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Microstructure and Mechanical Properties of Rope Drum Casting

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Abstract

Ductile iron is a high-carbon-containing iron-based alloy in which the carbon, as graphite, is present in a spheroidal shape. With its good mechanical properties, ductile iron approximates the properties of steel and the cost per unit of strength compared to other materials. With suitable metallurgical treatments, we can influence its microstructure and resulting properties. Incorrect manufacturing technology and metallurgical processes give rise to casting defects and decreased mechanical properties. The contribution is devoted to measures to prevent the occurrence of defects in the casting of rope drums and to achieve the required mechanical properties of these castings. The most-common defects in these castings are micro-shrinkages in casting heat centers and unsatisfactory mechanical properties such as tensile strength, yield strength, and elongation.

Keywords:

cast iron, defects in casting, rope drums, metallurgical treatments, mechanical properties

1. INTRODUCTION

Ductile iron is an alloy of iron and carbon, silicon, manganese, and other elements whose amount of carbon exceeds the maximum solubility value in austenite. The major part of carbon is already segregated at the cast state as spherical graphite. Segregated graphite disrupts the base metal significantly less, and this generates a significant increase in the strength properties; however, ductile iron also gains plastic properties and lower sensitivity to casting wall thickness [1].

The most-used way of producing ductile iron is melt modification (or the base phase of gray cast iron, most often of a eutectic composition with a lower content of impurities) by pure magnesium or by magnesium alloys Fe-Si-Mg (with 5 to 10% Mg). Some additives that are a part of ductile iron (Sn, Ti, As, Bi) disrupt the creation of smooth spherical graphite, thus, their concentration must be held to some sort of limit. The shape, size, quantity, and distribution of the graphite phase in ductile iron are the most-important microstructure parameters affecting the structure of the metal matrix and mechanical properties [2, 3].

Nodularization elements that are magnesium and cerium based affect the shape of ductile iron graphite. These elements increase the stability of the carbides; therefore, the modification is followed by an inoculation, or complex modifiers are used that contain the spheroidizing and inoculant elements. The metal matrix depends on the chemical composition and cooling speed and can contain pearlite (or a pearlite compound consisting of pearlite and ferrite) or ferrite.

The pearlite matrix has a higher tensile strength and lower ductility as compared to a ferrite matrix. The ferrite causes a decrease in strength limit and yield strength but causes an increase in toughness, machinability etc. [4–7].

Rope drums, which are made of pearlite-ferrite ductile iron in Slovak foundries, must achieve the mechanical properties required by the customer. Limit values for the mechanical properties of the material result from the dependence on wall thickness from DIN EN 1563:2012-03 for specific material EN-GJS-600. Carbon levels in ductile iron castings frequently fall within a range of 3.40–3.90% with higher values being typical for thin-section castings (<5 mm) and lower levels being selected for heavier sections (above 50 mm). The combination of the high carbon equivalent (CE) and low solidification rate (thick section) may result in graphite flotation and degeneration of the graphite shape. For the thinner section, the risk of flotation is practically nonexistent, and the avoidance of carbide (chill) becomes paramount in selecting higher CE levels [8]. A negative influence on the mechanical properties of castings is caused by shrinkage porosity. These usually create local clusters or chains of porosity along the length or height of a casting in its thermal axis. They form during the volumetric shrinkage of the metal during solidification, and it is possible to prevent their formation by metallurgical intervention. Regarding thin-walled castings, higher carbon and lower silicon contents are advised. On the other hand, a lower carbon content is advised in regards to more-massive castings. Another possibility is to adhere to a high melting temperature with the possibility of longer standing time before casting [9–12].

2. EXPERIMENT METHODICS AND ACHIEVED RESULTS

The preparation of liquid metal for the final cast iron regarding EN-GJS-600-5 was carried out at a foundry in a 10 t medium frequency induction furnace Junker. After melting the batch, the melt was heated up to 1420°C, and a sample was taken for spectral and chemical analysis. Treatment of the melt was carried out by the tundish-cover method. After modification, a treatment with FeSi75 was applied into the liquid metal stream. The amount of treatment agent was 0.6–1.0% weight of the entire melt. After pouring into the casting skillet, the molds were cast within 15 minutes due to the subside effect.

The finished casting of the rope drum is depicted in Figure 1. The diameter of the drum is 562 mm, and its height is 1566 mm. Regarding these drums, mechanical properties must be within the interval and proven on the added rod (Fig. 2), and they must be above the minimal values (400/500/5) specified by the customer (as follows):

- yield strength $R_{p0.2}$ = 400 MPa,
- tensile strength R_m = 500 MPa,
- ductility A_5 = 5%.

Fig. 1. Rope drum cast

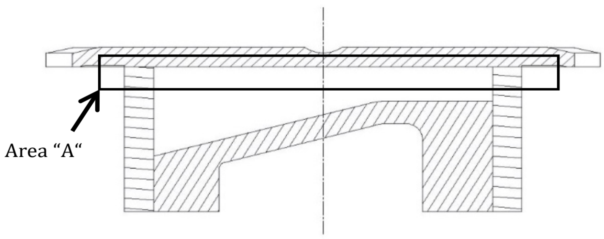

Fig. 2. Area "A" in rope drum

For experimental purposes, a test model was constructed (Fig. 3) at which the individual tests were realized after casting and sample collection (Fig. 4). The dimensions of the test model were 300 × 300 × 250 mm. The mechanical properties (yield strength $R_{p0.2}$, tensile strength R_m, ductility A_5) were measured on four parts of the test model. These parts correspond with the surface area of the rope drum cross section where the specified mechanical properties should be achieved. Part Y4 corresponds with area "A"on the drum casting, and its thickness was 75 mm. A metallographic analysis of the structures was carried out on samples taken from part Y4. Samples were prepared by the standard method, and the shape of the segregated graphite, size of the graphite, and portion of the pearlite in the structure was evaluated.

The boundary values for the mechanical properties of EN-GJS-600-5 depend on the thickness of the wall. According to DIN EN 1563: 2012-3, the mechanical values in the "A" area must be achieved on the stick.

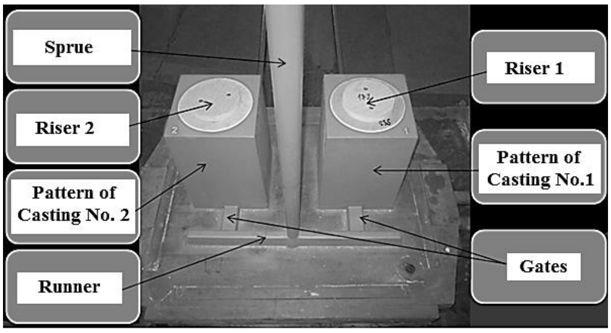

Fig. 3. Test model

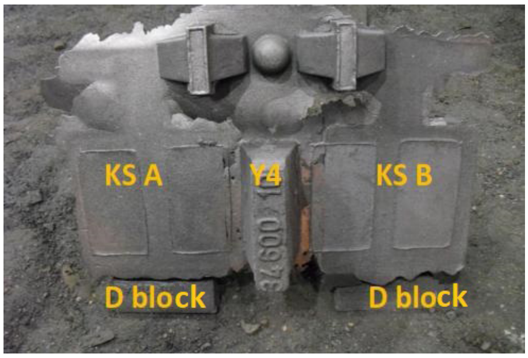

Fig. 4. Cast of test model

Overall, eight test melts were carried out, while the chemical composition was changed in such a way to obtain the desired mechanical properties. These were tested during the tensile stress tests of the test bar samples taken from the highlighted parts in Figure 4. The chemical composition of individual melts is shown in Table 1.

Melts 1 to 6 were performed with a higher C content (>3.6% C) and lower Si content (<2.5%). A heat treatment was realized in the melt of Sample 6, specifically pearlitization annealing at 921°C and annealing to remove the internal stress at 620°C. Melts 7 and 8 had a higher Si content (>4%) and were also heat-treated as in Melt 6. For all melts (1–8), the required saturation degree Sc (0.99–1.1) was achieved.

Results of the mechanical properties of samples from the experimental melts are documented in Table 2. According to the customer's conditions, the values of the mechanical properties obtained on the test pieces (Y4, D block, Ks A, Ks B, Fig. 4) must be as follows:

- yield strength $R_{p0.2}$ = 400 MPa,
- tensile strength R_m = 400–700 MPa,
- ductility A_5 = 5–20%.

Table 1
Chemical composition of melts

Melt No.	C	Si	Mn	Cu	P	S	Mg	Cr	Sn	Ni	Sc	Heat treatment
	wt.%											
1	3.63	2.25	0.611	0.782	0.028	0.007	0.049	0.017	0.004	–	1.014	–
2	3.69	2.40	0.347	0.964	0.027	0.006	0.048	0.018	0.004	–	1.008	–
3	3.63	2.45	0.492	0.734	0.029	0.008	0.049	0.020	0.004	0.061	1.033	–
4	3.60	2.49	0.499	0.731	0.026	0.007	0.048	0.018	0.013	–	1.037	–
5	3.60	2.00	0.579	0.950	0.027	0.008	0.055	0.026	0.017	0.009	0.960	–
6	3.60	2.20	0.512	0.776	0.024	0.008	0.048	0.020	0.004	–	1.002	HT
7	2.91	4.18	0.369	0.610	0.021	0.009	0.050	0.025	0.006	–	0.99	HT
8	2.94	4.192	0.423	0.629	0.025	0.009	0.050	0.029	0.006	–	0.991	HT

Table 2
Measured mechanical values of samples from individual melts

Melt No.	Samples	Mechanical properties						Achievement
		Without Heat treatment (cast state)			After Heat Treatment			
		$R_{p0.2}$, MPa	R_m, MPa	A_5, %	$R_{p0.2}$, MPa	R_m, MPa	A_5, %	
1	Y4, D block, Ks A Ks B	373 374 372 365	630 625 583 548	5.0 5.0 3.5 3.0	–	–	–	Not OK
2	Y4 D block Ks A Ks B	384 388 359 365	598 606 528 581	3.5 4.0 3.3 3.5	–	–	–	Not OK
3	Y4 D block Ks A Ks B	402 390 383 379	666 598 544 615	5.0 3.5 2.5 4.5	–	–	–	OK only for Y4
4	Y4 D block Ks A Ks B	386 401 394 390	627 598 509 546	4.5 2.5 1.5 2.0	–	–	–	Not OK
5	Y4 D block Ks A Ks B	388 384 368 376	679 640 579 620	4.5 3.5 2.5 3.0	–	–	–	Not OK
6	Y4 Ks A Ks B	447 364 348	785 629 596	6.5 11.5 11.5	447 437 448	785 774 796	6.5 7.5 7.0	OK after HT
7	Y4 Ks A Ks B	529 502 494	644 601 601	14.0 7.6 9.0	–	–	–	OK
8	Y4	517	635	13	–	–	–	OK

Based on the measured mechanical properties, satisfactory samples are from Melts 4 to 8, while the sample from Melt 6 became satisfactory only after heat treatment.

Results of a metalographic analysis of samples from the individual melts are documented in Table 3. The structure of the metalographically analyzed samples from Melts 1 to 8 are documented in Figures 5–12.

Results of the metallographic analysis show that the nodularity of the excluded graphite is within a range of 85–90%. The percentage of ferrite in the structure was between 70 to 90% for Melts 1 to 6. For Melts 7 and 8, the structure was 100% pearlite. The size of the graphite was wi-thin a range of 30–50 μm. For Melts 7 and 8, there was only a graphite excluded size of 25 μm.

Table 3
Results of metallurgical analyses

Melt No.	Ferrite, %	Graphite Nodule Size, μm	Nodularity, %
1	70	50	85
2	80	30	90
3	80	30	90
4	80	30	85
5	85	40	90
6	90	40	90
7	0	25	90
8	0	25	90

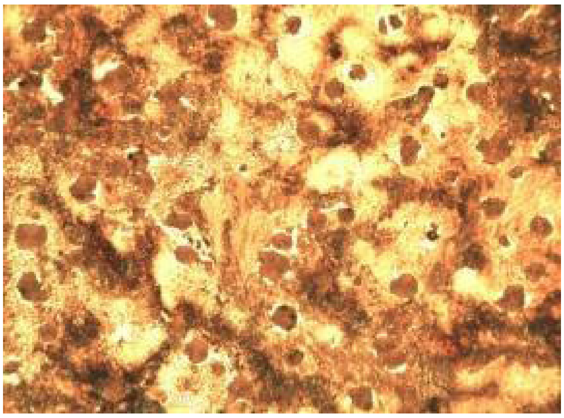

Fig. 5. Structure of Melt 1, etched by Nital 2%, mag. 100×

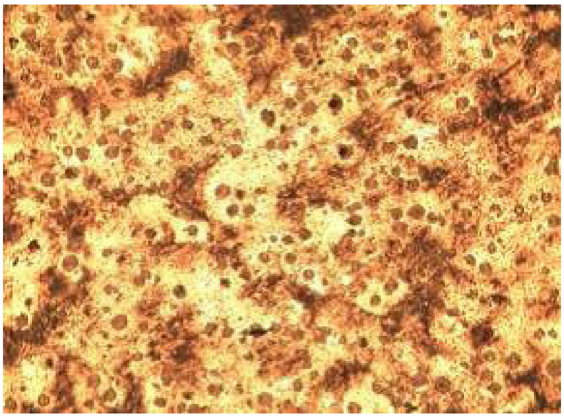

Fig. 6. Structure of Melt 2, etched by Nital 2%, mag. 100×

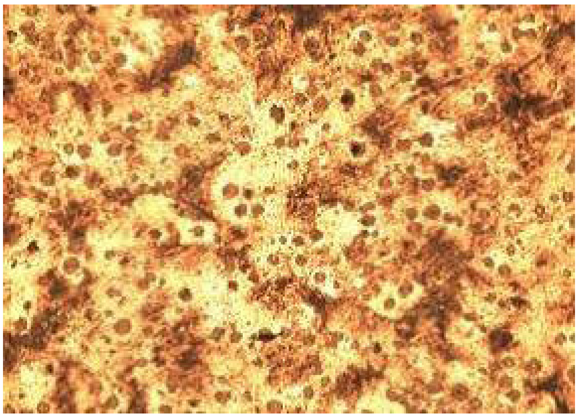

Fig. 7. Structure of Melt 3, etched by Nital 2%, mag. 100×

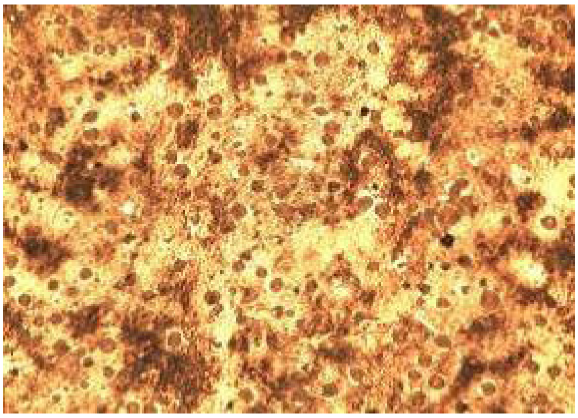

Fig. 8. Structure of Melt 4, etched by Nital 2%, mag. 100×

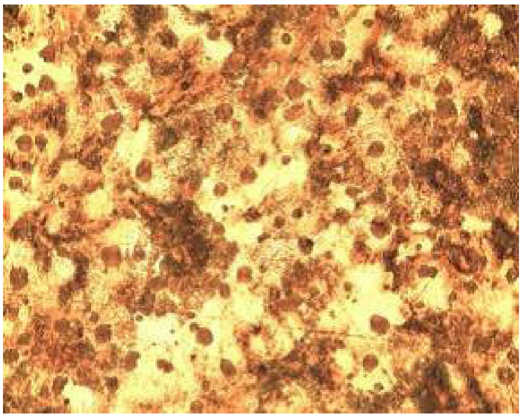

Fig. 9. Structure of Melt 5, etched by Nital 2%, mag. 100×

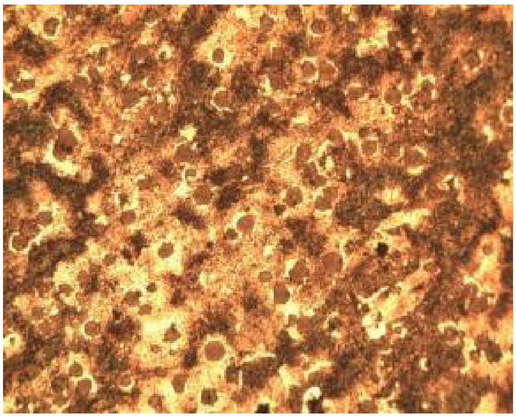

Fig. 10. Structure of Melt 6, etched by Nital 2%, mag. 100×

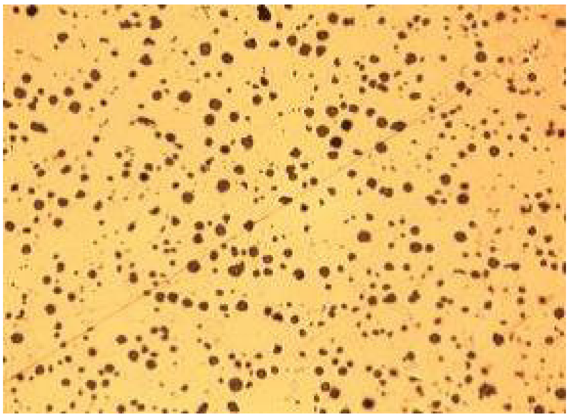

Fig. 11. Structure of Melt 7, etched by Nital 2%, mag. 100×

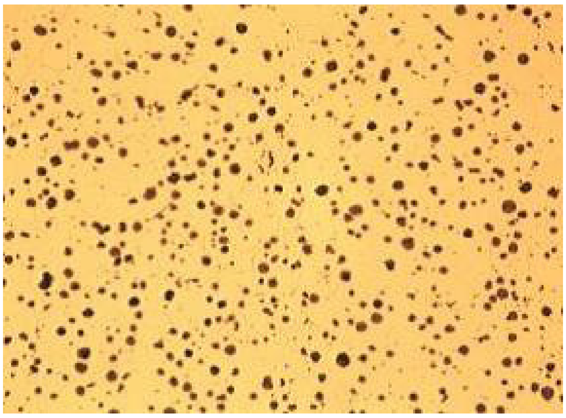

Fig. 12. Structure of Melt 8, etched by Nital 2%, mag. 100×

3. CONCLUSION

The casting of the rope drum must achieve the minimum mechanical properties (400/500/5) according to customer requirements in area "A". For this type of casting, depending on the thickness of the casting wall, the mechanical values (depending on DIN EN 1563:2013-3) must preferably be achieved on the manifold rod in area "A". As a casting with different wall thicknesses, uniform mechanical properties in a given part of the casting (area "A"). Based on the casting of the drum, a model was produced whose parts corresponded to the thickness of the casting walls. Altogether, eight melts were made in which the ratio of C and Si varied. With three melts (Melts 6 through 8), heat treatment was performed on the samples (annealing at 921°C and annealing to reduce stress at 620°C). For the samples from melts where thermal processing was not performed (Melts 1 through 5), the required mechanical values required by the customer were not achieved. In Melts 7 and 8 where the C content was lower (2.91 and 2.94%, respectively) and Si content higher (4.18 and 4.192%, respectively), these properties were achieved without heat treatment of the samples. The structure of the samples from these melts was ferritic or with a small portion of pearlite. This was manifested by increased tensile strength and elongation properties. For Melt 6, the desired values were obtained after heat treatment of the samples as for Melts 7 and 8. From an economic point of view, the production of the rope drum is more advantageous without heat treatment according to customer requirements, as it increases the cost of the casting production. A lower carbon content (<3% C) and higher Si content (>4% Si) are required to provide the desired properties in the cross-section of the drum, with the Sc ratio being 0.99–1.1.

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