DOI 10.18454/PMI.2016.5.675

UDC 622.76:669.712.1

DEVELOPMENT OF IMPORT SUBTITUTING TECHNOLOGIES FOR INCREASING PRODUCTIVITY OF SINTERING MACHINES AND STRENGTH OF AGGLOMERATES

V.L.TRUSHKO, V.A.UTKOV
Saint-Petersburg Mining University, Russia

A problem of industrial fluxed agglomerates self-destruction in the process of cooling after sintering has been examined. It has been revealed that the main reason of strength degradation is polymorphism of dicalcium silicate Ca_2SiO_4 (or short designation C_2S): β-$Ca_2SiO_4 \rightarrow \gamma$-$Ca_2SiO_4$. Ways for increasing the agglomerate strength by physical and crystal-chemical stabilization of the high temperature modification of C_2S have been proposed and tested.

Physical stabilization of C_2S agglomerate is increased with its structure reinforcement due to thickening of walls between large pores that is achieved by increasing height of the sintered layer through improvement of its gas permeability. The task is addressed by substituting the previously used import sintering ore with the polydisperse ore from the Yakovlevo field, which improves the charge pelletizing by 3-4 times and helps to bring the height of the sintered layer and the strength of the domestic agglomerate up to the international best practice standards, while eliminating a need to purchase import high-vacuum exhausters.

In practice crystal-chemical stabilization of C_2S within iron-ore agglomerate is ensured by adding an optimal multicomponent additive in the form of the waste product generated in production of alumina from bauxites, i.e. the red mud, to the initial sinter charge. Thus mechanical strength of agglomerates and pellets is increased by 5-10 % and their hot strength improves by 20-40 %. The productivity of sintering machines and blast furnaces improves by 5-10 %. Specific coke consumption reduces by 2-2.5 %. In production of iron-ore pellets red mud is substituting the import bentonite.

Key words: ferrous and nonferrous metallurgy, agglomerate, sintering machines, blast furnaces, fuel economy, Yakovlevo polydisperse ore, red mud.

How to cite this article: Trushko V.L., Utkov V.A. Development of import subtituting technologies for increasing productivity of sintering machines and strength of agglomerates. Zapiski Gornogo instituta. 2016. Vol.221, p.675-680. DOI 10.18454/PMI.2016.5.675.

Introduction. In most cases the iron ore prior to smelting in the blast furnace undergoes beneficiation. While after the ore crushing the iron-ore concentrate is briquetted using special methods for briquetting or fabrication of burnt pellets and agglomerates. A universal method is agglomeration, which allows to recycle the return dust, sludge, scale and sinter and pellet fines screened out prior to the blast furnace. The agglomerate is sintered with prevalent basicity (CaO/SiO_2 ratio) of 1.2-1.4, in order to avoid the feed of raw limestone to the blast furnace.

Such basicity creates a problem of explosive self-destruction of a strong hot agglomerate upon its cooling, leading to considerable economic losses. It has been determined, that increase in the amount of agglomerate fines in the blast-furnace charge by each percent results in a loss by the same percentage in a productivity of blast furnaces and overconsumption of expensive coke [1, 2, 4].

Self-destruction and agglomerate dust escape upon heating and recovery in the blast furnace lead to the loss of cast iron and increased dust load on the environment. That's why prevention of these phenomena is one of the pressing economic and environmental challenges of ferrous metallurgy.

Research methodology. Pelletizing and production of agglomerate was conducted in laboratory conditions and at metallurgical plants in the form of field tests.

Special attention was paid to the pelletizing of agglomeration charge.

Ability of charge to pelletizing [1-5, 10] was determined by the yield of granules sized +1.6 mm. As an indicator of sintering ore pelletizing properties the pelletizing coefficient was used, which reflects a share of the indicated fraction after pelletizing as compared to its initial content:

$$K = \frac{P_2 - P_1}{M} 100 \ \%,$$

where K is a pelletizing coefficient, %; P_2 is content of +1.6 mm fraction after pelletizing, g; P_1 is content of +1.6 mm fraction before pelletizing, g; M is a mass of the pelletized material, g.

Since there is almost a linear relationship between the vertical velocity of charge sintering and the consumption of air sucked [3, 4, 11], in order to determine the pressure loss after gas passing through a layer of the sintered charge the formula of L.K. Ramzin was used:

$$\Delta p = Ah\omega^n ,$$

DOI 10.18454/PMI.2016.5.675

where Δp – is the pressure loss in the layer, Pa; h is a height of the sintered layer, mm; ω is gas average velocity, m/s; *A, n* are empiric coefficients depending on the structure of the charge layer and the size and the shape of its particles. *A* coefficient is a function of filling layer density (ρ_{fill}), which is equivalent to diameter of particles (d_{eq}) and layer height (h), and calculated under the formula proposed by I.S.Bersenev:

$$A = \rho_{\text{fill}} \left(\frac{h}{d_{\text{eq}}} \right)^{0.37} .$$

Analysis of results. Self-destruction of sintered blast agglomerate leads to huge economic losses in metallurgical production. Increase in the amount of fines (particle size 0-5 mm) in the agglomerate by each 1 % is equivalent to the decrease by the same percentage in the blast furnace productivity and overconsumption of blast-furnace coke [4].

One of the main reasons of this phenomenon is polymorphism of dicalcium silicate (short designation C_2S) present within most spread fluxed agglomerates. Transition $\beta\text{-}Ca_2SiO_4 \rightarrow \gamma\text{-}Ca_2SiO_4$ is accompanied by an increase in the volume of crystal lattice by 10 %.The agglomerate being hard immediately after sintering at 1200-1300°C upon cooling at temperature about 675°C (of the indicated phase transition) suddenly starts cracking all around due to internal stresses emerging within the hardened body. The nature of this phenomenon is confirmed by the revealed [8] extreme dependency between the agglomerate strength and its basicity (CaO/SiO_2 ratio) with minimum strength at the agglomerate basicity of 1.2-1.35, when agglomerate glassy olivine bond by composition gets close to C_2S.

Physical stabilization of C_2S. The agglomerates with basicity over 2-2.5 have the bond consisting of strong calcium ferrites. It resists the emerging inner stresses. Physical stabilization of C_2S occurs. The amount of fines in the agglomerate reduces by 10-15 %.

In standard fluxed agglomerates with basicity of 1.2-1.4 the physical stabilization of C_2S is facilitated by monolithization of the sinter cake structure. It is achieved by increasing height of the sinter charge layer [4]. Each additional 10 cm in height of sinter layer bring reduction in the amount of fines (particle size 0-5 mm) in the agglomerate by 6-12 %. In this case polymorphism of the produced dicalcium silicate is prevented by a denser structure of the binding medium and its higher quantity.

The problem is that the height of the sinter charge layer is limited by its gas permeability. Generally it is ensured by pelletizing of the charge. But pelletizing is complicated by the amount of iron ore concentrates with low pelletizing ability the share of which keeps growing in the charges of sintering plants.

The ways to increase the gas permeability of such charges were explored in the context of feedstock parameters in the sintering plant Tulachermet LLC, where share of finely ground concentrates in the ore part of the charge reaches 70-80 %.The subject of research were the finely ground concentrates from KMA-Ruda plant and Stoilenskiy Mining and Beneficiation Plant (SGOK) and martite and hydrohematite ores from the Yakovlevskiy field substituting import Ukrainian sintering ore. Gas-dynamic properties of the pelletized charge containing KMA-Ruda concentrate and the ore from the Yakovlevskiy field are presented in tables 1.

Table 1

Gas-dynamic properties of the pelletized charge containing KMA-Ruda concentrate and the ore from the Yakovlevskiy field

Admix, mass %		KMA- ruda			SGOK		
		d_{eqv}, mm	A, pcs	$\Delta p/h$, Pa/m	d_{eqv}, mm	A, pcs	$\Delta p/h$, Pa/m
No admixes	0	0.22	37266	6123	0.29	32248	4698
Martite ore	15	2.38	9609	1579	0.75	14812	2158
	30	2.86	9198	1340	1.01	13491	1965
	45	3.15	8645	1259	1.37	12524	1824
Hydrohematite ore	15	1.33	11246	1638	0.69	13905	2026
	30	2.75	9002	1311	0.94	14036	2045
	45	2.77	9212	1342	2.69	9647	1905

DOI 10.18454/PMI.2016.5.675

As evidenced by data presented in Tables 1, polydisperse ores from the Yakovlevskiy field with high content of iron and astringent finely dispersed fraction are able to increase by a factor of 3-4 the gas permeability of the sinter charge layer containing iron ore concentrates [7].

Innovative technology is protected with a patent [6].

Maximum height of the sinter layer at the Russian sintering plants (Severstal PJSC) presently comprises 400 mm, while at the frontline foreign plants (Japan, China) it is 600-800 mm. The developed technology helps to improve the agglomerate strength properties and bring the height of the sinter layer to the best practice standards without incurring the costs for purchasing import (Japanese) expensive high-vacuum exhausters.

Crystal-chemical stabilization of C_2S. Crystal-chemical stabilization of dicalcium silicate is achieved by introducing to the system of a complex of oxides changing the state diagram and forming new solid solutions. There can be plenty of ways to do this. One of them is achieved through hardening of iron ore fluxed agglomerates by adding red mud (hereinafter the RM), which is a waste product of bauxite hydrochemical processing for alumina extraction, to the initial charge. RM is a complex of stabilizing C_2S oxides: iron, calcium, silicon, aluminum, potassium, sodium, titanium, vanadium and others.

The ability of red mud to harden agglomerates and pellets was proven [9] by solid laboratory and industrial tests (Table 2).

Table 2

Results of laboratory and field tests of the use of red mud for agglomeration of various iron ores and concentrates

IP	TS	AB	OF	RM	CLH	ISV	IOA	IPS	ROF
1	L	1.2	FGC	1	250/160	25	10	15	6.8
				2	250/160	44	10	15	30.8
				3	210/210	14		14	4.2
				2	300/200	22	10	15	7.7
2		1.3	FGC	1	600/200	8	10	10	10
				2	600/200	14	10	15	15
3		1.4	FGC+OSW	2	400/280	3.2	6.9	8	2.7
4	F	2	FGC	0.9	220/220	2	2	3.5	7
5		1.25		1	250/250				18
6		1.35		1	180/80			4	3.0
				1.5	180/180				10
7	I	1.36	FGC+OF	2	420/420		10.0-12.0	5.0 10.0	2.0-3.0
8	I	2.0	FGC+OF	1.7-2.2	400/400	3	10	8	5
	Average indicators (subject to compliance with technology)					3-7	5.8-8.0	5-10	2-5 %

Comments. IP – industrial plants: TS – testing stage; AB – agglomerate basicity CaO/SiO_2; OF – ore feedstock; RM – content of red mud in the charge, %; CLH – charge layer height, mm, (pilot/standard); ISV – increase in sintering velocity, %; IOA – increase in output of 'proper' (+10 mm) agglomerate, % rel.; IPS – Increase in productivity of a sintering machine, %; ROF – reduction in output of fines 0-5 mm in agglomerate after tests in the drum or capsule of the furnace, %; L – laboratory, F – field, I – industrial; FGC – finely ground concentrate; OF – ore fines; OSW – own sludge wastes).

In addition RM ability was revealed to increase not only mechanical (Table 2) but also hot strength of the agglomerates and pellets, i.e. resistance to destruction upon heating and recovery within charge in the blast furnace. Formation of dusty fraction sized 0-0.5 mm escaping from the blast furnaces is reduced by 20 % for pellets and by 40 % for agglomerates (Table 3) due to creation of a stronger alumoferrite bonding.

DOI 10.18454/PMI.2016.5.675

It has also been revealed that RM has astringent properties improving the granularity of iron one concentrates in charges of agglomerates and pellets. As a result the productivity of sintering machines is improved by 5-10 %.

Table 3

Impact of red mud on hot strength of pellets and agglomerates

Type of sinter cake	Binding	Formation of fractions. mm			
		%		% relative to basic cake	
		+10 (+5)	0-0.5	+10 (+5)	0–0.5
Pellets A	Bentonite	(61.4)	9.5	100	100
Pellets B	RM	(65.3)	7.8	106.4	82.1
Difference (B-A) = X		X1 = +3.9	X2 = –1.7	X3 = +6.4	X4 = –17.9
Pellets C	Bentonite	82.2	0.89	100	100
Pellets D	RM	89.8	0.65	108.5	73.1
Difference (D-C) = X		X1 = +7.0	X2 = –0.24	X3 = + 8.5	X4 = –27.0
Average for A-D		X1 = +5.4	X2 = –1.0	X3 = +7.4	X4 = –22.4
Agglomerates A	–	55.7	9.47	100	100
Agglomerates B	RM	77.2	7.01	138.5	74.0
Difference (B-A)		X1 = +21.5	X2 = –2.46	X3 = +38.5	X4 = –26.0
Agglomerates C	–	55.7	9.47	100	100
Agglomerates D	RM	82.2	4.13	147.6	43.6
Difference (D-C) = X		X1 = +26.5	X2 = –5.34	X3 = +47.6	X4 = –56.4
Average for A-D		X1 = +24.0	X2 = –3.9	X3 = +42.9	X4 = –41.2

Comment. A, C – basic pellets and agglomerates; B, D – pellets and agglomerates with admix of red mud.

In pellet production red mud can substitute the import bentonite, which is more expensive, but not able to increase the hot strength of pellets [9].

Some types of red mud contain increased amounts of sulfur and phosphorus, which impair the quality of metal and alkali, adversely affecting the strength of blast furnace lining.

The roasting tests for pellets from red mud revealed [8], that the concentration of these elements in the red mud prior to melting in blast furnace can be reduced by 20-40 % in the process of agglomerate and pellet sintering (Fig. 1, 2).Positive results were obtained for using red mud to harden agglomerates and pellets in representative by time blast-furnace melting at three industrial plants.

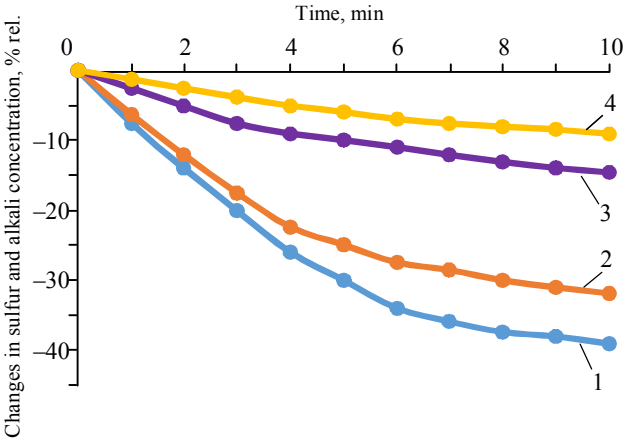


Fig.1. Changes in sulphur and alkali concentrations in RM pellets at different temperatures of oxidizing roasting:

1 – sulfur (1150°C), 3 – alkali ΣR_2O (1150°C), 2 – sulfur (1000°C), 4 – alkali ΣR_2O (1000°C)

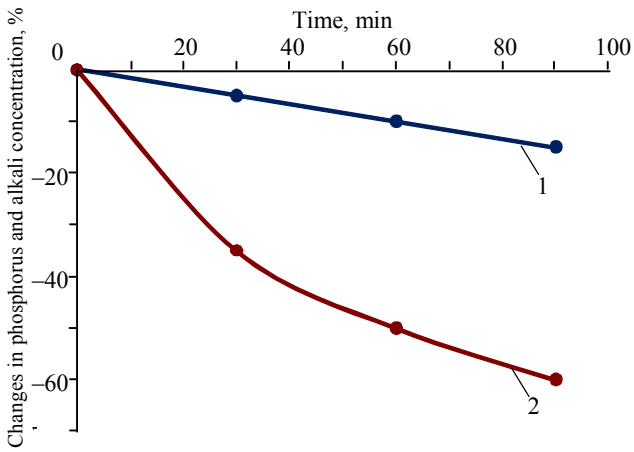


Fig.2. Changes in phosphorus and alkali concentration during reducing roasting of RM pellets:

1 – phosphorus, 2 – alkali ΣR_2O

DOI 10.18454/PMI.2016.5.675

Table 4 shows the results of using red mud in the agglomeration and blast furnace processes in ferrous metallurgy based on our technologies.

Table 4

Aggregate results of laboratory and industrial testing of the red mud use in agglomeration and blast-furnace processesin ferrous metallurgy

Scope of works	Number of experiments or field tests (feedstock varieties)	Productivity increase, %	Reduction in output of fines after strength tests, (% rel.)	Economy of process fuel, %
Laboratory pan roasting	Over 130 (21)	8-15	3-5 (7-20)	4-15
Tests at sintering plants	8 (7)	5-10	3-5 (10-15)	8-10
Guaranteed indicators		**5-10**	**3-5 (10-15)**	**8-10**
Tests in blast-furnace process	4 (4)	1.2-2.5	4-6 (12-17)	1.5-1.8
Guaranteed indicators		**1.2-2.5**	**4-6 (12-17)**	**1.5-1.8**

The use of red mud in metallurgy and other industries [12-15] also addresses an important environmental issue of liquidating sludge dumps where over 500 million tons of aluminum industry wastes have been accumulated.

Thus it is expedient to build red mud dispatch complexes instead of sludge dumps with estimated return of investment in 3-5 years.

Conclusion

1. One of the main reasons behind strength degradation of mass-produced industrial fluxed iron ore agglomerates is revealed, which is polymorphism of dicalcium silicate $2CaO \cdot SiO_2$ (C_2S); and possible ways for physical and crystal-chemical stabilization of high-temperature modification of this compound are proposed.

2. Physical stabilization is achieved through reinforcing binding medium of agglomerates, resisting internal stresses due to increase of agglomerate basicity (CaO/SiO_2 ratio) from 1.2-1.5 up to 2-5 and monolithic nature of its macrostructure by increasing the height of sintered layer.

3. Charge gas permeability increased by a factor of 3 or 4 is achieved by adding polydisperse fractioned sintering ore from Yakovlevskoye field, which helps to bring the height of the sintered layer and the quality of agglomerate to the international best practice standards without using import high-vacuum exhausters.

4. Crystal-chemical stabilization of 2 $CaO \cdot SiO_2$ with hardened agglomerate is achieved by adding to the initial charge of multicomponent industrial waste, i.e. the red mud (RM), after heat treatment of which by pellets agglomeration and roasting the excess sulfur and phosphorus are removed.

5. It has been determined that red mud cannot only substitute the import bentonite in production of iron ore pellets and agglomerates, but also increase their hot strength, i.e. resistance to destruction in the blast furnace.

REFERENCES

1. *Bersenev I.S.*, *Bokovikov B.A.*, *Klein V.I.*, *Kutuzov A.A.*, *Yaroshenko Yu.G.* Gas-Dynamic Properties of Initial Sinter Charge Layer. Stal'. 2010. N 9, p.16-18 [in Russian].

2. *Gerasimov L.K.*, *Zhuravleva L.G.*, *Frolov Yu.A., Dobryakov G.G.* Gas-Dynamic Properties of Agglomeration Charges. Izvestiya vuzov. Chernaya metallurgiya. 1984. N 2, p.31-32 [in Russian].

3. *Korotich V.I.*, *Frolov Yu.A.*, *Bezdenezhnyi G.N.* Agglomeration of Ore Materials. UGTU-UPI. Ekaterinburg. 2003, p.400 [in Russian].

4. *Vegman E.F.*, *Zherebin N.F.*, *Pokhvisnev A.N.*, *Yusfin Yu.S.*, *Kurunov I.F.*, *Paren'kov A.E.*, *Chernousov P.I.* Cast Iron Metallurgy. Moscow: Akademkniga. 2004, p.774 [in Russian].

5. *Panychev A.A.* Agglomeration Process Mathematical Model for Its Optimization and Automation. Obogashchenie rud. 2006. N 2, p.29-31 [in Russian].

6. Pat.2552218 RF. *Trushko V.L.*, *Utkov V.A.*, *Klyamko A.S.* Method for Agglomeration Charge Preparation to Sintering. Opubl.10.06.2015. Bul. N 17 [in Russian].

7. *Trushko V.L.*, *Utkov V.A.*, *Klyamko A.S.* Examination of Technological Properties of Sintering Ore from Yakovlevskoye Field. Zapiski Gornogo instituta. 2015. Vol.215, p.52-56 [in Russian].

8. *Utkov V.A.*, *Zyryanova O.V.* Modelling Dependency between Agglomerate Strength and Basicity. Zhurnal prikladnoi khimii. 2013. Vol.86. N 3, p.336-339 [in Russian].

9. *Utkov V.A.* Processing of Dump Sludge as a Part of Highly Technological Low Waste Technology for Production of Alumina from Bauxites and Nephelines. Tekhniko-ekonomicheskii Vestnik RUSALa. 2007. N 18, p.51-56. URL: http://www.aluminium-lider.com [in Russian].

DOI *10.18454/PMI.2016.5.675*

10. *Utkov V.A.*, *Leont'ev L.I.*, *Yakovlev M.G.* Reducing the Alkali, Sulfur and Phosphorus Concentration by Thermal Briquetting of Red Mud. Stal'. 2013. N 2, p.12-13 [in Russian].

11. *Frolov Yu.A.*, *Bezdenezhnyi G.N.*, *Baronbaev B.M.* Gas-Dynamic Calculation Method for Sintering Machines Network for Reconstruction and Design. Tsvetnaya metallurgiya. 2002. N 8-9, p.10-15 [in Russian].

12. *Ercag E.*, *Apak R.* Furnace smelting and extractive metallurgy of red mud. Recovery of TiO_2, Al_2O_3 and pig iron. J.Chem. Technol. Biotechnol. 1997. Vol.70, p.241-246.

13. *Wang Hong*, *She Xue-feng*, *Zhao Qing-qing et al*. Production of iron nuggets using iron rich red mud by direct reduction. J. Process Eng. China. 2012. Vol.12. N 5, p.816-821.

14. *Mohapatra B.K.*, *Mishra B.K.*, *Mishra C.R.* Proceedings of the Technical Sessios. TMS Annual Meeting and Exhibition. Febr. 27 – March 3, 2011. San Diego, Calif., p.140-145.

15. *Li Xiao-bin, Xiao Wei, Liu Wie et al.* Recovy of Alumina ferric oxid from Baer red mud rich in iron by reduction sintering. Trans Nonferrous Metals Soc. China. 2009. Vol.19. N 5, p.1342-1347.

***Authors*: V.L.Trushko**, *Dr. of Engineering Sciences*, *Professor*, *trushko@spmi.ru* (*Saint-Petersburg Mining University*, *Russia*), **V.A.Utkov**, *Dr. of Engineering Sciences*, *Professor*, *utkovva@yandex.ru* (*Saint-Petersburg Mining University*, *Russia*).

The paper was accepted for publication on 15 August, 2016.