IMPLEMENTATION OF CORED WIRE TECHNOLOGY INTO PRODUCTION OF DUCTILE IRON FOR CASTINGS DESIGNATED FOR EXTREME CONDITIONS

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https://doi.org/10.37904/metal.2022.4456

Abstract

Presented paper deals with the technology of production of ductile iron on industrial scale. Particularly, the material in question is EN-GJS-400-18-LT, which is suitable for castings intended for extreme conditions. Drawing on previous works, most attention has been paid to the implementation of the cored wire technology for modification and primary inoculation. Two technological options were compared, namely modification and primary inoculation by the pour method in the ladle and modification and primary inoculation by the cored wire using a twin-core feeder. Test samples within the inlet system of the moulds were cast during the pouring process to analyse the chemical composition, evaluate the microstructure and perform mechanical tests without interfering with the casting itself. The chemical composition was determined by optical emission spectrometry and combustion analysis. Metallographic analysis and microstructure evaluation were performed by optical microscopy and image analysis. Mechanical properties testing was focused on tensile test, impact test and hardness test. It was demonstrated that the foundry is capable of producing ductile iron of the required quality with the adoption of modern cored wire technology.

Keywords: Metallurgy, ductile iron, cored wire, inoculation, modification

1. INTRODUCTION

Cast iron with spheroidal graphite is a modern material with excellent mechanical properties [1-3]. Especially ferrite cast iron with spheroidal graphite achieves toughness and strength comparable with steel [4]. Compared to other steels used for castings, it features better castability [1]. Cast iron with spheroidal graphite is also relatively cheap [5]. Owing to its properties it is used, for example, for working machines manufacturing in automobile industry or for manufacturing of aerogenerator components [3,6]. Mechanical properties of cast iron are influenced by the graphite shape, nodularity and distribution [6,7]. A large amount of evenly distributed spheroidal graphite with high nodularity and small diameter has a positive influence on the cast iron properties [2]. Graphite is found standardly in cast iron in the form of flakes, however, after Mg or Ce addition, spheroidal graphite is formed [4, 8] and the material mechanical properties change. The cast iron structure and thus also its mechanical properties are influenced by its modification and inoculation. It is realized, for example, by the pouring method at tapping into a ladle or by a more modern cored wire technology [9]. The cored wire method can be used for melt from cupola furnaces and from electrical furnaces. [10]. In general, the cored wire advantage is automated control, manufacturing costs reduction and environment protection [11]. In case of the twin cored system, when one is modifying and the second inoculative, the process stability and quality is ensured and safety is increased, no dust escapes and melted metal does not overflow the ladle. The process is less susceptible to variable sulphur content, variable temperature and amount of the processed melt in the ladle, the control unit allows automatic recording of the process data. The efficiency increases and costs are decreased by reduction of thermal losses, reduction of the brick lining wear and reduction of manpower demands. [10,12].

As mentioned in the previous paper, [13], the foundry KOVOSVIT MAS Foundry a.s. is able to produce cast iron with spheroidal graphite of the required quality, with application of various combinations of charge materials, modifiers and inoculation material. Standardly, the pouring method is used for modification and inoculation in operating conditions. However, nowadays the cored wire modern technology is used in operating conditions for modification and inoculation, which makes the production process more efficient.

The SCHAFT 1 type casting designed for ship manipulators manufacturers for medium sized ships has been selected for experimental melts. Above-standard material quality is required in case of this casting type. The casting is manufactured from the EN-GJS-400-18-LT material, i.e. cast iron with spheroidal graphite and ferrite matrix with guaranteed value of impact strength at the temperature of -20 °C according to the standard ČSN EN 1563 [14]. Within the realized experiments series, the pouring method / sandwich was used for one part of the melts and the cored wire method was used for the other part. Simultaneously with the casting, testing samples, the so-called Y-Blocs, were added within the gating system; testing bodies for the mechanical properties tests and for the metallographic analysis [15-17] were manufactured from the testing samples [14]. The aim was to prove successful implementation of the cored wire into the technologic process and the ability to ensure standardized production of high-quality castings, using the relevant methodology.

2. CHARACTERISTIC OF THE SCHAFT 1 CASTING PRODUCTION PROCEDURES

In order to compare both technologies, one representative melt was selected from each of them. For the pouring method / sandwich it was the melt identified as TD75, for the cored wire method the melt was identified as TO93.

Chemical composition of the melt before tapping has been defined for production of the SCHAFT 1 casting and, for illustration, it is specified in **Table 1;** modification and inoculation will follow. Subsequently the final chemical composition of the melt for the casting was designed, which is shown in **Table 2**. It is appropriate to mention that the chemical composition of the melt was the same for the pouring method and for the cored wire method.

Table 1 Chemical composition of the EN-GJS-400-18-LT material before tapping

Range	Chemical composition (wt%)							
	C	Si	Mn	P	S	Cu	Mg	Cr
Min.	3.40	0.80	0.10	×××	×××	×××	×××	×××
Max.	3.50	0.90	0.15	0.040	0.015	0.05	×××	0.02

Table 2 Proposed final chemical composition of the EN-GJS-400-18-LT material for the SCHAFT 1 casting

Range	Chemical composition (wt%)							
	C	Si	Mn	P	S	Cu	Mg	Cr
Min.	3.30	1.70	0.10	×××	×××	×××	0.040	×××
Max.	3.40	1.90	0.15	0.040	0.010	0.05	0.060	0.02

The previous papers ascertain that the charge materials selection does not have any significant influence on final quality of the casting, providing the ratio and combination of the charge materials are calculated correctly for the required composition [13]. For illustration, the composition of the charge of both selected melts is shown in **Table 3**.

Table 3 Charge composition of melts TD75 and TO93 at production of the EN-GJS-400-18-LTmaterial

Melt identification	Ratio of individual melts charge materials (wt%)				
	Raw iron		Steel waste		Returnable material
	Sorel	Pig Nod	Cupol Mn 0.3 %	Si sheet	Starting block
TD75	38.5	20.0	27.7	13.8	×××
TO93	36.8	×××	36.8	×××	26.4

A series of experimental melts was realized within the operating experiments, when 2 combinations of various technologies of modification and inoculation were tested. The **basic technologic procedure** was used for experimental melts ≈ **pouring method / sandwich** and the **innovated technologic procedure ≈ cored wire, modification and inoculation.** Both technologic procedures differ by the modification and inoculation method only, while the relevant methods consist of the following steps:

- ✓ Charge → the charge composition and its selection was controlled individually, according to the metallurgical and chemical quality of available raw materials with guaranteed chemical composition. The following charge materials were used for the production: raw iron × steel waste × own returnable material in various ratios.
- ✓ Melt → it was conducted according to the required melt amount, corresponding to the number of casted castings; 1 or 2 pieces were casted. A medium-frequency furnace was used, with the capacity of 6 t.
- ✓ After the charge melting and when the sampling temperature was reached (t = 1350 to 1400 °C), the slag was removed thoroughly, the bath temperature was measured and a sample was taken for the 1st test, with focus on the following elements: C, Si, Mn, P, S, Cu and Cr. Subsequently, correction of the melt chemical composition was realized. Within the melt course, the melt was maintained at the minimum temperature.
- ✓ Before tapping, the chemical composition was verified by a chemical laboratory, with focus on the following elements: C, Si, Mn, P, S, Cu, Mg and Cr. The melt goal was to achieve the required chemical composition and maintain the correct temperature mode → $t_{max.}$ = 1380 °C to 1420 °C.
- ✓ Modification / pouring method / sandwich → before tapping, one Pig Nod pig iron is added to the bath for better formation of nuclei. Before modification, the ladle was rinsed by liquid metal for sufficient warming up of the refractory. Subsequently, master alloys were added on the bottom in the following sequence: FeSiMg731 – modifier, Inocast100 – inoculation material and shavings – for reaction delay.
- ✓ Besides the modification, primary inoculation is also realized at tapping, the so-called preoculation by inoculation material; **Figure 1** shows tapping into the ladle, at simultaneous modification and primary inoculation.
- ✓ Inoculation / pouring method / sandwich → is realized in two stages, at first within the course of tapping into the ladle partly - the so-called preoculation and, subsequently, the so-called main inoculation takes place, which is realized in the basin using inoculation blocks within the course of a casting casting. For illustration, the inoculation blocks in the pouring basin are shown on **Figure 2.**
- ✓ For the cast iron structure optimization by inoculation, the inoculation material Inocast100 was used for the so-called

Figure 1 Tapping into a ladle at simultaneous modification and primary inoculation

Figure 2 Detail of the pouring basin with prepared inoculation blocs

preoculation and inoculation blocks Germalloy for the so-called main inoculation. Selection of the inoculation material type and amount was realized in dependence on the liquid metal amount and the time of the selected casting casting.

- ✓ Modification / cored wire → it is realized after tapping using the modification box with cored wire of the Rumag 25HS type, as shown on **Figure 3**. The modifying cored wire amount is determined by calculation. The initial sulphur amount, modified metal amount and melt temperature are entered into the modification box software. According to the entered parameters (including the preset parameters representing the final content of Mg and Mg utilization), the program will calculate the modifying profile length.
- ✓ Inoculation / cored wire → it is realized in two stages, at first the so-called preoculation by the cored wire injection; subsequently, the so-called main inoculation proceeds, which is realized in a basin by inoculation blocks within the course of a casting casting.

- ✓ Primary inoculation / cored wire / so-called preoculation is realized by injection of the inoculative cored wire of the Inform SB13 type; it is shown for illustration on **Figure 4** in a modification box. Feeding of the inoculative cored wire starts by the end of the Rumag 25HS type modifying cored wire injection, so that both processes would be completed simultaneously.
- ✓ Secondary inoculation / so-called main inoculation are realized in a basin using the Germalloy type inoculation blocks within the course of the casting casting. Selection of the inoculation material type and amount was realized in dependence on the liquid metal amount and the time of the selected casting type casting.

Figure 3 Cored wire Rumag 25HS used for modification

Figure 4 Cored wire Inform SB13 used for inoculation

- ✓ Casting, finishing works and output inspection → slag was removed before casting. The casting and cooling was followed by the mould dismantling, the casting shakeout and blasting, and the casting transport to the storage area.
- ✓ Testing Y-Blocks were poured simultaneously to every casting in the mould; afterwards, testing bodies were made from the Y-Blocks for metallographic analysis and mechanical properties tests. The casting inspections, which include visual inspection and ultrasound inspection, followed.

3. ANALYSIS OF SAMPLES FROM EXPERIMENTAL MELTS

Melt samples with simultaneous temperature measuring were continuously taken from selected points within the course of experimental melts realization. Casting of Y-Blocks located in the gating system took place simultaneously. The taken samples were marked and analysed gradually; for illustration, individual analyses specifications are described below:

- ✓ Chemical composition analysis→ it was realised by means of optical emission spectrometry (OES) with excitation by high-energy spark discharge on the Q4 TASMAN device. Precise contents of C and S were specified by combustion analysis in an oxygen stream in a high-frequency furnace LECO CS230. Next, the CE carbon equivalent and the saturation level were calculated from the values measured.
- ✓ Metallographic analysis → it was focused on microscopic evaluation with the aim to specify the achieved structure of the EN-GJS-400-18-LT material. Metallographic analysis was realized on samples made from the type Y-Block testing bodies, using a light microscope and image analysis with focus on microstructure

of cast iron with spheroidal graphite. The graphite was evaluated according to the following standards: ČSN EN ISO 945-1 → focused on graphite classification by visual analysis, ASTM A247 → evaluation of graphite nodularity and ČSN 420461 → evaluation of cast iron matrixes. This way, it was possible to obtain a complex idea concerning the EN-GJS-400-18-LT material structure.

- ✓ Mechanical properties → they were focused on tension tests, hardness tests and bending impact tests (Charpy´s hammer). The relevant tests allowed specification of the tensile strength R_m, proof strength $R_{p0,2}$, ductility A_5, Brinell hardness HB and impact strength KV_2 at low temperature -20 °C.

4. RESULTS AND DISCUSSION

The experimental melts realization was followed by evaluation focused on specification of mechanical properties, metallographic evaluation and microstructure evaluation [14-17]. The results are summarized in the so-called metallographic cards. An example of such a card for the TD75 and TO93 melts is given in **Table 4** to **Table 7** and on **Figure 5** and **Figure 6**. The results present information on mechanical properties and resulting structure of the EN-GJS-400-18-LT material at casting of the SCHAFT 1 type casting with application of various modification and inoculation technologies.

Table 4 Characteristic of the modification and inoculation course

Technology	Melt identification	Modifier: name → amount (wt%)	Preoculation: name → amount (wt%)	Main inoculation: name → amount (wt%)
Pouring method / sandwich	TD75	FeSiMg731 → 1.8 %	SB10 → 0.1 %	Germalloy → 2x P2+P300
Cored wire method	TO93	Rumag 25HS → 0.51 %	Inform SB13 → 0.15 %	Germalloy → 2x P2+P300

Table 5 Achieved chemical composition of experimental melts

Melt identification	Chemical composition (wt%)								Parameters	
	C	Si	Mn	P	S	Cu	Mg	Cr	CE	S_C
TD75	3.32	1.74	0.11	0.049	0.008	0.01	0.053	0.02	3.86	0.90
TO93	3.44	1.81	0.13	0.035	0.010	0.03	0.051	0.03	3.99	0.94

Table 6 Achieved mechanical properties of experimental melts

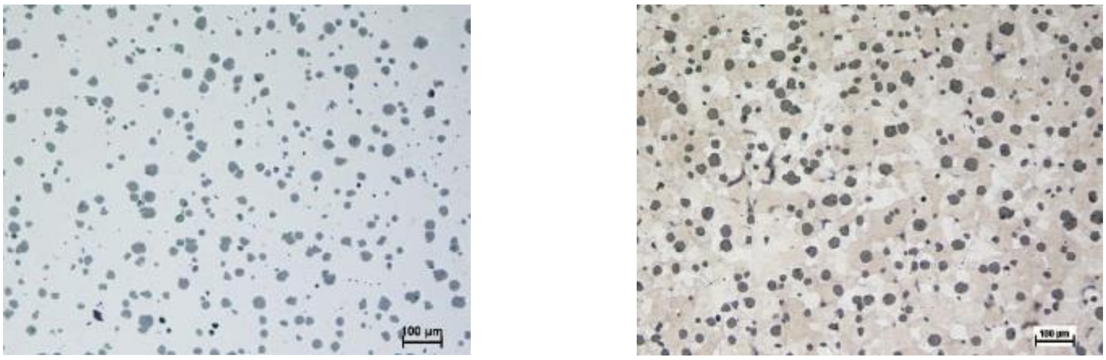
Parameters	Values according to ČSN EN 1563		Achieved values	
			Melt TD75	Melt TO93
R_m (MPa)	*Min. 360 MPa*		413 MPa	408 MPa
$R_{p0,2}$ (MPa)	*Min. 220 MPa*		251 MPa	287 MPa
A_5 (%)	*Min. 12 %*		21.4 %	18.4 %
Brinell hardness (HB)	*Min. 130 HB*		131 HB	164 HB
Min. value of KV_2 (J)	Low temperature (-20 ± 2) °C → melt TD75			
	Mean value (3 tests)	Individual value	Mean value (3 tests)	Individual value
	10 J	*7 J*	13 J	14 / 13 / 13 J
	Low temperature (-20 ± 2) °C → melt TO93			
	Mean value (3 tests)	Individual value	Mean value (3 tests)	Individual value
	10 J	*7 J*	17 J	17 / 18 / 17 J

The achieved chemical compositions specified in **Table 5** corresponds to the chemical composition required for the EN-GJS-400-18-LT material, as presented in **Table 2**, with the exception of several deviations in the order of a percent hundredths maximally in case of C, P and Cr. Nevertheless, such minor deviations have no negative impact on mechanical properties of the material, as presented below.

Table 6 shows clearly that in case of melt TD75, higher values of tensile strength R_m and of ductility A_5 have been achieved. In case of melt TO93 have been achieved higher values of yield strength $R_{p0,2}$, hardness HB and impact strength at -20 °C KV_2. Compared to the requirements according to ČSN EN 1563, it is evident that both melts comply with the requirements on mechanical properties for the EN-GJS-400-18-LT material, defined by the standard, at relevant wall thickness 60 < t ≤ 200 mm [14].

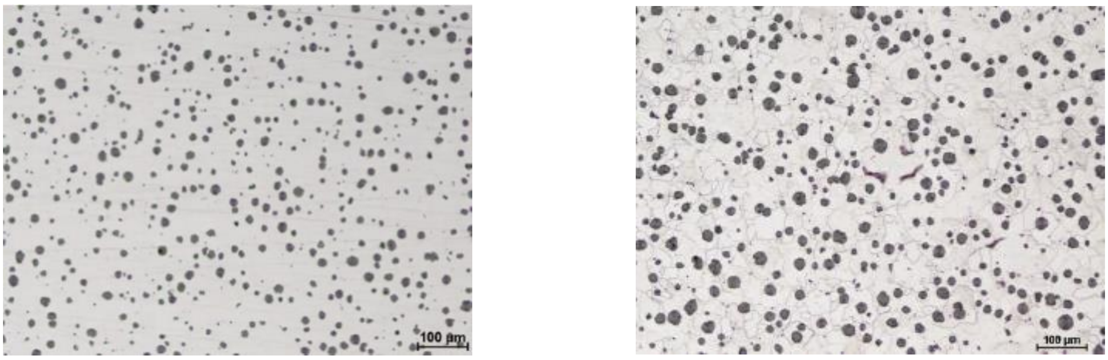
Table 7 Evaluation of experimental melts metallographic structure

Melt identification	ČSN EN ISO 945-1	ASTM AND 247	ČSN 420461
TD75	Graphite shape: 93 % VI + 7 % V	Nodularity: 93 %	Pearlite content P1: P0 (to 2 %)
	Graphite size: 6/7	Particles number/mm^2: 298	×××
	Size of graphite formations: 15–60 μm	×××	×××
TO93	Graphite shape: 94 % VI + 6 % V	Nodularity: 95 %	Pearlite content P1: P0 (to 2 %)
	Graphite size: 7/8	Particles number/mm^2: 269	×××
	Size of graphite formations: <15 to 30 μm	×××	×××



a) Photograph according to ČSN EN 945-1 *b) Photograph according to ČSN 42 0461*

Figure 5 Sample of photographs of cast iron with spheroidal graphite → melt TD75



a) Photograph according to ČSN EN 945-1 *b) Photograph according to ČSN 42 0461*

Figure 6 Sample of photographs of cast iron with spheroidal graphite → melt TO93

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and impact strength at -20 °C KV_2. Compared to the requirements according to ČSN EN 1563, it is evident that both melts comply with the requirements on mechanical properties for the EN-GJS-400-18-LT material, defined by the standard, at relevant wall thickness $60 < t \leq 200$ mm [14].

Regarding the results in **Table 7,** it was ascertained that in case of melt TD75, a slightly higher amount of larger size graphite particles was obtained than in case of melt TO93. Graphite shape and nodularity were comparable in both melts. Pearlite content was minimal in both the melts, up to 2 %. Thus, the obtained microstructure in both the melts corresponds to cast iron with spheroidal graphite with a large number of small size graphite particles, predominantly of a regular granular shape VI and with a ferrite matrix. **Figure 5** and **Figure 6** present photographs of both melts structures before etching → specification of the particles number, size, shape and nodularity, and after etching → determination of the ferrite/pearlite ratio [15-17].

5. CONCLUSION

Within the relevant paper two technologies of modification and inoculation in operating conditions were compared. Production of the SCHAFT 1 type casting from the EN-GJS-400-18-L material was evaluated in the KOVOSVIT MAS Foundry a. s. with the classic technology application → pouring methods / sandwich and the innovated technology → cored wire for modification and inoculation. The following results have been stipulated from the tests results:

- ✓ Both technological procedures of modification and inoculation fulfilled the parameters specified by the standard ČSN EN 1563, focused on the tensile strength, yield strength, ductility and impact strength at - 20 °C for the EN-GJS-400-18-LT material for the SCHAFT 1 type casting.
- ✓ Metallographic scanning and structure analysis ascertained that cast iron with spheroidal graphite containing a high number of graphite particles with high nodularity is obtained. The structure is predominantly ferrite, with less than 2 % of pearlite.
- ✓ Based on the presented results, it is therefore possible to state that the foundry KOVOSVIT MAS Foundry, a.s. has introduced successfully the cored wire technology for cast iron modification and preoculation. It can be also stated that the castings are comparable qualitatively to castings produced by the original pouring method.
- ✓ In the future, the production process can be improved by application of the cored wire modern technology with the twin cored system for modification and inoculation by the cored wire only, when one core will contain the modifier and the second the inoculation material.

ACKNOWLEDGEMENTS

The paper was prepared under the support of the Czech Ministry of Industry and Trade within the scope of the TRIO programme, as part of projects Reg. No. FV40036 "Research and development of complex technology of castings production from high-quality ductile iron castings".

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