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INVESTIGATION OF THE METALLURGICAL PROPERTIES OF THE BREX (EXTRUSION BRIQUETTES)[1]

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Abstract

Results of the recent developments of J.C.Steele&Sons Inc. do show that the stiff-extrusion technology can be very efficient for the agglomeration of disperse anthropogenic and natural metal containing and carbonaceous substances. The Brex (Extrusion Briquettes) have a mechanical strength sufficiently high for the transportation and for the stockpiling for further strengthening storage at the moment of extrusion through the die. We have investigated the cold (mechanical) strength, the behavior during heating under the reducing atmosphere as well as the hot strength (in accordance with ISO Standard) of the Brex made of the metallurgical sludge, iron-ore concentrates, manganese ore fines, coke breeze and coal. The results show that the metallurgical properties of the Brex allow for their successful utilization in various processes of the extractive metallurgy.

Key words: Stiff extrusion; Extruded briquettes; Sludge; Cold strength.

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1 INTRODUCTION

Stiff vacuum extrusion technology had been widely used for a long time for brick making. Recent developments of the J.C.Steele&Sons Inc Company demonstrated that this technology can be utilized efficiently for the agglomeration of the anthropogenic and natural metal-carbon- containing fine substances.[1] Extrusion briquettes (BREX) – elongated agglomerates of the regular geometric shapes (circle, oval, quadratic) do have the required strength values right after the extruder's die for their transportation and stockpiling for further strengthening. Mechanical strength, behavior during the heating under the reducing atmosphere and the hot strength of the brex made from metallurgical sludge, iron-ore concentrate, manganese-ore fines, metallized pellets fines and the Ferro Alloys fines, coke breeze and coal fines have been investigated. Metallurgical properties of the brex allow for their successful utilization for the variety of the metallurgical extractive technologies and for the steelmaking.

2 BREX FOR THE BLAST FURNACES

First recently published results of the industrial production of the brex based on anthropogenic and natural iron-containing raw-materials and their utilization as charge components for the small-scale Blast furnace[2] confirmed the conclusions of the previously held in Russia and in the USA investigations of the metallurgical properties of these substances. Successful operation of the BF with 80% brex share in charge is a very convincing argument in favor of the applicability of this charge material in Blast furnace process.

2.1 Strength of the BREX

Mechanical strength measurement was held both immediately after the brex production as well as after their strengthening exposition under the condition of the final strength values. In a view of the specific shape of the brex the mechanical strength tests can be performed in two different orientations – vertically staying cylinder (compressive strength) and cylinder lying on the flat surface (tensile splitting test GOST 28570-90 and GOST 10180-90). Because of the evidently prevailing of the latter orientation in the stock-pile and in the charge bed of the blast furnace the splitting strength had been chosen as a main variant of the test of the prepared brex fragment (Figure 1).

Figure 1. Position of the brex under tensile splitting test.

Among the possible components of the BF charge we have considered the sludge based brex (mix of BF and BOF sludge and Portland cement) and iron-ore-coke brex (mix of the iron-ore concentrate, coke breeze and Portland cement), the componential composition is given by the Table 1.

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Table 1 Componential composition of the sludge and ore-coke brex

Brex components	Mass share of the components, %	
	Brex#2	Brex#4
Portland cement ПЦ 500	9,1	9,0
Coke breeze	-	13,5
Bentonite	-	0,9
BF sludge	54,5	-
BOF sludge	36,4	-
Iron-ore concentrate		76,6

For the measurement of the compressive strength of these brex we have prepared cylindrical samples (diameter 25mm) with 30mm length. The load had been applied along the axis of the sample. We have tested the samples prior and after their heating under the reducing atmosphere (50% hydrogen +50 % nitrogen) up to 1150 ^{o}C with the rate 500 ^{o}C per hour with subsequent cooling in the nitrogen atmosphere. For the estimation of the strength we used 5 samples of each type. All the thermally treated samples kept their shape and sizes (Figure 2) As it can be seen from the results of the tests (Table 2) after the heating under the reducing atmosphere following the described schedule the strength of the sludge brex decreased by 8,2 %, for the iron-ore-coke brex the strength decreased by 14,5 %.


№2a


№2b


№4a


№4b

Figure 2. Samples of the brex #2 and #4 before (a) and after (b) thermal treatment under reducing atmosphere.

Investigation in the reflected light of the microstructure of the samples of the initial and reduced iron-ore-coke brex showed that in the initial state particles of the concentrate and coke are being connected by the cement binder providing for the brex strength (Figure 3). The strength of the reduced brex like in the briquettes produced by vibropressing[3] is being provided by the iron-silicate binding and by the metallic structure created by the iron particles (Figure 4).

Additionally we have estimated the splitting strength of two different iron-ore-coke brex made from the iron-ore being extracted by hydro-extraction technology (Table3).

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Table 2. Compressive strength of the brex

Sample #		Strength after thermal treatment, kgF/cm^2	Strength before thermal treatment, kgF/cm^2
#2	1	97,7	103,8
	2	124,7	89,4
	3	101,8	112,2
	4	105,0	124,7
	5	118,5	166,3
	Average	109,5	119,3
#4	1	93,5	124,7
	2	95,6	103,8
	3	106,0	110,1
	4	87,3	103,9
	5	93,5	114,3
	Average	95,2	111,4

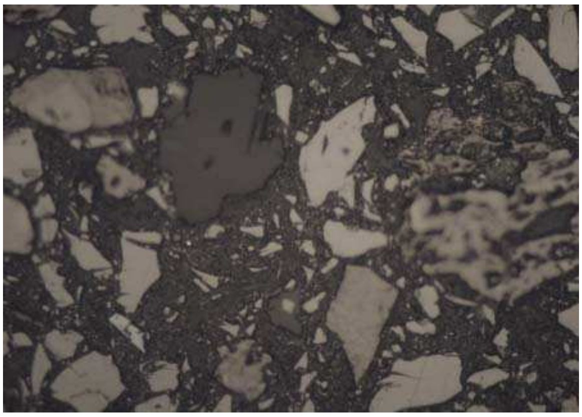

Figure. 3 Microstructure of the initial brex #4, magnification 500 (Light – particles of the magnetite concentrate, Light-gray – coke particles, dark-gray cement binder).

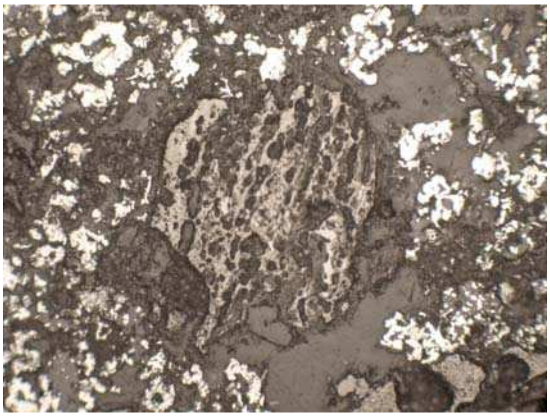

Figure. 4 Microstructure of the brex #4 after reduction, magnification 200. (gray – particles of the metallized iron, gray fields-- iron-silicate matrix, light-gray particles - coke).

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Splitting tensile strength we have measured by applying the load perpendicularly in respect to the horizontal axis of the brex. The test showed high values of the mechanical strength of the brex allowing their use in blast furnaces. We noticed that the pulp-ore and aspiration dust of EAF mix were significantly stronger than the iron-ore-coke brex (Table 4). The latter can be explained by the property of the aspiration dust of EAF to behave like a plasticizer and a binder increasing the strength of the brex right after the extruder's die and after their final strengthening.

Table 3 Componential compositions of the pulp-ore brex

Brex components	Mass share of the brex, %	
	Brex # 3.02	Brex#3.06
Portland cement ПЦ 500	5,55	5,6
Bentonite	0,45	0,95
Pulp ore	79	60,75
Aspiration dust of EAF	-	18,7
Coke breeze	15,0	14,0

Table 4. Tensile splitting strength of the pulp-ore brex

Sample #	Srength,kgF/cm^2					Average value
3.02	65,1	74,3	89,0	137,8	90,7	91,38
3.06	177,8	195,2	171,6	257,7	181,2	196,7

2.2 Brex Reducibility

Reducibility of the samples 3.02 and 3.06 we have investigated following the standard procedure (GOST 28658-90, ISO 7215-85) including the continuous weighing of the samples during their isothermal reduction at 900 ^{o}C by CO. Sample's heating as well its cooling after reduction had been performed under the nitrogen atmosphere. Degree of the reduction was calculated based on the weight loss of the sample with account of the mass share and its oxidation degree in the initial samples. The curves of the reducibility are represented by Figure 4-5.

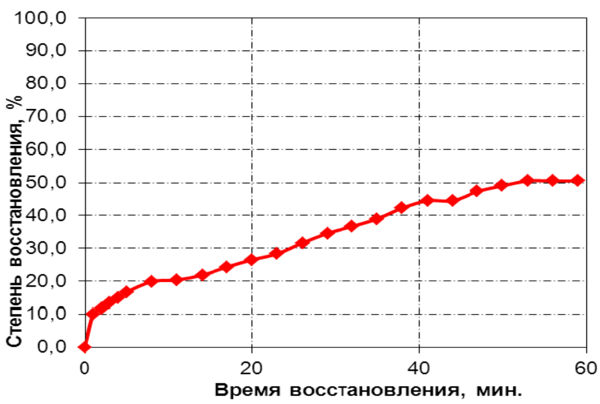

Figure 4. Reducibility curve for brex #3.02.

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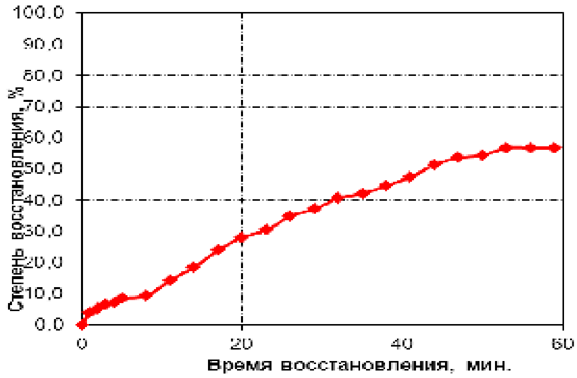

Figure 5 Reducibility curve for brex #3.06.

Weight loss of the samples in these tests is not the only result of the iron oxides reduction but the dehydration of the cement stone and of the calcium hydroxide contributed to this (sample 3,06). This is why the calculated value of the reducibility degree for this sample was higher.

Investigation of the strength of the reduced brex based on pulp-ore showed that this value for the sample 3.02 decreased almost in two times and for the sample 3.06 – in 4 times. Such a reduction which is significantly higher than that during their heating under the reducing atmosphere up to 1150 ^{o}C (Table 2) can be explained by the decay of the cement binder in the brex and by the insufficient time of their exposure at the 900 ^{o}C for the creation of the strengthening matrix during the solid-phase reactions from the silicates and for the creation of the metallized iron structure. On the contrary during the heating till 1150 ^{o}C the creation of such matrix compensated the strength loss after the decay of the cement binder. As a result the strength of the reduced samples decreased insufficiently in comparison with the initial brex.

2.3 Hot Strength of Brex

Hot strength of the brex purposed to be used as the component of the BF charge we have estimated in accordance with ISO 4696 Standard based on the standard equipment. The following were the compositions, %:

1. Iron-ore-coke Brex (БРК): concentrate -76,9; coke breeze – 13,6; Portland cement - 9; lignin – 0,5.
2. Sludge Brex (БШ): BF sludge-54,5; BOF – 36,4; Portland cement – 9,1.

For the sake of comparison we have simultaneously measured following the same standard the hot strength of the sintered agglomerates made of the iron-ore concentrates of the different basicity (Table 5).

Table 5. Hot strength parameters for brex and sintered agglomerates of different compositions

Tested substance	Parameter RDI (-3,15), %	Parameter RDI (+6,4), %
Brex БРК	38	62
Brex БШ	3,5	96,5
Agglomerate (basicity 1,2)	16,9	64
Agglomerate (basicity 1,4)	15,1	60
Agglomerate (basicity 1,6)	8,9	77

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Hot strength of the Iron-ore-coke Brex is comparable with the hot strength of the sintered agglomerate of the basicity 1,2 and 1,4 but is less than the hot strength of the agglomerates with the basicity 1,6. At the same time the sludge brex hot strength is significantly higher than all the figures for the sintered agglomerates.

3 BREX FOR FERRO ALLOYS PRODUCTION

3.1 Strength

Investigations of the strength of the brex of different compositions made of the manganese-containing substances and wastes and purposed for the silicomanganese production were performed following the same procedures with the load being perpendicular to the longitudinal axis of the brex (Table 6).

Composition of the Brex #1 produced industrially with the minimum amount of the Portland cement binder (3 %) and tested by the independent laboratory (L.ROBERT KIMBALL & ASSOCIATES, INC., Ebensburg, Pennsylvania, USA) had been chosen for the full-scale trials which we have performed at the industrial submerged EAF in the USA [2]. A lot of 2,000 Mt of these brex has been smelted without the furnace productivity reduction and with the same good quality of the produced alloy. Electrical energy consumption decreased by 9%.

Table 6. Splitting tensile strength of the Mn-ore containing brex

Brex components	Components content , %						
	#1	#2	#3	#4	#5	#6	#7
Manganese ore	70	70	70	-	-	70	-
Baghouse dust	30	30	30	15	30	30	-
Silicomanganese fines	-	-	-	85	70	-	-
Coke breeze	-	-	15*	-	-	-	94,5
Coal	-	10*	-	-	-	5*	-
Portland cement	3*	4*	5*	5*	3*	3*	5
Bentonite	-	-	-	-	-	-	0,5
Splitting strength, kgF/cm^2	211	156,8	156,3	344,5	116,8	77,1	180,0

*Note: * - on top of 100 %*

3.2 High-temperature Heating Behavior

We have investigated the brex of the following compositions:

#2-1 - Mn ore fines 50%, bag house dust 50%, Portland cement (PC) 5% (on top of 100%);

#2-2 - Mn ore fines 70%, bag house dust 30%, PC 5% (on top of 100%);

#2-3 - Mn ore fines 56%, bag house dust 24%, coal 15%, PC 5%.

We have applied the method of the thermal analysis to discover the processes which take place within the brex while heating. Investigations were performed with the help of the device STA 449 C (Germany) with the nitrogen atmosphere during the

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heating of the powdered samples (50-70mg) in the temperature range 20 - 1400 °C with the rate of 20 °C/min.

Analysis of the thermo grams of the samples #2-1 and #2-2 showed weak endothermic effects in the range 300 – 450 °C due to the decay of the hydrates Endothermic peaks in the range of 1120 – 1225 °C were the results of the iron-ore and manganese oxides reduction by the carbon containing in bag house dust. The similar peaks can be observed in the thermo grams of the sample #2-3 at 1123 and 1213 ^{o}C.

Thermal stability of the brex had been investigated by the immersion of the samples (length 50mm) in the bucket made from the tungsten into the furnace heated up the 1200 ^{o}C or 1500 ^{o}C, with further exposition during 5 minutes in the air atmosphere. Samples ## №2-1 and 2-2 after this 5 minutes in the furnace at the temperature of 1200 ^{o}C kept their shape and sizes with the very small sintering observed. Sample #2-3 after immersion into the furnace at the temperature of 1500 ^{o}C softened and melted within ~1 minute (Figure. 6).

Figure 6. Sample #2-3 before and after thermal exposition at T= 1500^{o}C.

Samples of the brex made from the silicomanganese fines (#4 and #5, Table 4) have also conserved their shape and integrity during 15 minutes long exposition at the temperature of 1200 ^{o}C. After sinking into the melted slag with the temperature 1580 ^{o}C the samples melted smoothly. Total duration of the melting of the individual brex (length and diameter – 25mm) was around 10 minutes.

4 COKE BREEZE BREX

Brex made of the coke breeze can be used as the cheap substitution of the coke nuts in the Ferro Alloys production and in BF. The investigation of the coke breeze brex (94,5% coke breeze, 5 % Portland cement, 0,5 % Bentonitea) showed their high values of the tensile splitting strength (180 kgF/cm^{2}). Besides we have observed visually the decay of the brex in the rotating drum. The original length of the brex decreased in 3-4 times with the creation of the negligible amount of fines (Figure 7).

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Figure 7. Coke breeze brex prior and after the tumble in rotating drum.

The measurements of the coke brex hot strength performed by the independent laboratory showed the following values: CSR = 20 %. CRI = 45,6 %. It is quite evident that these coke breeze brex can substitute the coke nuts in the blast furnaces with their shares in the charge at the amounts not more than 15-25 kg/t of hot metal. They can be also used as the reducing agents for the Ferro Alloys production.

5 BREX MADE FROM THE FINES OF THE DRI FINES

Fines generated during the production of the HBI (hot briquetted iron) from the metallized pellets we have used for the production of the brex to allow the utilization of the fine metallized wastes for metal production. Brex (Fig. 8) had the following composition: HBI fines -92 %, Molasses – 4 %, lime – 4 %, Bentonite – 0,5 % (on top of 100%).

Figure 8. Brex made from HBI fines.

Compressive strength of these brex was in the range 50 -122 kgF/cm^2. Duration of the sample melting in the Tamman's furnace at the temperature 1513 ^{o}C was around 10 minutes.

6 CONCLUSIONS

Stiff extrusion can be successfully applied for the agglomeration of the wide range of fine substances (natural and anthropogenic) for their subsequent use as a charge in blast furnace, Submerged EAF, steelmaking furnaces;

Mechanical strength of the brex is sufficiently high even at the exit from the extruder's die and allows for the very easy handling of the green brex including transportation and stockpiling; Brex strength after curing assures their integrity during storage, transportation, transshipments and in the charge bed of the metallurgical furnaces till their melting.

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Hot strength of the brex also meets all the requirements of the metallurgical processes. Hot strength of the brex for BF corresponds with the hot strength of the sintered agglomerates and for certain applications is even larger than that.

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