Abridged version

KAWASAKI STEEL TECHNICAL REPORT
No.7 (March 1983)

Application of Flame Gunning to Hot Fettling of BOF

Tadashi Morimoto, Shigeru Ogura, Teruo Hiramatsu, Masuto Simizu, Ryoji Uchimura

Synopsis :
A thermal spraying technique in which dead burnt magnesia powder is partially fused in flames made by combustion of premixed coke powder in oxygen flow gas and bonded to the furnace wall has been applied to the hot repair of BOF. The technique is called the "flame gunning" and introduced to No.1 steelmaking shop at Chiba Works, were hard operation such as stainless steel blowing is carried out. As the flame gunned layer has such low porosity as that of burnt magnesia-dolomite brick, it can withstand 2 hearts of stainless steel blowing and 11 hearts of low alloy steel blowing. By the introduction of flame gunning, the total refractory cost has been reduced to 26% less than the cost without the gunning. As the flame gunning has many advantages such as short repairing time, high corrosion resistance of the gunned layer and low cost, it can be said that the flame gunning is a desirable technique for the future BOF operation in which an increase in the continuous casting ratio and rising of tap temperature are inevitable.

The body can be viewed from the next page.

Application of Flame Gunning to Hot Fettling of BOF*

Tadashi MORIMOTO** Shigeru OGURA ** Teruo HIRAMATSU **
Masuto SHIMIZU ** Ryoji UCHIMURA ***

A thermal spraying technique in which dead burnt magnesia powder is partially fused in flames made by combustion of premixed coke powder in oxygen flow gas and bonded to the furnace wall has been applied to the hot repair of BOF. The technique is called the "flame gunning" and introduced to No. 1 steelmaking shop at Chiba Works, where hard operation such as stainless steel blowing is carried out.

As the flame gunned layer has such low porosity as that of burnt magnesia-dolomite brick, it can withstand 2 heats of stainless steel blowing and 11 heats of low alloy steel blowing. By the introduction of flame gunning, the total refractory cost has been reduced to 26% less than the cost without the gunning.

As the flame gunning has many advantages such as short repairing time, high corrosion resistance of the gunned layer and low cost, it can be said that the flame gunning is a desirable technique for the future BOF operation in which an increase in the continuous casting ratio and rising of tap temperature are inevitable.

1 Introduction

The life of lining materials for BOF has steadily been extended as a result of advances in various operation techniques, improvements in refractory materials and advances in the technique of measuring wear profile and in the gunning technique. However, an increase in ladle refining and degassing treatment along with a rise in the continuous casting ratio and the sophistication of the types of steel melted resulted in a lowering of furnace life and an increase in refractory consumption.

The gunning technique, one of the conventional measures for extending furnace life, poses a problem in that sufficient time can not be spared for gunning because a rise in the continuous casting ratio entails an increase in the continuous-continuous ratio and the tapping time of BOF must be scheduled to meet casting time.

In the case of the semi-wet gunning material which consists of phosphate bonding material together with a little water, there has been a problem in that when blowing special steel such as stainless steel, the gunned layer cannot withstand even one heat and that the pickup of [P] takes place.

A number of trials have been made to cope with this problem of gunning, by the application of the thermal spraying technique[1]. Among them, the technique of thermal spraying in which coke powder (as a thermal spraying heat source) premixed with refractory material, is discharged together with the oxygen gas flowing into the furnace interior is attracting attention because of the following advantages:

(1) Since solid fuel powder such as coke powder is used as the heat source for thermal spraying, the energy cost is low.
(2) It is possible to secure enough heat quantity to partially melt the refractory powder at any time by mixing the powder with a constant quantity of coke.
(3) Therefore, the heat quantity is sufficient to discharge a large quantity of refractory material in a short time, and thus repair time can be shortened.
(4) The refractory powder in the spray material is bonded to the furnace wall in a partially fused condition. The adhesion of the gunned layer to the furnace wall surface is strong, and moreover, the close structure of the gunned layer itself displays excellent endurance.

This thermal spraying technique is called "Flame Gunning." Remarkable effects have been achieved at the Chiba Works of Kawasaki Steel Corporation by introducing this flame gunning technique to the 85-t BOF at the No. 1 steelmaking shop which melts many types of high temperature steels, including stainless

---

* Originally published in *Kawasaki Steel Giho*, 14 (1982) 3, pp. 29–36
** Chiba Works
*** Research Laboratories

steel. The following describes the equipment, rapair methods, effects, etc. of flame gunning.

2 Features of Flame Gunning

In flame gunning, a mixture of dead burnt natural magnesite or seawater magnesia clinker powder and coke powder is used as the gunning mass. The gunning mass is conveyed by N_2 gas, and is discharged together with oxygen into the hot furnace from the nozzles at the lance tip introduced into the BOF. The coke in the discharged material is burnt by oxygen, producing a high temperature flame. The refractory powder, of which impurities on the surface are partially fused while flying through the flame, runs against the furnace wall, and adheres to it. To realize such flame gunning, the equipment factor that permits discharge of the gunning mass into the hot furnace as well as the thermal factor that permits partial fusing of the material are of importance.

As for the thermal factor, investigations were made, as described in a separate paper, and the following conditions were established as the conditions for obtained a dense gunned layer:

Furnace wall temperature before gunning:	Over 1 200°C
Discharge quantity of gunning mass:	220 kg/min
Coke ratio in gunning mass:	35%
Optimum gunning distance	2.1–2.2 m

As for the equipment factor, as will be described later, the water-cooled lance having nozzles at the tip is introduced into the furnace and serves the functions necessary for the flame gunning operation. The schematic illustration of the flame gunning operation is given in **Fig. 1**.

3 Outline of System

This system is roughly divided into two parts; a gunning mass feeding system and a lance holding vehicle with a lance. The entire configuration of the flame gunning system is shown in **Fig. 2**. The following describes the features of the system.

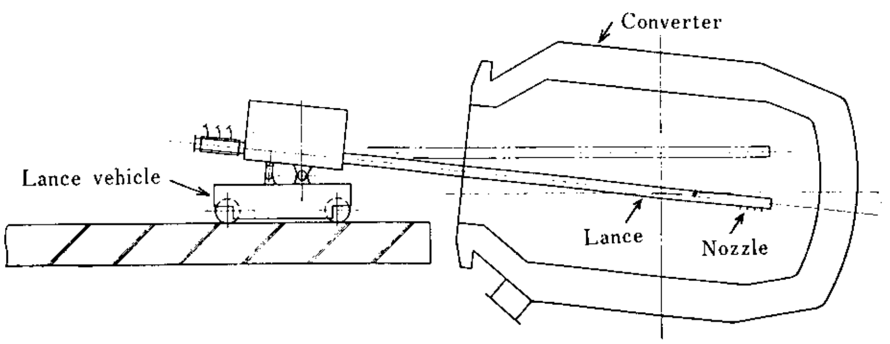

Fig. 1 Schematic illustration of flame gunning operation

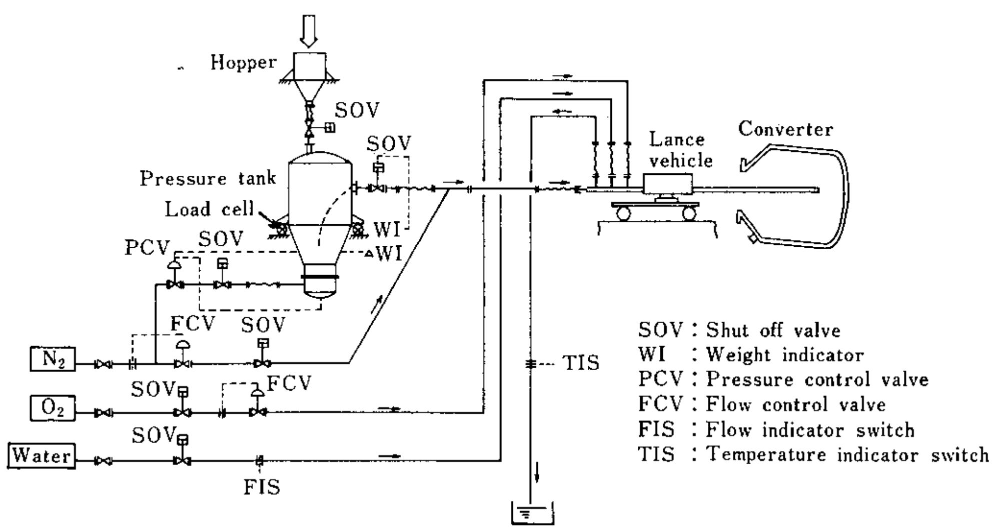

Fig. 2 Outline of flame gunning system

3.1 Gunning Mass Feeding System

This system stores gunning mass, transports it to the gunning lance and feeds it together with oxygen into the furnace interior from nozzles at the lance tip. It consists of a pressure tank and transport piping. The pressure tank is a cylindrical cone type: the inside of the tank is pressurized, and fluidized gunning material is fed from the bottom of tank by a top draining method.

To fill the tank with the gunning mass, a shut-off valve provided at the top of the tank is opened, and the gunning mass is supplied via a hopper. The pressure tank is provided with a weigher using a load cell, which is used not only for control of the storage quantity of the gunning mass but also for setting of the feeding quantity and control of the feeding rate. The feeding rate is set by controlling the tank pressure and the flow rate of carrier gas (N_2).

The diagram of the gunning mass feeding characteristic in this system is shown in **Fig. 3**. A stable transport condition is obtained in the area above the broken line in the diagram, and the actual operation is arrived out on the basis of this diagram.

In addition to this, a bag filter dust collector is provided in order to prevent dust from scattering at the time the gunning mass is fed in and the tank pressure is released. The main specifications of this system are shown in **Table 1**.

In order to control this system, a sequencer with a CRT display unit and an arithmetic processing unit is used, thus facilitating the setting and changing of conditions. Included in the control items are the tank pressure, the nitrogen gas flow rate and the oxygen gas flow rate; the programmed control for setting tank pressure and nitrogen gas flow rate so as to restrain acute climb of feeding rate at the gunning start; and also the oxygen flow ratio control corresponding to a feeding rate variation so as to maintain optimum combustion condition during gunning. Moreover, this system is provided with alarm functions for the following situations to ensure safety and reliability:

(1) Reduction in flow rate and pressure of the lance cooling water, and temperature rise of return water

(2) Reduction in pressure of oxygen and nitrogen gasses below the level for optimum combustion and transportation.

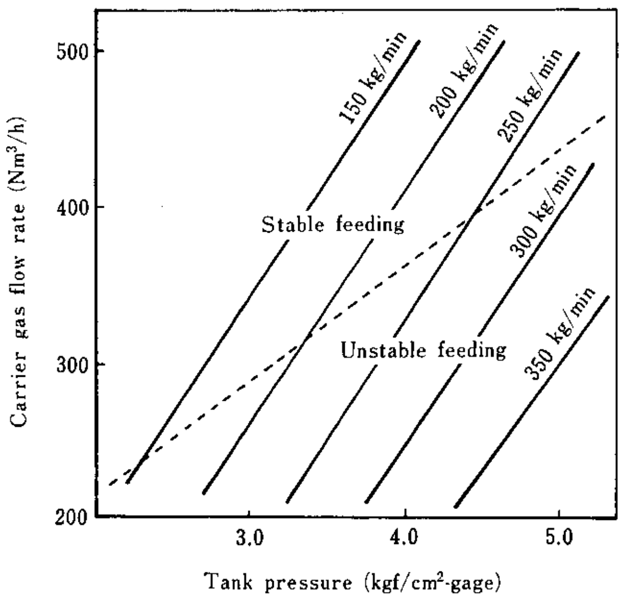

Fig. 3 Diagram of gunning mass feeding

Table 1 Specification of gunning mass feeding system

Item	Specification
Pressure tank	Vertical cylinder type Capacity NET 2.5 m^3 Weigher load cell 2.5 t Max. pressure 7 kgf/cm^2-gage
Feeding rate	Max. 300 kg/min
Carrier gas flow rate	7 Nm^3/min
Transport distance	80 m in horizontal direction 5.5 m in vertical direction
Properties of gunning mass	Bulk density 1.0 g/cm^3 Particle size under 100 μm

3.2 Lance and Lance-holding Vehicle

As shown in **Fig. 4**, the lance has a quadruplex tube

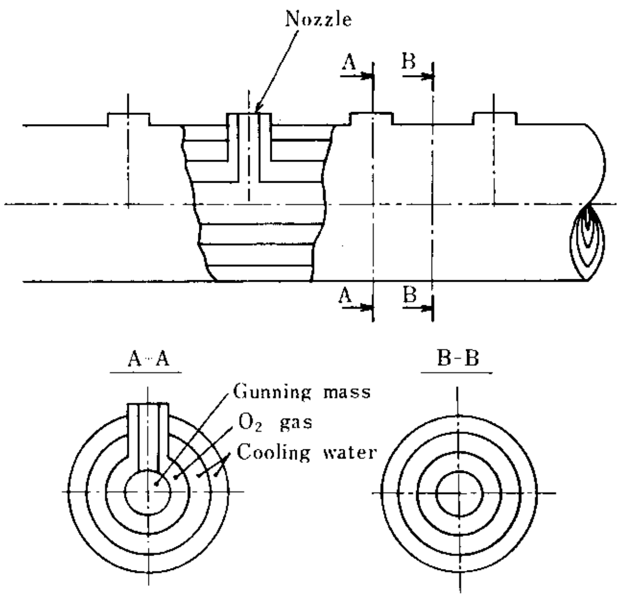

Fig. 4 Schematic illustration of lance structure

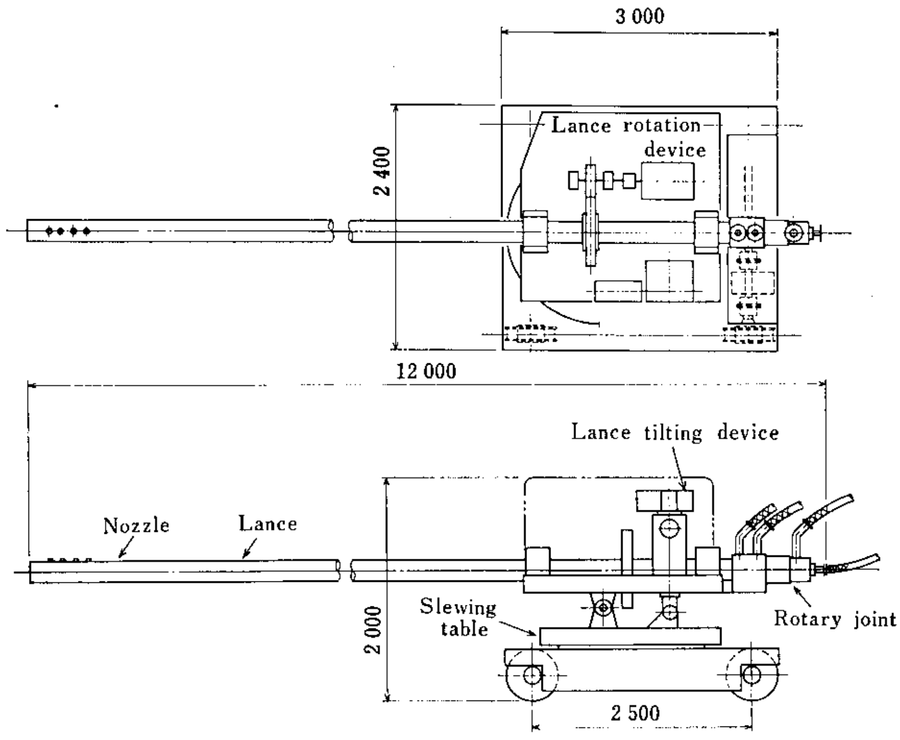

Fig. 5 Lance vehicle

construction with a 200 mm outside diameter and a 12 m total length each path aligned from inside out for the gunning mass, oxygen gas, return cooling water and forward cooling water, respectively. There is no special limitation to the length of the lance, which depends upon the matching condition between the dimensions and the circumference of the furance.

As is clear from **Fig. 4**, the nozzles at the tip are of double structure, the inner tube of which is connected with the path of gunning mass and outer tube is connected with the path of oxygen gas. Since powder passes through the inner tube, an alumina tube is inserted into the inner tube's interior to prevent abrasive wear, and the whole inner tube is designed to be detachable.

Then, the lance is placed on the lance holding vehicle, as shown in **Fig. 5**. It is designed to make ① forward and backward motion, ② rotation, ③ titling and ④ revolution on its own axis, so that the nozzle position can be adjusted to any optional position that requires repairing inside the BOF. All these movements are performed electrically. A turntable is provided on the movable vehicle, and on the turntable, a worm jack for tilting movement is installed. In addition to this, a lance holding base is provided which supports the lance on bearings. The revolution of the lance on its own axis is performed by driving the gears mounted on the lance. At the rear end of the lance, the aforementioned gas and water paths are connected to respective piping by the quadruplex tube rotary joint construction, permitting each fluid supply during the lance rotation on its own axis. Moreover, the front section of the vehicle is provided with a heat protection cover in order to protect each device from the radiant heat radiated from the opening of BOF during flame gunning.

The main specifications of the lance holding vehicle are shown in **Table 2**. For the lance driving, all flame gunning works are classified in advance into about 20 patterns for the purpose of automating flame gunning works in addition to manual operation, so that the lance position as well as the nozzle direction

Table 2 Specification of lance vehicle

Function	Rate	Range of Movement	Motor capacity
Foward and backward movement	27 m/min	9 m	AC 2.2kW
Horizontal lance movement	0.23 rpm	+15° - 90°*	AC 1.5kW
Vertical lance movement	0.08 rpm	+10° - −15°**	AC 2.2kW
Lance rotation	1.0 rpm	Unlimited	AC 7.5kW

* The angles between lance direction and the center axis of furnace

** 0° is the angle from the horizon

can be regulated by the sequencer according to each pattern. Thus, once lance's initial setting and pattern selection have been performed prior to the start of flame gunning, all gunning works can be carried out automatically.

3.3 Utilities

In this system, (a) lance cooling water, (b) oxygen gas for combustion and (c) nitrogen gas for gunning mass transportation are used, as described above. The main specifications of the utilities for flame gunning are shown in **Table 3**.

Table 3 Utilities of flame gunning

	Gunning mass	N_2	O_2	Cooling water
Pressure (kgf/cm^2-gage)	—	7	15	7
Flow rate (Nm^3/min)	220 kg/min	7	145	2

4 Repairing Technique

Two 85-t BOF units are installed in the No. 1 steelmaking shop at Chiba Works, where the operation mainly consists of the refining of stainless steel and other special steel such as silicon steel, high carbon steel, etc. In 1981, moreover, the units were remodelled from top-blown BOF to combined blown BOF (K-BOP), and the blowing ratio of stainless steel is increased. The kinds of steel production and average tap temperature over the 6 month period from August, 1981 are shown in **Table 4**. As is clear from the table, the tap temperature is high, which makes operating conditions for the BOF refrectory material very severe. Moreover, the type of steels to be refined are so varied, as described above. Magnesia-carbon bricks cannot be used for stainless steel, and magnesia-chrome bricks cannot be used for high silicon steel. Accordingly, burnt magnesia-dolomite bricks (CaO 23%) combined with natural dolomite clinber are mainly used as lining refractory material.

This markedly reduces the furnace life, and under the present conditions, the furnace operation itself cannot be continued without an effective hot repairing method.

Table 4 An example of operating condition of No. 1 steelmaking shop at Chiba Works

	Stainless steel	Low alloy steel
Production ratio	34.5%	65.5%
Average tap temperature	1 689°C	1 674°C

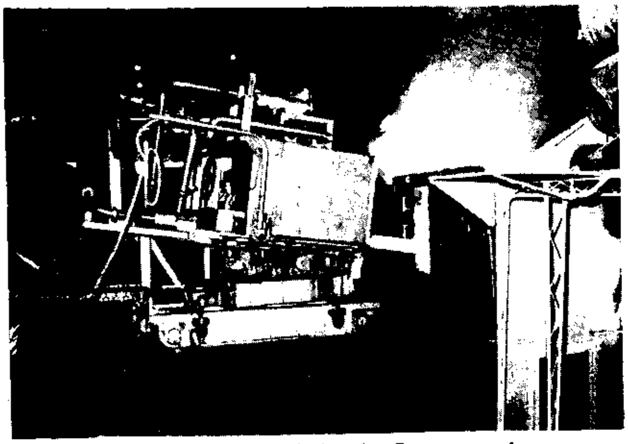

Photo 1 Hot repair by the flame gunning

In the case of stainless steel and other types of steel, an operation is continued respectively for 5 heats to 15 heats. During these heats, the repair of the furnace lining by flame gunning is carried out when changing over to stainless steel blowing and during the interval of stainless steel blowing which causes significant wear of refractory material. Although the gunning frequency averaged once every 4–5 heats for all types of steel blowing, different repairing methods are employed in the first and second halves of a furnace campaign according to the wear condition of lining refractory material. The repairing condition by flame gunning is shown in **Photo 1**.

For repair, the partial repairing method for portions with noticeable wear is employed in the first half of the campaign in order to ensure uniform wear of the entire lining, while the whole repairing method is mainly employed in the second half of the campaign in order to repair the entire lining of the furnace. However, even in case where partial repairing is employed, it is difficult to obtain a firmly adhered layer since the furnace wall temperature and the flame temperature are both low at the beginning of flame gunning.

Therefore, a pattern is set in which the entire furnace is repaired prior to partial repair and partial repair is made after the furnace wall temperature and the flame temperature are sufficiently high. As for the gunning method, whole repair mainly of both trunnion sides is carried out by the method shown in **Fig. 6** (a), and partial repair by the method shown in **Fig. 6** (b). In both cases, a better gunned layer can be obtained when the gunning direction is close to the tangential direction than when it is vertical to the furnace wall.

In the top-blown BOF prior to the introduction of flame gunning, the tendency of partial wear was noticeable, and it was impossible to obtain sufficient

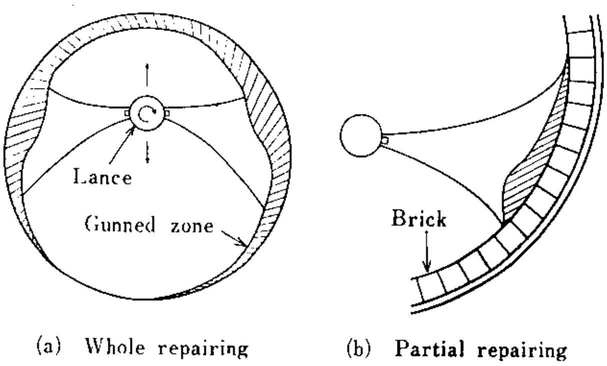

Fig. 6 Schematic illustration of repairing by gunning method

repair effect in the repair method using the semi-wet gunning mass of phosphate bonding. The wear condition in this case is shown in **Fig. 7** (c): the safety lining was exposed at the portion where the slag lines at the time of sampling and at the time of blowing were crossed; there were many cases where the operation of BOF was forced to be stopped. When flame gunning was initially introduced, the partially worn-out parts referred to were preponderantly repaired to avoid partial wear and to prolong the life of the furnace, as shown in **Fig. 7** (b). However, the safety lining was exposed in other parts. The BOF operation in this case was also forced to be stopped. The improved gunning method mentioned above brought apositing result as shown in **Fig. 7** (a). A nearly uniform wornout profile could be obtained through the employment of the above-described repairing method in spite of the fact that the stirring condition of steel and slag bath is severe, compared with that in the top-blown BOF.

A gunned layer obtained by flame gunning has a thickness of about 20 mm when the gunning quantity is 1.5 tons per one gunning operation, though it depends upon the area of repair. A condition of a gunned layer, which was gunned after final blowing in the furnace campaign and sampled, is shown in **Photo 2**. This gunned layer displays the durability of about 2 heats in the case of stainless steel blowing and 11 heats max. in the case of low alloy steel blowing at a tap temperature of 1 600–1 650°C. Average porosity of the gunned layer is 10–18%, which is nearly equal to the porosity (15–17%) of burnt magnesia-dolomite brick and is much lower (denser) than the porosity (30–40%) of semiwet gunning mass. Since the gunned layer of the flame gunning has dense structure, it is considered that it displays high durability[2].

To investigate the adhesive efficiency of flame gunning, dust produced at the time of gunning was collected and examined. The SEM image of the dust is shown in **Photo 3**. The grain diameter is as small as under 2 μm, and the shape is nearly spherical. The main component of the dust is FeO, and it has little MgO. Therefore, the dust is considered to be oxidized metal adhered to the inside of the furnace. The adhesive efficiency of gunning mass derived from the area of the gunned layer and the thickness distribution after the final blowing is approximately 95%, and thus it is estimated to have very high adhesive efficiency.

The results of comparison of the refractory consumption and costs with and without flame gunning in some campaigns having nearly the same stainless steel blowing ratio (about 30%) are shown in **Table 5**. The consumption of flame gunning mass means the

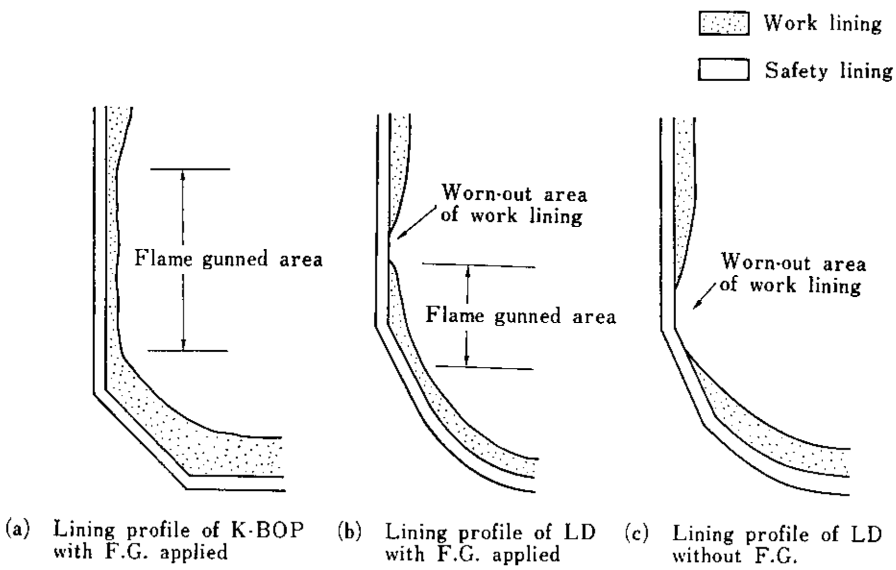

Fig. 7 Worn-out lining profile of LD and K-BOP

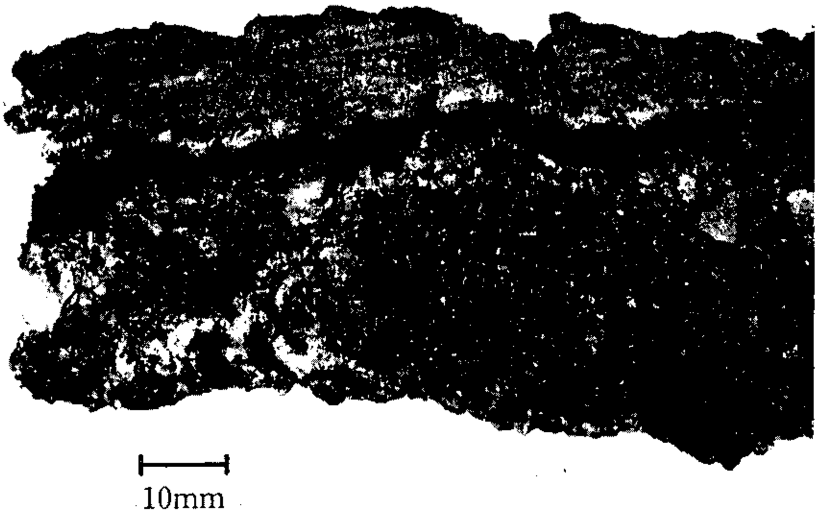

Photo 2 Section of gunned layer

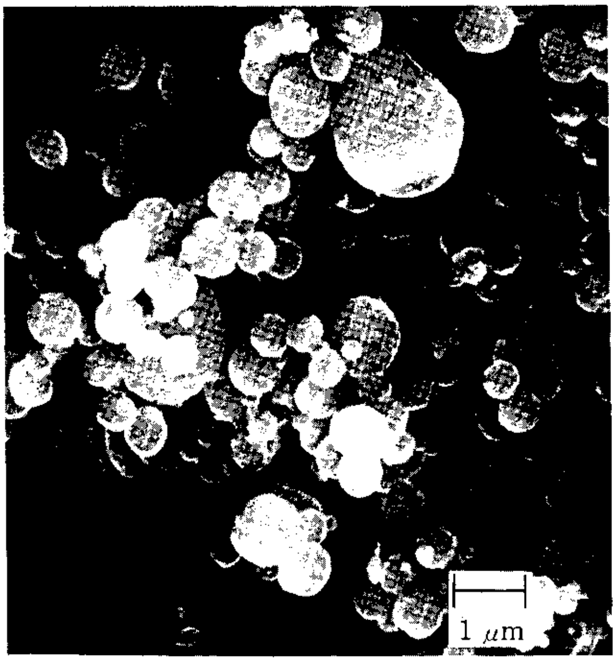

Photo 3 SEM photograph of dust during flame gunning

consumption of magnesia powder, and though fuel coke is not included, the calculation of the refractory cost ratio is based on the gunning mass cost including coke. As is clear from the table, 26% reduction in refractory cost was obtained because coke powder low in cost is used, though the refractory consumption is high.

Table 5 Refractory cost merit with the flame gunning applied (Stainless steel: 30%)

	Without flame gunning	With flame gunning applied
Lining life (heats)	246	365
Brick consumption (kg/t)	10.49	7.07
Gunning mass consumption (kg/t)	0	2.0
Total refractory consumption (kg/t)	10.49	9.07
Refractory cost (ratio)	1.00	0.74

5 Conclusion

Under the flame gunning technique, the gunning mass of a mixture of magnesia and coke powder is burnt in an oxygen gas flow and magnesia powder is fettled to BOF wall. For flame gunning, a gunning mass feeding system as well as a lance with a lance holding vehicle is required; and a number of new ideas have been put into effect for the operation of each equipment, considering the security and stability of material feed, safety as well as reliability, and simplicity of flame gunning works. Effective repair has also been made possible thanks to the employment of automatic operation, repair methods well fit to the wear condition of the furnace, etc. Owing to the improvement of the repairing technique coupled with the high durability of the gunned layer produced through flame gunning, a 26% reduction in refractory material cost has been achieved, compared with the conventional technique.

Flame gunning has many advantages such as

(1) Short gunning time
(2) High corrosion resistance of the gunned layer
(3) Low heat source cost.

Consequently, it is expected that flame gunning will play an important role in the future BOF operation which will inevitably entail an increase in the continuous casting ratio and a rise of tap temperature.

References:

1) E.g. A. Katada & K. Hiragushi, *Kinzoku*, **51** (1981) 7, p. 23
H. Fukuoka et al., *Tetsu-to-Hagané*, **67** (1981) 4, S164
O. H. Цемерис et al., *МЕТАЛЛУРГ*, **21** (1978), p. 3.
2) T. Morimoto et al., *Taikabutsu*, **34** (1982) 290, pp. 137–145