# Experimental Research at the Industrial Level for the Production of Ferrous Agglomerates from Iron Ores and Ferrous Waste

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*One of the basic issue~~s~~ to be solved during this period is to simultaneously neutralize and efficiently make use of the resulting waste from the production processes. The objective of the experimental research was to make a special ferrous agglomerate from a mixture of iron ores and ferrous waste and to test its use in the blast furnace. Research has shown a normal functioning of the blast furnace with this type of special agglomerate, obtaining a white pig iron with standardized structure and composition. The introduction of ferrous waste into the agglomeration is a long-term recycling solution with very low costs and with beneficial influences on the environment through the use of dusty waste.*

*Keywords: blast furnace, ferrous sinter, ferrous waste, recycling, waste recovery.*

In the ferrous metallurgy, waste is mostly represented by the sludge from the blast furnace gas cleaning, the dust contained in the blast or steel furnace, and the dross from the rolling of the steels [1-3].

Blast furnace gas, ferrous slags from blast and steel furnaces are not considered as waste,-but by-products, for which recovery processes were designed [1].

The experimental researches presented in this paper aimed to demonstrate that the blast furnace represents the technological aggregate in which ferrous scraps can be recycled.

Large amounts of ferrous scraps from the pig iron and steel production processes can be introduced as raw materials to produce the ferrous agglomerate.

Process variables are the following: contents of slag, blast furnace flue dust, blast furnace and converter sludge which were introduced 1 to 2% above the actual technological flow [1, 2].

It can be noticed that the scraps above can be used to a well-determined limit in the agglomerate composition, considering the ratio between mechanical strength characteristics and the blast furnace optimal performance [3 ÷ 5].

## Experimental part

The experimental researches were based on the pilot technological flow from ICEM Bucharest.

The equipment of the pilot technological stream contains the following devices: a mixer for the raw materials homogenization, agglomerating box, material-testing machine for determining the agglomerate resistance and vibrating screen for establishing the granulometric composition of the agglomerate and the apparatus for determining the Reduction Degradation Index (RDI), after reduction process.

Agglomeration box has been considered the main equipment, which has a height of 400 mm and the surface of the aspiration grate of 0.1024 $m^2$.

Pressure decreasing was achieved by using an extractor with a flow rate of 300 $Nm^3/h$, working pressure of 1.35 atm, engine speed of 1930 rot/min and engine power of 7.5 kW.

Material-testing machine for determining the agglomerate resistance has: internal diameter - 1000 mm; width - 250 mm; engine characteristics - 0.8 kW/1420 rot/min; drum speed - 25 rot/min; work duration - 3 min.

On the generators inside the drum, four corner beads (100 x 100 x 4 mm) at 90 degrees angle have been welded.

Vibrating screen for determining the granulometric composition of the agglomerate has: sifting surface - 0.25 $m^2$; round mesh sizes - 5, 8, 10, 20, 30, 50 mm; engine characteristics - 0.8 kW/420 rot/min; vibrating run - 80 ÷ 800 mm.

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Apparatus for determining the RDI index - degradation resistance after reduction - recorded the weight loss of the material sample because of the reduction process of the iron oxides, in terms of “thermal balance” phenomena.

The granulation of the agglomerated sample is between 15 and 20 mm and its weight are calculated according to the chemical analysis so that 100 g of oxygen is bound as part of iron oxides.

After the chemical reaction ending, the sample was cooled down and introduced into the Nedelman drum for subjecting to a degradation process for 20 min. The resulted sample was placed then on a 3 mm sieve for 3 min.

The 3 mm fraction was weighed and it was determined the ratio of the remaining amount of more than 3 mm versus the total amount of tested material, as well.

In terms of comparative analysis of the results, there were made three types of mixtures of raw materials, which also included ferrous waste.

Each type of mixture had five different recipes, as follows:

Series I - variable content of blast furnace sludge from 6.7 to 23.3 %;

Series II - variable content of cumulative blast furnace dust and sludge from 6.7 to 13.7%;

Series III - variable content of dross between 6.7 and 28%.

The charge composition is shown in Tables 1, 2 and 3.

**Table 1**

COMPOSITION OF THE HOMOGENIZED RECIPE FOR EXPERIMENTAL SERIES I [1]

| Series I | R1 | | R2 | | R3 | | R4 | | R5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | % | kg | % | kg | % | kg | % | kg | % | kg |
| Iron ore | 33.3 | 10 | 30 | 9 | 23.3 | 7 | 20 | 6 | 16.7 | 5 |
| Blast furnace dust | 10.0 | 3 | 10 | 3 | 10.0 | 3 | 10 | 3 | 10.0 | 3 |
| Blast furnace sludge | 6.7 | 2 | 10 | 3 | 16.7 | 5 | 20 | 6 | 23.3 | 7 |
| Returned agglomerate | 28.0 | 8.4 | 28 | 8.4 | 28.0 | 8.4 | 28 | 8.4 | 28.0 | 8.4 |
| Metallurgical coke | 2.0 | 0.6 | 2 | 0.6 | 2.0 | 0.6 | 2 | 0.6 | 2.0 | 0.6 |
| Limestone | 20.0 | 6 | 20 | 6 | 20.0 | 6 | 20 | 6 | 20.0 | 6 |
| Total | 100.0 | 30 | 100 | 30 | 100.0 | 30 | 100 | 30 | 100.0 | 30 |
| Humidity | 8 | | 8 | | 10 | | 15 | | 15 | |

**Table 2**

COMPOSITION OF THE HOMOGENIZED RECIPE FOR EXPERIMENTAL SERIES II [1]

| Series II | R1 | | R2 | | R3 | | R4 | | R5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | % | kg | % | kg | % | kg | % | kg | % | kg |
| Iron ore | 39.7 | 11.9 | 39.6 | 11.88 | 40.2 | 12.07 | 40.4 | 12.38 | 39.6 | 17.8 |
| Blast furnace dust | 4.0 | 1.2 | 3.4 | 1.02 | 2.8 | 0.85 | 6.5 | 2 | 4.2 | 1.9 |
| Blast furnace sludge | 6.2 | 1.86 | 5 | 1.5 | 3.9 | 1.18 | 7.2 | 2.22 | 6.2 | 2.8 |
| Returned agglomerate | 28.0 | 8.4 | 30 | 9 | 31.0 | 9.3 | 24.5 | 7.5 | 28.0 | 12.6 |
| Metalurgical coke | 2.0 | 0.6 | 2 | 0.6 | 2.0 | 0.6 | 1.8 | 0.54 | 2.0 | 0.9 |
| Limestone | 20.0 | 6 | 20 | 6 | 20.0 | 6 | 19.6 | 6 | 20.0 | 9 |
| Total | 100.0 | 29.96 | 100 | 30 | 100.0 | 30 | 100.0 | 30.64 | 100.0 | 45 |
| Humidity | 8 | | 8 | | 8 | | 8 | | 8 | |

**Table 3**

COMPOSITION OF THE HOMOGENIZED RECIPE FOR EXPERIMENTAL SERIES III [1]

| Series III | R1 | | R2 | | R3 | | R4 | | R5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | % | kg | % | kg | % | kg | % | kg | % | kg |
| Iron ore | 16.7 | 5 | 13.3 | 4 | 10 | 3 | 6.7 | 2 | 3.3 | 1 |
| Blast furnace dust | 10.0 | 3 | 10.0 | 3 | 8.3 | 2.5 | 8.3 | 2.5 | 8.3 | 2.5 |
| Blast furnace sludge | 17.3 | 5.2 | 14.0 | 4.2 | 12.3 | 3.7 | 12.3 | 3.7 | 11.7 | 3.5 |
| Returned agglomerate | 28.0 | 8.4 | 28.0 | 8.4 | 28 | 8.4 | 28.0 | 8.4 | 26.7 | 8 |
| Dross | 6.7 | 2 | 13.3 | 4 | 20 | 6 | 23.3 | 7 | 28.0 | 8.4 |
| Metalurgical coke | 1.3 | 0.4 | 1.3 | 0.4 | 1.3 | 0.4 | 1.3 | 0.4 | 2.0 | 0.6 |
| Limestone | 20.0 | 6 | 20.0 | 6 | 20 | 6 | 20.0 | 6 | 20.0 | 6 |
| Total | 100.0 | 30 | 100.0 | 30 | 100 | 30 | 100 | 30 | 100.0 | 30 |
| Humidity | 15 | | 15 | | 15 | | 15 | | 15 | |

Best technical recipe for testing and characterization of the results has been chosen from several pre-tested technical recipes.
The experimental stack structure has been configured based on one of these technical recipes. Therefore R1- Series III was considered the closest alternative on both the material structure of the homogenized stack and mechanical characteristics.

The parameters considered for manufacturing the agglomerate with large additions of ferrous waste are, as following: granulation spectrum of the mixture, determination of the estimated Fe content and basicity index, micro-pelletizing parameters control of the raw mixture in the mixing drum, through the specific diameter, $d_n$ [2, 8].

Granulation structure based on material types is presented in Table 4.

**Table 4**
GRANULOMETRIC STRUCTURE OF THE MIXTURE
OF RAW MATERIALS [1]

| Class type | Diameter, mm | Percentage share, % |
|---|---|---|
| Fine class | Under 0.5 | 23 - 45 |
| Neutral class | Between 0.5 and 2.5 | 14 - 35 |
| Core class | Over 2.5 | 26 - 63 |

Every 4 hours homogenized samples were taken during the material evacuation from the secondary mixing drum (SMD).

A one-kilogram sample weight was dried and passed through a 0.3 to 5mm separator. Values of the plus mesh (%) are enlisted in a logarithmic diagram (Rosin - Ramler - Benet granulation diagram) [1, 2, 4].

The intersection of the straight-line with the indicating line 1 on the abscissa is considered the specific diameter and represents the diameter for which 33 % of the separated material weight has higher dimensions than this value.

Laboratory experiments have shown that an optimal value for the homogenized mixture at a specific diameter of 2.6 to 2.9 mm, is registered (see Figure 1).

Homogenized mixture refers to an approximate corresponding content of ferrous waste (slags, blast furnace dust and blast furnace sludge).

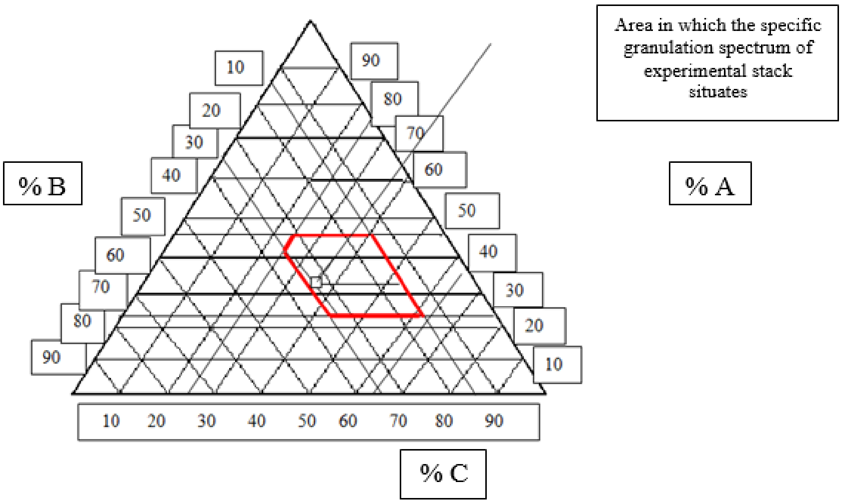

Fig. 1. Ternary diagram of granulometric classes specific to dusty materials used in agglomeration [1]
A - fine material class, under 0.5 mm; B - neutral material class, between 0.5 mm and 2.5 mm
C - core material class, over 2.5 mm. nside the marked area should fit all size compositions of dusty materials

Slag content either increases the stack's concentration of iron or replaces more poor iron ore. It is desirable to increase the proportion of Fe as long as constant agglomerate productivity is required. Pre-homogenization parameters control is accomplished by chemical analysis of Fe element or $CaCO_3$ by taking sequential samples on the route between the stack and PMD.

The parameters of the agglomeration process were: agglomeration layer thickness - 500 mm; pressure level under the grill - 0.88 atm; layer's combustion front velocity - 60 mm/min; belt speed - 6 m/min.

The chemical composition of the agglomerate resulting from experimental waste additions is shown in Table 5.

**Table 5**
THE CHEMICAL COMPOSITION OF THE AGGLOMERATE RESULTING FROM EXPERIMENTAL WASTE ADDITIONS [1]

| Nr. crt. | Recipe | The chemical composition % | | | | | |
|---|---|---|---|---|---|---|---|
| | | $Fe_{tot}$, % | FeO, % | $Fe_{met}$, % | $SiO_2$, % | CaO, % | Ib |
| 1 | SI R1 | 34.74 | 14.34 | 0.28 | 12.36 | 24.40 | 1.97 |
| 2 | SI R2 | 33.10 | 13.56 | 0.61 | 12.22 | 24.61 | 2.01 |
| 3 | SI R3 | 32.17 | 14.90 | 0.55 | 12.88 | 25.56 | 1.98 |
| 4 | SI R4 | 34.27 | 13.38 | 0.94 | 12.71 | 21.95 | 1.72 |
| 5 | SI R5 | 32.21 | 16.02 | 0.95 | 12.69 | 26.87 | 2.11 |
| 6 | SII R1 | 41.20 | 24.32 | 0.39 | 9.65 | 21.90 | 2.27 |
| 7 | SII R2 | 41.31 | 21.70 | 0.95 | 9.73 | 22.23 | 2.28 |
| 8 | SII R3 | 39.40 | 16.06 | 0.67 | 9.98 | 21.50 | 2.15 |
| 9 | SII R4 | 40.31 | 21.83 | 0.89 | 9.88 | 21.50 | 2.17 |
| 10 | SII R5 | 38.58 | 20.17 | 0.61 | 9.60 | 20.26 | 2.11 |
| 11 | SIII R1 | 39.58 | 11.26 | 1.1 | 11.41 | 21.38 | 1.87 |
| 12 | SIII R2 | 37.51 | 16.93 | 1.09 | 12.60 | 24.52 | 1.94 |
| 13 | SIII R3 | 40.66 | 17.46 | 0.70 | 9.62 | 24.46 | 2.54 |
| 14 | SIII R4 | 43.57 | 16.02 | 1.23 | 8.75 | 26.05 | 2.97 |
| 15 | SIII R5 | 41.66 | 19.85 | 0.69 | 8.23 | 23.50 | 2.85 |

The technological characteristics of the charge composition and the resulting agglomerate are shown in Tables 6, 7 and 8.

**Table 6**
THE TECHNOLOGICAL CHARACTERISTICS OF THE CHARGE COMPOSITION AND THE RESULTING AGGLOMERATE FOR SERIE I [1]

| Recipe | | R1 | R2 | R3 | R4 | R5 |
|---|---|---|---|---|---|---|
| Homogenized mass in the agglomeration box | kg | 27.7 | 28.3 | 26 | 26.8 | 24.9 |
| Ferrous agglomerate mass obtained | kg | 21.6 | 21.8 | 19.4 | 19.1 | 19.2 |
| Percentage of ferrous agglomerate obtained | % | 77.98 | 77.03 | 74.62 | 71.27 | 77.11 |
| Productivity | $t/m^2 \cdot h$ | 1.016 | 0.854 | 1.201 | 0.499 | 0.868 |
| Layer height | m | 0.375 | 0.375 | 0.385 | 0.385 | 0.375 |
| Homogenized density | $kg/m^3 \cdot 10^3$ | 1.44636 | 1.47769 | 1.32233 | 1.36302 | 1.30016 |

**Table 7**
THE TECHNOLOGICAL CHARACTERISTICS OF THE CHARGE COMPOSITION AND THE RESULTING AGGLOMERATE FOR SERIE II [1]

| Recipe | | R1 | R2 | R3 | R4 | R5 |
|---|---|---|---|---|---|---|
| Homogenized mass in the agglomeration box | kg | 28.05 | 28.2 | 28.3 | 27.5 | 40.3 |
| Ferrous agglomerate mass obtained | kg | 21.5 | 22.5 | 22.2 | 21.5 | 30.9 |
| Percentage of ferrous agglomerate obtained | % | 76.65 | 79.79 | 78.45 | 78.18 | 76.67 |
| Productivity | $t/m^2 \cdot h$ | 0.505 | 0.420 | 0.428 | 0.308 | 0.542 |
| Layer height | m | 0.39 | 0.39 | 0.39 | 0.38 | 0.475 |
| Homogenized density | $kg/m^3 \cdot 10^3$ | 1.408306 | 1.415837 | 1.420858 | 1.417026 | 1.66127 |

**Table 8**
THE TECHNOLOGICAL CHARACTERISTICS OF THE CHARGE COMPOSITION AND THE RESULTING AGGLOMERATE FOR SERIE III [1]

| Recipe | | R1 | R2 | R3 | R4 | R5 |
|---|---|---|---|---|---|---|
| Homogenized mass in the agglomeration box | kg | 27.6 | 23.8 | 26.3 | 23.8 | 24.7 |
| Ferrous agglomerate mass obtained | kg | 22.3 | 19.3 | 21.5 | 19.9 | 20.3 |
| Percentage of ferrous agglomerate obtained | % | 80.797 | 81.092 | 81.749 | 83.613 | 82.186 |
| Productivity | $t/m^2 \cdot h$ | 0.583 | 0.436 | 0.526 | 0.936 | 0.884 |
| Layer height | m | 0.375 | 0.37 | 0.37 | 0.375 | 0.37 |
| Homogenized density | $kg/m^3 \cdot 10^3$ | 1.441 | 1.259 | 1.391 | 1.242 | 1.307 |

The analysis of these results indicates both technological possibilities: waste recovery in various agglomeration recipes (blast furnace powder, blast furnace sledge and slags in relatively high proportions) and waste utility as raw material for blast furnaces.

## Results and discussions

The purpose of the industrial experiment was to test the operation for 36 hours of a blast furnace from ARCELOR MITTAL GALAŢI with a congestion load with the addition of 5.4 % blast furnace dust, 3.88 % blast furnace sludge and 4.86 % fine dross.

The experiment was carried out during six working periods (6 hours per working period). During this time, the furnace produced pig iron.

To achieve the objective, special agglomerate with fine ferrous waste was added, such as blast furnace dust, blast furnace slurry, and fine iron ore resulting in agglomeration return, and ground ferrous slags.

The percentage of the iron content of ferrous waste used in the agglomerate production recipe for the experimental campaign is shown in Table 9.

**Table 9**

THE PERCENTAGE OF THE IRON CONTENT OF FERROUS WASTE USED IN THE AGGLOMERATE PRODUCTION RECIPE [1]

| Nr. crt. | Ferrous wastes | The percentage of iron, % |
|---|---|---|
| 1 | Blast furnace dust | 35.95 |
| 2 | Blast furnace sludge | 43.13 |
| 3 | Dross | 72.32 |

The blast furnace operating parameters in the 36-hour experimental campaign are shown in Table 10. The main technical indicators of the blast furnace, during the experimental period, are presented in Table 11.

**Table 10**

THE BLAST FURNACE OPERATING PARAMETERS IN AN EXPERIMENTAL CAMPAIGN [1]

| Day | Hour | Q, $Nm^3/h$ | $T_{air}$, °C | $P_{air}$, atm. | $P_{gas}$, atm. | $T_{gas}$, °C | CO % in gas | $CO_2$ % in gas | $H_2$ % in gas |
|---|---|---|---|---|---|---|---|---|---|
| Day 1 | 14 | 241667 | 945 | 1.94 | 0.91 | 192 | 22.68 | 18.44 | 1.61 |
| Day 1 | 15 | 245823 | 957 | 2.01 | 0.98 | 226 | 22.60 | 18.38 | 1.68 |
| Day 1 | 16 | 245833 | 954 | 2.01 | 1.05 | 160 | 21.54 | 19.10 | 1.68 |
| Day 1 | 17 | 245833 | 955 | 1.92 | 0.95 | 207 | 20.62 | 18.78 | 1.70 |
| Day 1 | 18 | 245833 | 924 | 1.69 | 0.72 | 271 | 21.31 | 19.03 | 1.74 |
| Day 1 | 19 | 228033 | 930 | 1.79 | 0.87 | 199 | 22.05 | 19.56 | 1.43 |
| Day 1 | 20 | 223714 | 867 | 1,83 | 0,95 | 134 | 19.21 | 19.29 | 2.01 |
| Day 1 | 21 | 235250 | 890 | 1,81 | 1,05 | 130 | 12.47 | 12.56 | 1.48 |
| Day 1 | 22 | 233139 | 907 | 1,90 | 1,05 | 119 | 13.77 | 3.61 | 0.92 |
| Day 1 | 23 | 232281 | 890 | 1,90 | 1,07 | 110 | 14.74 | 1.39 | 0.65 |
| Day 2 | 24 | 213146 | 902 | 1,94 | 1,1 | 104 | 16.18 | 0.85 | 0.59 |
| Day 2 | 1 | 213129 | 916 | 1,88 | 1,15 | 129 | 13,23 | 0.63 | 0.57 |
| Day 2 | 2 | 200073 | 900 | 1,76 | 1,00 | 109 | 14,45 | 0.51 | 0.55 |
| Day 2 | 3 | 205393 | 915 | 1,83 | 1,05 | 118 | 16,41 | 0.45 | 0.57 |
| Day 2 | 4 | 194520 | 841 | 1,81 | 0,95 | 127 | 0.00 | 0.39 | 0.57 |
| Day 2 | 5 | 195237 | 727 | 1,86 | 1,01 | 106 | 0.00 | 0.33 | 0.55 |
| Day 2 | 6 | 204836 | 816 | 1,88 | 1,2 | 126 | 0.00 | 0.26 | 0.54 |
| Day 2 | 7 | 190878 | 702 | 1,81 | 1,15 | 95 | 0.00 | 0.20 | 0.52 |
| Day 2 | 8 | 191998 | 691 | 1,76 | 1,16 | 95 | 0.00 | 0.16 | 0.51 |
| Day 2 | 9 | 101520 | 680 | 0,97 | 0,86 | 94 | 0.00 | 0.13 | 0.50 |
| Day 2 | 10 | 51434 | 669 | 0,67 | 0,43 | 94 | 0.00 | 0.13 | 0.50 |
| Day 2 | 11 | 53432 | 659 | 0,45 | 0,45 | 94 | 0.00 | 0.14 | 0.50 |
| Day 2 | 12 | 53671 | 649 | 0,47 | 0,55 | 94 | 0.00 | 0.16 | 0.50 |
| Day 2 | 13 | 104669 | 639 | 0,93 | 0,75 | 93 | 0.00 | 0.16 | 0.50 |
| Day 2 | 14 | 205783 | 747 | 1,68 | 0,95 | 149 | 18.47 | 5.54 | 1.18 |
| Day 2 | 15 | 241908 | 837 | 1.81 | 1,12 | 337 | 19.87 | 16.70 | 1.40 |
| Day 2 | 16 | 245763 | 954 | 1.75 | 1,05 | 200 | 20.41 | 16.83 | 1.55 |
| Day 2 | 17 | 245763 | 983 | 1.82 | 1,05 | 211 | 19.96 | 18.06 | 1.40 |
| Day 2 | 18 | 237553 | 956 | 2.13 | 1.03 | 222 | 21.28 | 18.37 | 1.37 |
| Day 2 | 19 | 245763 | 935 | 2.08 | 0.97 | 160 | 17.49 | 15.47 | 1.00 |
| Day 2 | 20 | 241591 | 954 | 1.96 | 0.91 | 168 | 21.01 | 19.35 | 1.18 |
| Day 2 | 21 | 245763 | 972 | 1.76 | 0.75 | 260 | 21.69 | 19.45 | 1.38 |
| Day 2 | 22 | 245672 | 980 | 1.99 | 0.88 | 219 | 23.29 | 18.55 | 1.40 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Day 2 | 23 | 245763 | 955 | 1.99 | 0.91 | 216 | 22.71 | 18.85 | 1.35 |
| Day 3 | 24 | 236603 | 965 | 1.56 | 0.78 | 155 | 22.70 | 19.68 | 1.49 |
| Day 3 | 1 | 245763 | 966 | 2.07 | 0.97 | 192 | 22.03 | 18.89 | 1.38 |
| Day 3 | 2 | 245763 | 982 | 1.99 | 0.95 | 221 | 21.75 | 19.06 | 1.40 |
| Day 3 | 3 | 245763 | 947 | 2.05 | 0.96 | 284 | 21.79 | 19.08 | 1.42 |
| Day 3 | 4 | 245763 | 960 | 2.01 | 0.95 | 218 | 22.73 | 19.07 | 1.22 |
| Day 3 | 5 | 245763 | 986 | 2.06 | 0.92 | 153 | 21.37 | 19.18 | 1.22 |
| Day 3 | 6 | 245763 | 993 | 2.04 | 0.95 | 175 | 21.86 | 19.85 | 1.39 |
| Day 3 | 7 | 242582 | 1004 | 2.04 | 0.93 | 289 | 22.84 | 18.77 | 1.46 |
| Day 3 | 8 | 241731 | 946 | 2.06 | 0.97 | 192 | 22.92 | 19.04 | 1.48 |
| Day 3 | 9 | 245833 | 954 | 2.07 | 0.99 | 213 | 22.22 | 19.21 | 1.79 |
| Day 3 | 10 | 237500 | 941 | 1.85 | 0.86 | 288 | 23.02 | 18.75 | 1.96 |
| Day 3 | 11 | 245833 | 935 | 1.95 | 0.98 | 184 | 21.81 | 19.43 | 1.78 |
| Day 3 | 12 | 245828 | 952 | 1.95 | 0.94 | 162 | 21.19 | 19.95 | 1.57 |
| Day 3 | 13 | 245833 | 991 | 2.00 | 0.98 | 155 | 21.69 | 20.00 | 1.55 |
| Day 3 | 14 | 245832 | 1001 | 2.21 | 1.13 | 191 | 21.89 | 19.91 | 1.51 |

**Table 11**

THE MAIN TECHNOLOGICAL INDICATORS OF THE BLAST FURNACE, DURING THE EXPERIMENTAL PERIOD [1]

| Day | Hour | Structure of ferrous load of blast furnace (agglomerate, pellets, iron ores) | | | Pig iron at unloading | Hourly iron production | Pig iron composition, % | | Coke cons. Kt | $CH_4$ cons. | Slag basicity Ib |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Aggl., % | Pellets, % | Ores, %. | t | t/h | Si | Mn | kg/t | $Nm^3/t$ | |
| Day 1 | 14 | 75 | 17.5 | 7.5 | 334 | 111 | 0.68 | 0.54 | 519 | 33.4 | 1.21 |
| Day 1 | 15 | 75 | 17.5 | 7.5 | | 111 | 0.68 | 0.54 | 521 | 34.5 | |
| Day 1 | 16 | 75 | 17.5 | 7.5 | | 111 | 0.68 | 0.54 | 523 | 32.4 | |
| Day 1 | 17 | 75 | 17.5 | 7.5 | 286 | 143 | 0.57 | 0.63 | 522 | 36.7 | 1.26 |
| Day 1 | 18 | 75 | 17.5 | 7.5 | | 143 | 0.57 | 0.63 | 529 | 38.6 | |
| Day 1 | 19 | 75 | 17.5 | 7.5 | 321 | 107 | 0.76 | 0.6 | 527 | 35.9 | 1.23 |
| Day 1 | 20 | 75 | 17.5 | 7.5 | | 107 | 0.76 | 0.6 | 526 | 28.6 | |
| Day 1 | 21 | 75 | 17.5 | 7.5 | | 107 | 0.76 | 0.6 | 525 | 27.7 | |
| Day 1 | 22 | 67.5 | 22.5 | 10 | 178 | 89 | 0.86 | 0.64 | 519 | 28.9 | 1.27 |
| Day 1 | 23 | 65 | 25 | 10 | | 89 | 0.86 | 0.64 | 519 | 29 | |
| Day 2 | 24 | 65 | 25 | 10 | 223 | 74.3 | 0.91 | 0.7 | 517 | 28.8 | 1.28 |
| Day 2 | 1 | 65 | 20 | 15 | | 74.3 | 0.91 | 0.7 | 518 | 25.7 | |
| Day 2 | 2 | 65 | 20 | 15 | | 74.3 | 0.91 | 0.7 | 516 | 29.7 | |
| Day 2 | 3 | 65 | 20 | 15 | 258 | 129 | 0.88 | 0.68 | 514 | 35.5 | 1.25 |
| Day 2 | 4 | 65 | 20 | 15 | | 129 | 0.88 | 0.68 | 514 | 37 | |
| Day 2 | 5 | 65 | 20 | 15 | 201 | 67 | 0.76 | 0.67 | 513 | 36.6 | 1.25 |
| Day 2 | 6 | 62 | 25.5 | 15 | | 67 | 0.76 | 0.67 | 515 | 35 | |
| Day 2 | 7 | 62 | 25.5 | 15 | | 67 | 0.76 | 0.67 | 514 | 39.7 | |
| Day 2 | 8 | 62 | 25.5 | 17.5 | 269 | 89.6 | 0.75 | 0.55 | 519 | 38 | 1.26 |
| Day 2 | 9 | 65 | 22.5 | 17.5 | | 89.6 | 0.75 | 0.55 | 518 | 40.3 | |
| Day 2 | 10 | 65 | 22.5 | 17.5 | | 89.6 | 0.75 | 0.55 | 522 | 41.3 | |
| Day 2 | 11 | 67.5 | 20 | 17.5 | 387 | 129 | 0.72 | 0.46 | 524 | 42 | 1.26 |
| Day 2 | 12 | 67.5 | 20 | 17.5 | | 129 | 0.72 | 0.46 | 523 | 44.2 | |
| Day 2 | 13 | 67.5 | 20 | 17.5 | | 129 | 0.72 | 0.46 | 528 | 42.1 | |
| Day 2 | 14 | 67.5 | 20 | 17.5 | 322 | 107.3 | 0.67 | 0.48 | 529 | 39.4 | 1.24 |
| Day 2 | 15 | 67.5 | 20 | 17.5 | | 107.3 | 0.67 | 0.48 | 433 | 35.6 | |
| Day 2 | 16 | 60 | 22.5 | 17.5 | | 107.3 | 0.67 | 0.48 | 531 | 38.7 | |
| Day 2 | 17 | 60 | 22.5 | 17.5 | 311 | 103.6 | 0.71 | 0.56 | 534 | 41.1 | 1.27 |
| Day 2 | 18 | 60 | 22.5 | 17.5 | | 103.6 | 0.71 | 0.56 | 539 | 44.3 | |
| Day 2 | 19 | 60 | 22.5 | 17.5 | | 103.6 | 0.71 | 0.56 | 534 | 42.8 | |
| Day 2 | 20 | 60 | 22.5 | 17.5 | 280 | 93.3 | 0.76 | 0.56 | 533 | 39.5 | 1.27 |
| Day 2 | 21 | 60 | 22.5 | 17.5 | | 93.3 | 0.76 | 0.56 | 529 | 39 | |
| Day 2 | 22 | 60 | 22.5 | 17.5 | | 93.3 | 0.76 | 0.56 | 527 | 41.2 | |
| Day 2 | 23 | 60 | 17.5 | 22.5 | 264 | 132 | 0.82 | 0.67 | 526 | 44.8 | 1.26 |
| Day 3 | 24 | 60 | 17.5 | 22.5 | | 132 | 0.82 | 0.67 | 525 | 46.9 | |
| Day 3 | 1 | 60 | 17.5 | 22.5 | 228 | 76 | 0.74 | 0.55 | 522 | 45.5 | 1.25 |
| Day 3 | 2 | 60 | 17.5 | 22.5 | | 76 | 0.74 | 0.55 | 529 | 42.8 | |
| Day 3 | 3 | 60 | 17.5 | 22.5 | | 76 | 0.74 | 0.55 | 528 | 43.9 | |
| Day 3 | 4 | 60 | 17.5 | 22.5 | 219 | 109.5 | 0.79 | 0.55 | 539 | 45.3 | 1.25 |
| Day 3 | 5 | 60 | 17.5 | 22.5 | | 109.5 | 0.79 | 0.55 | 537 | 41.2 | |
| Day 3 | 6 | 60 | 17.5 | 22.5 | 245 | 81.6 | 0.81 | 0.59 | 533 | 38.4 | 1.27 |
| Day 3 | 7 | 60 | 17.5 | 22.5 | | 81.6 | 0.81 | 0.59 | 529 | 39.5 | |
| Day 3 | 8 | 60 | 17.5 | 22.5 | | 81.6 | 0.81 | 0.59 | 527 | 36.6 | |
| Day 3 | 9 | 60 | 17.5 | 22.5 | 302 | 101 | 0.87 | 0.64 | 538 | 37.9 | 1.27 |
| Day 3 | 10 | 60 | 17.5 | 22.5 | | 101 | 0.87 | 0.64 | 534 | 41.8 | |
| Day 3 | 11 | 60 | 17.5 | 22.5 | | 101 | 0.87 | 0.64 | 528 | 42.6 | |
| Day 3 | 12 | 60 | 17.5 | 22.5 | 246 | 82 | 0.8 | 0.55 | 521 | 38.2 | 1.26 |
| Day 3 | 13 | 60 | 17.5 | 22.5 | | 82 | 0.8 | 0.55 | 524 | 36.2 | |
| Day 3 | 14 | 60 | 17.5 | 22.5 | | 82 | 0.8 | 0.55 | 531 | 37.1 | |

In the experimental period in which special agglomerates were used, the blast furnace operating parameters had approximate constant values, except for a five-hour period in which a quarter of the capacity was reduced due to technical failures of the charger and the gas analyzers.

Pig iron production, the specific consumption of methane, air, steam and oxygen gas had values close to those of a conventional blast furnace operation without a special agglomerate.

The average pig iron output per discharge was 270.7 t/discharge and the average hourly pig iron production was 99.8 t/hour.

Average specific technical coke consumption, methane gas, $CH_4$ was 523 kg/t and 37.98 $Nm^3/t$.

In the experimental period, the average content of pig iron silicon was 0.768% and the average content of pig iron-manganese was 0.585 %.

The mean average composition of cast iron during the experimental period is presented in Table 12.

**Table 12**

COMPOSITION OF CAST IRON DURING THE EXPERIMENTAL PERIOD

| C % | Mn % | Si % | S % | P % | Cr % | Ni % | Cu % | As % | Sn % | Co % | Fe% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.94 | 0.585 | 0.768 | 0.0034 | 0.0094 | 0.001 | 0.003 | 0.003 | 0.009 | 0.001 | 0.01 | ball. |

White pig iron is produced in the blast furnace. The microscopic analysis of a solidified cast iron sample is shown in Figure 2, without chemical attack sample and in Figure 3 with Nital 2% chemical attack sample.

The hard iron obtained through this technology has a chemical composition and characteristic structure (ledeburite / graphite), falling within the standards of the field.

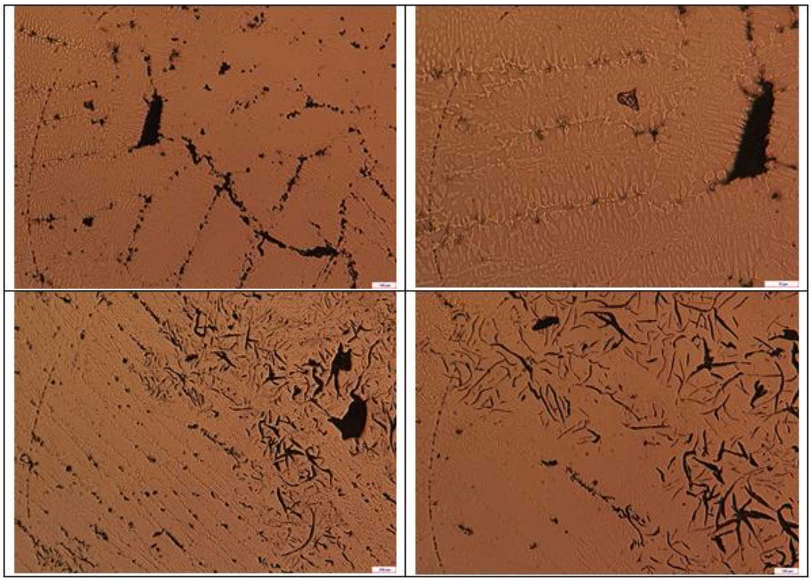

Fig. 2. White pig iron - Ledeburita and graphite, optical microscopy

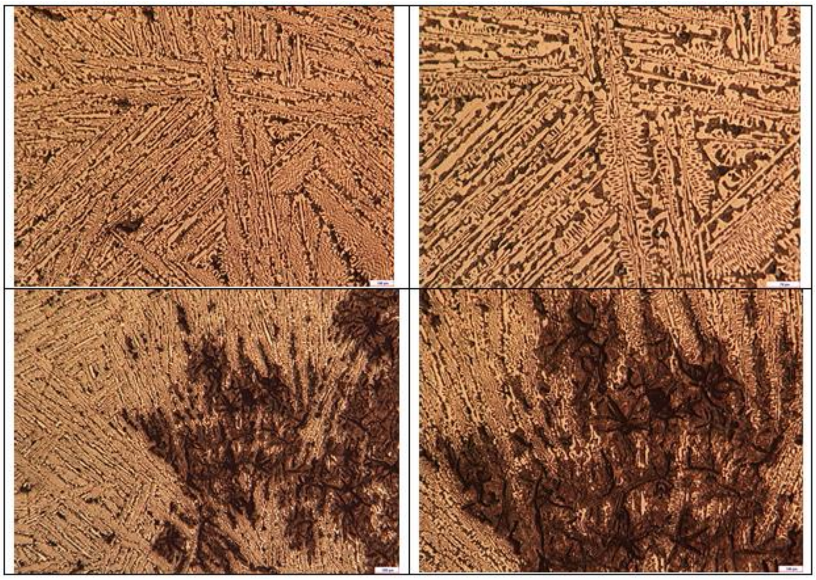

Fig.3. White pig iron - Ledeburite and graphite,
optical microscopy, with Nital 2% attack

In the images, the presence of the specific ledeburite in white cast iron, but also areas where the carbon appears as graphite. It is noted that the pig iron parameters fall within normal limits, close to time, which shows the stability of the blast furnace in these conditions.

The determinations were made using the image analysis software BUEHLER - OMNIMET ENTERPRISE, on the computerized system (optical microscope, REICHERT UnivaR type; video camera with adapter; image acquisition board (interface); PC compatible I.B.M.; printer).

## Conclusions

Significant amounts of ferrous scrap resulted from pig-iron and steel production flow can be recycled as agglomerate materials, successfully used as part of 2700 m$^3$ blast furnace charge.

The percentage of scrap can be increased by 1.5 to 2% on average, without affecting the agglomerates quality.

There is a significant decrease in productivity of the agglomeration machine due to the introduction of low-iron materials content and lower volumetric density as well as due to the wetting and granulating characteristics, consequently.

Blast furnace sludge causes a significant decrease in productivity from 1.1 to 0.5 t.aggl. /m$^2$·h due to very low bulk density and low iron content.

The experimental results show low overall productivity of about 0.67 t.aggl./m$^2$·h, but it is important to note the increase of productivity with increasing the slag content from 0.43 to 0.93 t.aggl./m$^2$·h.

The variation could be explained by the high iron content of dross, 67.5 %, due to the volumetric density of 2.6·10$^{-3}$ kg/m$^3$, but low average productivity might be partly determined by low wetting capacity, as well.

Since the sterile for the studied materials is like that of the basic and return materials, the direct influence on the mechanical characteristics is relatively small.

The optimal recipe for testing and characterization of the results was chosen from several recipes previously tested in the laboratory from which the recipe 1 was considered as basic on the experimental stack structure from both points of view: best mechanic characteristics and closest homogenized stack.

The experimental results have also demonstrated the possibility of agglomeration plant to process significant quantities of ferrous waste and that the introduction of ferrous waste into the agglomeration procedure is a long-term recycling solution with very low costs.

The use of this kind of waste is effective as it increases the iron content of the homogenized material, on one hand, and thus the iron content of the agglomerate by 2.2 to 5 % and reduces the necessary quantity of coke powder for the agglomeration process.

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