ADVANCES IN CERAMICS • VOLUME 13

NEW DEVELOPMENTS IN MONOLITHIC REFRACTORIES

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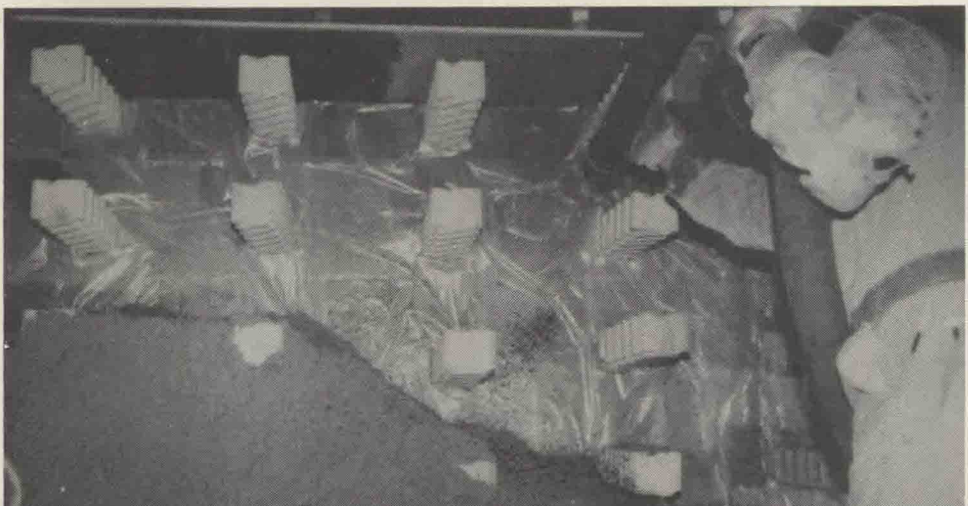
Edited by
Robert E. Fisher



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NEW DEVELOPMENTS IN MONOLITHIC REFRACTORIES

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The American Ceramic Society, Inc.
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PREFACE

The International Symposium on New Developments in Monolithic Refractories was held on April 30 and May 1, 1984 in Pittsburgh, Pennsylvania in conjunction with the 86th Annual Meeting of the American Ceramic Society (ACerS). The symposium was jointly sponsored by Committee 547 on Refractory Concrete of the American Concrete Institute and the ACerS. The present volume, number 13 of the series *Advances in Ceramics* published by the ACerS, comprises the symposium proceedings.

The organizing committee consisted of:

Robert E. Fisher, Plibrico Co., U.S.
William E. Boyd, Kaiser Refractories, U.S.
John L. Evans, British Steel Corp., U.K.
Timothy J. Fowler, Monsanto Corp., U.S.
Joseph Kopanda, Alcoa, U.S.
Wolfgang Kronert, Technical Institute, Aachen, Germany
Earl Seward, Lehigh Portland Cement Co., U.S.
Kiyoshi Sugita, Nippon Steel Corp., Japan
Raymond W. Talley, General Refractories, U.S.
Alfred F. Woolley, Dravo Engineers, Inc., U.S.

The symposium provided a state-of-the-art picture of this rapidly evolving area of refractories technology. Interest in the subject was evidenced by the fact that 200 or more attended the technical sessions in Pittsburgh. Refractories technologists from more than 30 countries requested information. The international nature of the syposium was evident from the seven nationalities of the authors.

The editor is especially grateful to Messrs. Boyd & Evans from the organizing committee, who also acted as associate editors on the manuscripts. Dr. David Lankard (Chairman of ACI 547) and Dr. Jess Brown (a member of ACI 547) also deserve thanks for their efforts in editing the manuscripts.

R. E. Fisher
Plibrico Co.

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The Evolution in Worldwide Monolithic Refractories Usage

Recent Progress in Monolithic Refractories Usage in the Japanese Steel Industry

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The use of monolithic refractories in the Japanese steel industry is approaching 50% of the total refractories used in this industry. In the technology for using monolithic refractories, material selection techniques and lining techniques are closely connected. Typical methods of lining with monolithic refractories include casting, vibration, and ramming, and these refractories are applied to a wide variety of equipment, including iron troughs, ladles, and tundishes. Further technical studies must be made on (1) drying and heating techniques, (2) highly corrosion-resistant materials, and (3) techniques for controlling the quality of refractory linings.

About 30 years have passed since monolithic refractories were introduced into Japan, and today monolithic refractories are indispensable to steel manufacturing technology.

At first they were used mainly for the lining of slab reheating furnaces and soaking pits. Influenced by the introduction of the sand-slinger method for lining ladles in the early 1970s, such various lining methods as casting, ramming, and vibration-forming were developed, with the result that monolithic refractories came to be widely used to line molten metal troughs and vessels as well.

Repair techniques were also developed for furnace life extension and refractory cost reduction; monolithic refractories play an important role in this area, also.

With these circumstances for a backdrop, the use of monolithic refractories by the Japanese steel industry has continued to increase and now comprises nearly 50% of refractories consumed by the industry (Fig. 1).[1]

This paper reports mainly on technology for using monolithic refractories in the Japanese steel industry's major equipment. Future subjects for study, and prospects for the future regarding these materials are also described.

Monolithic Refractories for Ironmaking

Iron Trough Refractories

Technical innovations for iron trough refractories began to develop rapidly in the late 1970s. Although ramming had been the traditional method used to line iron troughs, vibration-forming, casting, and other new methods also came to be used to raise the lining efficiency, save lining labor, and extend the service lives of iron runners. The fact that these new lining

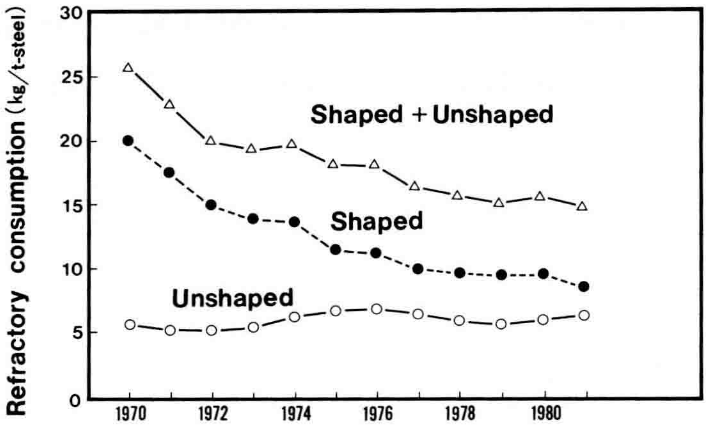

Fig. 1. Refractory consumption in the Japanese steel industry.

methods can effectively perform intermediate repairs is significant both technically and economically.

The advent of these new lining methods was made possible by the development not only of new lining devices but also new material techniques. The use of ideas and principles of powder technology and rheology (and particularly the utilization of submicrometer particles) made an important contribution to the development of new lining materials.

Vibration-Forming Method: The vibration-forming (VF) process and the Shinagawa vibration process (SVP) method are the methods presently used in Japan.[2,3] The VF process, which was developed in the early 1970s, provided a basis for developing subsequent processes. This process utilizes the thixotropic properties of low-moisture, refractory particle mixes that become fluid when mechanically vibrated and return to the hardened state upon standing. Figure 2 shows the repair of a main iron trough using this process. The

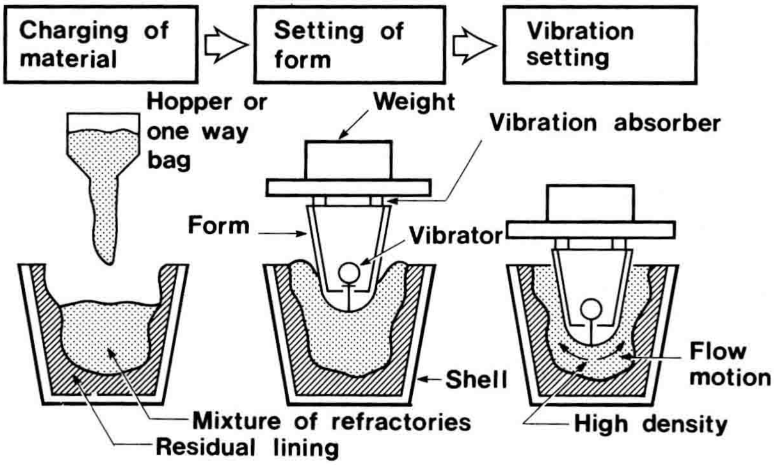

Fig. 2. Trough relining procedure using the VF process.

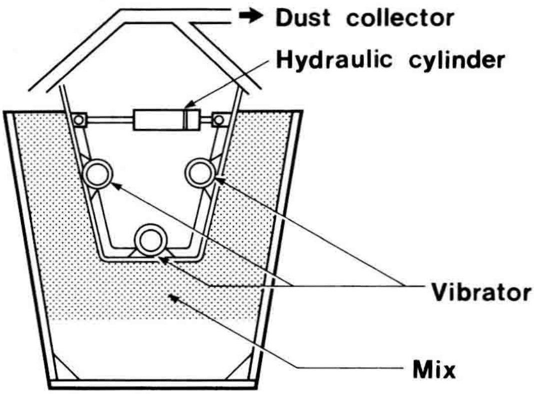

Fig. 3. SVP vibration process for trough relining.

refractory material is charged into the iron trough, and the form is settled into the material and vibrated to reline the trough.

Figure 3 shows a schematic view of the SVP method, a dry-type vibration method developed in the late 1970s. While the VF process uses a mix containing about 5% moisture, the SVP method uses a mix which contains no liquid binder (except 0.5% oil for dust prevention). This method produces a lining that does not need drying and is free from the problem of explosion

Table I. Properties of Trough Lining Materials

	VF Process		SVP Method	
Chemical composition (%)				
Al_2O_3		77		76
SiO_2		3		2
SiC + C		17		15
Water content (%)		5.0		0
Apparent porosity (%)	110 °C/24 h	17.2	180 °C/18 h	26.1
	1400 °C/ 1 h	22.2	1500 °C/ 3 h	25.0
Bulk density (g/cm^3)	110 °C/24 h	2.92	180 °C/18 h	2.72
	1400 °C/ 1 h	2.82	1500 °C/ 3 h	2.71
Modulus of rupture (kg/cm^2)	110 °C/24 h	51	180 °C/18 h	55
	1400 °C/ 1 h	10	1500 °C/ 3 h	35

Table II. Performance Result of Main-Trough Linings

	VF Process	SVP Method
Life (day)	25 ~ 35	30 ~ 32
Hot metal throughput (tons)	50 000 ~ 100 000	60 000 ~ 70 000

even on rapid heating. It is a lining method particularly suitable for stationary troughs.

Tables I and II show examples of the properties and the performances of iron trough refractories in which the vibration-forming methods were used.

Casting Method: The first trough refractory casting method, the N-CAST process, is based on the mechanization and systematization of the element operations in the conventional forming of refractory concretes.[4]

The refractory material is mixed in a large, continuous mixer, transferred to the site by feed pump, and cast into a preplaced form. Figure 4 is a diagram of these operations. The greatest advantage of this method is that relining can be performed without having to demolish the residual lining, thereby greatly saving refractory material.

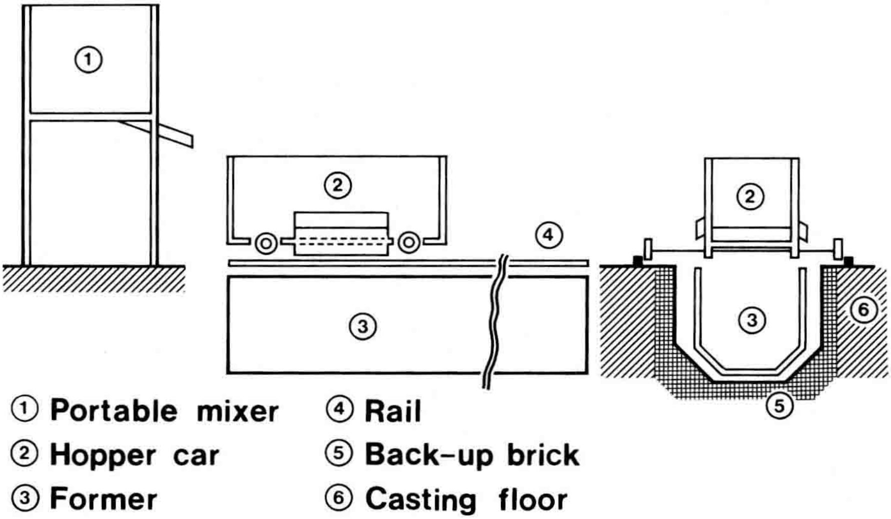

Fig. 4. N-CAST process for trough relining.

Figure 5 shows an example of the reduction in the refractory consumption at large blast furnaces achieved by the use of this method.[5]

Utilizing the colloidal property of clay, both fluidization and solidification characteristics are imparted to the refractories used in the N-CAST process by the addition of small quantities of binders. Table III shows an example of the quality of trough refractories used in the N-CAST process.

Although casting methods other than the N-CAST process have been developed and commercialized, they are not much different from the N-CAST process in principle and technique.[3] All these casting methods have spread rapidly over Japan and are now used by almost all Japanese steelmakers.

Refractories for Hot Metal Transfer Equipment

Hot metal transfer equipment consists of hot metal ladles and mixer cars. The sand-slinger method was used to line hot metal ladles in some cases

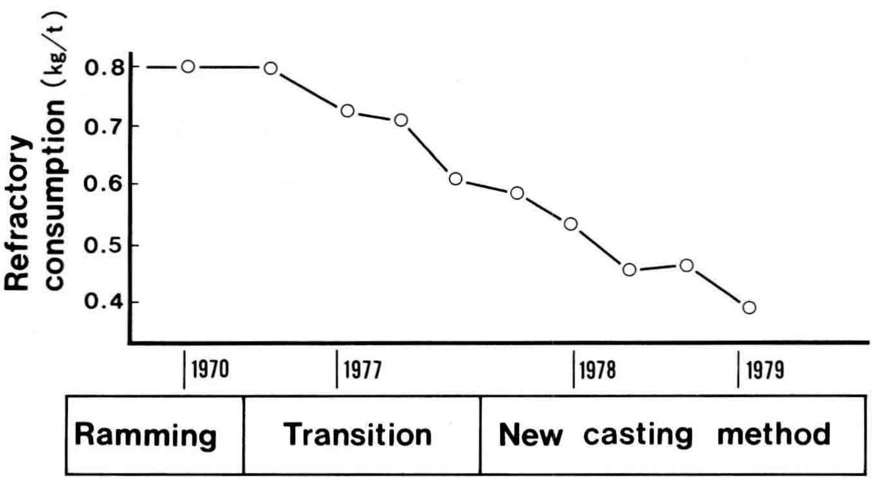

Fig. 5. Typical trend in main trough-lining consumption.

in the past, but at present this is rarely used for this purpose.[6] There are two reasons for this: (1) hot metal ladles are being superseded by torpedo ladles, and (2) the method of lining hot metal ladles was influenced by the change in the method of lining molten steel ladles (as described later) because the ladles lined using the sand-slinger method were used as both hot metal ladles and molten steel ladles. In torpedo cars, monolithic refractories are used mainly for lining the mouth and for intermediate relining of the cars. High-alumina, low-cement, castable refractories are mostly used as monolithic refractories for lining the mouths of mixer cars.

Table III. Properties of Trough Lining Material (N-CAST Process)

Chemical composition (%)	SiO_2	3- 4
	Al_2O_3	67-68
	SiC	17-18
	F·C	5- 6
Water content (%)		9.0
Bulk density (g/cm³)	110 °C/24 h	2.63
	1450 °C/ 2 h	2.62
Apparent porosity (%)	110 °C/24 h	21.8
	1450 °C/ 2 h	25.3
Modulus of rupture (kg/cm²)	110 °C/24 h	12.7
	1450 °C/ 2 h	36.9
Crushing strength (kg/cm²)	110 °C/24 h	150.0
	1450 °C/ 2 h	209.0
Reheat linear change (%)	1450 °C/ 2 h	0.0

Blast Oven Furnaces (BOF)

Although monolithic refractories are applied to some BOF linings in the United States, the application has not yet been commercialized in Japan. Firebrick is used for BOF brickwork in this country.

In the late 1950s when BOF was introduced into Japan, the furnace life was 100–400 heats, and the refractory consumption was 6–12 kg/ton steel. In the 1970s, furnace lives of over 5 000 heats were recorded in succession, and even the record of 10 000 heats was broken due to the subsequent progress in operation techniques and refractory techniques.[7] The progress of gunning repair and other repairing techniques greatly contributed to prolonging BOF life, although dynamic furnace control operation, slag control, and other operational techniques also made considerable contributions to extending lining life.

The BOF gunning repair method was introduced in Japan in the late 1960s. At first the wet-type gunning repair method was used, but in the late 1970s it was replaced by the more durable dry-type gunning repair method.

Silicate binders were first used for the gunning mix. Phosphate binders developed in the early 1970s showed much better results, and at present these are used in most cases, except for the repair of stainless steel refining furnaces. Table IV shows the quality of representative gunning mixes.

Table IV. Properties of Gunning Mixes (BOF)

	Phosphate Bond	Silicate Bond	Phosphate Bond + Carbon Bond
Chemical Composition (%)			
MgO	80	93	76
CaO	11	1	10
P	2		2
C			5
Max. grain size (m/m)	3	3	3
Hot modulus of rupture (kg/cm^2) 1400 °C/15 min	4	4	14

In the 1980s, a new repairing technique, flame gunning repair, is being commercialized[8-10] (Fig. 6). Flame gunning repair for BOFs developed or introduced in Japan are classified into three types by the kind of the fuel used: gaseous fuel, liquid fuel, and solid fuel. With all three fuels, refractory particles are melted or half-melted in a 2000°–2800°C flame obtained by burning fuel with oxygen, and jetting the molten or half-molten particles onto the part to be repaired to obtain a dense and highly corrosion-resistant lining. The flame gunning method is far more effective than conventional gunning repair.

Table V shows the features of the various flame gunning methods commercially used in Japan for repairing BOFs. Figure 6 shows the gaseous-fuel-type BOF lava flame device.

Table V. Flame Gunning Repair for BOF

		A	B	C
Fuel		Coke	Kerosene	Propane
Capacity (ton/h)		9 ~ 36	3	1.5
Flame temperature (°C)		1800 ~ 2000	2400 ~ 2500	2300 ~ 2400
Gunning mix		$MgO-SiO_2$	$MgO-SiO_2$	$MgO-SiO_2$
Energy consumption (kcal/ton·mix)		2700×10^3	6500×10^3	3500×10^3
Durability	SUS	max. 2 ch	max. 9 ch	max. 8 ch
	Plain steel	max. 11 ch	max. 23 ch	max. 18 ch

Although BOF gunning mix consumption is decreasing due to the change in BOF operating conditions (such as the advent of highly durable magnesia carbon brick), the share of gunning mixes in the total consumption of refractories for BOFs is still large at about 30%.

Ladles

The use of monolithic refractories for ladles in Japan began with the introduction of the sand-slinger method in the early 1970s. The sand-slinger method was introduced from Europe to cope with the short supply of ladle brick in Japan in those days, as well as to meet the requirements for mechanization of ladle relining to save labor. These needs served as a stimulus to the development of the ramming, vibration-forming, and casting methods.

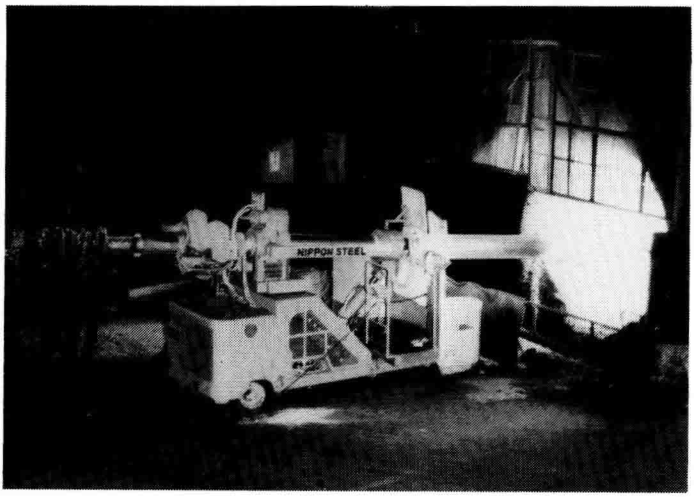

Fig. 6. Flame gunning for BOF.