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## ELIMINATION OF NEGATIVE IMPACTS OF STEEL SCRAP AS A CHARGE COMPONENT DURING THE PRODUCTION OF SYNTHETIC CAST IRON

*The article presents the research results of omitting the steel scrap component from the production process of synthetic gray cast iron. The quality of synthetic iron produced in electric induction furnaces (EIF) is influenced by numerous factors. Its characteristic attributes are high values of mechanical properties ( $R_m$ , HB), but also its tendency to form chill out and shrinkages, foundry stress and sensitivity to hardness change at different casting wall thicknesses. Possibilities of offsetting and eliminating such negative effects were tested by introducing metallurgical countermeasures based on the properties of flake graphite alloys.*

**Keywords:** Synthetic cast iron, charge materials, steel scrap, mechanical properties, microstructure.

### 1. Introduction

Production of synthetic cast iron was enabled by the development of sleeve-type EIF. In addition to using up to 100% of the relatively cheaper steel scrap in the steel preparation, the main benefit is the possibility to produce liquid metal of specific and precise chemical composition. Right from the very beginning of its production, the better mechanical properties ( $R_m$  - tensile strength, and HB - hardness) of synthetic iron were discovered, in comparison to iron cast with high volume of expensive pig iron, compared at the same carburization degree (Sc).

It is explained as the effect of high nitrogen content in the steel, although this has not yet been verified in practice. The increase of cast iron mechanical properties (on average by about 20%) in practice represents a considerable advantage.

During the formation of solid solutions and phases, the nitrogen inhibits graphitization and increases pearlite stability. At the same time, due to the modifying effect, nitrides of the AlN, BN, TiN type can soften the structure and graphite during the initial stage of crystallization [1-5].

Carbon and silicon reduce the solubility of nitrogen in pig iron [6-7]. The alloying with metallic Ti, as well as of FeTi oxides and  $TiO_2$  ( $FeTiO_3$ ) neutralizes the effect of nitrogen. Increasing the temperature of molten metal improves the solubility of nitrogen in the liquid iron [8-10].

### 2. Experimental tests

The main goal of the experimental tests was to produce cast iron alloy with properties matching the EN-GJL-250 cast iron alloy standard (Sc carburizing degree of 0.87 - 0.93; C content of 3.1 - 3.3; Si content of 1.7 - 1.9) under operating conditions in foundries in high-volume electric induction furnaces. Overall six experimental melts have been designed and realized. The tests examined the impacts of the increased steel scrap levels in the charge. They also evaluated the possibilities to eliminate the negative impacts of high steel scrap content on the final iron quality by:

- a) increasing the temperature of heat treatment (1 500 °C, typically 1 420 °C) and inoculation,
- b) alloying with titanium (by heat treatment to 1 500 °C and inoculation),
- c) increasing the carbon content (+ 0.5%) and by reduction of the Si content.

The cast iron alloy properties from these experimental melts were compared to conventionally prepared semisynthetic cast iron (with the ratio of steel scrap in the charge of about 33%). The castings from each melt were compared and analyzed. In order to properly compare the properties of both alloys, the following tests were performed:

- Chemical analysis of both samples.

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- Stairs test (R-Block with three thicknesses of 100, 50 and 20mm - standard thickness of the walls castings, Fig. 1), to determine the sensitivity difference between the walls' thickness and the castings' hardness (cooling rate).
- Rm - tensile strength comparison - performed on test bars with diameter of 30 mm.
- Comparison of wedge-shaped test bar properties [11].
- Comparison of the samples to determine the difference in the propensity towards shrinkage occurrences (tested on cylinders with diameter of  $\phi$  95 mm and height of 150 mm). The cylinder dimensions and volumes were measured before and after the shrinkage occurrence.
- Samples comparison in regard to determining the nitrogen content.

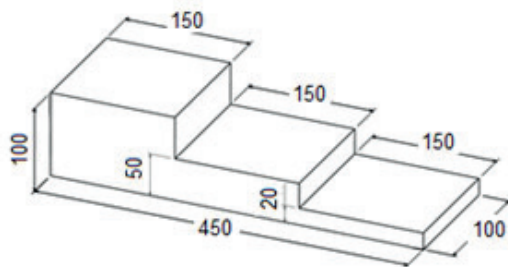


Fig. 1 Stairs-test (R-block)

The samples for metallographic analysis were prepared in a form of test bars; they were prepared in a traditional manner.

R-Block was cut in each of the cross sectional areas. For every section the Brinell hardness was measured. The hardness was measured using the HPO 3000 durometer (setting: 10/3000/10).

Tensile strength was measured on test-bars ( $\phi$  30mm) on a standard testing machine of ZWICK brand. The percentages of the charge materials content for each melt are shown in Table 1.

### 3. Results and discussion

The results of the chemical analysis and the results of mechanical tests comparing the properties for each melt are shown in Table 2.

The chemical composition of cast alloy matched the requirements of identical Sc 0.848 - 0.869 (slightly different). Melt No. 4 with high carbon content of C = 3.79 %, and a low content of Si = 1.026 %; Sc = 0.951 - which corresponds to the GJL - 250 standard. The nitrogen content in the experimental melts showed the lowest amount in melt No. 4 ( $N_2 = 0.0073\%$ ) where there was a high carbon content (C = 3.79 %), and in melt No. 3 ( $N_2 = 0.0091\%$ ) where there was titanium added. Low nitrogen content of these melts was caused by the reduced solubility of  $N_2$  by increasing the content of C and Si, where carbon has a significant effect [12]. There was an unexpected effect, namely high levels of gaseous nitrogen in the electric induction furnace, caused by the large surface area of the many steel scrap fragments (thin metal sheet cuttings). There were nitrogen levels in the charge of 60 to 80 ppm, whereas for the synthetic iron alloy (for melts No. 5 and 6) the levels were 175 and 205 ppm respectively. The change in the HB hardness depending on the wall thickness of the casting was verified by the Stairs test on an R-block (Fig. 1). The results are presented in Fig. 2.

Charge materials content for each melt

Table 1

| Charge materials                             | Melt No.              |       |       |       |            |       |
|--|-----------------------|-------|-------|-------|------------|-------|
|  | 1.<br>(standard melt) | 2.    | 3.    | 4.    | 5.         | 6.    |
|  | wt / %                |       |       |       |            |       |
| Steel scrap (sheets)                         | 32.8                  | 35.5  | 35.5  | 82.7  | 97.8       | 97.5  |
| Return material                              | 53.3                  | 52.9  | 52.9  | -     | -          | -     |
| PIG iron                                     | 10.0                  | 9.8   | 9.8   | 13.0  | -          | -     |
| FeSi 75 %                                    | -                     | 0.12  | 0.12  | 0.22  | 0.59       | 0.6   |
| FeMn 80 %                                    | 0.4                   | 0.5   | 0.5   | 0.47  | 0.4        | 0.47  |
| Recarburizer                                 | 1.30                  | 0.98  | 0.98  | 3.45  | 0.67       | 0.67  |
| Inoculant (added during reladling)           | 0.2                   | 0.2   | 0.2   | 0.2   | 0.34+0.2** | 0.5   |
| FeTi 60 %                                    | -                     | -     | 0.28* | -     | -          | 0.26* |
| Heat treatment temperature / °C              | 1 420                 | 1 500 | 1 500 | 1 450 | 1 450      | 1 520 |
| *FeTi60 - into the furnace                   |                       |       |       |       |            |       |
| **SiC - primary inoculant (into the furnace) |                       |       |       |       |            |       |

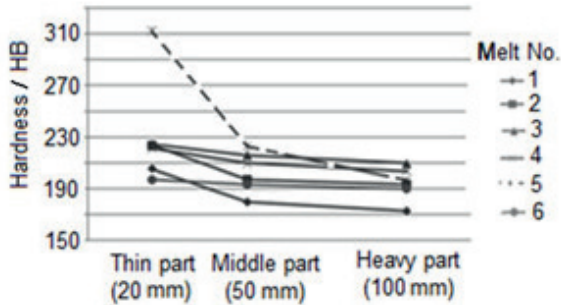


Fig. 2 Change of HB hardness on R - block

The most significant change between the HB hardness of the thinnest (20 mm) and the thickest (100 mm) casting wall was found on a sample from melt No. 5. In this melt, there was also the highest hardness recorded (on average by 243 HB) and the steepest increase in HB hardness in accordance to the decreasing wall thickness of the cast, with a difference of 59%. It is clear that a high content of steel scrap in the charge, that is an increased nitrogen content, increases the hardness and the tensile strength of alloy. A more substantial hardness increase occurred on the thin wall of the castings where the hardness reached 312 HB for melt No. 5. In contrast, in melt No. 2, where the proportion of steel scrap reached only 35.5%, there was the smallest variance of hardness between the thinnest and thickest wall of the casting - only 15%.

Thus, the impact of nitrogen in the charge was not as pronounced. Also, a sufficient level of heat treatment temperature (1 500 °C) affected the refinery processes. The results of the measured chill out are documented in Table 3.

The greatest shrinkages occurred in melt No. 5 where shrinkage penetrated to a depth of 15 mm and had the greatest cross section - 30 mm (volume of 1.5 ml). This case also demonstrates the negative impact of nitrogen in the alloys, as a carbonizing element with a tendency to cause shrinkages. In other melts, flat shrinkages occurred.

The microstructure of all melts was pearlitic with a 92 - 96% portion of pearlit, Fig. 3 - melt No 1. In melt No. 5 (synthetic gray iron) there was a fully pearlitic microstructure and there were carbides detected, Fig. 4. The occurrence of carbides was the reason for the increased hardness in this gray iron alloy.

Depth of the chill out Table 3

| Melt No. | Chill out depth / mm |
|----------|----------------------|
| 1.       | 5                    |
| 2.       | 1                    |
| 3.       | 1                    |
| 4.       | 6                    |
| 5.       | 10                   |
| 6.       | 2                    |

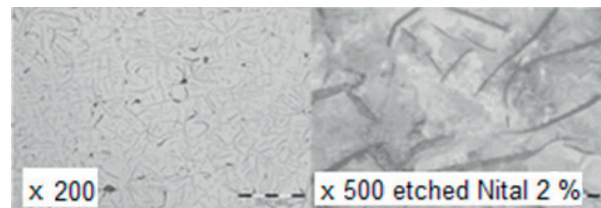


Fig. 3 Microstructure of gray iron alloy in melt No. 1

Results of chemical analysis and of mechanical properties tests

Table 2

| No. | Steel scrap ratio / % | wt. / % |       |       |       |       |       |                | Sc    | CE / % | Rm / MPa | HB         |
|-----|-----------------------|---------|-------|-------|-------|-------|-------|----------------|-------|--------|----------|------------|
|     |                       | C       | Si    | Mn    | P     | S     | Ti    | N <sub>2</sub> |       |        |          |            |
| 1.  | 33.0                  | 3.23    | 1.612 | 0.657 | 0.024 | 0.025 | -     | 0.0113         | 0.848 | 3.721  | 297      | 186 *(205) |
| 2.  | 35.5                  | 3.33    | 1.52  | 0.664 | 0.024 | 0.021 | -     | 0.0113         | 0.868 | 3.793  | 352      | 204 *(223) |
| 3.  | 35.5                  | 3.32    | 1.486 | 0.658 | 0.023 | 0.021 | 0.183 | 0.0091         | 0.863 | 3.773  | 268      | 217 *(224) |
| 4.  | 81.7                  | 3.79    | 1.026 | 0.773 | 0.018 | 0.012 | -     | 0.0073         | 0.951 | 4.103  | 256      | 211 *(221) |
| 5.  | 97.8                  | 3.28    | 1.69  | 0.84  | 0.06  | 0.061 | -     | 0.0175         | 0.869 | 3.805  | 258      | 243 *(312) |
| 6.  | 97.5                  | 3.13    | 1.61  | 0.79  | 0.016 | 0.011 | 0.192 | 0.0205         | 0.821 | 3.618  | 220      | 197 *(209) |

\* hardness HB measured on the thin wall of the casting (20 mm)

Besides the standard evaluation of cast iron quality by measuring the tensile strength, and hardness, the quality criteria were also evaluated and compared to chemical composition [13 and 14]:

$$RG = \frac{Rm_{measured}}{Rm_{calculated}} \cdot 100\% \quad (1)$$

where  $Rm_{calculated} = 1\ 000 - 800 \cdot Sc$

$$RH = \frac{HB_{measured}}{HB_{calculated}} \cdot 100\% \quad (2)$$

where  $HB_{calculated} = 100 + 0.44 \cdot Rm_{measured}$

A value higher than 100% means a high quality of gray iron.

The quality number (*GZ*) or the quality factor (*m*) is calculated by dividing the *RG/RH* or by *Rm/HB* - measured values. Quality gray iron shows high strength at low hardness values.

The calculated values of the quality criteria are shown in Table 4. The quality criteria values quantitatively describe the effects of particular production conditions on the produced cast iron properties in comparison to the optimal statistically valid conditions. A cast iron alloy of truly high quality should show high maturity values *RG* and low relative hardness values *RH*.

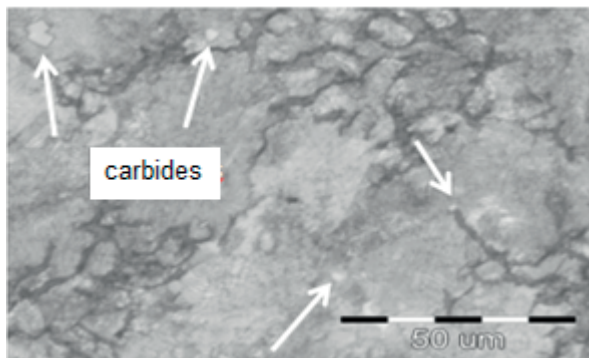


Fig. 4 Microstructure of gray iron in melt No. 5

The quality criteria

Table 4

| Melt No. | Quality criteria |       |       |         |
|----------|------------------|-------|-------|---------|
|          | RG / %           | RH    | m     | GZ      |
| 1.       | 94.25            | 0.805 | 1.599 | 117.036 |
| 2.       | 117.4            | 0.803 | 1.719 | 146.166 |
| 3.       | 88.3             | 0.996 | 1.235 | 88.643  |
| 4.       | 109.2            | 0.996 | 1.210 | 109.643 |
| 5.       | 86.2             | 1.143 | 1.057 | 75.427  |
| 6.       | 65.38            | 1.001 | 1.117 | 65.317  |

Based on the calculated quality criteria (Table 4) it can be stated that melt numbers 1, 3, 5 and 6 are of 100% maturity level and that their tensile strength is smaller than that of a corresponding sample of such chemical composition. For melt number 2, the heat treatment temperature of 1 500 °C showed its positive influence on the final quality, also reflected by the highest quality number “*GZ*” (146.166), by the maturity level “*RG*” (117.4%) and also by the highest quality factor “*m*” (1.719). Melt No. 5 (synthetic iron) demonstrated a high relative hardness “*RH*” (1.143), which reduces the quality number “*GZ*” (75.427). A similar effect was also observed for melt number 6 where a high relative hardness was suppressed by the Ti micro-alloying.

#### 4. Conclusion

The achieved results demonstrate, in particular:

- A significant increase in mechanical properties and quality criteria values for heat treated and inoculated synthetic iron, its low dispersion HB for varying thickness and very good foundry properties.
- A slight decrease in the mechanical properties of cast iron with higher C content and lower Si, but improvement of its mechanical properties, in particular the reduction of HB variance.
- More significant decrease of mechanical properties of cast iron alloyed with titanium, but also significant improvement of monitored mechanical properties, particularly change of hardness for different wall thickness.

The best results were achieved by the heat treatment of liquid metal at 1 500 °C and a high-quality vaccination. The alloy showed the highest tensile strength (*Rm* 352 MPa, for melt No. 2) and excellent quality criteria. Melts alloyed with titanium (Ti = 0.2 to 0.3%) experienced a reduction in mechanical properties, but, on the other hand, showed improved foundry properties, especially a reduced tendency to chill out. Such melts are suitable especially for thin walled castings. There was also an improvement of the casting properties even after the increase of the C content (3.79% - melt No.4) compared to the current practice (3.1 to 3.3% C) in GJL-250. The cast alloy exhibited lower hardness differences depending on the wall thickness (a change of 8.73% from 20 to 100 mm).

A new finding indicates a major presence of nitrogen gasses, in particular if small steel scrap with large surface area is used (small metal sheet cuttings used in the melts No. 6). A double or even a threefold increase in nitrogen amount was observed.

#### Acknowledgement

This work was supported by the Slovak Research and Development Agency under the grants VEGA No. 1/0216/13.

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