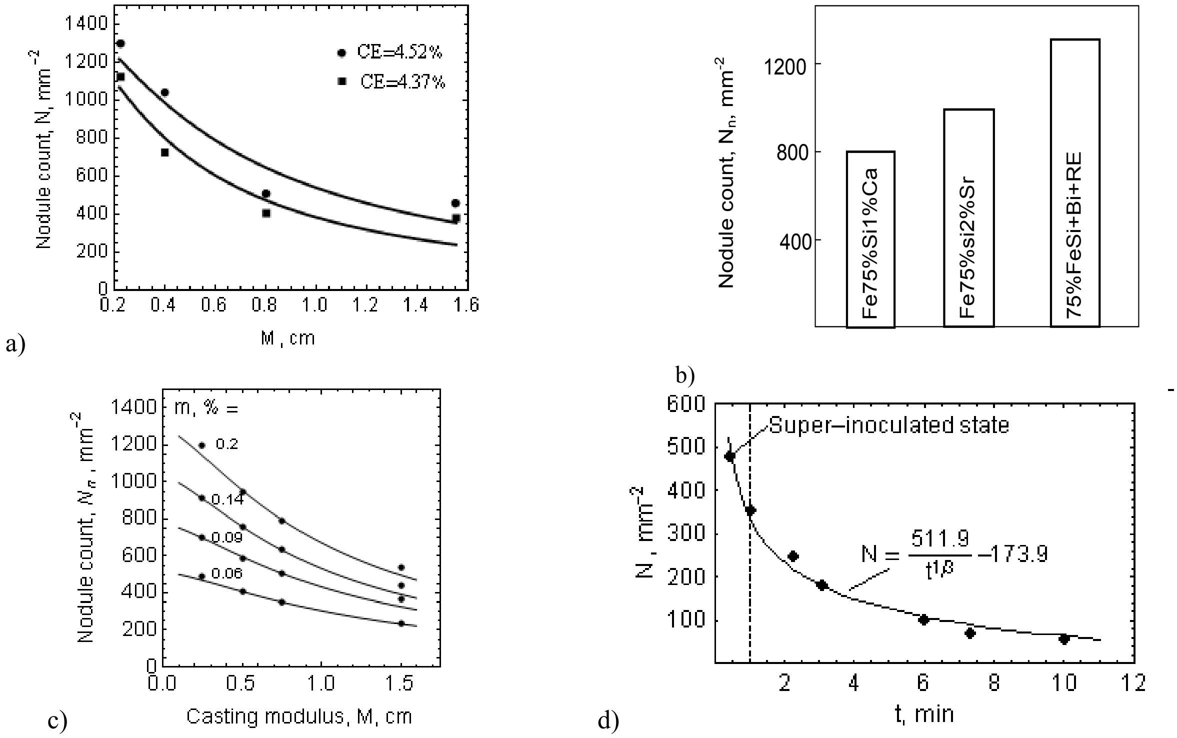


Fig. 4. Nodule count for various carbon equivalent values (CE), CE = C + 0.33Si (a), the type of inoculant (b), amount of inoculant (c) and time after inoculation (d)

2.2. Fluidity distance

The high cooling rate (small wall thickness of casting) of thin-walled castings significantly shortens metal flow in the mold channels and may cause misrun and cold shuts. Fluidity distance (spiral length L) in mold channel with wall thickness of 1, 2 and 3 mm is shown in Fig. 5. In case of castings with constant wall thickness fluidity length depends on pouring temperatures and carbon equivalent (Fig. 6).

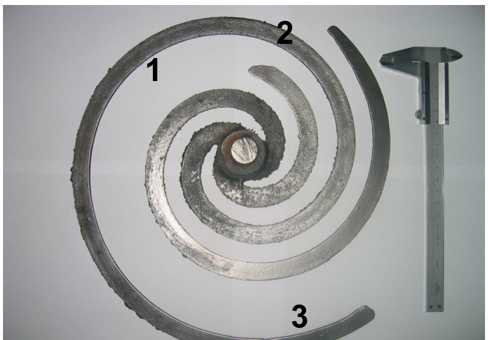


Fig. 5. Photograph of Archimedes spiral and fluidity distance L; 1- wall thickness 1 mm, L =200 mm, 2 - wall thickness 2 mm, L =650 mm, 3- wall thickness 3 mm, L =1090 mm

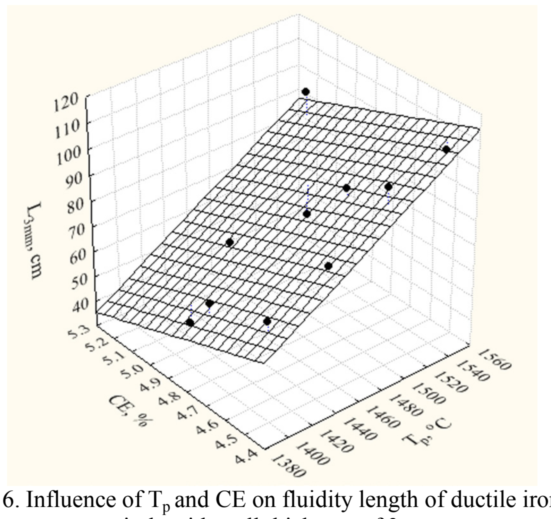


Fig. 6. Influence of T_p and CE on fluidity length of ductile iron in spirals with wall thickness of 3 mm

In the thin-walled castings fed with a single inlet there is a high temperature drop during mould filling along the length of the casting (Fig. 7), which can cause structural gradients and misruns [10]. For this reason, it is preferable to use several metal inlets.

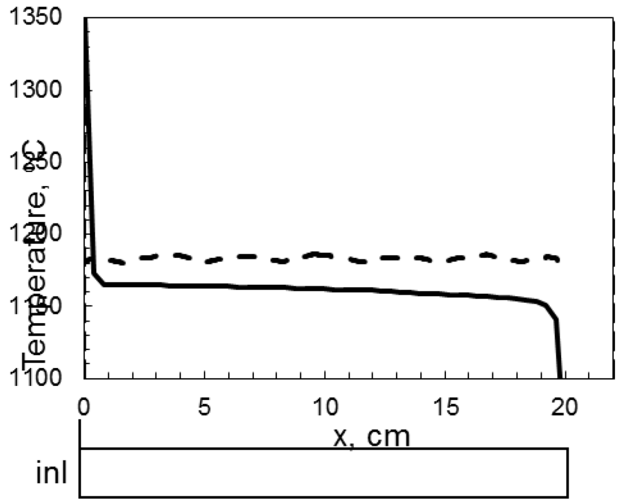


Fig. 7. Temperature of metal cavity along its length after mold filling: Solid line casting without riser, Dotted line – casting with three inlets

In summary, the elimination of casting defects such as misruns, and chills in thin wall castings is achieved by increasing the pouring temperature and the carbon equivalent and the use of multiple supplying inlets.

2.3. Thin walled automotive wheel rim made of ductile iron

The aim of this work was to perform casting made of ductile iron as a counterpart of aluminum alloy. Wheel rim made of aluminum alloy was selected in order to show that it can be replaced by means of lighter casting made of ductile iron without detriment to its properties.

a) b)

Fig. 8. Wheel rim made of aluminum alloy (Al-Si7Mg) – a), and wheel rim made of ductile iron – b)

Silica sand (1 K of a fraction 100-200 μm) and urea-furfuryl resin Kaltharz 404U (1.3 wt.%) with a hardener from a group of paratoluenesulfonic acids 100 T3 (0.5 wt.%) were used, and the foundry mold was made using a paddle mixer (Ms-017A). Melts were produced using an electric induction furnace. The raw materials were Sorelmetal, steel scrap and commercially Fe-Si alloy. The metal was preheated at 1500 ^{o}C and then poured into the mold, which was equipped with a inmold reaction chamber for spheroidization and inoculation processes. Figure 8 shows wheel rim made of aluminum alloy (mass 5.30 kg) as well as and their thin wall counterpart made of ductile iron casting (mass 5.23 kg).

In Figure 9 it is shown cross section of casting of wheel rim made of ductile iron and location of metallographic examinations. For the quantitative metallographic studies microscope Leica MEF - 4M coupled with automatic image analyzer Leica QWin was used.

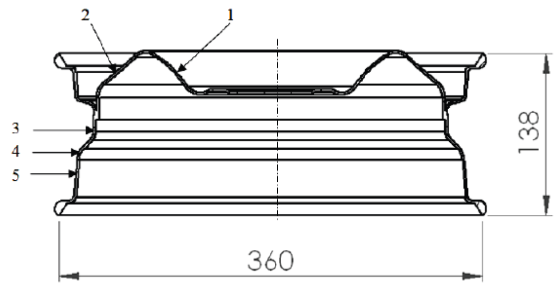


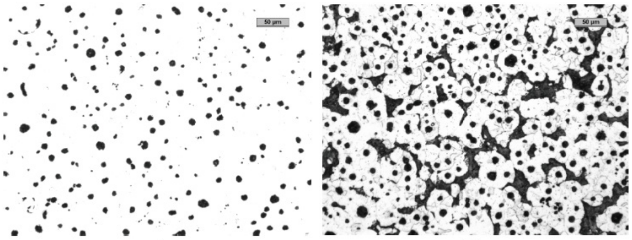
Fig. 9. Cross section of wheel rim made of ductile iron and location of metallographic examinations

Results of metallographic examinations are summarized in table 1. The table shows the results of calculations of the number of graphite nodules according to the eq. (1).

Table 1.
Nodule count and ferrite fraction in the structure of wheel rim according to the measuring points shown in Figure 9

Spot	Wall thickness, mm	Nodule count, mm^{-2} (measured)	Critical nodule count, mm^{-2} Eq.(1)	Ferrite fraction, %
1	2.1	1218	1060	78
2	2.2	1193	966	80
3	2.0	1173	1169	72
4	2.0	1353		76
5	2.0	1336		77

Analysis of these data indicates that the achieved casting is of ferritic – pearlitic matrix. Nodule count ranges from 1173 to 1353 mm^{-2}, and the ferrite fraction in the matrix ranges from 72 to 80%. It is worth noting that in the structure there is a lack of chills (Fig. 10). Nodule count calculated by the formula (1) is smaller than the measured values. This ensures the receiving the casting without chills.



a) b)

Fig. 10. Microstructure of ductile iron in wheel rim: a) Unetched, b) etched with 5% Nital

Research of wheel rim made of ductile iron have shown that sound thin-walled castings can be successfully produce without chills, which according to previous studies [4] has good indicators of the strength properties.

3. Concluding remarks

1. The present paper deals with the technological aspects associated with the preparation of sound (without chills, cold laps and misruns), thin walled castings of ductile iron. In particular, it was shown that the production method of thin wall ductile iron castings should provide a higher nodule count of the number obtained from the empirical formula (1). In addition, the study shows that it is possible to produce thin wall ductile iron castings with considerable length. In thin walled castings fed with a single inlet temperature drops are high along its length. For this reason, it is preferable to use several supplying inlets.
2. It has been shown that thin wall wheel rim made of ductile iron can have the same weight, and better mechanical properties, than their substitutes made of aluminum alloys.

Acknowledgments

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References

[1] Stefanescu, D. & Ruxanda R. (2002). Lightweight iron castings-can they replace aluminum castings? *Proceedings of the 65th World Foundry Congress*. Gyengju, Korea, 71-77.

[2] Loper, Jr.C.R., (2002). Cast iron-essential alloys for the future. *Proceedings of the 65th World Foundry Congress*. Gyengju, Korea, 169-179.

[3] Hornung H. (1995). Thin-section ductile iron castings. *Proceedings of the 61th World Foundry Congress*. Beijing, China, 75-83.

[4] Fraś, E., Górny, M. & Lopez, HF. (2009). Thin wall ductile and austempered iron castings as substitutes for aluminum alloy castings. *International Foundry Research.* 61(3), 2-10.

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

[6] Stefanescu, D. M., Dix, L. P., Ruxasnda, R. E., Corbitt-Coburn, C. & Piwonka, T. S. (2002). Tensile properties of thin wall ductile iron. *AFS Transactions.* 112, 1149-1162.

[7] Fraś, E. & Górny M. (2012). Wniosek patentowy. Sposób otrzymywania supercienkościennych odlewów z żeliwa sferoidalnego, AGH. Kraków.

[8] Fraś, E. & Lopez H. (2010). Eutectic Cells and Nodule Count-An Index of Molten Iron Quality. *International Journal of Metalcasting*. Summer 10, 35-61.

[9] Fraś, E. & Górny M. (2008). Fading of inoculation effects in ductile iron. *Archives of Foundry Engineering*. 8(1), 83-87.

[10] Górny, M. (2010). Structure Formation of Ultra-Thin Wall Ductile Iron Castings. Akapit Ed., Cracow.