Stiff Vacuum Extrusion Agglomeration in Ferro Alloys Production

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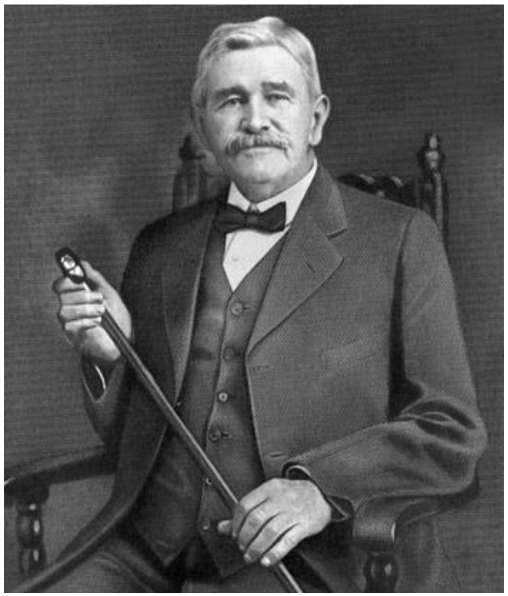
Milestones of Extrusion Agglomeration

1889, J.C.Steele&Sons



1899, The Gröndal Process. Equipment similar to applied for shaping of clay bricks. BF charge. (Finland)

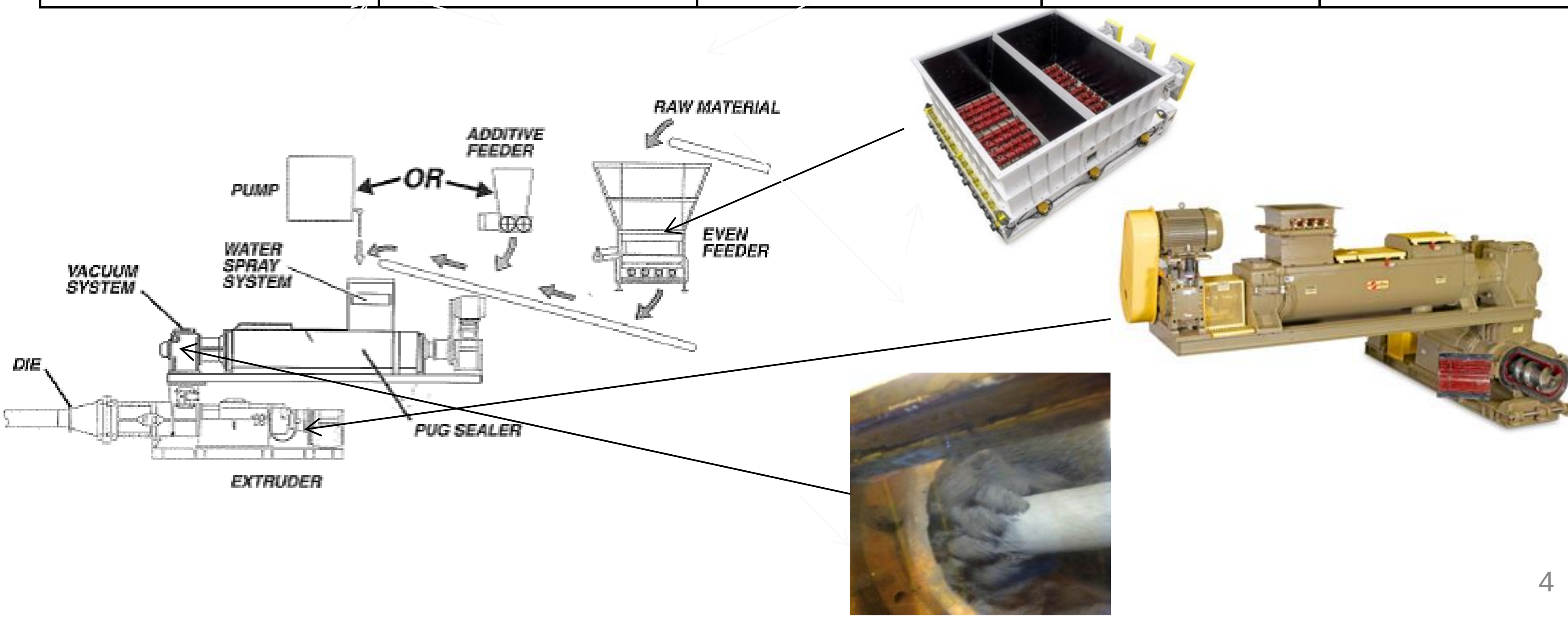
1990s, J.C.Steele&Sons,Inc. Auger agglomeration of BOF sludge, BF charge. Bethlehem Steel, USA.

2018, J.C.Steele&Sons,Inc. Stiff Extrusion Agglomeration of iron ore concentrate, and coke , sludge, NLMK Group, Russia

Stiff Extrusion for Brick Making

Classification of Extrusion Types

Type of extrusion	Low pressure extrusion	Medium pressure extrusion	High pressure extrusion	
Description used in ceramic industry	Soft extrusion	Semi-stiff extrusion	Stiff extrusion	
Extrusion moisture	10-27	15-22	12-18	10-15
Extrusion vacuum pressure, MPa	0.4-1.2	1.5-2.2	2.5-4.5	Up to 30



Spiral Couette-Poiseuille Flow in Simplified Model of Extruder

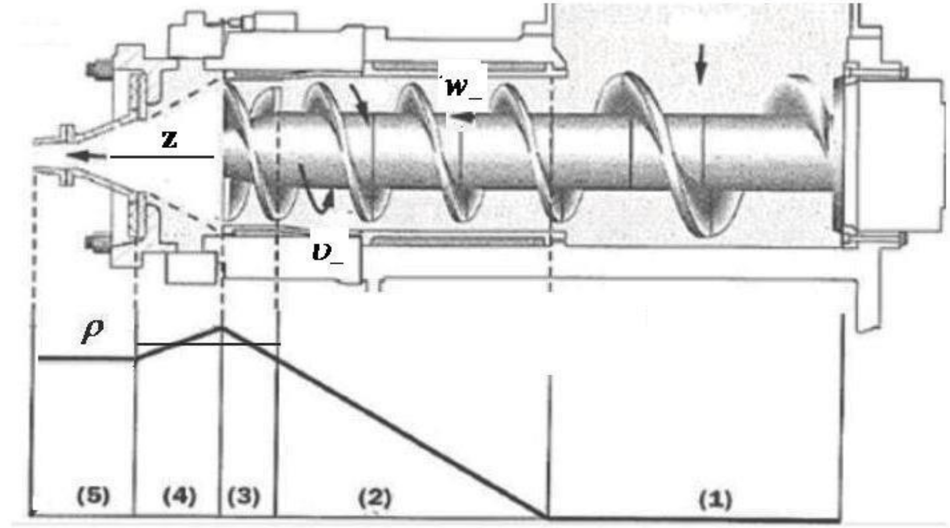
$$w = \frac{\varepsilon^{\gamma_+} w_+ - w_-}{\varepsilon^{\gamma_+} - \varepsilon^{\gamma_-}}\left(\frac{r}{a}\right)^{\gamma_-} + \frac{\varepsilon^{\gamma_-} w_+ - w_-}{\varepsilon^{\gamma_-} - \varepsilon^{\gamma_+}}\left(\frac{r}{a}\right)^{\gamma_+}$$

$$+\frac{-p_z a^2}{\mu(4-\alpha)}\left(\frac{\varepsilon^{\gamma_+} - \varepsilon^2}{\varepsilon^{\gamma_+} - \varepsilon^{\gamma_-}}\left(\frac{r}{a}\right)^{\gamma_-} + \frac{\varepsilon^{\gamma_-} - \varepsilon^2}{\varepsilon^{\gamma_-} - \varepsilon^{\gamma_+}}\left(\frac{r}{a}\right)^{\gamma_+} - \left(\frac{r}{a}\right)^2\right)$$

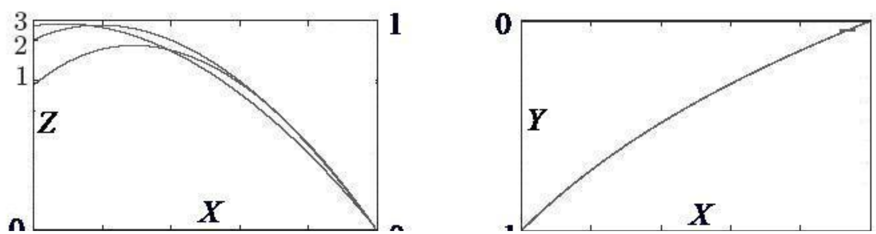
$$\gamma_{\mathrm{m}} = \frac{\alpha}{2}\,\mathrm{m}\sqrt{\left(\frac{\alpha}{4}-1\right)\alpha} \qquad \left(\frac{\alpha}{4}-1\right)\alpha > 0$$

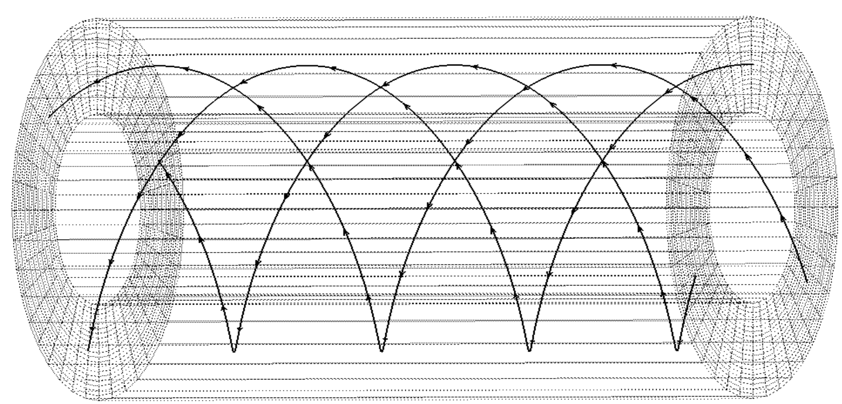
$$\upsilon = \frac{\varepsilon^{\beta_+}\upsilon_+ - \upsilon_-}{\varepsilon^{\beta_+} - \varepsilon^{\beta_-}}\left(\frac{r}{a}\right)^{\beta_-} + \frac{\varepsilon^{\beta_-}\upsilon_+ - \upsilon_-}{\varepsilon^{\beta_-} - \varepsilon^{\beta_+}}\left(\frac{r}{a}\right)^{\beta_+}$$

$$\beta_{\mathrm{m}} = \frac{\alpha}{4}\,\mathrm{m}\left(\frac{\alpha}{2}+1\right) = -\frac{\alpha}{4}-1, \frac{3\alpha}{4}+1$$



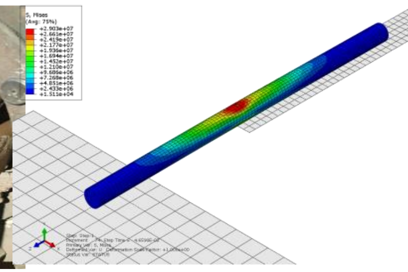
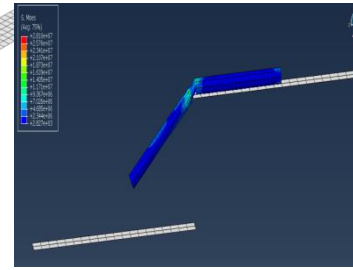
1 conveying, 2 densifying, 3 – metering, 4 pressure distributing, 5- die



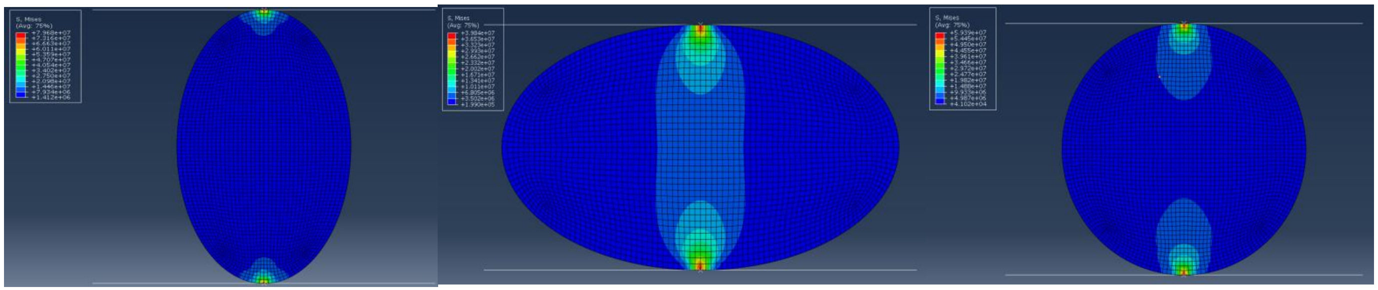


Specific Features of Stiff Extrusion

Length

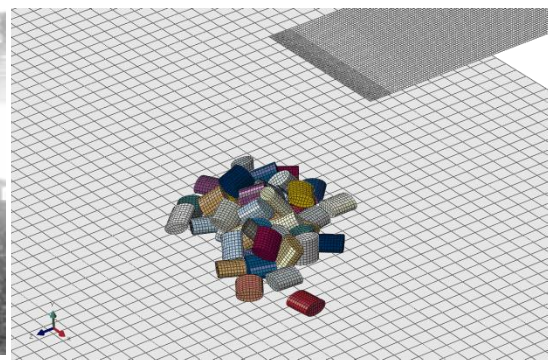





Shape



39.8 MPa 79.6 MPa 59.3 MPa

Stockpiling of extrusion briquettes

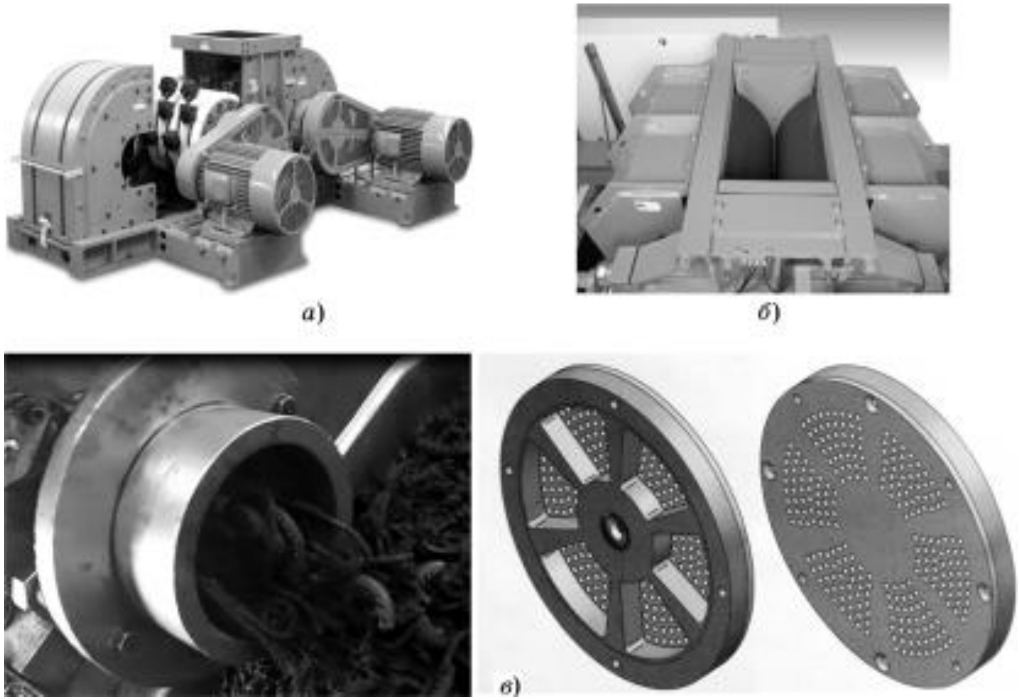
Statistics of briquettes orientation in the pile: 56.25% have the orientation of the "flat" (the long axis of the oval is parallel to the horizon), 12.5%- target long axis perpendicular to the hearth, 12.5%- stands vertically and 18.75% on the "edge".

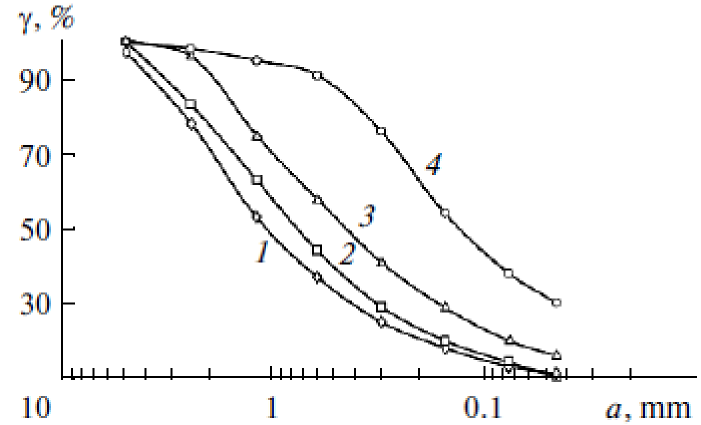
Migration of fines


$$V = \frac{\rho}{12\mu}(u - U)\frac{du}{dy}r^2$$

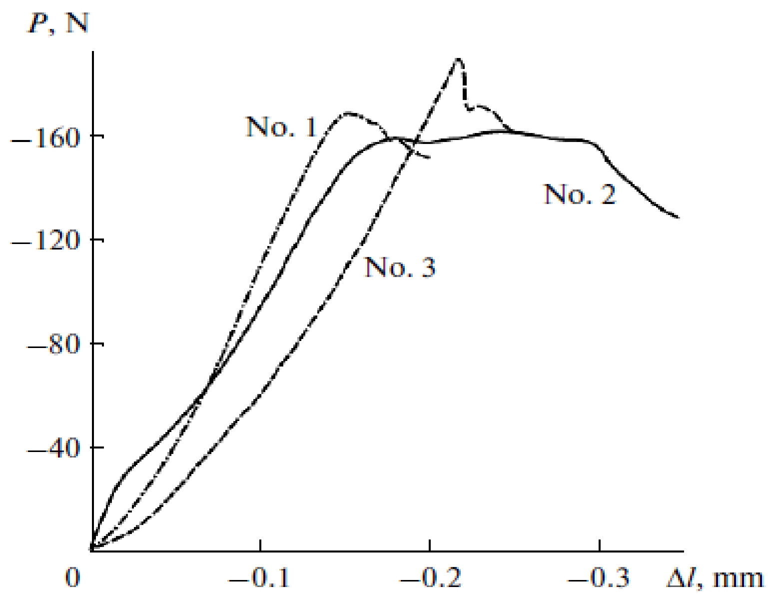
$$V_{large} = -\frac{r_{large}^2}{r_{small}^2}V_{small} = -9V_{small}$$

Influence of Shear Stress





Granulometric composition of coke breeze in the following states: (1) initial and (2–4) after additional grinding in a hammer mill, in a roll crusher, and double extrusion in an extruder. respectively.



Extruded briquettes made of coke breeze(94%; 5% PC; 1% Bentonite.

No.1 – roll crusher
No. 2 – double extruded
No. 3 – hummer milled

Briquetting Technologies Main Parameters Comparison

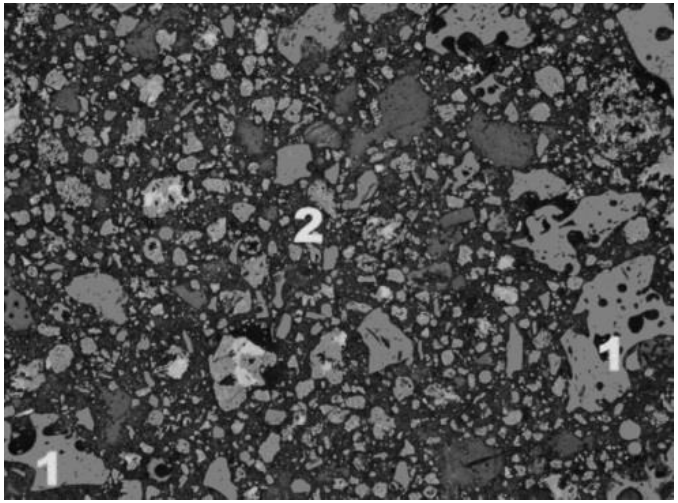
The characteristics of the process and properties of briquette	Machines for briquetting and their characteristics		
	Vibropress	Roller-press	Extruder
Maximum capacity, ton/hour	30	50	100
Cement binder content,%	8-10	15-16	3-9
Thermal processing of raw briquettes	80 ^{o}C (16-20 hours)	-	-
Wastes generation	-	30 % of production	-
Shape of briquette	cylinder, prism	pillow	any
Dimensions, mm	+80x80	30x40x50	5-35
Moisture content of charge,%	<5%	<10%	8-15%
Possibility of immediate stacking of raw briquettes	-	possible	possible

Testing of Metallurgical Properties of Extruded Briquettes for Blast Furnace

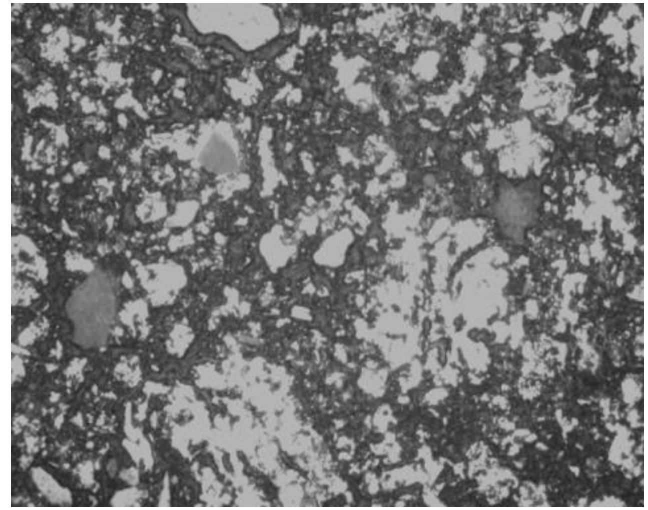
Components	Mass share, %	
	#1	#2
Portland cement	9.1	9.0
Coke breeze	-	13.5
Bentonite	-	0.9
BF sludge	54.5	-
BOF sludge	36.4	-
Iron ore concentrate	-	76.6

Test material	$RDI_{(+6.3)}$, %
Extruded briquette #1 (1.93)	**61.9**
Extruded briquette #2 (basicity 0.75)	**96.5**
Sinter (basicity 1.2)	64
Sinter (basicity 1.4)	60
Sinter (basicity 1.6)	77

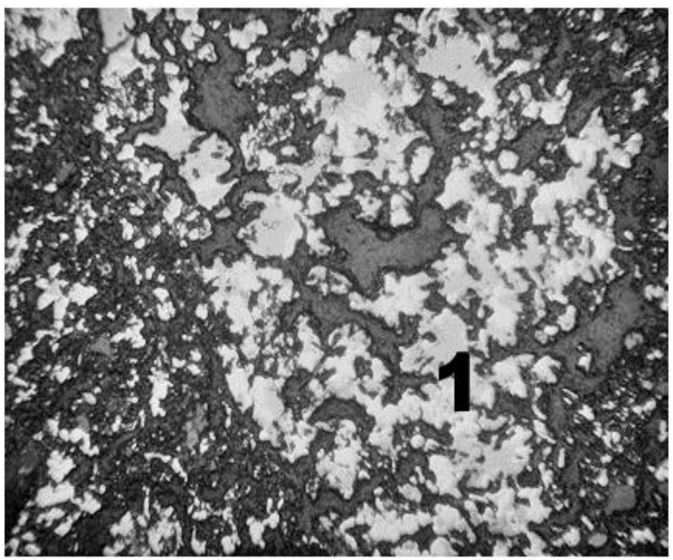
Mineralogical Study of Raw and Reduced Extruded Briquettes



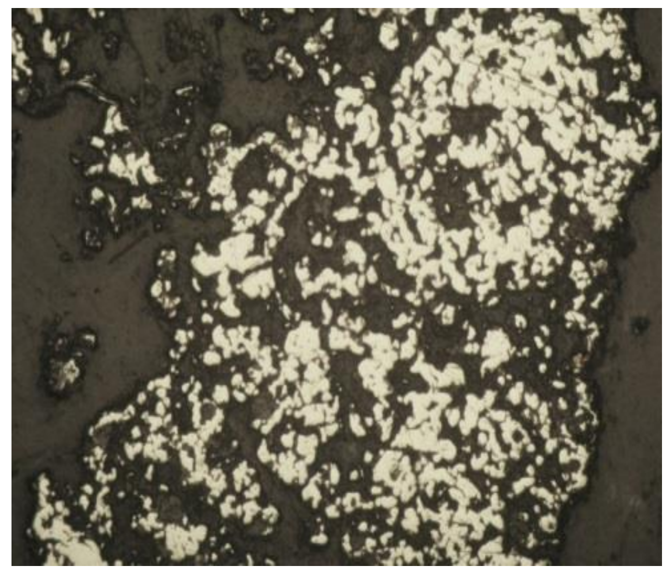
1 – Coke breeze; 2 – iron ore



Core, 900 °C

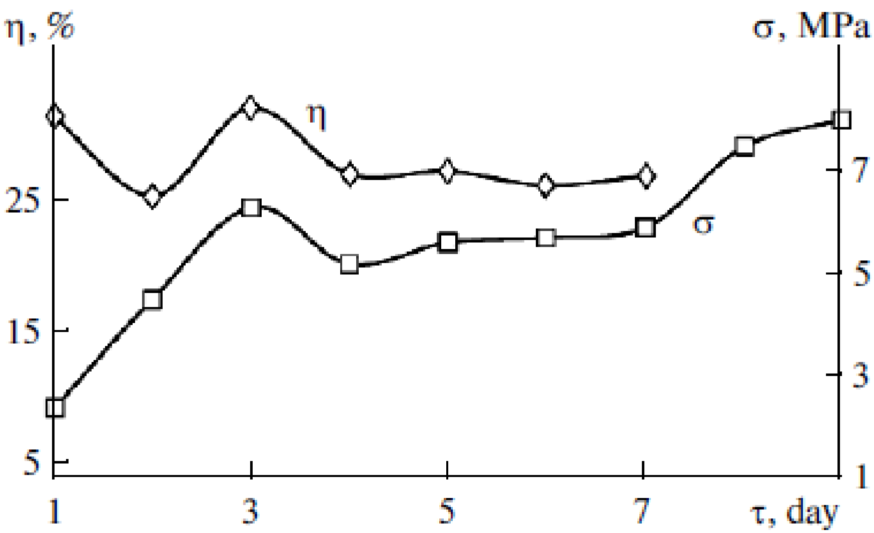


1 – metal, shell, 900°C,

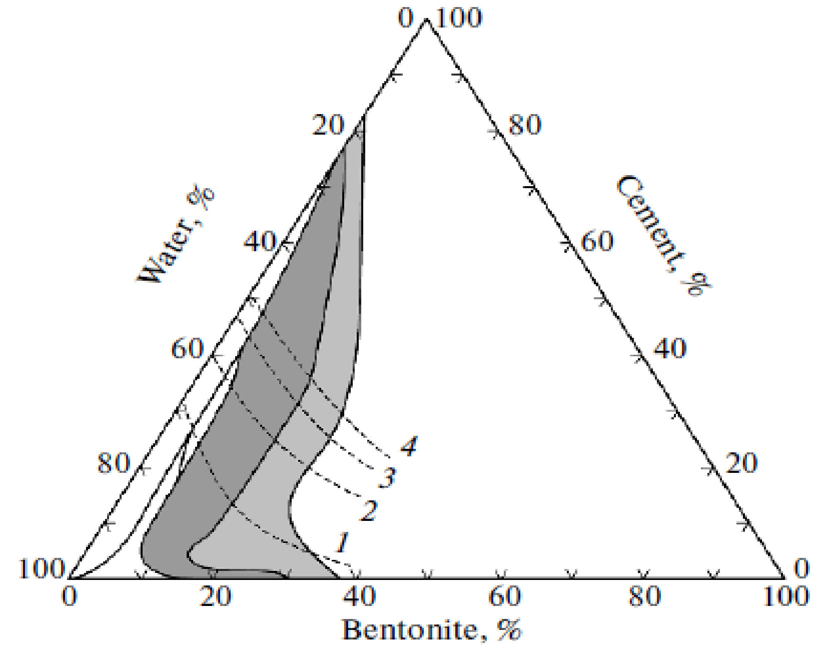


Shell, 1100 °C

Industrial Extruded Briquettes for Blast Furnace



Changes in compressive strength σ and porosity η of brex during strengthening 9-day storage.



Compressive strength

day 3 day 7

Tensile splitting

day 3 day 7

Blast Furnace Operation with 100% of Extruded Briquettes

The performance of blast furnace	100 % iron ore	80 % extruded briquettes	100 % extruded briquettes
Consumption, kg/t:			
Iron ore	1500	372	-
extruded briquettes	-	1425	1960
limestone	150	-	-
Dolomite	144	-	29
scrap	132	-	-
Quartzite	-	-	13
Mn ore extruded briquettes	-	19	75
Coke, 15-25mm	680	530	490
$Fe_{total.}$ in fluxed charge, %	57.6	50.4	45.5
Capacity, t/m^3 per day	1.9	1.62	2.0
Blow temperature, ^oC	925	900	1000
Blow pressure, kg/cm^2	0.5	0.34–0.38	0.38–0.42
[Si], %	1.0–1.8	1.0–1.5	0.8–1.1
[Mn], %	0.2	0.4–0.5	0.7–0.8
[C], %	3.8–4.0	3.75–3.90	3.80–3.95
[S], %	0.050–0.060	0.038–0.050	0.038–0.042
Hot metal temperature, ^oC	1380–1440	1400–1450	1410–1450
(CaO), %	34.86	33.12	38.0–39.0
(SiO_2), %	31.98	30.23	30.0–32.0
(Al_2O_3), %	23.87	17.98	16.0–18.8
(MgO), %	9.46	9.48	8.0–9.5
(FeO), %	1.01	1.26	0.6–1.15
(MnO), %	0.35	0.75	1.3-1.4

Briquettes in the skip of Blast furnace

Simulation of BF with extrusion briquettes in the charge

Mathematical model of BLAST FURNACE on the basis of software developed in Moscow Institute of Steel and Alloys (DOMNA).

Blast furnace volume **4297 m^3**.

Charge of 3-components- sinter, pellets and briquettes The share of pellets is determined by the capacity in pelletizing factory (6 million tons of pellets per year).

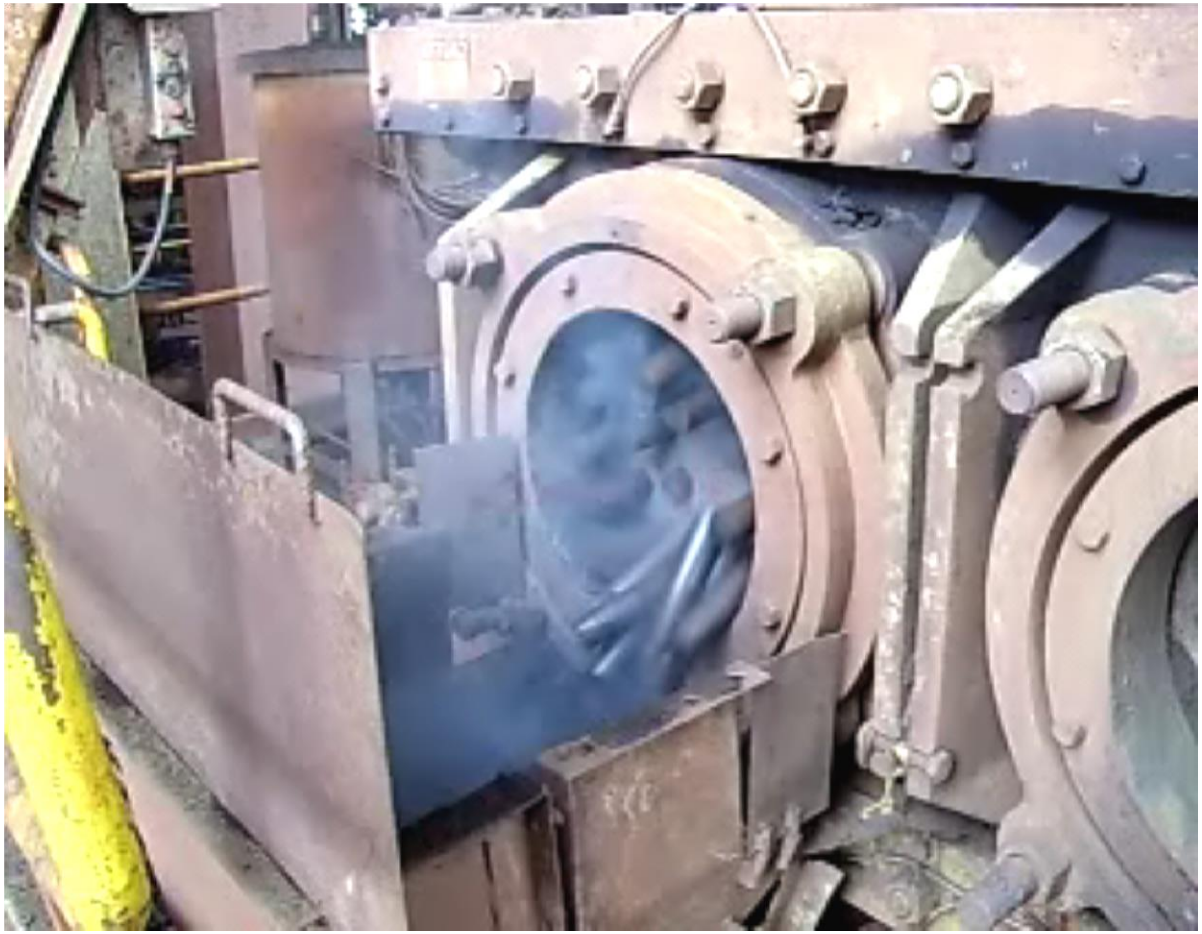
Basicity of briquettes consisting of iron ore concentrate and coal is determined on the basis of the binder share in the mass (6%) and bentonite (1%), basicity of briquettes (B2) is **0.50-0.55**.

Basicity of sinter is determined on the basis of the accepted concept of replacing the sinter by briquettes and by their basicity. When replacing 50% of sinter in blast furnace by briquettes sinter basicity should be between **2.8-3.2**. It should be noted that in the structure of sinter of this basicity dominating are the phases with increased strength compared with sinter with basicity in the range **1.5-1.7** (produced by NLMK at present).

Simulation results

The performance of the furnace	Traditional charge	Option 1	Option 2
Sinter consumption B2 = 1.7 kg/ton	1109	-	-
Sinter consumption B2 = 3.0 kg/ton	-	557	575
Pellets consumption, kg/ton	546	557	541
Extruded briquettes consumption, kg/ton	-	557	575
Iron ore consumption, kg/ton	-	17	-
Fe content in charge, %	58.2	57.45	57.15
Coke rate, kg/ton	391	354	284
Natural gas consumption, nm^3/ton	125	125	35
Pulverized coal consumption, kg/ton	-	-	160
Blow rate, m^3/min	7483	7568	7340
Blow temperature, ^oC	1240	1240	1240
O_2 content in blow, %	30,5	30,5	30,5
Blast humidity, g/m^3	10	10	20
Top gas, m^3/ton	1545	1540	1470
Top gas pressure, kPa	240	240	240
CO content,%	24.4	24.9	26.2
CO_2 content, %	23.2	22.6	23.9
H_2 content, %	9.7	9.9	8.2
Slag ratio, kg/ton	318	314	323
Slag basicity, B2	1,01	1,01	1,02
Capacity, ton/day	12465	12624	12708
Capacity, ton/m^2·day	92,48	93,66	94,3
Reduction efficiency,%	94.2	94.2	1515

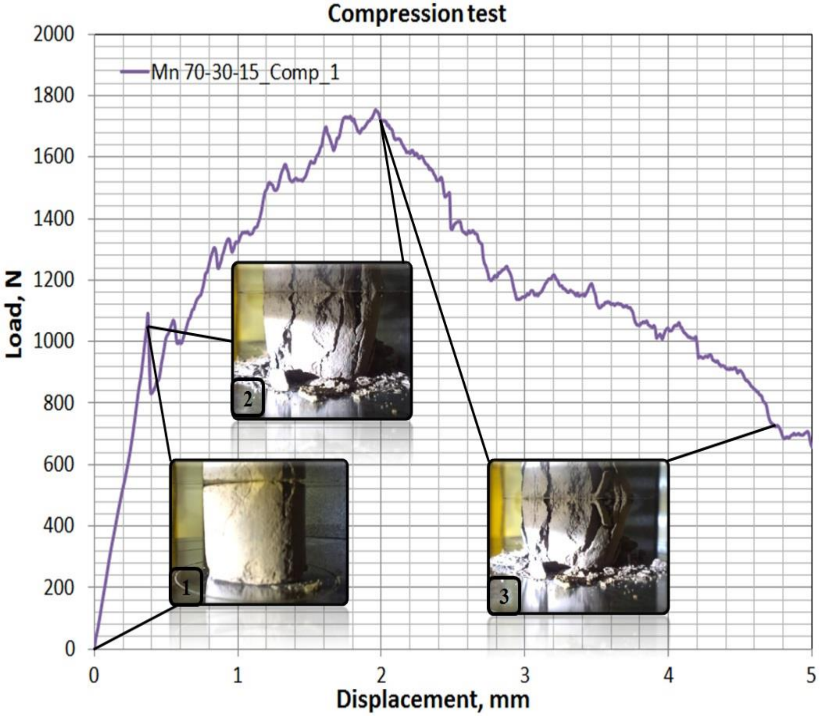
Brex for Ferronickel smelting in Cerro Matoso (Columbia, BHP Billiton) since 1996. Capacity 700 kty. Same capacity in Brazil (Vale).

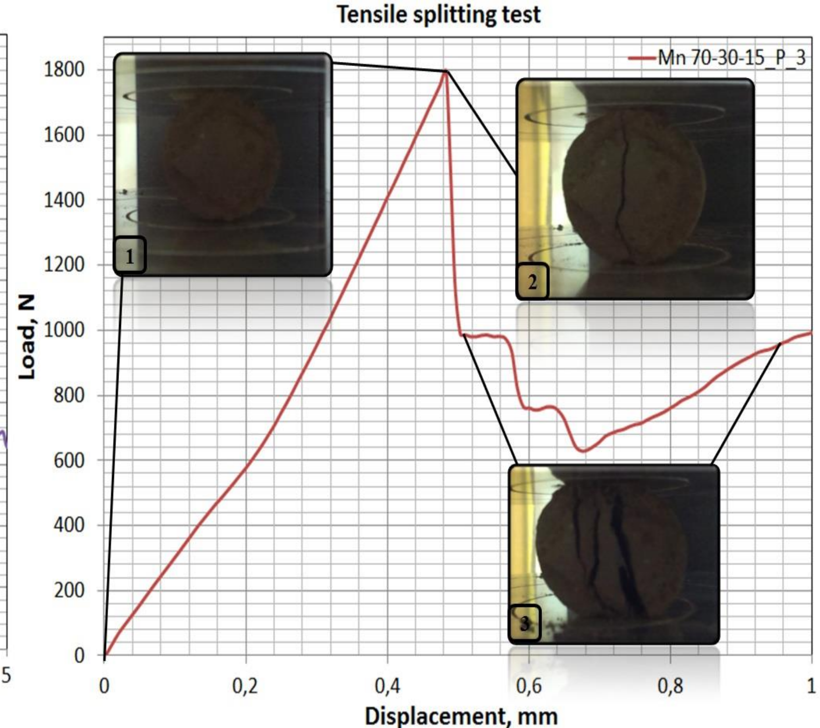


Full-Scale Testing of SiMn production with Brex in the Charge of Submerged EAF

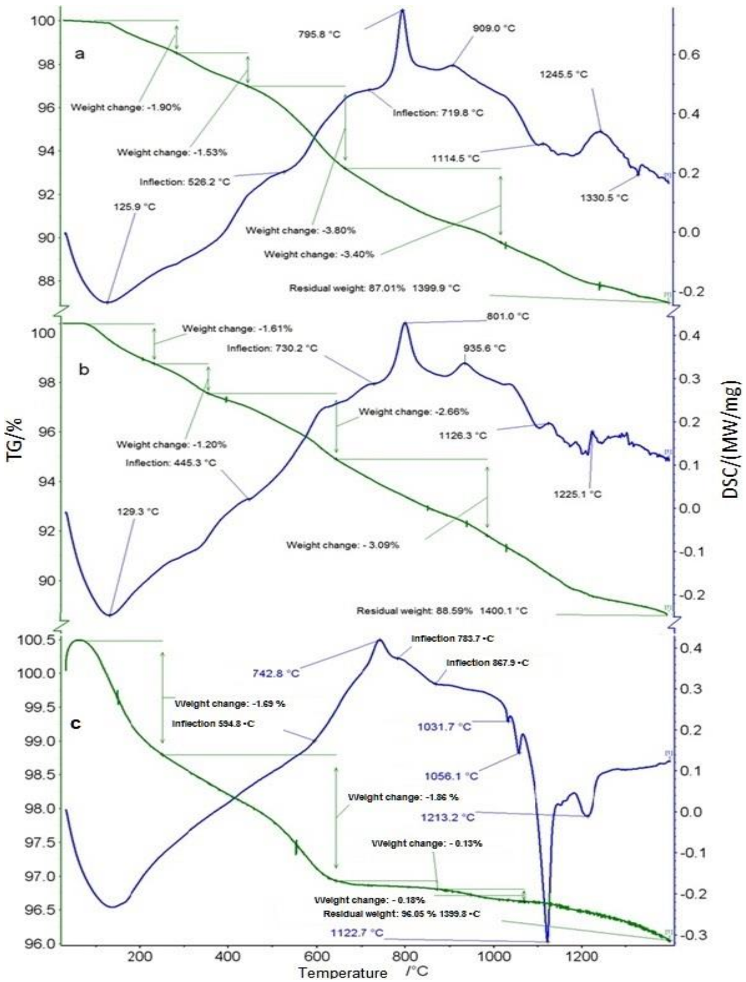
Component	# 1	# 2	# 3
Manganese ore concentrate	47.6	66.7	56.0
Coke breeze	-	-	15.0
Baghouse dust	47.6	28.6	24.0
Portland cement	4.8	4.7	5.0

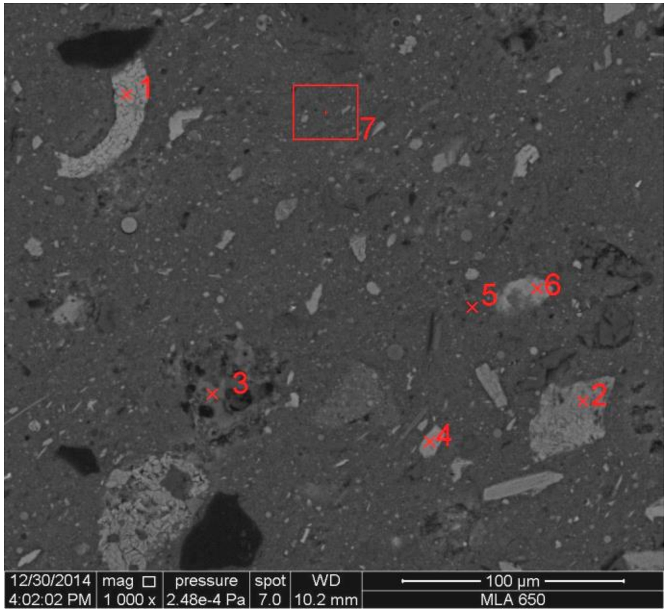
Mechanical Strength of the Experimental Brex



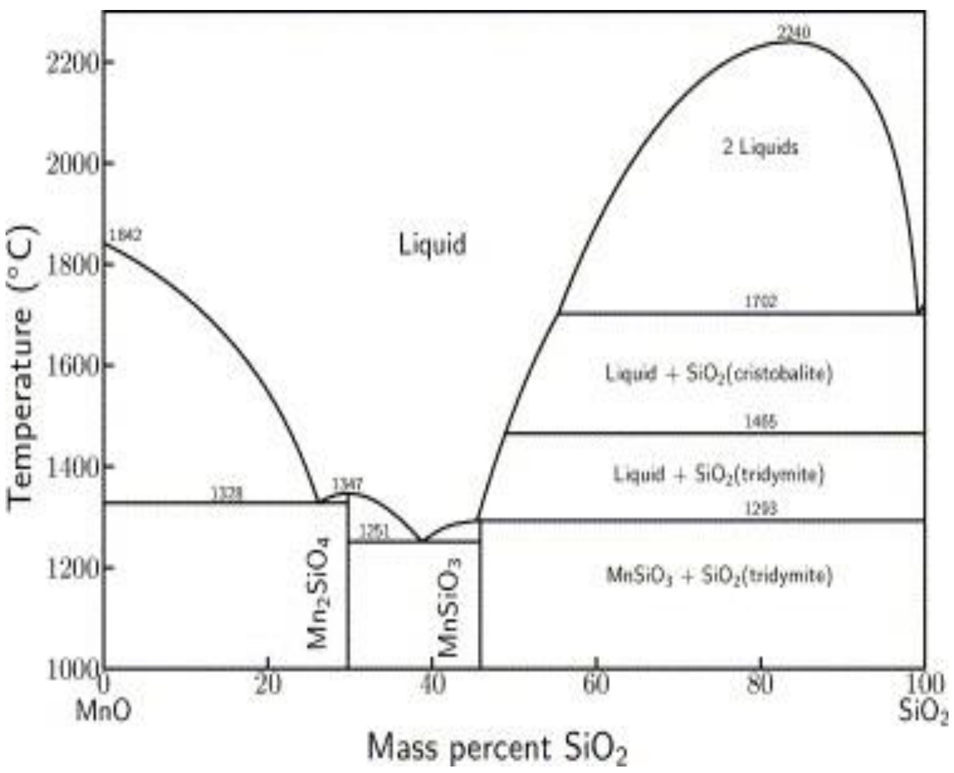


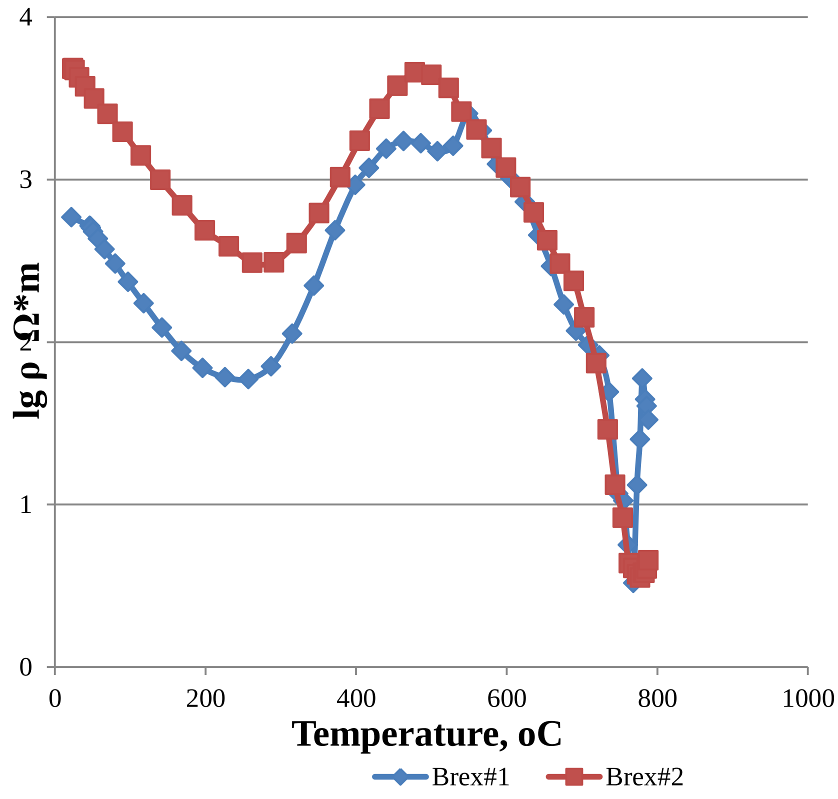
Brex #	Tensile splitting strength	Compressive strength
1	18.3	160.8
2	28.6	291.2
3	13.1	124.6





Backscattered electron image of Brex # 2 structure. (1-pyrolusite, 2-gaussmanite, 3-diopside, 4-fayalite, 5 - mullite, 6 - pyrolusite, 7 - solid solution of Ca_2SiO_4-Mn_2SiO_4)


2240
2 Liquids
Liquid
1842
1702
Liquid + SiO_2(cristobalite)
1465
Liquid + SiO_2(tridymite)
1328
1347
1251
1293
Mn_2SiO_4
$MnSiO_3$
$MnSiO_3$ + SiO_2(tridymite)
Temperature (°C)
2200
2000
1800
1600
1400
1200
1000
0
20
40
60
80
100
MnO
SiO_2
Mass percent SiO_2


4
3
2
1
0
lg ρ Ω*m
0
200
400
600
800
1000
Temperature, oC
Brex#1
Brex#2

Prtoduction and Shipment of Brex for Full-Scale Testing

Steele 75 Extruder, 50 Mtph

Discharge after 2-5 minutes

20 handling operations in a period of 30 days: manufacturer - extruder, conveyors, dumps truck, stockpiles, wheel loader, truck; port of loading - stockpiles, wheel loader, hopper, bucket, barge; port of discharge - grab, hopper, conveyors, truck; ferroalloy plant ore storage yard - stockpiles, front loader, factory warehouse, furnace. Total fines (less than 6 mm) generated during these operations did not exceed 10%.

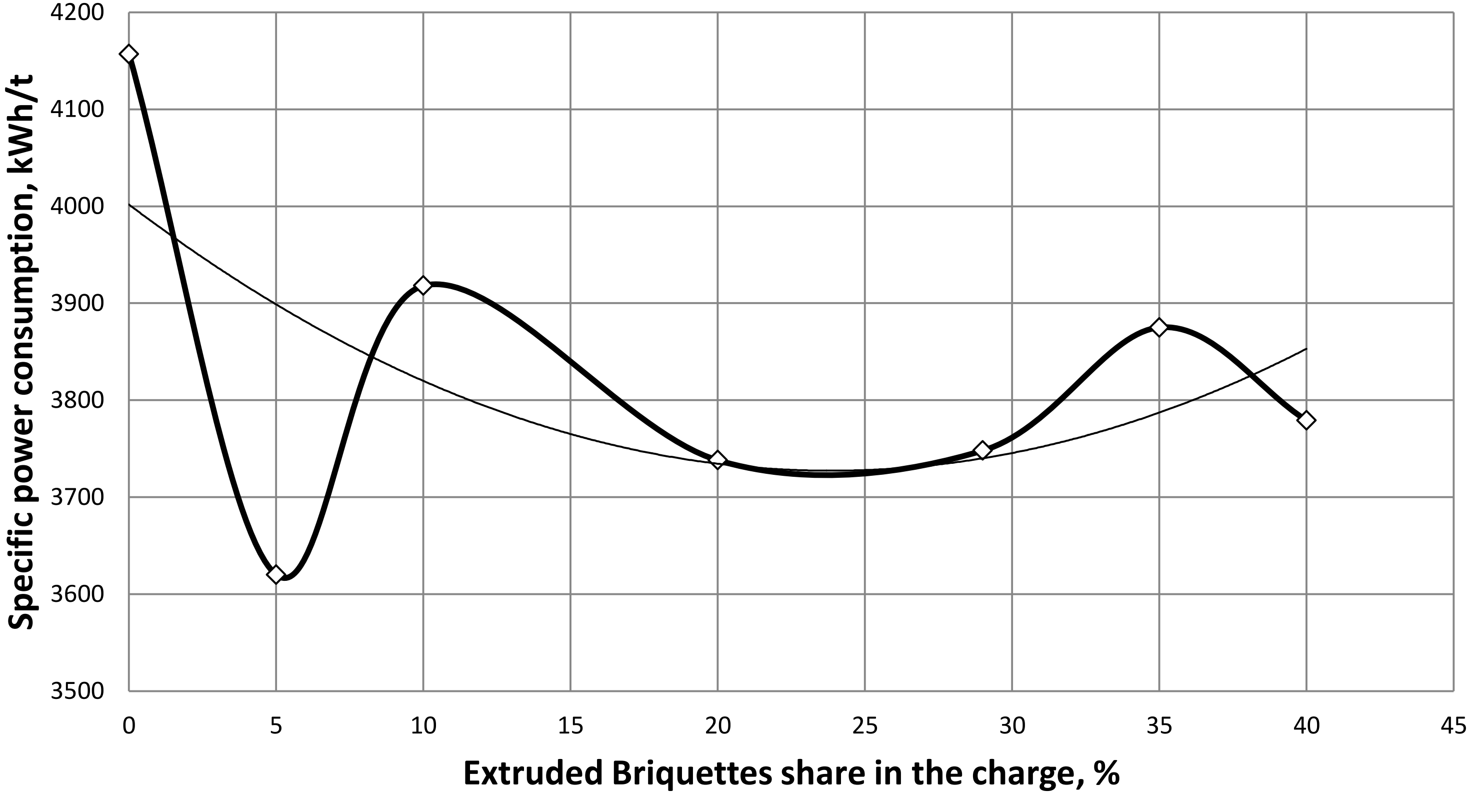
Full-scale testing of SiMn production with Extruded Briquettes

Component of the charge	Reference and Full scale trial periods						
	Reference period	1	2	3	4	5	6
Mn Ore-1	0.526 (30%)	0.525 (30%)	0.525 (30%)	0.525 (30%)	0.525 (30%)	0.525 (30%)	0.525 (30%)
Mn Ore-2	1.205 (70%)	1.12 (65%)	1.03 (60%)	0.855 (50%)	0.705 (41%)	0.6 (35%)	0.525 (30%)
BREX	–	0.087 **(5%)**	0.175 **(10%)**	0.35 **(20%)**	0.5 **(29%)**	0.605 **(35%)**	0.69 **(40%)**
Estimated weight of charge	1.73	1.732	1.73	1.73	1.73	1.73	1.74
Incoming manganese with:							
Ore-1	0.262 (43%)	0.262 (42.6%)	0.262 (42.6%)	0.262 (42.4%)	0.262 (42.2%)	0.262 (42.1%)	0.262 (41.8%)
Ore-2	0.35 (57%)	0.325 (53%)	0.299 (48.6%)	0.224 (40.1%)	0.205 (32.8%)	0.174 (27.9%)	0.152 (24.2%)
BREX	–	0.027 (4.4%)	0.054 (8.8%)	0.109 (17.5%)	0.16 (25%)	0.188 (30%)	0.214 (34%)
Manganese charge weight	0.612	0.614	0.614	0.619	0.622	0.624	0.628
Average manganese content, %	35.4	35.5	35.6	35.8	36	36.1	36.1

Full-scale testing of SiMn production with Extruded Briquettes

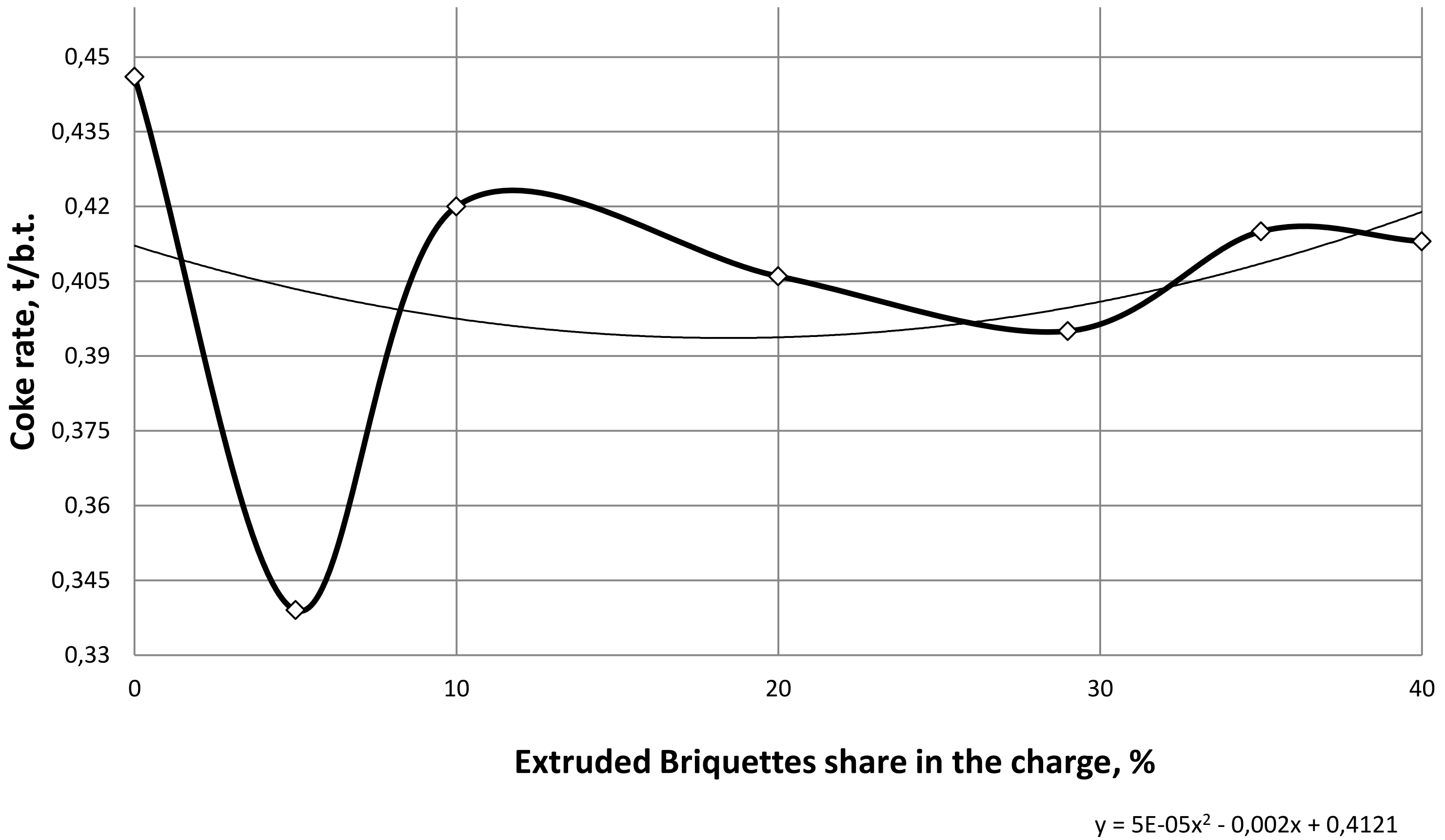
Parameter		Reference and Full scale trial periods						
		Reference period	1	2	3	4	5	6
Actual metal production over a period of time, t	ton	816.323	298.4	277.1	196.6	570.6	397.2	757.2
	b.t (basic ton)	839.670	300.7	285.8	199.5	584.75	393.2	767.8
Actual furnace performance, %		98.9	97.6	97.4	99.7	96.2	98.6	93.6
Power consumption, MW		3 339.27	1 078.2	1 085.4	734.7	2 120.8	1 536.3	2 821.48
Specific power consumption, kW*h/b.t		3 977	3 586	3 798	3 682	3 627	3 908	3 675
Ore-2	t (29%Mn)/b.t	1.106	0.933	0.892	0.714	0.635	0.626	0.492
	t (48%Mn)/b.t	0.668	0.563	0.539	0.431	0.383	0.378	0.297
Ore-1	t (49.5%Mn)/b.t	0.565	0.505	0.482	0.509	0.480	0.524	0.484
	t (48%Mn)/b.t	0.582	0.520	0.497	0.525	0.495	0.540	0.499
BREX	t (31.37%Mn)/b.t	0	0.077	0.164	0.273	0.387	0.571	0.605
	t (48%Mn)/b.t	0	0.050	0.107	0.178	0.252	0.373	0.395
The total consumption of raw manganese ore	t/b.t	1.671	1.515	1.538	1.496	1.502	1.721	1.581
	t (48%Mn)/b.t	1.250	1.133	1.143	1.134	1.130	1.291	1.191
Coke, t/b.t		0.446	0.339	0.420	0.405	0.395	0.415	0.413
Quartzite, t/b.t		0.419	0.499	0.524	0.465	0.529	0.456	0.475
Silicomanganese fines Briquettes t/b.t		0.158	0.082	0.103	0.092	0.120	0.110	0.094
Scrap (Mn content in scrap,%), t/b.t		0.358 (23.3)	0.601 (29.9)	0.462 (33.0)	0.477 (35.3)	0.461 (32.0)	0.455 (25.8)	0.373 (38.6)
Electrode mass, t/b.t		0.034	0.032	0.030	0.035	0.028	0.033	0.028
Manganese extraction from the ore component, %		80.1	79.8	80.7	80.7	83.6	79.1	79.9

Power consumption vs Extruded Briquettes share

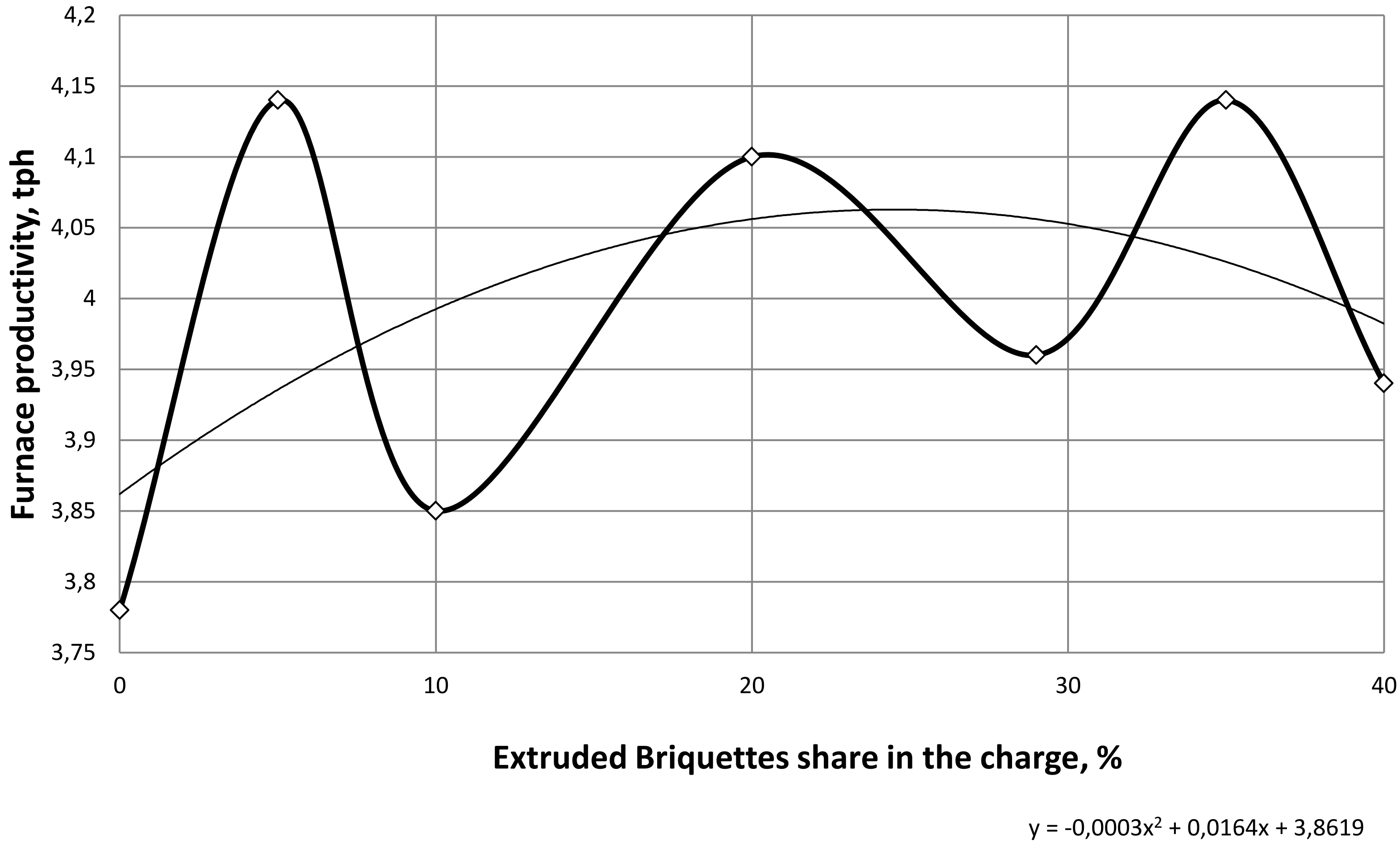


$y = 0{,}4824x^2 - 23{,}011x + 4001{,}7$

Coke rate vs Extruded Briquettes share



Furnace productivity vs Extruded Briquettes share



The main conclusions of the results of R&D for the applicability of stiff extrusion in for metallurgy are:

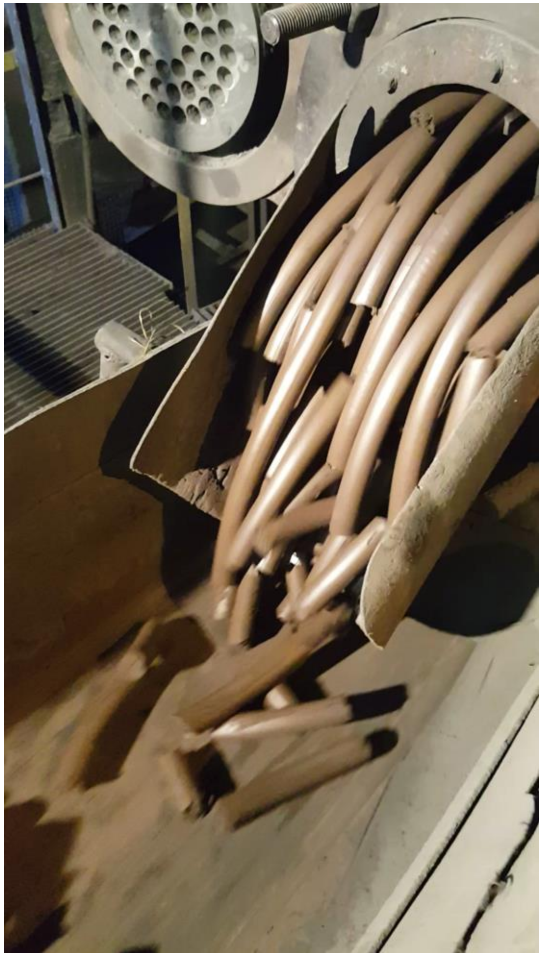
Stiff extrusion can be competitive as the technology of fine iron containing materials agglomeration, which could also provide for efficient partial or complete substitution for sinter production;

Three years of continuous operation demonstrated the economic efficiency of operating blast furnaces with a charge of 100% extruded briquettes.

Full-scale industrial trial confirmed the efficiency of the extruded briquettes use as the charge components of Submerged EAF (up to 40% of the charge). Stiff extrusion is the only technology that efficiently agglomerates

Cr Ore and Dust Agglomeration

Mn Ore Concentrate Agglomeration



Drop Test of Chromium Containing Materials Brex

Mn Containing Brex making

THANK YOU FOR ATTENTION!