ON THE MECHANICAL STRENGTH OF EXTRUSION BRIQUETTES (BREX) FOR FERROALLOY PRODUCTION

A.M. Bizhanov[1], V.Ya.Dashevskii[2]

[1] J.C.Steele&Sons, Inc., NC, USA, abizhanov@jcsteele.com
[2] Baykov Metallurgy and Materials Institute (IMET), Russia, vdashev@imet.ac.ru

Abstract

The efficiency of the preliminary homogenization of the extrusion briquettes (BREX) charge from the point of view of enhancing their mechanical strength is being demonstrated. The strengthening rate of the industrially produced extrusion briquettes bonded by the composite binder of Portland cement and Bentonite has been investigated. A new effect of the compressive strength's local maximum on the day three of the strengthening has been discovered. This effect is also related with the change in the briquette destruction scenario from fragile to viscous-plastic.

The influence of the method of the Coke breeze pulverization on the mechanical strength of the extruded briquettes has been studied. The size, shape and topography of the surface of the particles affect the character of destruction of the extrusion briquette. Application of the shearing extruder for preliminary grinding can promote viscous-plastic nature of the destruction of the BREX, increasing its impact resistance.

Keywords: *extrusion briquette (BREX); stiff vacuum extrusion (SVE); mechanical strength, Bentonite; plastic destruction; granulometric composition; particle shape.*

Agglomeration of the fine natural and anthropogenic substances by briquetting is becoming more and more widely used in metallurgical practice. Among the most prospective technologies there is the Stiff Vacuum Extrusion (SVE) allowing the highest possible capacities combined with the excellent metallurgical properties of the extrude briquettes (BREX) suitable for Iron- and Steelmaking as well as for the Ferroalloys production [1–3].

Plasticity of the briquetting mixture is being usually controlled by addition of the required amount of the plasticizers of which the Bentonite is a most popular one. Necessary amount of bentonite content in the mixture varies in the range of 0.25-1.0% by weight. The plasticity achieved in this way has the important consequence of the growing value of the mechanical strength of the BREX and could change even the nature of their destruction (from fragile to viscous-plastic).

Certain improvement of the BREX mechanical strength after the addition of the Bentonite can be also achieved by the preliminary homogenization of the BREX charge mixture (without binder) during the 24 hours of the so called "souring". We have studied the effect of souring on the mechanical properties of various compositions of the BREX (Table 1).

The results of the test of the tensile splitting strength of the one-week cured BREX are listed in Table 2. The results show that the application of Bentonite in combination with Portland cement leads to the enhanced mechanical strength of BREX. In some cases, the values of strength increase significantly. We also discovered that by this the very nature of the destruction of BREX changes, gaining features of the viscous-plastic destruction. In this case, the BREX are better able to withstand shock loads that occur during their transportation to the places of use.

Table 1. BREX compositions for testing the efficiency of souring, %

Component,%	BREX #					
	1	2	3	4	5	6
BF sludge	42,8	41,8	41,8	41,2	47,8	28,3
LD sludge	39,8	38,8	38,8	38,2	43,7	25,4
Iron ore concentrate	–	–	–	–	–	29,3
Mil scale	13,0	13,0	13,0	12,1		10,7
Portland cement	4,0	4,0	6,0	8,0	8,0	5,8
Bentonite	0,4	0,4	0,4	0,5	0,5	0,5
Micro silica	–	2,0	–	–	–	–

Table 2. Tensile splitting strength values of the BREX, MPa

Parameter	BREX #					
	1	2	3	4	5	6
No souring	0,86	1,93	2,08	1,00	1,01	0,77
With souring	2,45	3,83	5,76	1,88	1,29	1,26
Strength ratio	2,85	1,98	2,76	1,88	1,28	1,64

We have studied the influence of such combined Binder not only on the compressive strength of the BREX but also on their strengthening under natural conditions. BREX made on industrial SVE line belonging to the Suraj Products Ltd (India) were selected for the tests. BREX composition, %: BOF sludge – 47.2; flue dust – 28.3; iron ore fines – 18.9; Portland cement – 4.7; bentonite – 0.9. Cement and bentonite were mixed in the dry state manually and further added to the mixture prior the Pug sealer. For the chosen BREX samples we measured daily: compressive strength, apparent porosity and density. Compressive strength was measured on a "Tonipact 3000" (Germany) in accordance with the standard DIN 51067. Apparent porosity was measured according to DIN 51056. Density was measured using scales Metler (United States). The measurement results are listed in Table 3. The curves showing the changes of porosity and strength of BREX during strengthening are presented in Fig. 1.

Table 3. Physical properties of the Suraj Products Ltd BREX during strengthening

Curing time, days	Apparent porosity,%	Density g/cm^3	Compressive strength, kg/cm^2
1	31,5	2,42	24
2	25,4	2,66	45
3	32	2,43	63
4	27	2,44	52
5	27,2	2,45	56
6	26,2	2,45	57
7	26,8	2,46	59
8	–	–	75
9	–	–	80

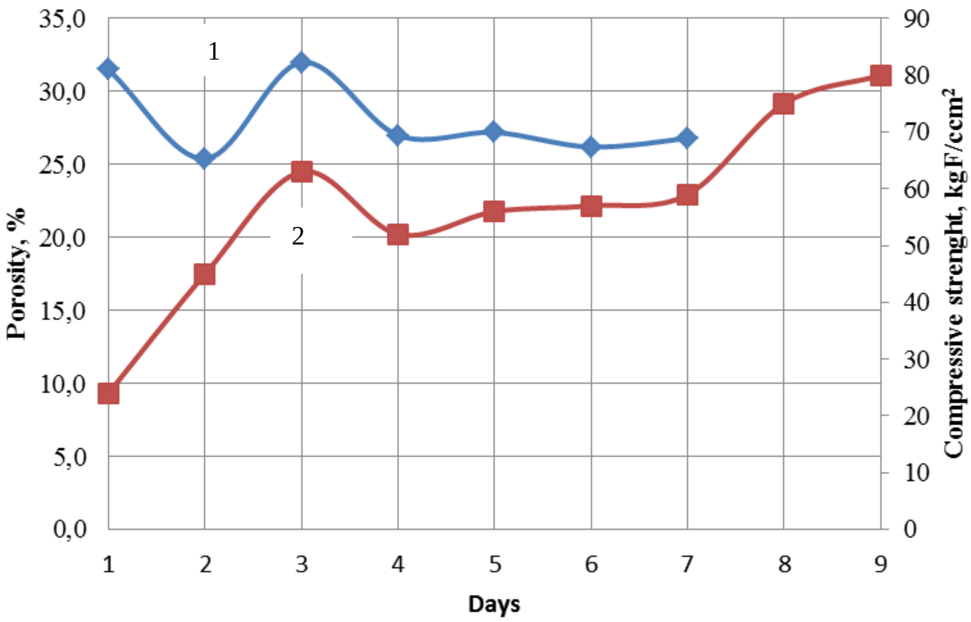

Fig. 1. Porosity and compressive strength of the Suraj Products Ltd BREX during strengthening under natural conditions (1 – porosity; 2 – compressive strength)

One can see that the strengthening schedule has an obvious local maximum on the third day which is followed by further loss of strength during the next day and ending finally by the strength growth. The value of the strength of the BREX directly prior to strength loss is about 84% of the strength of the BREX after a week of strengthening. The apparent porosity evolution virtually repeats that of the strength, with the exception of the first days of strengthening. Reduction of porosity is obviously connected with the swelling of the Bentonite that fills the pore space [4]. This effect of the non-monotonic strengthening of the briquettes with the cement binder with the local strength maximum accompanied by viscous-plastic character of their decomposition under the load has never been previously experienced, and has not been described in the literature.

In our view, such an effect takes place due to the properties of BREX bonded by composite cement-Bentonite binder and is the result of the creation of the coagulation structures in the cement-bentonite-water system leading to the modifications of the properties of the binder. Similar structures are known to be formed in gel-cement solutions used for the cementation of oil wells. The driving force of such structures creation is the attraction of the negatively charged particles of bentonite to positively charged particles of Portland cement, leading to very rapid coagulation of particles and to the creation of the independent structure, which weighed particles of cement are suspended in. Hydrating cement particles are gradually being covered by impermeable shell of scaly particles of bentonite. Gradually this structure will collapse as a result of coagulating action of calcium ions and will be replaced by a structure of hardening cement stone. Reduced strength, observed on the third day after the peak, is mainly due to the collapse of the described structures. Further increase in strength is fully controlled by the cement hydration.

The discovered effect may have practical significance allowing to use the BREX bonded by bentonite-cement binder as a component of the charge of metallurgical furnaces no later than the third day of strengthening under natural conditions, leading thus to reduction of the required storage size of totally cured BREX.

In some cases preparation of the suitable briquetting charge for SVE with the given plasticity might require the reduction of the particle size distribution of the charge material (crushing, grinding, etc.).

To study the influence of the grinding method on the strength of cement-Bentonite bonded BREX we have compared the properties of BREX made of the Coke breeze, pulverized by three different ways: a hammer mill, smooth roller crusher and double shearing through the extruder die. Results of particle size analysis of the differently pulverized Coke breeze are shown in Fig. 2.

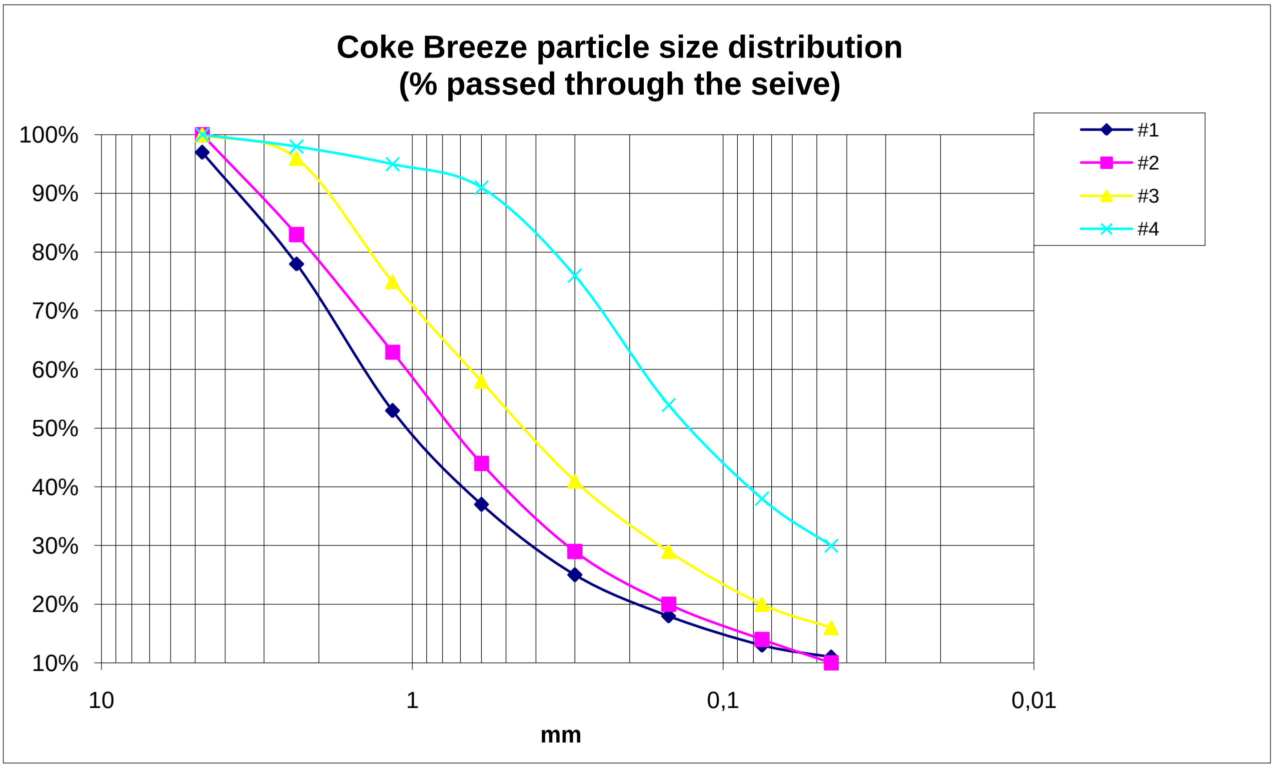

Fig. 2 Grain sizes distribution of the differently pulverized Coke breeze (#1 – as-received; #2 – hummer/milled; #3 – smooth-rolled; #4 – double-sheared).

One can see that the greatest degree of grinding of Coke breeze ensured a double shearing through the plate in the extruder. Effect of deep grinding is achieved in this case by the application of high shear stress. Application of the hammer mill for such substance has proved to be ineffective and, as a result, granular composition of ground material differs only slightly from the original Coke breeze granular composition. All Coke BREX had the same composition: 94% of Coke breeze, 5% of Portland cement and 1% of Bentonite.

Respectively to the applied method of grinding we have attributed to the BREX the following numbers: #1 – the coke breeze pulverized by the smooth roller crusher; #2 – Coke breeze was double-sheared through the extruder die; #3

– Coke breeze pulverized by the hammer mill. Extrusion parameters and physical properties of BREX are shown in Table 4.

The difference in the values of compressive strength of BREX #1 and #2 is not high and can only indicate the earlier development of fracture in BREX #2. The data also shows that the density of a BREX made of the charge subjected to double shearing was 2.5% higher than the density of two other BREX compositions. It is clear that tighter packing of the particles within BREX #2 was the result of a higher degree of the grinding of the material. In this case, by the way, there has been no dewatering of the charge mixtures during extrusion, in contrast to BREX #1 and #3.

The difference in the values of compressive strength of the BREX of coke breeze of the single party, but differently pulverized, may be due to a number of reasons related to the difference in the size of particulate, their shapes as well and in the relief of their surface. Particle shape after grinding may depend on the characteristics of the material itself, and on the way of pulverization [5–7].

In Fig. 3 there is the picture of the Coke breeze particle obtained by scanning electronic microscope JEOL JSM-6490 LV (Japan).

Table 4. Extrusion parameters and physical properties of the Coke breeze BREX

BREX sample (grinding method)	**Moisture content, %**	**Vacuum, mm Hg**	**Temperature, ^{o}C**	**Density, g/cm^3**	**Compressive strength, kgF/cm^2**
#1(smooth roller crusher)	16.5	15.24	30.56	1.630	37.76
#2(double sheared)	16.7	17.78	33.33	1.674	34.32
#3(hummer mill)	16.6	81.28	55.56	1.627	20.25

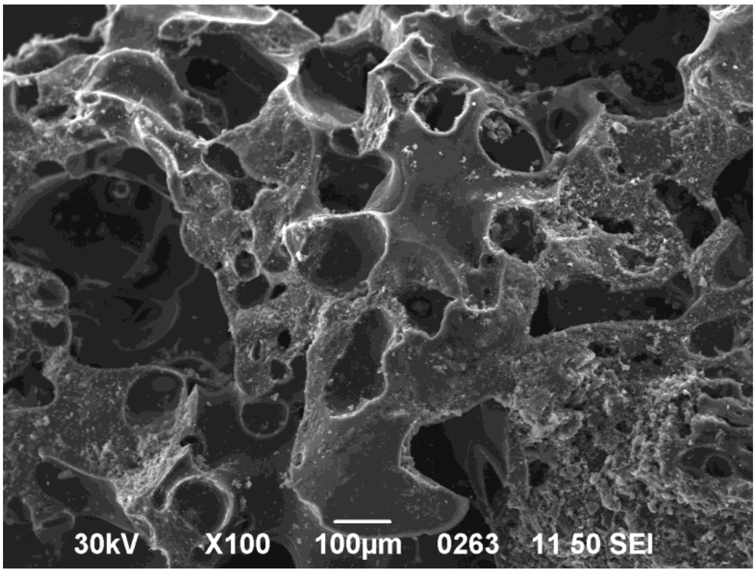

Fig. 3. Coke breeze particles structure (SEM, magnification 100)

BREX samples were further tested by us on the splitting tensile strength in the desktop single-column electromechanical testing machine Instron 3345. In Fig. 4, the test results are given for specially prepared samples of BREX #1–3 (diameter 25 mm, height 20 mm, cylindrical shape).

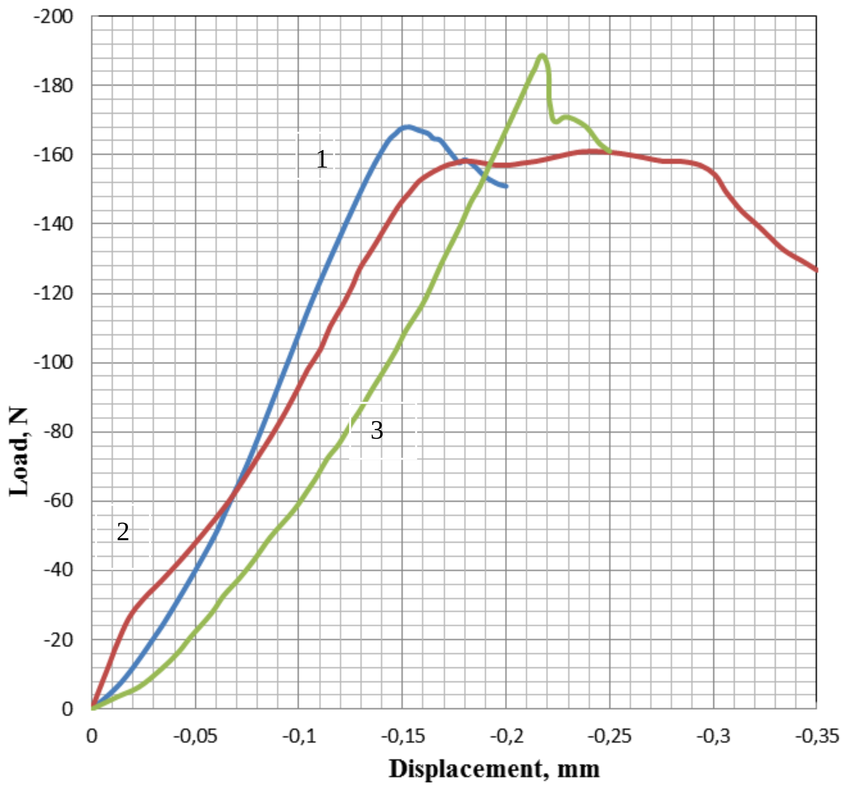

Fig. 4. Load-displacement dependence for the BREX during tensile splitting test (1- brex#1; 2- brex#2 – #2; 3- brex#3)

It follows from the obtained results that at about the same load-bearing capacity BREX reacted differently to an external load. The difference in the size of the maximum load can be associated with some defects of this given samples. However, the difference in behaviour is due to the fundamentally different reasons. BREX # 2 showed the viscous nature of the destruction, as evidenced by the existence of a "plate" (the horizontal component of the curve). This phenomenon is, in our view, can be explained in terms of the Hall-Pitch effect [8].

Method of the Coke breeze pulverization can affect the particles size, shape, and surface topography. Such effects would depend on the characteristics of the material (porosity, primarily). Coke breeze particle size distribution affects not only the value of compressive strength, but also determines the nature of the destruction of BREX under static and dynamic loads. Depending on the degree of grinding, the fragile nature of the destruction may be replaced by viscous-plastic, resulting in increased impact strength BREX. In order to achieve the desired fineness of the Coke breeze the shearing extruder can be used.

REFERENCES

[1] Kurunov I.F., Bizhanov A.M. Stiff vacuum extrusion of Steele – a promising way of agglomeration of metallurgical raw materials and waste // Bulletin: Ferrous metallurgy. 2012. # 4. P. 46–49.

[2] Bizhanov A.M., Kurunov I.F., Durov N.M. et al. Study of mechanical strength of BREX. Part 1 // Metallurgist. 2012. # 7. P. 32–35.

[3] Bizhanov A.M., Kurunov I.F., Durov N.M. et al. Study of mechanical strength of BREX. Part 2 // Metallurgist. 2012. # 10. P. 36–40.

[4] Komine Hideo, Ogata Nobuhide. Can. Geotech. J. 2003. V. 40. P. 460–475.

[5] Kaya E., Glogg R., Kumar S. R. 2002. Particle shape modification comminution. Kona., 20, pp. 185–195.

[6] Ulusoy U., Hicyilmaz C., and Yekeler M. 2003a Role of shape properties of calcite and barite particles on apparent hydrophobicity. Chem. Eng. Process., 43, pp. 1047–1053.

[7] Ulusoy U., Yekeler M., and Hicyilmaz C. 2003b Determination of the shape, morphological and wettability properties of quartz and their correlations. Mineral Eng., 16, pp. 951–964.

[8] Malygin G.A. Durability and strength of nano-and microcrystalline material (Review). Solid-State Physics. Vol 49. #. 6, 2007. P. 961–982.