The Study Of Influence Of Fine Coal Fraction Addition To Coking Blend And Its Partial Briquetting On Coke Quality Parameters

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Abstract. Paper presents the results of study of influence of fine coal fraction addition to coking blend and its partial briquetting on coke quality parameters CRI and CSR. CRI and CSR are currently the key quality parameters of coke commonly used to assess its technological suitability for blast furnace coke. The raw materials used for the research were coals and fine coal fractions (flotation concentrates) from one of the domestic producers of coking coals. These coals are the basic components of blends used in the domestic coke industry. Studies have shown that increase in the content of flotation concentrates (FC) in the coal blend results in a significant reduction of the bulk density of the coal charge. As a consequence of the decrease in the density of the coal charge, coke reactivity CRI increased and coke strength after reaction CSR decreased. To minimize the adverse impact of FC addition, partial batch briquetting was implemented. Briquetting of the coal charge made it possible to produce coke with qualitative parameters similar to the same blend without the addition of a flotation concentrate and allows to improve the quality of coke produced or to produce coke of the same quality but with a higher share of semi-soft coals.

1. Introduction

The dynamic technological development of the metallurgical industry observed during the last decade (operation of blast furnaces with an increasing volume, use of substitute fuels) has led to a significant increase in the requirements for the quality of coke, including in particular its strength parameters [1]. Achieving quality parameters with the values demanded by its customers requires a high share of the highest quality coking coals in the charge mixture, which significantly translates into the increase in unit production costs (approx. 75% of the production cost is the cost of the charge mixture) [2]. This is particularly important for the Polish coke industry which has been the world's leading coke exporter in recent years, targeting its product to demanding Western European consumers.

The problem of domestic coke producers is the lack of coking coals with the best quality parameters in the domestic mining structure and considerable variations in the quality of domestic coking coals. Over the last several years, there has also been an unfavorable upward trend, in coal concentrates sent to coking plants, of the finest fraction (<0.5 mm), which results in a reduction in the bulk density of the charge mixture and, consequently the quality of the coke obtained. Currently,
domestic producers take advantage of the import of high quality overseas coals (mainly Australia, the USA) and introduce them as additional components of the blends which enables the production of coke of the appropriate quality. The volume of share of imported coals in the coke production increases year by year and the share of domestic coals decreases.

In addition, there is a problem (on the part of the coal producers) of the use of fine coal fractions (FCF) from the production of coking coals which, in accordance with the applicable legal acts (Regulation of the Minister of Energy regarding quality requirements for solid fuels, resolution of provincial assemblies under the so-called anti-smog law [3]) have been virtually eliminated from the fuel market. FCF, in particular from the coking coal flotation, has proper coking parameters, however, its very fine graining and relatively high moisture content, virtually prevent its use in top (gravity) charging batteries, due to its unfavorable impact on the density of the coal charge (as a consequence on the quality of coke) and the economics of the coking process (energy for evaporation of additional moisture). A solution that allows for significant reduction of the above problems, is the use of appropriate technology to increase the density of coal charge, directly affecting not only the quality of the obtained coke but also the productivity of coke oven batteries [4][5][6]. The introduction of such technology makes it possible to improve the quality of coke when using a high-quality coal-blend or to maintain the quality of coke with partial replacement of these coals with domestic coals of worse coking parameters. Briquetting of a part of the coal charge is one of the most effective methods of compacting it, possible to be implemented with coke oven batteries for top (gravity) charging system, designed for continuous operation. It gives an option of compacting FCF and introducing it into a charge blend in the form of a compacted component (briquette or pellet). The response to the aforementioned problems is to develop and implement into practice a technology for the production of compacted component of FCF mixtures in the batteries for top charging. Briquette / pellet component thus produced will be a component of the coke mixture intended for the coking process.

The aim of study was to assess the influence of fine coal fraction addition to the coking blend on crucial coke quality parameters i.e. coke reactivity index CRI and coke strength after reaction CSR.

2. Materials and methods

2.1. Raw materials

The raw materials used for the research were coals and fine coal fractions (flotation concentrates) from one of the domestic producers of coking coals. These coals are the basic components of blends used in the domestic coke industry. The basic physicochemical parameters of coal raw materials are presented in Table 1.

The analyses of single coals were performed according to proper standards procedures. Ash content A\text{d} was determined according to PN-ISO 1171:2002. Carbon (C\text{d}), hydrogen (H\text{d}) and nitrogen (N\text{d}) contents were determined according to procedure ISO 29541:2010 and sulfur content according ISO 19579:2006. Alkalinity index (AI) were calculated based on ash chemical composition (determined according to ICHPW procedure Q/LP/55/B:2016) with use of following formula:

\[
AI = A^d \times \frac{Na_2O + K_2O + Fe_2O_3 + MgO + CaO}{Al_2O_3 + SiO_2}
\]

where:
A\text{d} – ash content (dry basis), %
Na\text{d}, K\text{d}, Fe\text{d}, Mg\text{d}, Ca\text{d}, Al\text{d}, Si\text{d} – content of individual components, %

For coking tests, coking blends with a composition similar to those used in industrial practice for coke top (gravity) charged coke oven batteries. Coals (C1-C3) and flotation concentrates (F1-F3) correspond to type 35 (hard) (according to PN-G-97002: 1982P), while the other coals and flotation
concentrates correspond to type 34 (semi-soft). The compositions of coking blends were agreed with the industrial partner of the project – JSW KOKS S.A. The B20 blend is a reference blend with 20% type 34 (semi-soft) coal content. B30 and B40 blends contain 30 and 40% of type 34 coals, respectively. The shares of the remaining coals were reduced proportionally.

| Parameter     | Coals       |       |       |       |       |
|---------------|-------------|-------|-------|-------|-------|
|               | C1          | C2    | C3    | C4    | C5    |
| Ad, %         | 6.0         | 9.2   | 6.4   | 6.3   | 4.3   |
| Cdaf, %       | 89.6        | 86.9  | 89.3  | 86.9  | 86.8  |
| Hdaf, %       | 4.7         | 5.1   | 4.6   | 5.1   | 5.0   |
| Ndaf, %       | 1.3         | 1.2   | 1.0   | 1.1   | 1.0   |
| Sdaf, %       | 0.52        | 0.69  | 0.48  | 0.46  | 0.68  |
| AI –          | 1.84        | 2.11  | 2.81  | 1.87  | 3.82  |

**Table 1. Properties of raw materials used.**

| Flotation concentrates |       |       |       |       |       |
|------------------------|-------|-------|-------|-------|-------|
|                        | F1    | F2    | F3    | F4    | F5    |
| Ad, %                  | 6.0   | 9.2   | 6.4   | 6.3   | 4.3   |
| Cdaf, %                | 89.2  | 87.36 | 89.80 | 86.50 | 85.99 |
| Hdaf, %                | 4.70  | 4.92  | 4.71  | 4.98  | 5.01  |
| Ndaf, %                | 1.38  | 1.35  | 1.10  | 1.21  | 1.28  |
| Sdaf, %                | 0.60  | 0.76  | 0.43  | 0.60  | 1.15  |
| AI –                   | 1.60  | 1.21  | 1.46  | 3.60  | 4.51  |

**Table 2. Composition of coal blends for coking tests.**

| Share of coals, %  | Coking blend |       |       |       |
|--------------------|--------------|-------|-------|-------|
|                    | B20          | B30   | B40   |       |
| C1/F1              | 30.0         | 26.3  | 22.4  |       |
| C2/F2              | 35.0         | 30.6  | 26.3  |       |
| C3/F3              | 15.0         | 13.1  | 11.3  |       |
| C4/F4              | 15.0         | 20.0  | 25.0  |       |
| C5/F5              | 5.0          | 10.0  | 15.0  |       |

2.2. Research methodology

The assessment of the possibility of increasing the use of fine coal fractions (in the form of flotation concentrates) and increasing the share of type 34 (semi-soft) Polish coals was carried out on the basis of laboratory coking tests in the Karbotest® installation (4 kg of coal charge). Generally, in coal concentrates sent to domestic coking plants, there are some quantities of flotation concentrates, however their participation is limited.

The first series of tests assessed the impact of flotation concentrates share in the coking blend on the coal blend bulk density and crucial coke quality indicators, i.e. CRI (coke reactivity index) and CSR (coke strength after reaction). The B20 blend without a flotation concentrate addition (an ideal
case) is a reference blend – composition similar to blends used in domestic coke making industry (top charged batteries). To the aforementioned blend, 15, 30, 40 and 50% of flotation concentrates (blended) were added. The composition of a part of the blend composed of flotation concentrates corresponded to a coal blend composition without the addition of flotation concentrates (Table 2).

In the second series of tests, the optimum share (proportion) of briquettes in the coal charge was determined (in the aspect of maximum coal blend bulk density). The possibility of introducing of flotation concentrates into the reference blend was also investigated using the method of partial briquetting of the charge – for an optimal share of briquettes.

The third series of coking tests was carried out using blends B20, B30 and B40 (semi-soft coal content respectively: 20, 30 and 40%) with 30% flotation concentrates content and optimal share of the briquettes. Two coking tests were performed for each of the blends: the first test included briquetting a mixture of coals and flotation concentrates, the second test included briquetting only a part consisting of flotation concentrates. For the briquetting process, coal tar was used as a binder in the amount of 5% m/m. Dimensions of the produced briquettes were: approx. 24 x 24 x 13 mm. Device for briquetting (roller press) and the general appearance of the briquettes are presented in Fig. 1. As in the previous test series, the impact of aforementioned technological operations on the bulk density of the coal blend and the quality of the produced coke was carried out.

![Briquetting Press and Briquettes](image)

**Figure 1.** General view of briquetting press, forming elements and produced briquettes.

### 3. Results and discussion

Density of coal charge influences the quality of the obtained coke and coke oven chambers production capacity [1][2]. As results from the research presented in Figure 2, the increase in the content of flotation concentrates (FC) in the coal blend results in a significant reduction of the bulk density of the coal charge. The value of the coal charge density decreased from 746.5 kg/m$^3$ (for a blend with no flotation concentrate) to 716.8 kg/m$^3$ for a blend with the addition of 50% flotation concentrate. This is mainly due to the very fine graining of the flotation concentrates i.e. d(0.1) 17.0 μm, d(0.5) 224.5 μm and d(0.9) 737.9 μm. Fine graining and hence the higher surface area of the coal grains hinders their rearrangement during the gravitational loading of the coal charge. This is the result of the increase in the adhesion associated with the higher grain surface.
CRI and CSR are currently the key quality parameters of coke commonly used to assess its technological suitability for blast furnace coke, used all over the world. As a consequence of the decrease in the density of the coal charge, an adverse increase in the reactivity of the produced coke was noted (Fig. 3). The value of coke reactivity index CRI increased from 31.7 to 36.9%. At the same time, the CSR value of coke decreased (from 56.8 to 47.0%) which is clearly visible in Fig. 4. The test results clearly indicate that the addition to the coal charge of flotation concentrates in a loose form negatively affects the efficiency of the coking process. Both the density of the charge (which determines the productivity of coke oven batteries) and the key quality parameters of the coke obtained have decreased. In the case study, both the coal blend and the blend of flotation concentrates were characterized by a fixed moisture content of 9%. In industrial practice, the flotation concentrates are characterized by a higher content of moisture reaching even more than 25%. In that case their influence could be even more visible.

![Figure 2. Influence of flotation concentrate share on bulk density of coking blend.](image)

![Figure 3. Influence of flotation concentrate share in coking blend on coke reactivity index CRI.](image)
In order to counteract the adverse effect of the flotation concentrate additive, it is necessary to simultaneously limit the main effect that this concentrate causes, i.e. the decrease in bulk density of the charge. This can be achieved by implementing an effective method of increasing the density of the coal charge. I that case, there is the technological possibility to use a certain amount of flotation concentrates in the coal charge and/or to increase the share of cheaper components in the coal charge. There are a few possibilities to increase the coal charge bulk density [2][4][5][6]: adjusting the grain size distribution, moisture content (drying), oil addition and mechanical treatment (e.g. partial briquetting or stamping). For coke oven batteries with gravity charging, the use of stamping of the charge is impossible and the most effective technology (in the aspect of density increase) from the above mentioned is partial briquetting. The mentioned technology consists in separating and briquetting a part of the coal charge, and then mixing the briquetted and loose parts and subjecting them to the coking process. The key point in the application of this technology is the proper selection of the share of briquettes in the coal charge in order to maximize the density of the charge. The research shows that the highest density is obtained for 30% briquettes content in the coal charge (Fig. 5). The increase in density in relation to the coal charge without briquettes amounted to approx. 6.7%. Therefore, the value of 30% of briquettes was considered to be the optimal value – used in further tests.

**Figure 4.** Influence of flotation concentrate share in coking blend on coke strength after reaction CSR.

**Figure 5.** Influence of briquettes share on coal charge bulk density (assessed for B30 blend containing 30% flotation concentrates).
In Figure 6 the influence of semi-soft coals share and partial briquetting implementation on coke CRI was presented. Red dots represent coal blend with 30% content of flotation concentrates in a loose form. The black dots represent a blend without flotation concentrate, while the green dots refer to partially briquetted coal blends containing 30% flotation concentrates. It is clearly visible that the increase in the share of semi-soft coals caused a decrease in the quality of coke – an increase in coke reactivity index CRI. At the same time, with the use of partial briquetting technology, beneficial results in the form of reduced CRI were observed. The value of the reactivity index decreased by 1.7 percentage points on average. Consequently, the CSR improvement was also noted (Fig. 7). The value of post-reaction strength increased on average by 4.2 percentage points.

According to the presented data, the use of partial briquetting technology allows to improve the quality of coke produced or to produce coke of the same quality but with a higher share of semi-soft coals. Moreover, in the case of B20 blend with 30% flotation concentrate content, briquetting of the coal charge made it possible to produce coke with qualitative parameters similar to the same mixture without the addition of a flotation concentrate. Blue dotted lines in Figure 7 show the possibility of increasing the share of semi-soft coals, maintaining the quality of the coke corresponding to the
reference coal blend B20. In the case of the CRI index, the quality of coke can be maintained with the introduction of 6.8% more semi-soft coals, while in the case of CSR – even 12.9% more. In industrial practice, this would allow for a significant reduction in the costs of preparing a coking coal blend. Obtained test results, however, require confirmation in industrial conditions, which will be implemented in the further stages of the project.

4. Conclusion

Based on the conducted research, the following conclusions can be formulated:

– the increase in the content of flotation concentrates (FC) in the coal blend results in a significant reduction of the bulk density of the coal charge
– as a consequence of the decrease in the density of the coal charge, an adverse increase in the reactivity CRI and decrease of post-reactive strength CSR of the produced coke was noted
– briquetting of the coal charge made it possible to produce coke with qualitative parameters similar to the same blend without the addition of a flotation concentrate
– the use of partial briquetting technology allows to improve the quality of coke produced or to produce coke of the same quality but with a higher share of semi-soft coals.

5. References

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Acknowledgments

Work carried out as part of the project by the acronym DensiCoal by the consortium JSW Innowacje S.A / JSW Koks S.A / JSW S.A. The executor of the presented research part of Project is the Institute for Chemical Processing of Coal, Zabrze (ICHPW, Poland).

The presented results are part of the research carried out as part of the project POIR.01.02.00-00-0203/17 pt. "Technology for production of densified component of coal blends with use of fine coal fraction (FCF) for top charged coke oven batteries", co-financed from the European Regional Development Fund.