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INFLUENCE OF INTENSIFICATION FACTORS ON QUALITY OF Fe AGGLOMERATES MADE WITH ALTERNATIVE FUEL

Currently is the biggest problem of metallurgical companies the increase of fossil fuel prices and strict environmental regulations. As a result of this, companies must look for alternatives that would reduce the amount of fossil fuels and reduce emissions. Wood sawdust has huge energy potential, which can be used in the process of agglomerate production. This type of energy is locally available, has some similar properties as fossil fuels and is economically advantageous. For these reasons, experimental study using laboratory agglomeration pan was realized to study the possibility of agglomerate production with a mixed fuel. Experimental results show the viability of mixed fuel use in the agglomeration process, but also show significant possibility for improvement. The maximum acceptable substitution ratio, which corresponds to qualitatively suitable agglomerate is 20% of pine sawdust. Based on the realized experiments and the obtained results we have acceded to the intensification of the agglomeration process with an objective to increase the amount of added substitution fuel while maintaining the required quality of agglomerate.

Keywords: processing; sintering;intensification; microstructure; agglomerate; fuel

1. Introduction

The worldwide increase in the volume of steel production closely affects the consumption of coal. Almost 3/4 of steel produced is directly related to the coal and metallurgical enterprises annually use about 15% of the total coal consumption [1]. Coking coal prices have fallen to about half of the record prices with possible further decline because of the conditions of steel production in China [2].The price of coke still fluctuates at the levels from 200 to 500 USD depending on the quality and moderately increases [3]. Research in the area of the agglomeration process is majority focused on reducing of energy consumption, reducing of pollutants and to increase of the production of agglomerate [4-7]. The price of fossil fuels and environmental policies of countries (e.g. EU 27) is the driving force behind many of the global steel producers, who conduct research in partnership with research institutions. The studies are focused on the use of various types of biomass in the production of agglomerate or its partial application in the coke production and similar. In most cases, locally available biomass and waste products are used thus reducing input costs, which is an important feasibility precondition [8-9]. Zandi (2010) used filter cake from sugar cane and olive residues, Ooi (2008) used sunflower seed hulls for research, Gan (2012) and Cheng (2016) used charcoal, dry straw and sawdust as an alternative fuel [10-13]. The largest biomass resource in Slovakia in terms of use in the agglomeration process is forest dendromass, the amount of which is around 2.432 mil. tonnes and the corresponding energy potential is 26.8 PJ. Next come wood processing industry with an amount of about 1.835 million. tonnes (22 PJ), or agricultural biomass for burning at the amount of 2.031 million. tonnes (28.6 PJ). An important source of biomass can also be purpose-grown rapidly growing plants (4.05 mil. tonnes, i.e. 40.6 PJ) [14-15]. These can be used in several ways, e.g. for briquettes, wood chips, sawdust, or for refinement by pyrolysis to charcoal, thus the quality of the product becomes closer to the level of fossil fuels. The wood processing industry produces 3 major items: cuttings, which make up to 36.1%, black liquor (25%) and sawdust (about 16%). Utilization of wastes is around 50%, whereas large companies are able to make use of these materials [16]. In the context of experiments aimed at the application of biomass in the agglomeration charge in the laboratory with aim to reduce emissions and improve quality, several types of biomass have been used. The first series of studies focused on the use of charcoal [17]. In a second series pine sawdust was used as an alternative fuel and in the third series oak sawdust was used [18-19]. As a partial replacement of coke breeze soft wood – pine sawdust was also used. Scots pine (Pinussylvestris) ranks among the most represented woody plant species in Slovakia, its overall share of forest trees in SR is 7%. It belongs to trees with a minimum requirements for growth, its structure makes it suitable for use in construction, or packaging industry [20]. Wood sawdust resulting from wood processing or packaging industry may become a fuel source in agglomerate production process, which is a part of steel production worldwide [21-22].

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2. Experimental materials and methods

To study the impact of selected parameters change on the course of the agglomeration process and the quality of agglomerate there was carried out a series of sinterings. As a standard agglomerate mixture was used a mixture with 14% share of pine sawdust, which corresponds to a mixture with the highest proportion of fossil fuel and with the acceptable properties of the agglomerate. Our aim was to increase the proportion of pine sawdust from 14% to the highest possible limit by setting up intensification measures. Sinterings were identified as BOR1 to BOR5. BOR1 stands for standard sintering in which there were implemented no intensification measures and served for a comparison with sinterings BOR2 to BOR5, i.e. sinterings in which there were implemented intensification measures. BOR2 was a sintering in which the negative pressure was changed to 3 kPa. In BOR3, process of blending the mixture was changed so that all the fuel was added into the dry mixture and sawdust was added in the end. In BOR4 return agglomerate was used and blending was the same as in BOR3. In BOR5 was also used return agglomerate and the mixture was blended in three different ways. In the first case sawdust was fed into the dry mixture and the coke was added progressively throughout the blending of the mixture. In the second case, 2/3 of coke and sawdust were added into the dry mixture and the remaining 1/3 of coke and sawdust was added before the completion of pelletization. In the third case, the coke and sawdust were mixed together and then dosed into a dry mixture. Standard procedure for the preparation of the agglomerate mixture is as follows: Materials for agglomeration charge are accurately weighed according calculated material balance using PC software, and then stored for 7 days in homogenization pile. Subsequently, the material is homogenized, divided into thirds and made ready for pelletization. One third of the prepared mixture and 2/3 of fuel are charged into the pelletization device and gradually water is added by means of a dispenser. Before completing the pelletization process the remaining 1/3 fuel is added pelletization is finished and permeability of the mixture is measured. This process is repeated 3 times. If the mixture complies, it is fitted into a heated sintering pot and a sintering of the mixture takes place. Standard negative pressure during sintering is from 2 to 5 kPa. Analysis of coke breeze and pine sawdust is shown in Table 1. BOR5 agglomerate made with pine sawdust as a fuel was subjected to microscopic analysis and EDX analysis on a JEOL 6380 scanning electron microscope. The porosity of the BOR 5 agglomerate was evaluated microscopically on a Nikon Epiphot 200 optical microscope. Using the NIS-ELEMENT 2.3 program, the individual pore dimensions and percentage porosity was evaluated. The principle of porosity measurement was to use ROIs programme to analyze and measure binary 2D objects. The strength of the agglomerates was evaluated by a drum test based on STN ISO 3271 (441570) norm.

TABLE 1

Fuel analysis

Properties	Symbol	Unit	Coke breeze	Pine sawdust
Analysis Moisture	(W)	[%]	0.8	4.5
Ash	(A)	[%]	14.5	0.9
Volatiles	(V^{daf})	[%]	3.5	85.6
Sulfur	(S^{d})	[%]	0.59	0.05
Hydrogen	(H^{daf})	[%]	0.79	6.15
Carbon	(C^{daf})	[%]	96.9	50.3
Nitrogen	(N^{daf})	[%]	0.84	0.08
Gross calorific value	(Qs^{daf})	[MJ/kg]	33.46	21.02
Calorific value	(Q^{ir})	[MJ/kg]	28.16	15.94
Net calorific value	(Q^{id})	[MJ/kg]	28.39	18.81
Phosphorus	(P^{d})	[%]	0.044	—
Chlorine	(Cl^{d})	[%]	0.03	—

3. Results and discussion

By applying intensification measures a reduction of the total sintering time was achieved (Fig. 1). The most significant time reduction occurred for sinterings in which return agglomerate was used and the method of blending the mixture was changed (BOR4 and BOR5). In this case the sintering speed BOR4 increased by 103.6% to 16.150 mm/min. These positive impacts can be attributed to the use of return agglomerate in the mixture and change in blending of the mixture. As can be seen in Table 2, despite increased moisture of the mixture during sinterings with return agglomerate no problems with mixture pelletization occurred. This fact is indicated by values of the pouring mass of the mixture, which in these cases reached the lowest values

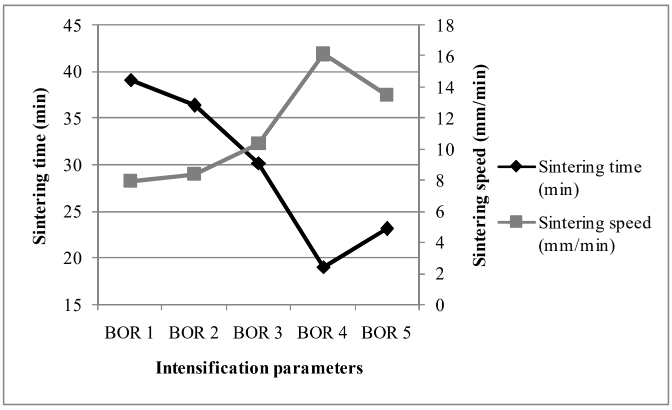


Fig. 1. The speed and time of sintering using intensification factors

TABLE 2

Parameters of agglomeration mixture

Parameter	BOR1	BOR2	BOR3	BOR4	BOR5
Bulk density of aglocharge [kg/m^3]	1781.1	1737.06	1846.48	1640.47	1704.1
Moisture [%]	10.4	8.8	8.6	9.6	10

Agglomeration mixture was therefore characterized by higher permeability. Interestingly, there was an increase in the rate of sintering and decrease in the overall time of sintering for BOR2 although the negative pressure was set to 3 kPa. Also in this case the preparation and blending of the mixture played an important role.

Production of agglomerate increased when intensification measures were applied (Fig. 2). The highest production was calculated for sintering BOR4. The difference against the standard sintering represented in this case 91.33%. In the calculations of production the time of sintering is considered. The sintering time was shortest for BOR4 sintering, in the case of sintering BOR5 time increased therefore the level of production declined to 108.32 kg/h. This value represents the difference 87% compared to the standard. The lowest increase in production compared to the standard was calculated for sintering BOR2 and the difference was 2.49%. The effect of changes in blending the mixture and the use of return agglomerate is positively reflected in the production of agglomerate.

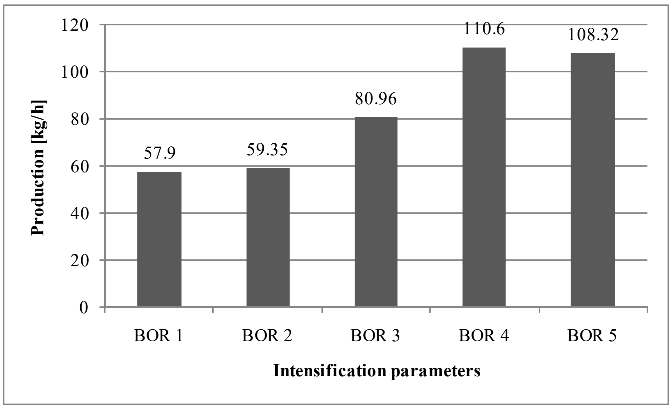


Fig. 2. The impact of intensification factors on agglomerate production

Sinterings BOR4 and BOR5 required higher amount of water for pelletization. Higher amount of water together with the lower amount of material in the model device have caused that the total amount of agglomerates was lower. Due to the higher permeability of mixtures which have been subjected to intensification measures, the rate of sintering increased. This phenomenon, together with a higher moisture content of the mixture caused insufficient heat accumulation in the sintered layer. In the elementary layers a significant portion of the heat was consumed for the removal of free or bound water (Table 3). In a lighter and more porous charge with a higher moisture content in the input micropellets (typical for the use of biomass) may occur due the condensation of water vapor in the sintered layer and higher rates of cooling of the sinter to record of lower temperatures. The resulting heat deficit was then reflected in a lower amount of resulting agglomeration melt. Therefore produced agglomerates had higher values of undersize agglomerate (i.e. the agglomerate grain size below 5 mm) determined by sieve analysis. Sintering BOR5 had the highest content of undersize material – 38.07%.

TABLE 3

Maximum measured temperatures of sintering layer

Thermocouple	BOR1	BOR2	BOR3	BOR4	BOR5
T1 [°C]	791	937	1017	1070	1004
T2 [°C]	983	753	1066	736	774
T3 [°C]	922	570	502	214	525

Therefore, a microscopic analysis was carried out on agglomerate BOR 5 on the granulometric class 5-10 mm, which pointed the possible causes for the formation of a large amount of undersize fraction of this agglomerate. The microstructure of this agglomerate consisted of iron oxides – magnetite, hematite and calcium ferrites (Fig. 3a). Hematite is present in the primary form. Primary hematite grains form unsintered parts of the hematite ore and they have comparable size to the magnetite grains. The size of magnetite grains is 30.96 μm and the size of hematite grains is comparable – 25.6 μm. There is an area of transition between the unsintered (the darkest area picture) and the melted structure of the silicate phase (medium gray area) (Fig. 3b). Surface analysis of this unsintered mixture area identified SiO_2.

The obtained agglomerate contains 19.2% of pores with a maximum average size of 186 μm (Fig. 4a). For comparison,

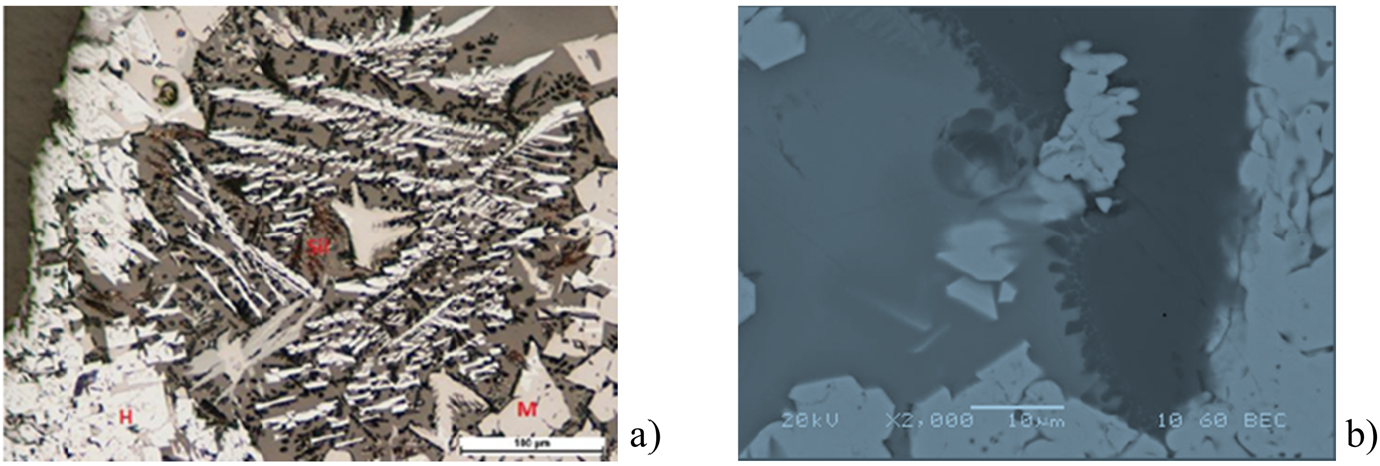
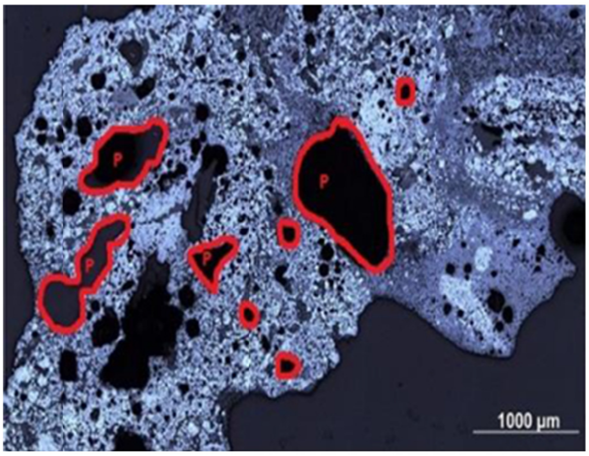
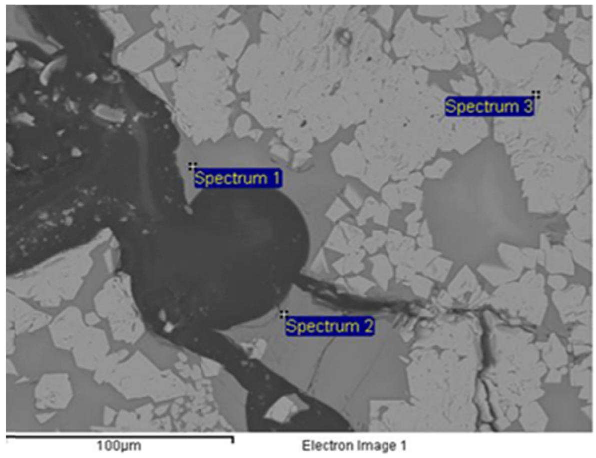


Fig. 3. Microstructure of agglomerate BOR 5 a) hematite, magnetite and calcium ferrites, b) grains area of unsintered and melted mixture



a)



b)

Fig. 4. Microscopic analysis of agglomerate BOR 5 a) porosity of the agglomerate, b) EDX analysis of pore margin

a standard agglomerate made with coke as a fuel has a porosity of 12-14%. The margin of the pores is surrounded by the undesirable silicate phase and the phase of calcium ferrite. The iron oxide phases are more distant from the area of pores. For agglomerates made with pine sawdust, using point analysis of the pore margin (Fig. 4b), potassium and aluminum were also found (Table 4). The oxides of these elements (Al_2O_3 and K_2O) are significantly represented in the ash of pine sawdust.

TABLE 4

EDX analysis of pore margin

	wt. (%)			at. (%)		
	1	2	3	1	2	3
O	41.16	45.34	30.8	61.66	65.38	60.84
Mg	1.21	1.1	—	1.19	1.04	—
Al	0.76	0.81	—	0.68	0.69	—
Si	18.35	18.5	—	15.66	15.2	—
K	1.76	0.29	—	1.08	0.17	—
Ca	23.41	21.4	—	14	12.32	—
Fe	13.36	12.56	69.2	5.74	5.19	39.16
Total	100	100	100	100	100	100

For the analysis of strength and abrasion indexes of the agglomerates were used granulometric classes 10-25 mm and + 25 mm. Strength and abrasion of agglomerate achieved positive results due to intensification measures (Fig. 5). The strength of the agglomerate from sintering BOR4 was at the level of 62.43%. There was a 23.37% gain in strength in comparison with standard agglomerate. The value of abrasion was 5.95% for sintering BOR4. In this case there was a decrease in the abrasion of 36.63%. The increased strength of agglomerate in these sinterings was caused by the presence of the return agglomerate. As indicated above, this agglomerate has already passed the sintering process. Due to the presence of refractory phases there did not occur a creation of sufficiently strong bonds, i.e. larger pieces of agglomerate and a corresponding increase in the values of quality parameters. During sintering, these grains were under the influence of the melt. As a result of grain irregularity

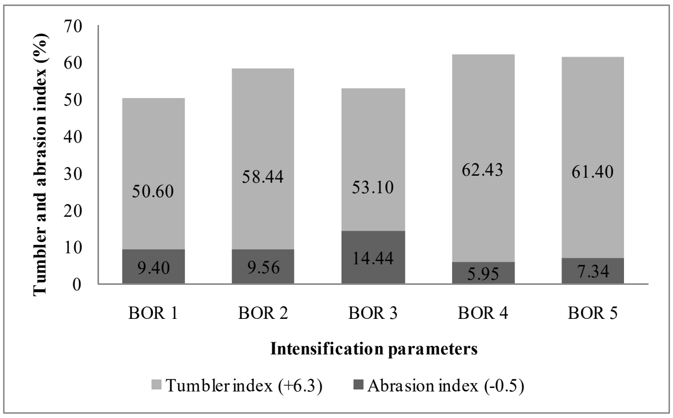


Fig. 5. Effect of intensification factors on strength of the agglomerates

and higher porosity, those spaces were filled with agglomerate melt. Thus, formed grains were characterized by higher strength + 6.3 mm and lower abrasion – 0.5 mm.

4. Conclusion

Due to the intensification measures applied in the sintering process with the addition of pine sawdust there was an improvement in the quality and technological parameters of sintering. The positive effect was most pronounced during sinterings which used return agglomerate. Its presence had a positive effect on the pelletization of mixtures, which influenced the rate of sintering. The values of strength (tubler index) of agglomerate increased as well. The results show that the preparation and pelletization of agglomeration mixture have a significant impact on the course of sintering and agglomerate quality. Despite realized intensification measures, there is still possibility for improvement in terms enhancement of sintering conditions and the quality of agglomerate containing alternative fuels. It is important to devote attention to the kinetics of pelletization of mixtures containing sawdust. Taking into account the characteristics of alternative fuels, it is necessary to study the methodology of charge preparation and to look for the optimum conditions for pelletization of agglomerate mixture with a composite fuel. From experience so far, it is clear that the addition of non-fossil fuel into the agglomerate mixture significantly changes the conditions of pelletization. Only well pelletized agglomerate mixture is a good basis for technological process control and high quality product. Generally, it is possible to consider an application of pine sawdust in the agglomeration process as viable. Pine sawdust is characterized by considerable potential, and by selecting appropriate technological procedure, it is possible to fully exploit this potential.

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