ISSN 0543-5846
METABK 45 (1) 13-16 (2006)
UDC - UDK 621.74:669.13.7=111

EFFECT OF MELTING TECHNIQUES ON DUCTILE IRON CASTINGS PROPERTIES

Received - Primljeno: 2005-03-01
Accepted - Prihvaćeno: 2005-09-01
Original Scientific Paper - Izvorni znanstveni rad

The study was designed to investigate the effects of the charge, melting conditions, nodularizing and inoculation on the ductile iron castings properties. Results showed that the temperature and holding time of the melt in an induction furnace and the intensity of spheroidizing effect on the carbon and residual magnesium contents in the ductile iron castings. The same grade of ductile iron may be obtained using different chemical compositions. The castings of ductile iron will be ferritic as-cast only when large amount of pig iron in the charge and in addition some-steps inoculating treatment are used.

Key words: *ductile iron, melting, inoculation, properties*

Utjecaj postupaka taljenja na svojstva odljevaka od nodularnog lijeva. Studija je namijenjena istraživanju utjecaja uloška, uvjeta taljenja, nodulariziranja i cijepljenja na svojstva odljevaka od nodularnog lijeva. Rezultati su pokazali kako temperatura i vrijeme zadržavanja taljevine u indukcijskoj peći te intenzitet nodulariziranja utječu na sadržaj ugljika i zaostalog magnezija u odljevcima od nodularnog lijeva. Ista vrsta nodularnog lijeva može se dobiti korištenjem različitog kemijskog sastava. Odljevci od nodularnog lijeva bit će feritni u lijevanom stanju samo ako se koristi velika količina sirovog željeza u ulošku i, osim toga, određeni korak inokulacijske obrade.

Ključne riječi: *nodularni lijev, taljenje, inokulacija, svojstva*

INTRODUCTION

Ductile iron is one of the most important engineering materials, in view of its excellent castability, significantly better mechanical properties and low cost [1, 2]. It represents the fastest growing segment of the iron market. In the medium term, it is to be expected that the market share of nodular iron will level off at 40 % to 45 % [3]. Achieving the full potential of ductile iron requires superior metallurgical process control, as well as the highest levels of skill in melting the ductile iron base, spheroidizing and inoculation [4].

The first step of the production of ductile iron castings is the careful selection of the charge materials. Manganese and chromium have the most influence on all mechanical properties [5]. For this reason, their concentration in metal is of particular importance. These elements arise in the charge from steel scrap, iron units and returns. It is recommended practice to purchase steel scrap so that the average Cr content remains below 0,1 percent. Ideally, the same advice would be given for Mn but, unfortunately, all steel scraps contain Mn, the majority being at the 0,5 percent level. The amount of steel scrap in the charge must be that amount which will give castings that are as free of carbides as possible [4]. It is particularly important for the production of ferritic ductile iron [6]. Charge materials result in the average size of graphite spheroids. The amount of steel scrap affects metallic matrix structure too. It increases the pearlite formation [7]. The graphite structure is affected by the carbon content too. If initial metal does not contain the amount of the carbon enough then graphite particles are of compact form [8]. The carbon equivalent affects the grain size too [9]. The metallic matrix structure is affected not only by carbon equivalent but by C/Si ratio too. Increasing this ratio in ductile iron decreases the proportion of ferrite and increases the proportion of pearlite [10].

All equipment in use for melting steel, grey or malleable iron can be used to melt ductile iron base. Each type has its advantages and drawbacks in a situation. The vast majority of ductile irons cast today are melted in cupolas and induction melting furnaces [11]. Ductile iron is particularly prone to the formation of primary carbides during solidification [12]. One of reason for this susceptibility is high superheat temperatures [13]. Increasing of holding time in a furnace increases the number of primary carbides too [14].

The addition of magnesium or magnesium alloy to cast iron with the purpose of changing graphite shape from flake to spheroidal is an essential processing step for manufactur-

S. Bockus, Kaunas University of Technology, Kaunas, Lithuania, A. Dobrovolskis, Join-Stock Company “Kauno ketaus liejykla”, Kaunas, Lithuania

ing ductile iron. The choice of a treatment method (open ladle, sandwich, tundish cover, in-mould, plunger, converter, injection and others [15]) for an individual foundry must be based on the circumstances present in foundry.

Inoculation is a necessary step for production of ductile iron castings. It may take place at different process in combination or separately. Inoculation is a procedure whereby the microstructure and properties of cast iron are controlled by increasing the number of nucleating sites for eutectic solidification. Several variables influence the effectiveness of inoculation: charge materials, temperature of the melt, inoculant, time, casting method, section size, mode of inoculation, and others. It is known about 1500 inoculants. Most inoculants are ferrosilicons. Inoculation has a vital role to play in the continuing progress of ductile iron [16].

This very brief survey shows that, although considered as a mature technology, recent process and product developments open new avenues to this family of materials. In this work, efforts have been focused on the study of change in chemical composition of the melt from its temperature and holding time in a furnace and on the effect of inoculation on the ductile iron castings matrix microstructure and properties.

EXPERIMENTAL PROCEDURE

The metal was melted in the standard line frequency induction furnace of capacity the 10 t. We used pig iron, mild steel; return scrap, ferrosilicon FeSi75 and carburizing agent as the charge materials. Variables studied included composition, section size, base iron pre-conditioning, inoculation type and practice. The average composition of the melts was 3,76 % C, 2,6 % Si, 0,21 % Mn, 0,05 % Cr. Chemical composition of the cast iron has been determined by spectrometer Spektrolab, liquid metal temperature has been measured by device Mikron and thermometer W50A with S type thermocoupl (Pt and 10 per cent Rt-Pt). The spheroidization process was been carried out in the special ladle [18] at about 1500 °C by tundish treatment. Spheroidizing was performed by means of 2,1 % of FeSiMg7. After spheroidizing, the melt was poured into the casting ladle. We investigated the influence of the time of spheroidizing treatment in the ladle on the graphite content in the liquid ductile iron. Three kinds of sphero-idizing process have been studied: very fast (with evaporation and burning of the magnesium) (4 seconds), medium (15 seconds) and very slow (100 seconds).

Inoculation was performed by means of SB5 (68 % Si, 1,5 % Al, 1,5 % Ca, 2,3 % Ba). The metal stream, ladle and in-mould inoculation methods were applied. During in-mould inoculation the inoculants was placed in a reaction chamber within the gating system of the individual mould. Standard test pieces for microstructural and mechanical properties testing were machined from the samples which were cast separately in green sand moulds under representative spheroidization and inoculation treatments. Test pieces were prepared in accordance with LST EN1563:2001. Effect of section size on the metallographic structure was carried out with 6 - 30 mm-thick sections. During the tests the metallic matrix was only examined because it is known [6] that graphite spheroids are larger and usually less well formed in heavy sections than in thin ones.

RESULTS AND ANALYSIS

On the basis of experimental findings, the initial chemical composition of the melt depends on its temperature and holding time in a furnace. Figure 1. shows the change of the carbon

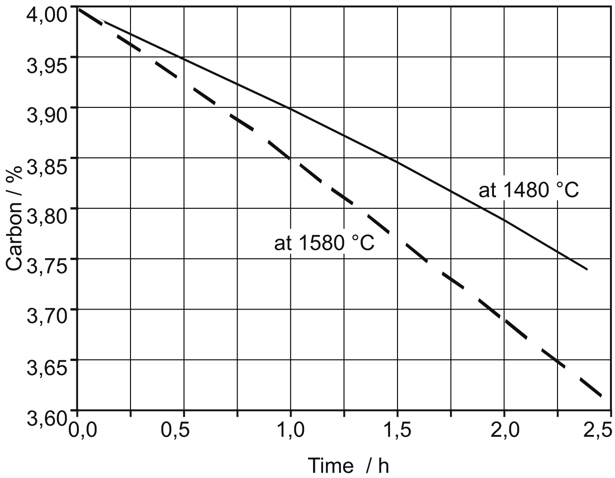

Figure 1. **Change of the carbon content of melt held in a furnace**
Slika 1. **Promjena sadržaja ugljika u talini držanoj u peći**

content of melt held in a furnace. It can be seen that carbon contain decreases from 4,00 to 3,72 percent (at temperature of 1480 °C) or to 3,61 percent (at temperature of 1580 °C) if melt is held in the furnace 2,5 hours. But, as Litovka et al [14] have observed, the effectiveness of spheroidizing process

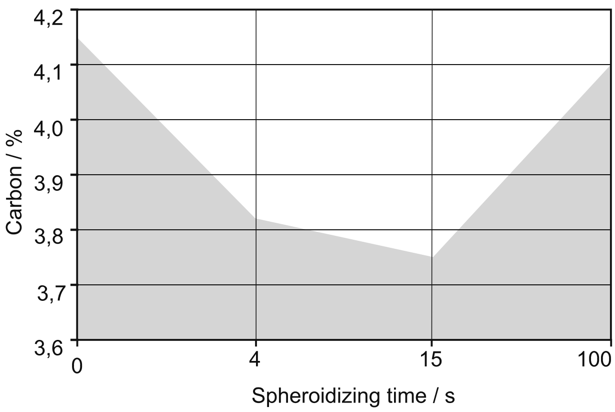

Figure 2. **Effect of spheroidizing time on the carbon content**
Slika 2. **Utjecaj vremena nodulariziranja na sadržaj ugljika**

had decreased with increasing holding time in the furnace of melt. The decrease in effectiveness of spheroidizing process of cast iron contained less amount of carbon has been also observed by [8]. Therefore, it is introduced the inoculation in the furnace and in the ladle before spheroidizing treatment.

Carbon content depends also on the intensity of the spheroidizing. Figure 2. shows the decreasing of it with increasing of spheroidizing time.

The spheroidizing intensity effects also on content of the residual magnesium. This content is the highest (about 0,05 percent) when the spheroidizing continuance is about 15 seconds (Figure 3.). When the spheroidizing continuan-ce

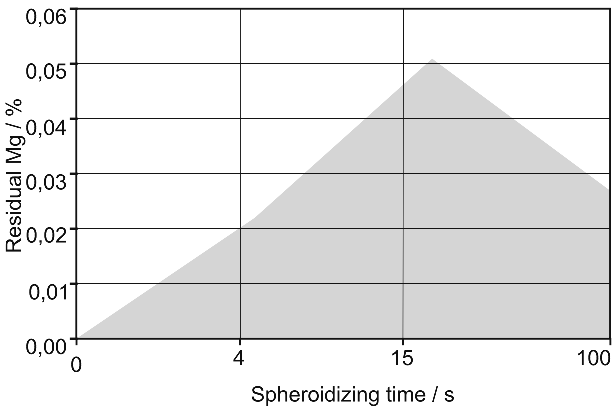

Figure 3. **Effect of spheroidizing time on the content of residual magnesium**

Slika 3. **Utjecaj vremena nodulariziranja na sadržaj zaostalog magnezija**

is very short (4 s) or very long (100 s) then residual magnesium contents are 0,024 and 0,027 percent, respectively.

The effect of the amount of pig iron in the charge on the mechanical properties of castings (tensile strength and

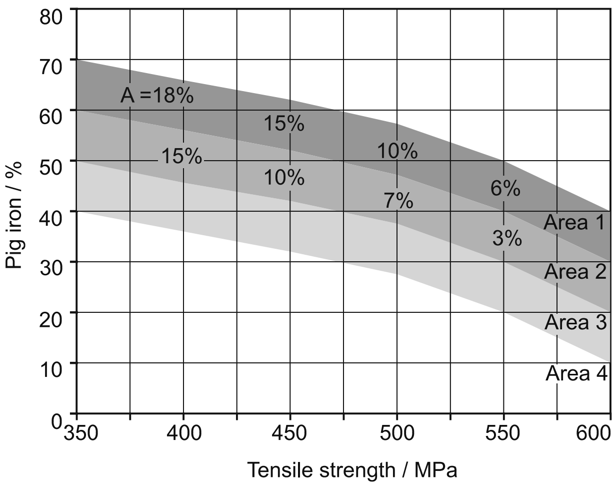

Figure 4. **Effect of the amount of pig iron in the charge on tensile strength and elongation A of castings**

Slika 4. **Utjecaj količine sirovog željeza u ulošku na vlačnu čvrstoću i izduženje A odljevaka**

elongation) is summarized in Figure 4. It is evident, that ferritic ductile iron requires larger amount of pig iron. Areas 1 and 2 represent the stable processes. Kapilevich et al. [18] have also obtained the similar results. They reported that the amount of pig iron in the charge of ferritic ductile iron grade 400 as-cast must be higher then 53 percent as in the present work. But there are some differences between their and our results with the other grades. They recommended 34,5 percent of pig iron for the grade 500 and 31 percent for the grade 600. We did not get the stable results with that amounts of pig iron.

Figure 5. presents the effect of chemical composition on ductile iron grades. It is seen that the same ductile iron grade can be produced using different chemical compositions. These results are very useful for the manufacturer for producing the desirable ductile iron grade. For instance, ductile iron with R_m = 500 MPa can be manufactured using

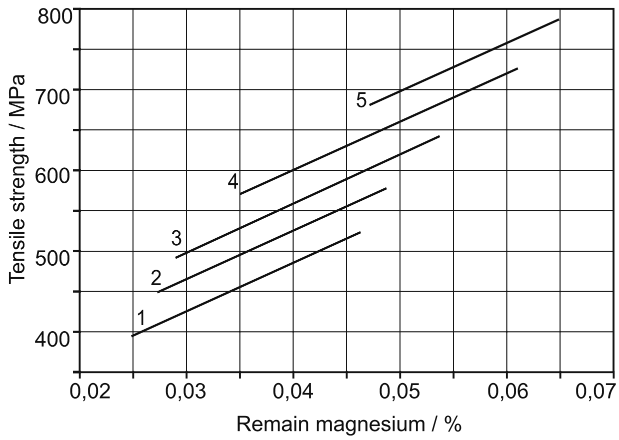

Figure 5. **Tensile strength R_m of ductile iron as a function of Mg_{rem}, manganese and chromium: 1 - Mn 0,2 %, Cr = 0,03 %; 2 - Mn = 0,26 %, Cr = 0,06 %; 3 - Mn = 0,36 %, Cr = 0,09 %; 4 - Mn = 0,45 %, Cr = 0,15 %; 5 - Mn = 0,55 %, Cr = 0,15 %**

Slika 5. **Vlačna čvrstoća R_m nodularnog lijeva kao funkcija preostalog magnezija Mg_{rem}, mangana i kroma: 1 - Mn 0,2 %, Cr = 0,03 %; 2 - Mn = 0,26 %, Cr = 0,06 %; 3 - Mn = 0,36 %, Cr = 0,09 %; 4 - Mn = 0,45 %, Cr = 0,15 %; 5 - Mn = 0,55 %, Cr = 0,15 %**

metal No 2 (Figure 5.), which containing 0,0375 % remain magnesium Mg_{rem} or No 3, which containing 0,032 % Mg_{rem}. Ductile iron with R_m = 700 MPa we can get with metal No 4, which containing 0,058 % Mg_{rem} or with metal No 5, which containing 0,052 % Mg_{rem}. Data of Figure 6. show that the variant No 1 is an optimum chemical composition of metal for getting ductile iron with R_m < 450 MPa. The variant No 2 is suitable for getting ductile iron with R_m = (450-500) MPa, variant No 3 - for getting R_m = (500-600) MPa, variant No 4 - for getting R_m = (600 - 700) MPa and variant No 5 - for getting ductile iron with R_m > 700 MPa.

The chemical composition of the ductile iron varies with the matrix structure. For instance, the amount of ferrite in the structure of the ductile iron No 1 (Figure 5.)

is (100 - 94) %. Ductile iron No 2 has (80 - 94) % ferrite in its structure, No 4 has (35 - 45) %, and ductile iron No 5 has (20 - 30) % ferrite in its structure.

The effect of the section size on the amount of ferrite in the ductile iron castings is shown in Figure 6. It clearly shows that it is very difficult to produce thin section of ferrite ductile iron as-cast. This' is associated with high solidification rate and formation of carbides.

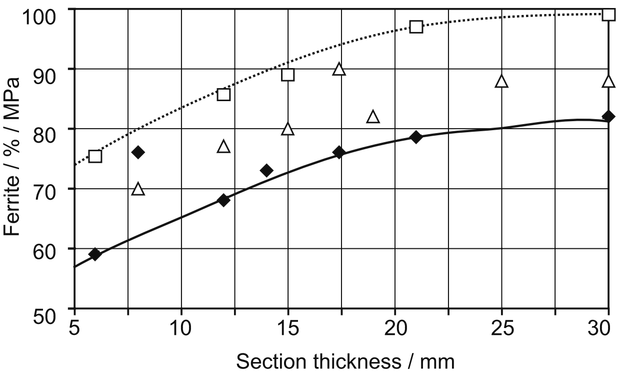

Figure 6. **Correlation between the section thickness and the amount of ferrite**

Slika 6. **Korelacija između debljine stijenke i količine ferita**

The manufacture of thin section ferritic ductile iron castings presents all the processes common for other castings plus one more, complex inoculation. Figure 7. shows the various methods of the melt treatments have been used during these investigations.

$$a)\ S_3 \Rightarrow G_4;\ b)\ G_1 \Rightarrow S_3 \Rightarrow G_4;\ \ c)\ S_3 \Rightarrow G_6;\ d)\ S_3 \Rightarrow G_7;$$
$$e)\ G_2 \Rightarrow S_3 \Rightarrow G_4;\ f)\ G_2 \Rightarrow S_3 \Rightarrow G_7;\ \ g)\ G_3 \Rightarrow S_3 \Rightarrow G_4;$$
$$h)\ G_3 \Rightarrow S_3 \Rightarrow G_6;\ \ i)\ G_3 \Rightarrow S_3 \Rightarrow G_7;\ \ \ \ l)\ S_7 \Rightarrow G_7;$$
$$j)\ G_3 \Rightarrow S_3 \Rightarrow G_4; \Rightarrow G_7;\ \ k)\ G_3 \Rightarrow S_3 \Rightarrow G_6; \Rightarrow G_7;$$

Figure 7. **Schematic flowsheets of the melt treatments. Letters show the method of treatment: *S* - spheroidizing; *G* - inoculation. Numbers show the place of treatment: 1 - the furnace; 2 - the furnace stream during filling a transfer ladle; 3 - a treatment ladle; 4 - the ladle stream during filling a pouring ladle; 5 - the pouring ladle; 6 - a stream while pouring; 7 - a mould**

Slika 7. **Shematski tok obrade taljevine. Slova označuju postupak obrade: S - nodulariziranje; G inokulacija. Brojevi označuju mjesto obrade: 1 - peć; 2 - mlaz iz peći tokom punjenja prijelaznog lonca; 3 - lonac za obradu; 4 - mlaz iz lonca tokom punjenja livnog lonca; 5 - livni lonac; 6 - mlaz tokom lijevanja; 7 - kalup**

The results of industrial experiments show that the most effective treatment technique of the melt for the pouring 6 - 12 mm-thick ferritic as-cast sections consists of four steps. It is *j*-variant (Figure 7.): inoculation in the treatment ladle, spheroidizing in the treatment ladle, inoculations the treatment ladle stream during filling a pouring ladle and in the mould or *k*-variant: inoculation in the treatment ladle, spheroidizing in the treatment ladle, inoculations in the stream while pouring and in the mould. However, heavy ductile iron castings need only two steps, for example, *a*-, *c*-, *d*- or *l*-variant.

Based on research results, ferritic as-cast ductile iron castings with 6 - 12 mm wall thickness have been introduced into production.

CONCLUSIONS

It was found by industrial experiments that the initial chemical composition of the melt was changed from its temperature and holding time in an induction furnace. High temperature and long holding time decreases carbon content but increases silicon one. Chemical composition of the melt changes from intensity of spheroidizing process too. Very intensive and very slow spheroidizing process decreases carbon and residual magnesium contents in the ductile iron.

It was observed that microstructure of ductile iron castings depends on the charge, chemical composition and section size. The castings of ductile iron will be ferritic as-cast only when more than 50 percent of pig iron in the charge is used. However, the producing of as-cast ferritic thin-section ductile iron castings needs in addition several steps inoculating treatment. The same grade of ductile iron may be obtained using different chemical compositions. Results of the present investigation give some recommendations how to produce the desirable grade of ductile iron.

REFERENCES

[1] B. I. Imasogie, A. A. Afonja, A. Ali, Scandinavian Journal of Metallurgy 30 (2001) 2, 91 - 102.
[2] N. Fatahalla, S. Bahi, O. Hussein, Journal of Materials Science 31 (1996) 21, 5765 - 5772.
[3] K. Urbat, Proceedings, Conference: Balance Opening - the European Foundry Industry 2004 and beyond economic facts and consequences of the EU enlargement, Kielce, Poland, 2003, p. 24 - 35.
[4] V. A. Chaykin, V. V. Ishutin, Lit'jo i metallurgija 4 (2002), 71 - 75.
[5] S. J. Karsay, Ductile Iron Production Practices, American Foundrymen's Society, Des Plaines, Illinois, 1994, p. 78 - 88.
[6] C. F. Yeung, H. Zhao, W. B. Lee, Materials Characterization 40 (1998) 4 - 5, 201 - 208.
[7] V. J. Krestyanov, Liteynoje Proizvodstvo 11 (1998), 7 - 8.
[8] I. A. Shaprikov, Liteynoje Proizvodstvo 11 (1992), 6 - 7.
[9] G. Rivera, R. Boeri, J. Sikora, International Journal of Cast Metals Research 16 (2003) 1 - 3, 23 - 28.
[10] L. A. Solncev, et al., Liteynoje Proizvodstvo 6 (1976), 3 - 4.
[11] N. M. Sytnik, Metal Science and Heat Treatment 33 (1991), 317 - 322.
[12] G. M. Goodrich, AFS Transactions 105 (1997), 669 - 683.
[13] C. Labrecque, M. Gagne, Canadian Metallurgical Quarterly 37 (1998) 5, 343 - 378.
[14] V. I. Litovka, A. A. Sheyko, B. G. Zeliony, Liteynoje Proizvodstvo 4 (1983), 13 - 14.
[15] Y. S. Lerner, Foundry Trade Yournal 177 (2003), 19 - 21.
[16] R. Carl, Jr. Loper, Proceedings, 65th World Foundry Congress, World Foundrymen Organization, Gyeongju, Korea, 2002, p. 169 - 179.
[17] S. Bockus, A. Dobrovolskis, Materials Science (Medziagotyra) 8 (2002) 4, 372 - 374.
[18] A. N. Kapilevich, et al. Liteynoje Proizvodstvo 3 (2001), 4 - 6.