

## Performance Assessment of Partially Pre-fused Synthetic Flux in Basic Oxygen Steel Making

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**Abstract:** Lump lime as the most common flux and iron ore as a coolant are used in basic oxygen steel making. However, high melting point, poor dissolution property, fines generation tendency and hygroscopic nature of lump lime often create problems in operation. As the combination of both iron oxide ( $\text{Fe}_2\text{O}_3$ ) and CaO shows eutectic at 1 230 °C, a combined mass of iron oxide and lime melts at lower temperature and dissolves faster in a molten bath. A partially pre-fused synthetic flux (PSF) was prepared through an innovative way in combination of iron oxide fines viz. Linz Donawitz converter sludge and blast furnace flue dust and lime fines by micro-pelletization of the mix followed by coke breeze free sintering. The developed PSF shows good cold handling strength, low melting point (1 180 °C), good thermal shock resistance, etc. As a low melting synthetic flux, its performance was assessed through dissolution/melting study in hot metal bath and refining of hot metal in a simulated bottom blown converter using (i) PSF, (ii) only lump lime and (iii) lump lime with iron ore when keeping other conditions identical. Very fast dissolution (27–80 s for 1–3 g lumps), enhanced removal of C and P (11–12 min), controlled slag foaming, and reduced oxygen consumption was obtained for using PSF.

**Key words:** synthetic flux; melting; refining; basic oxygen converter

Lump lime is traditionally used as a flux in the basic oxygen steel making furnace (BOF). However, charging of lump lime involves operational problems owing to its tendency of fine generation and hygroscopic nature. Featured with high melting point (approximately 2 700 °C), poor dissolution property and lighter in mass, the dissolution of lump lime in hot metal bath of BOF is difficult. After a certain time of blowing only when sufficient amount of iron oxide is formed, dissolution of lump lime starts and the basicity increases subsequently. Therefore, it takes a long time to make the basic oxidizing slag for dephosphorization.

The  $\text{Fe}_2\text{O}_3$ -CaO binary phase diagram indicates that a mixture of iron oxide ( $\text{Fe}_2\text{O}_3$ ) and lime (CaO) in a suitable proportion has a very low melting point<sup>[1]</sup>. Any flux material, which can form a basic oxidizing slag at low temperature, would help in the BOF refining process. Flux material with iron oxide and lime in a combined form has the possibility to meet all the above requirements.

Several investigators have used iron oxide fines in BOF in the form of briquettes<sup>[2-8]</sup>, pellets<sup>[7,9-11]</sup>, or sinter<sup>[12]</sup> to enhance refining. In Inland Steel<sup>[3]</sup>, waste oxides viz. dewatered sludge, girt and mill scale were used to make waste oxide briquettes (WOB), which were used in BOF. The Mc.Lauth Steel<sup>[13]</sup> used briquettes of iron-rich materials (IRM) both as flux and iron source in the basic

oxygen steel making process. The above investigators found faster dissolution of fluxes, faster refining, better metallic yield, etc. The faster decarburization is due to good emulsification behavior of FeO or  $\text{Fe}_2\text{O}_3$  enriched slag and faster reaction rate<sup>[5]</sup>.

Takano et al.<sup>[7]</sup> and Imazumi et al.<sup>[10]</sup> adopted cold bonded pellets. However, it took 28 days for curing the pellets, which was too long for industrial application. Furthermore, 10%–20% of Portland cement in the pellets may increase slag volume. Lime pellets coated with iron was used to enhance slag formation in the BOF<sup>[9]</sup>. However, the difficulties encountered in coating of lime pellets restrict their commercialization. Pal et al.<sup>[11]</sup> developed lime fluxed iron oxide pellets without using binder. It shows good performance in BOF refining. Although it was a combination of CaO and  $\text{Fe}_2\text{O}_3$ , it was not a pre-fused material.

Irmeler et al.<sup>[12]</sup> found that the use of the fluxed sinter promoted better dissolution, greater removal of both sulfur and phosphorous, and increase in metallic yield without any slopping. Nakano et al.<sup>[14]</sup> produced sinter utilizing BOF sludge without coke breeze and simultaneously dezincified up to 50% in a laboratory scale. However, their objective was to use the produced sinter for blast furnace but not high flux (lime) containing sinter suitable for LD converter.

Briquetting requires high percentage of binders and

forms fines due to disintegration at high temperature. Furthermore, it contains significant amount of moisture attached with lime which may form hydrogen at high temperature of converter with risk of explosion<sup>[8]</sup>. Cold bonded pellets prepared from iron oxides also contained costly binders and took long curing time (28 days for cement bonding). Most of these agglomerates could be used as a replacement of iron ore only but not as lime-iron oxide flux.

It is obvious that a combined mass of iron oxide and lime in pre-fused condition would be a better flux from dissolution and refining point of view. In the current study, a partially pre-fused synthetic flux (PSF) was made in combination of waste iron oxides and lime fines through sintering route. PSF does not contain any hydrated lime, that is, all lime is expected to be in a combined form. Therefore, the above problems of moisture, binder content, etc. may be alleviated. The PSF has been produced in conventional sintering strand after micro-pelletization of ultrafine wastes viz. Linz Donawitz converter sludge (LDS), blast furnace flue dust (BFD) and lime fines without using any coke breeze. Mainly, oxidation of metallic iron, wustite and magnetite in LDS was the heat source in sintering, the details of which have been reported earlier<sup>[15, 16]</sup>. This paper aims at assessing the per-

formance of the produced PSF in BOF refining through its dissolution/melting characteristics in a hot metal bath and refining of hot metal in a simulated bottom blown laboratory scale facility using this flux.

## 1 Experimental

Primary raw materials used for this study were LDS, BFD and commercial grade burnt lime. LDS and BFD were collected from Tata Steel, India. Chemical analyses of these three ingredients are presented in Table 1. 68.5% in size of LDS is below 150  $\mu\text{m}$  and 49.2% is below 45  $\mu\text{m}$ , while 71% in size of BFD is below 150  $\mu\text{m}$  and 28.8% is below 45  $\mu\text{m}$ . It may be noted that the majority of the waste oxide particles is too fine for direct agglomeration through sintering. Accordingly, micropellets of 2–6 mm in size were first prepared in a pelletizer. Then, they were treated with  $\text{CO}_2$  containing gas for strength development. The developed micropellets were then sintered in a 10 kg scale sinter pot to make PSF. Since the making procedure and the development process of micropellets<sup>[15]</sup> and PSF<sup>[16]</sup> have already been reported, only the important properties of the developed micropellets and PSF used in this study are represented in subsequent discussion for the sake of completeness.

**Table 1 Chemical compositions of raw materials**

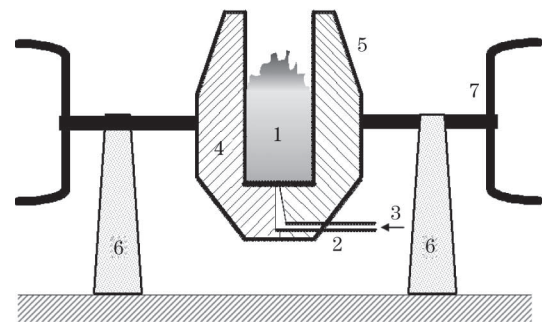
Material	Total Fe	Metallic Fe	CaO	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	MgO	Na <sub>2</sub> O	K <sub>2</sub> O	ZnO	C	mass%
LD sludge	65.5	17.80	7.67	1.79	1.02	2.48	0.73	0.53	0.17	–	
BF dust	34.14	–	1.84	6.29	4.66	2.4	0.22	1.25	0.11	33.1	
Lime	–	–	95.11	0.73	1.12	0.8	–	–	–	–	

### 1.1 Dissolution study

Dissolution of PSF was studied in an electrically heated high temperature furnace. A liquid pool of hot metal was first prepared by melting pig iron chips in a graphite crucible in the temperature range of 1 350–1 500 °C inside the furnace. Pre-weighed PSF sample was charged into the molten hot metal from the top hole of the furnace. Single pieces of block shaped PSF samples were charged one after another. The progress of melting or dissolution was observed through the top view port by charged-coupled device (CCD) camera video graph and recorded in the computer. The time needed for complete melting has been termed as “dissolution time”.

### 1.2 Refining study for performance assessment

In order to assess the performance of PSF, the refining of hot metal was carried out in a bottom blowing facility. It was a mild steel ladle lined with ramable magnesite, the schematic of which is presented in Fig. 1. The bottom of the ladle was fitted with an “L” shaped tapered quartz tube embedded in the magnesite lining and the other end of the tube was connected to oxygen gas cylinder through PVC piping to allow bottom blowing.



1—Chamber; 2—Oxygen nozzle; 3—O<sub>2</sub> inlet; 4—Magnesite lining; 5—Shell; 6—Stand; 7—Handle for tilting.

**Fig. 1 Schematic of bottom blowing facility**

The hot metal was first prepared by melting 9.7 kg pig iron chips (C 3.5%–4.5%, Si 1.40%–1.85%, Mn 0.3%–0.5%, P 0.22%–0.30% and S 0.04%–0.06%) in an induction furnace of 50 kVA at a temperature of around 1 650 °C. Prepared hot metal was shifted to the bottom blowing facility, which was preheated to around 800 °C by gas flame. Temperatures at different stages of the experiment were measured by an infrared radiation (IR) py-

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