ARCHIVES
of
FOUNDRY ENGINEERING
DOI: 10.24425/123610
Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (2299-2944)
Volume 18
Issue 3/2018
101 – 106
18/3

The Influence of Copper on the Properties of Ductile Iron for Producing Centrifugally Cast Rolls

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Received 08.05.2018; accepted in revised form 27.07.2018

Abstract

An intentional change in material properties is an important condition for castings production. It is one way how to meet the casting requirements of how to adapt the material properties to the operating conditions. Centrifugally cast rolls are multi-layer rollers, castings. The working layer of the barrel is called the "shell" and the body of the roll and the necks rolls are called "core". The article deals with the influence of the properties of the core iron. Earlier laboratory experiments were primary analysed for metallographic analysis and mechanical properties. These data were compared back to the experiments. The results of these laboratory working were later applied in the operating conditions of the roll foundry Vítkovitcké slévárny, spol. s r.o. The spun cast roll produced with the applied metallurgical processing change was supplied to the hot strip mill. There were monitored the positive effect of the change of the metallurgical process of the production of the core iron on the useful properties of the centrifugally cast roll. The experiment was done in order to increase the mechanical properties of ductile pearlite ductile iron. The copper in these core iron material increases the hardness and strength primarily.

Keywords: Centrifugally cast rolls, Microstructure and mechanical properties, Copper alloys, Ductile iron

1. Introduction

The production of spheroid graphite cast iron is relatively well known. The history of production ductile iron dates form the first half of the twentieth century. For example, researchers H. Morrough and W. Williams have made extensive research, which has subsequently served as a scientific basis for production. The processes of production globular graphite iron with the addition of cerium were patented in 1946, as write in [1]. Since then, many metallurgical processes have been developed to influence the shape of graphite.

Perhaps the most widespread method of graphite modification in the iron is the use of modifier on Mg base. The way, how to adding a modifier into melting iron is a lot of. Their use is influenced by a number of factors such as: the quantity of liquid metal, the time consuming, the chemical composition of the desired metal, the mechanical properties, the shape of the castings, the availability of the pans, tapping temperature, pouring temperature etc [2].

Modification is achieved by a number of negative phenomena such as pyroefect, vapour generation, different usability of Mg, slag production and next. A brief overview of common methods of modifying their advantages and disadvantages is given in Figure 1.

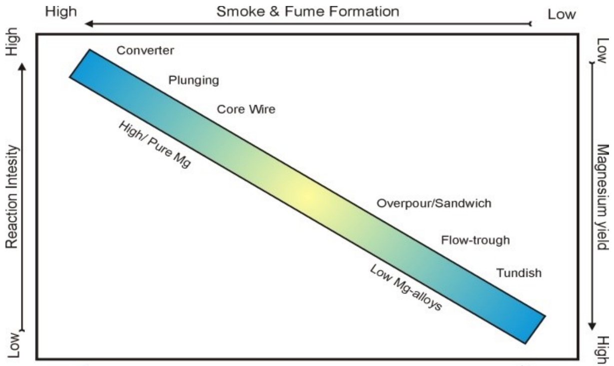

Fig. 1. Processes of modification, their advantages and disadvantages [3]

2. Description of the approach, work methodology, materials for research, assumptions

The experiment was focused on increasing the useful properties of materials for centrifugally cast roll. Rolls produced by centrifugal casting are so-called multi-layer rolls. The layer forming the working layer of the roll is technologically called a "shell" layer. The second layer, which forms the roll body and the roll necks, is called the "core" layer - cast iron. These rolls are designed for hot strip mills.

The working layer is made of alloy with high chromium content of HiCr, chrome-molybdenum-nickel cast iron ICDP, high chromium and molybdenum steel or high-speed steel marked HSS according to the use of the roll, in the work stands of the mill.

The core layer (iron) is predominantly cast from cast iron with spheroidal graphite. Core irons are alloyed with nickel, chromium, manganese and molybdenum. The schematic drawing of the roll and the distribution of the layers is shown in Figure 2. The production of multi-layer rolls by centrifugal casting is a highly sophisticated technology [3].

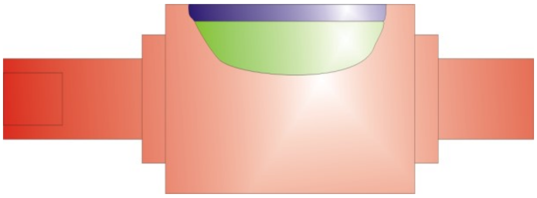

Fig. 2. The schematic drawing of the roll and the distribution of the layers, purple as shell, green as core

There are utilizing outstanding knowledge of material properties, metallurgical process and perfect knowledge of the manufacturing process. These knowledges in order to ensure excellent manufacturing conditions ensuring good bonding between layers [4].

From the point of view of foundry technology, it is a high-tonnage, thick casting. Diameter of body is in range 500 – 1 050 mm. A length of roll is up to 7 200 mm. Weight up to 27 000 kg.

The experiment was realized in the laboratories of VŠB-TU Ostrava. The basic melt for this experiment was melted on induction furnaces. The modification was made by the overpouring method. The inoculation was done in the ladle. There were cast test castings in the laboratory. The castings were tested for mechanical properties and metallorgraphical analysis of the shape of the graphite and the structure of the basic metal matrix. The melt was controlled by chemical analysis by thermal analysis during the melting process.

As stated above, core cast iron is a cast iron specially designed for use in the manufacture of centrifugally cast roll. It has special requirements for high final hardness, tensile strength, thermal expansion etc. The informative chemical composition of this cast iron is shown in tab. 1. The specifications for hardness and mechanical properties are shown in Table 2. For these very hudge castings are used scleroscope for measured of hardness, units Shore C. It was measured by equipment Equotip 3. These values were converted to HV by conversion table for hardnes scales – cast rolls [11].

Table 1.
Chemical composition of core iron

C (%)	Mn (%)	Pmax (%)	Smax (%)	Ni (%)	Mo (%)	$Mg_{residual}$ (%)
2.80 – 3.50	0.10 – 1.00	0.060	0.020	0.60 – 1.20	0.05 – 0.30	0.030 – 0.080

Table 2.
Specifications hardness and mechanical properties of core iron

Hardness	245 – 322 HV
Tensile strength min.	350 MPa
Bending strength min.	540 MPa

The aim of this experiment was to increase the tensile strength of the core iron of the centrifugally cast roll material while maintaining the current ductility and required hardness. There are steps of the experiment in block diagram illustrated in Fig. 3.

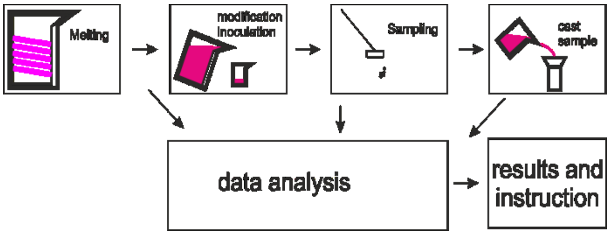

Fig. 3. The block diagram of the experiment

The experiment was therefore divided into basic steps:

- melting, process of alloying
- modification and inoculation
- sampling tests
- cast the test casting.

Next step was the main step:

- determination of mechanical properties, chemical composition, metallographic analysis and data comparison.

The results were then used as the basic building blocks for the creation of a metallurgical method for melting of core material and for the optimization of the charge for the production of core iron with globular graphite.

2.1. Experiment

The experimental testing was aimed on enhancing mechanical properties by alloying, specifically by addition copper. The influence of this alloy on the mechanical and structural properties of the iron was monitored.

Why a copper? Copper supports graphitization, reducing the ductile cast iron tendency to metastable solidification. In this respect, 1% of copper has the same effect on graphitization as 0.3% of silicon. Copper also prevents the fertilization of the cast iron, supports the formation of the perlite and its refinement. The ability to stabilize the perlite is enhanced if the ductile cast iron contains a low amount of silicon.

The stabilizing ability of perlite by copper is about 2 times higher than for manganese. Copper is preferably used as a alloy to compensate for the adverse effect of chromium, which increases the stability of the carbides. In many cases, there is causes a tendency to a higher shrinkage of cast iron with the addition of copper [1].

Because copper increases the solubility of magnesium, it can be used as a cover material when modifying the magnesium pre-alloy. This leads to higher use of Mg in the modification [8].

Copper increases the amount of perlite and fine its morphology [10], so it is possible to monitor the increase in strength and hardness as illustrated in Figure 4. There is evident that maximum strength can be achieved at about 1% Cu, as well as hardness growth is slowed down from said point. But copper has a negative impact on elongation, as in Fig. 4.

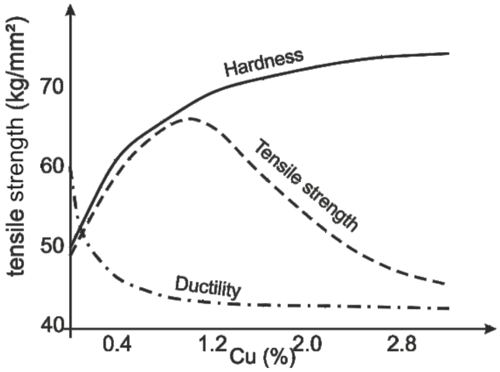

Fig. 4. Influence of copper on the mechanical properties of ductile cast iron, valid for chemical composition according to [4]

In many cases, copper is added to the casting as a cover material for the magnesium alloy, thereby improving the regeneration of magnesium. Like silicon, a copper also increases the solubility of magnesium.

In general, copper is limited to 1.0% of perlite castings. If copper itself is insufficient to obtain a perlite requirement, either because of the casting mass or in the presence of boron, materials such as a tin and a manganese can be added [5].

The modification and inoculation process have been kept unchanged. This means that these processes were in line with the production conditions. [6,7.9]

The Lynchburg test was used as test cast. The dimensions of this specimen cast iron fig. 5.

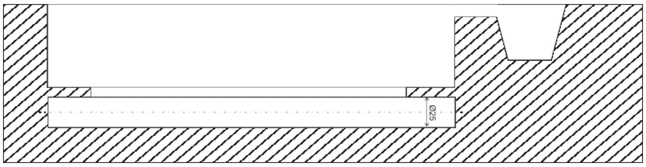

Fig. 5. Schematic a drawing of test casting

2.2. Laboratory tests

The melting of basic cast iron was performed on an electric induction furnace with a capacity of 50 kg, the charge weight of each other melt was 30 kg. The modification was done by the overpouring method. The composition of the charge, meaning the proportions of the charge materials, is shown in Table 3.

Table 3.
A percentage of the charge

	[%]
Pig Iron	64
Steel scrap	34
Alloys	1.0-1.5
Other (Carbon, FeSi)	0.5-1.0

The treatment of the melt in the ladle was done by a combination of modifiers and inoculants.

- Chemical composition of a modifiers on NiMg basis
  82-84% Ni, 15-16% Mg, 0-1% Ce
- Chemical composition of a modifiers on FeSiMg basis
  6-6.5% Mg, 1.9% Ca, 45% Si
- Chemical composition of inoculants
  62-68% Si, 1.8-2.4% Ca, 0.8-1.2% Bi,
  0.8-1.2% Se, 1.8-2.4% Ca, max. 1.0% Al

Samples for a tensile, hardness and a metallography were cast by using the Lynchburg test cast. The informative final chemical compositions of the melts are shown in Table 4. The chemical compositions were analysed by using the spectrometer and the Leco analyser.

The metallography analysis was made at two areas of each of specimens.

- Axis of test casting, fig. 6, 8, 10 and 12.
- Edge of test casting fig. 7, 9, 11 and 13.

The metallography analysis was performed at 100x magnification. The quantity of graphite G and phase (ferrite F, pearlite P, and ledeburite L) of structure on the metallographic sample were evaluated by the graphical analysis. Data are shown in the table 5.

Table 4.
A final informative chemical compositions of the melts

Sampe / melt	C [%]	Mn max. [%]	Si [%]	P max. [%]	S max [%]	Cr+Ni+Mo [%]	Mg [%	Cu [%]
A	3.05 - 3.20	0.40	2.00-2.20	0.040	0.020	0.70 – 2.50	0.040-0.070	0.00
B	3.05 - 3.20	0.40	2.00-2.20	0.040	0.020	0.70 - 2.50	0.040-0.070	0.50
C	3.05 - 3.20	0.40	2.00-2.20	0.040	0.020	0.70 – 2.50	0.040-0.070	1.00
D	3.05 - 3.20	0.40	2.00-2.20	0.040	0.020	0.70 – 2.50	0.040-0.070	1.50

Table 5.
Data of structure phase

Sample	P [%]	F [%]	G [%]	L [%]
A_edge	72	10	5.0	16
B_edge	82	0	6.5	10
C_edge	80	0	8.5	10
D_edge	83	0	8.0	9

G as graphite, F as ferrite, P as pearlite, L as ledeburite

2.3. Results of metallography

Sample A – Axis Fig. 6 vs Edge Fig. 7
In both structure were found type of graphite VI, size 5. There were calculated 61 noduls/mm^2 in the axis and 67 noduls/mm^2 in the Edge.

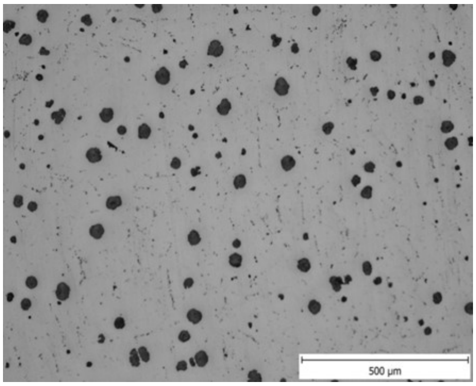

Fig. 6. Metallography of sample A – Axis, mag. 100x

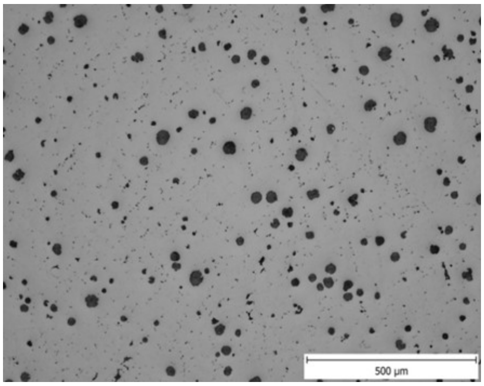

Fig. 7. Metallography of sample A – Edge, mag. 100x

Sample B – Axis Fig. 8 vs Edge Fig. 9.
In both structure were found type of graphite VI, size 5. There were calculated 68 noduls/mm^2 in the axis and 47 noduls/mm^2 in the Edge.

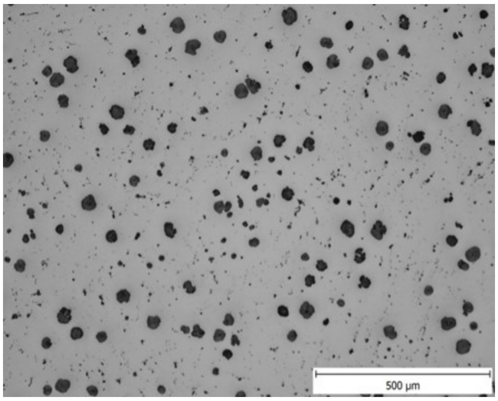

Fig. 8 Metallography of sample B – Axis, mag. 100x

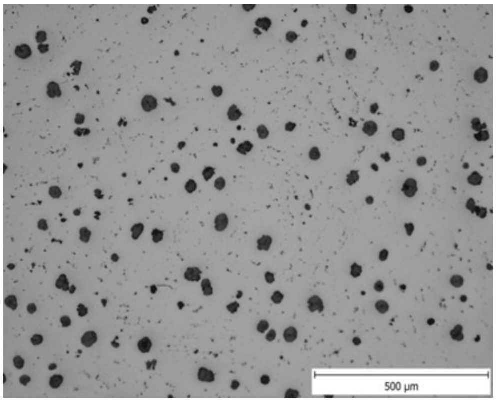

Fig. 9. Metallography of sample B – Edge, mag. 100x

Sample C – Axis Fig. 10 vs Edge Fig. 11.
In both structure were found type of graphite VI, size 5. There were calculated 60 noduls/mm^2 in the axis and 49 noduls/mm^2 in the Edge.

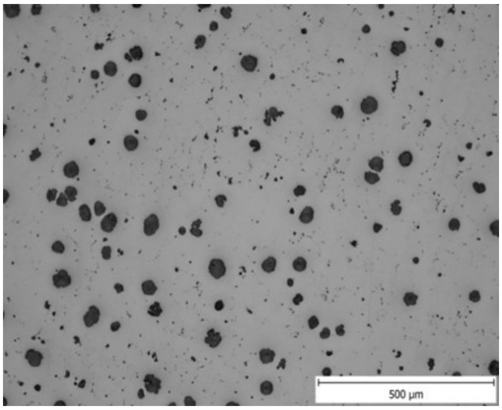

Fig. 10. Metallography of sample C – Axis, mag. 100x

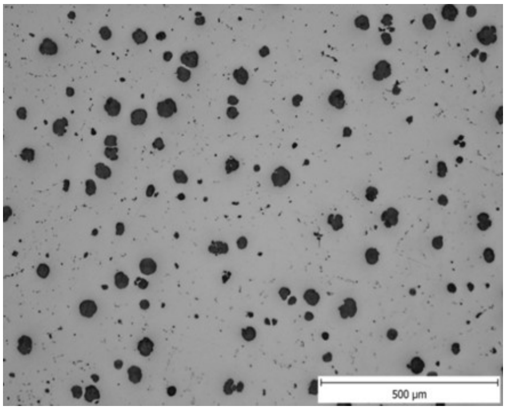

Fig. 11. Metallography of sample C – Edge, mag. 100x

Sample D – Axis Fig. 12 vs Edge Fig. 13.
In both structure were found type of graphite VI, size 5. There were calculated 75 noduls/mm^2 in the axis and 70 noduls/mm^2 in the Edge.

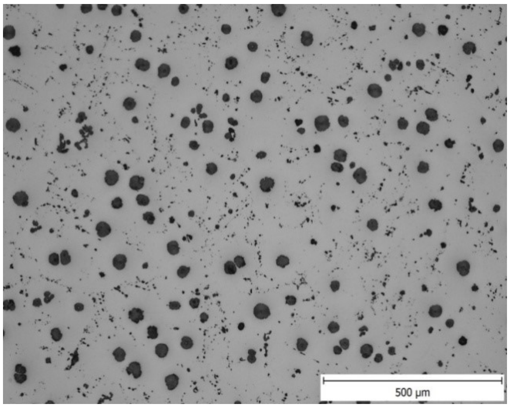

Fig. 12. Metallography of sample D – Axis, mag. 100x

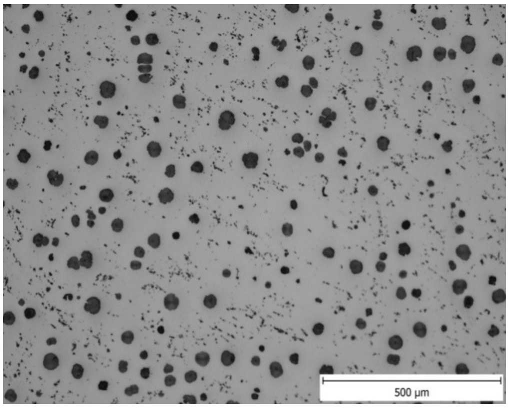

Fig. 13. Metallography of sample D – Axis, mag. 100x

The size, number of nodules, and the quantity of phases were measured by image analysis. The Quick PHOTO Industrial 3.0 program was used for metallographic image analysis. Image analysis was determined from 3 typical fields of each sample.

2.4. Results of mechanical properties

From the test cast were made specimens for mechanical properties testing. There were shown tensile strange Rm, elongation A5 and harnesses HB in the table 6. The test samples were first removed from the cast. They were then processed to the required shape. Tension tests were made in a reputable laboratory according norm. Hardness tests were performed on specimens in the laboratories of VŠB-TU Ostrava. Hardness was made according to Brinell: diameter of identor 2.5 mm, load: 62.5 kg. Hardness was expressed from 5 injections per sample.

Table 6.
Mechanical properties data

Sample	Rp0,2 [MPa]	Rm[MPa]	A5 [%]	HB
A	324	572	1.30	267±7
B	379	751	3.60	277±9
C	390	809	4.18	281±6
D	423	855	4.10	281±9

3. Results and discussion

Graphic dependencies were compiled from the measured values. This is the effect of copper on tensile strength. the influence amount of copper to elongation. Because it supports the design of the perlite, copper should have a positive effect on hardness. As mentioned above, copper should have a negative effect on the elongation of the cast iron.

The effect of copper on the change in yield and tensile strength is shown in Fig. 14. It is interesting to see Fig. 15, which graphically expresses the dependence of the resulting hardness and elongation of the sample on copper.

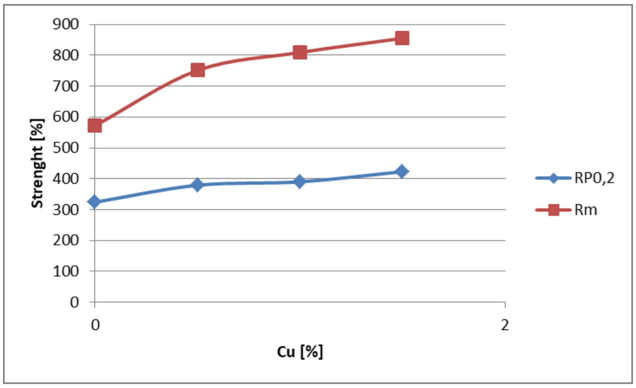

Fig. 14. There was measured dependence on yield, tensile strength on Cu amount

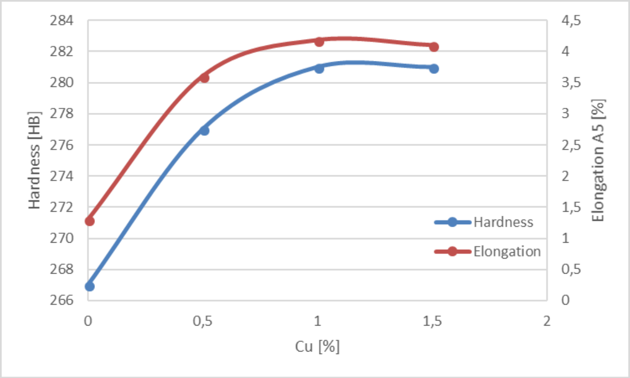

Fig. 15. There was measured dependence on hardness and elongation A5 on Cu amount

4. Conclusions

1) The experiment was done in order to increase the mechanical properties of ductile pearlite ductile iron. It means are especially tensile strength and hardness. As one of the partial means of improving the centrifugally cast roll useful properties. The results of the experiment revealed following.
2) The copper in these core iron material increases the hardness and strength primarily. This can be explained by a close link with structural change. Copper supports the shape of the perlite in the structure of core iron. It has a positive effect on the amount of graphite with minimal negative impact on its shape. As documented in Table 6.
3) The copper effect on these core materials is very strong, alone 0.5% Cu has increased the strength by 31%, but 1% Cu increased the strength by 41% and the Cu 1.5% increase by only 49%. It follows that a higher percentage of copper in the charge is inefficient.
4) It was fully benefit the fact that copper had a positive impact on the elongation of this special ductile cast iron in this application. This experience was inconsistent with theoretical hypothesis like is shown upper on fig. 4 [4]. There is negative influence elongation on Cu amount. In this case, the elongation increased from the original 1.3% to 4.1 without decreasing hardness values. Even in this case was observed the strong effect is up to 0.5%.

Acknowledgements

This paper was made with the support of TA CR within the project ev. no. TA04010223.

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