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In-Plant Training Workshop on
the Production of Refractories

Pilsen, Czechoslovakia

11-28 June 1974

BODY COMPOSITION AND PROCESSING OF CASTABLES, MOULDABLES AND MORTARS [1/]

F. Tomšů* and A. Adamovic**

* Refractories Research Institute, Bratislava, Czechoslovakia.
**Termostav, Bratislava, Czechoslovakia.

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The paper is devoted to some progressive kinds of refractory materials – i.e. monolithic refractories, namely:

- castables - refractories containing a hydraulic binder,
- mouldables and ramming mixes - refractories containing a clay type binder or chemical bond,
- mortars - refractories used for joining refractory bricks.

Various raw materials necessary for making the above kinds of monolithic materials, i.e. the granular aggregates, bond clays, and the substances forming hydraulic and chemical bonds are described.

The production process of the main kinds of monolithic materials is presented in the form of technological schemes.

The composition and general properties of typical castables, mouldables, ramming mixes, and mortars are given in tables.

It is typical for monolithic materials that a part of the production process - forming of monolith - is transferred from producer to user. Therefore the main procedures for the installation of monolithic linings and their effect on the properties of monolith are described.

The technical and economical virtues of monolithic linings are emphasized. These virtues consist in the easy construction of complex linings, speedy installation, better isolating ability of monolith, excellent resistance to thermal shock, and increase of tha lining life.

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COMPOSICION Y ELABORACION DE LA PASTA PARA COMPUESTOS MOLDEABLES Y MORTEROS[1]

F. Tomšu* y A. Adamovic**

RESUMEN

La monografía está dedicada a ciertos tipos de materiales refractarios modernos; concretamente, a los refractarios monolíticos, que son los siguientes:

a) los materiales refractarios moldeables que contienen un aglomerante hidráulico (castables),

b) los materiales refractarios moldeables -inclusive las mezclas para apisonar- que contienen un aglomerante arcilloso o un aglutinante químico (mouldables), y

c) los morteros, o sea, los materiales refractarios utilizados para unir ladrillos refractarios.

Se describen diversas materias primas necesarias para la elaboración de los mencionados materiales monolíticos; es decir, los áridos granulares, las arcillas de cohesión y las sustancias que constituyen aglomerantes hidráulicos y químicos.

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El proceso de producción de las principales clases de materiales monolíticos se presenta en forma de esquemas tecnológicos.

La composición y propiedades generales de los compuestos moldeables, las mezclas para apisonar y los morteros se exponen en forma de cuadros.

Es corriente que, cuando se trata de materiales monolíticos, se transfiera del productor al usuario una parte del proceso de producción: el modelado de la estructura monolítica. Por consiguiente, se describen los principales procedimientos para la instalación de revestimientos monolíticos y sus efectos sobre las propiedades de la estructura monolítica.

Se subrayan las virtudes técnicas y económicas de los revestimientos monolíticos. Esas virtudes consisten en la facilidad de construcción de revestimientos complejos, la rapidez de su instalación, la mayor capacidad aislante de la estructura monolítica, su excelente resistencia al choque térmico y la mayor duración del revestimiento.

We regret that some of the pages in the microfiche copy of this report may not be up to the proper legibility standards even though the best possible copy was used for preparing the master fiche

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INTRODUCTION

Castables, mouldables and mortars which are generally called monolithic refractories represent the progressive kinds of refractory materials and are gradually substituted for the classical linings consisting of fired bricks in various furnaces.

The development of the production and the use of monolithic refractories is characterized best by these data: in a five-year period in which the total production of refractory materials increased in USA by 14 %, the production of monolithic refractories increased by more than 75 % while castables and mouldables showed the highest increasements /1/. According to the Japanese statistic book the production of castables in Japan grew 394 % during the last 10 years and the production of mouldables grew even higher, i.e. 727 %.

The rapid propagation of monolithic refractories is due to their technical and economical virtues.

The production process of monolithic refractories consists essentially of equal stages like the production processes of fired shaped refractories with the only difference that a part of this process passes from producer to consumer. The grinding of raw materials and preparation of mass rests with the producer while the moulding of monolith and its firing in lining is with the consumer. Due to this fact the production process of monolithic mass and the formation process of monolith right in the furnace cannot be separated. If the producer of monolithic refractories wants to be successful with his products, he must provide service for the consumer. This service provides the preparation of first-rate monolith, its drying and firing at the first heating of the furnace.

The individual sorts of monolithic materials will be dealt with

/a/ materials for the formation of monolithic linings,

/b/ materials for joining shaped bricks.

I. MATERIALS FOR MONOLITHIC LININGS

The majority of refractory materials for monolithic lining fall into two categories:

/a/ those containing hydraulic cement

/b/ those containing a heat setting binder such as clay or an air setting binder, i.e. chemical bond.

The refractories containing a hydraulic binder are usually called castables or refractory concretes whilst those containing a clay type binder are referred to as mouldables or plastic refractories. Ramming materials are usually very similar to mouldables, but are less plastic and require much higher energy in order to form a monolith. Those products especially developed for application by gunning can be similar to either castables or mouldables, or similar in some respect to each.

The following basic requirements must be fulfilled by all kinds of monolithic refractories:

/a/ They must provide a formation of sufficiently strong monolith

/b/ The monolith made of them must keep volume stability at drying and in heat up to the temperature of use.

All kinds of monolithic refractories are composed of

/a/ granular refractory aggregate which is the basic substance with reference to the heat properties and volume stability of monolith,

/b/ bonding components which make possible to install a monolithic lining and determine the strength characteristics of this lining. As stated before, these bonding substances are represented by the hydraulic binders in castables, the clay binders in heat setting mouldables and ramming materials, and the chemical binders in cold setting mouldables and ramming materials.

A. Granular aggregates for monolithic refractories

The granular aggregates form the basic skeleton of monolithic refractories. There are different kinds of granular aggregates in use and the selection of a correct kind is determined by the temperature and other conditions to which the monolith will be subjected under operation. As a rule, these are the equal kinds of refractory aggregates which are used in the mixtures for the production of fired refractory bricks. For heavy monoliths various dense aggregates are used while for thermal insulating monoliths various lightweight aggregates are used.

The basic kinds of granular aggregates used for monolithic refractories as well as their characteristics are given in Table 1 and Table 2. The maximum temperature of use is defined as a temperature at which the aggregates themselves, i.e. without binding agent remain still volume stable. The formation of monolithic materials by mixing the aggregates with binders usually brings about a decrease in the maximum temperature of use.

Before processing the granular refractory aggregates are ground and sieved. Thus 2 - 4 fractions of different granularity are obtained and these fractions may be used for the preparation of the massea which fill up densely the space. The correct size distribution of the refractory

Table 1. Typical dense granular aggregates for heavy monolithic refractories

Aggregate	Content of main components	Bulk density /g.cm^{-3}/	Max. service temperature /^{o}C/
fused alumina	98% Al_2O_3	3.9	1900
tabular alumina	98% Al_2O_3	3.8 - 3.9	1900
fused mullite	72% Al_2O_3 26% SiO_2	3.1 - 3.2	1700
sintered mullite	72% Al_2O_3 26% SiO_2	3.0 - 3.2	1700
sillimanite	63% Al_2O_3 35% SiO_2	2.8 - 3.1	1600
fireclay grog	40% Al_2O_3 56% SiO_2	2.2 - 2.4	1500
quartz sand	98% SiO_2	2.6	1700
silicon carbide	95% SiC	3.1 - 3.2	1600
dead burned magnesite	86 - 88% MgO	3.2 - 3.4	1800
	95 - 98% MgO	3.2 - 3.4	2000
chrome ore	36% Cr_2O_3 26% Al_2O_3	4.1	1800
zircon	66% ZrO_2 33% SiO_2	4.6	1700

Table 2. Typical lightweight aggregates for insulating monolithic refractories

Aggregate	Content of main components	Bulk density /g.cm^{-3}/	Max.service temperature /°C/
bubble alumina	96% Al_2O_3	0.6 - 0.7	1800
lightweight high alumina grog	65% Al_2O_3 32% SiO_2	0.9 - 1.1	1500
lightweight fireclay grog	38% Al_2O_3 57% SiO_2	0.5 - 0.7	1300
vermiculite	45% SiO_2 14% Al_2O_3 27% MgO	0.15-0.25	1050
expanded perlite	62% SiO_2 18% Al_2O_3	0.1 - 0.2	900

aggregates in monolithic refractories is decisive for a good density and volume stability of monolithic linings at drying and firing.

B. Castables

Castables consist of a granular refractory aggregate and a suitable hydraulic binding agent. The kind of granular aggregate and hydraulic binder is chosen according to the use and temperatures to which the monolith is subjected.

The cements applied to the production of castables are valued according to the content of major component which affect their heat resistance and are divided into two main groups:

/a/ Cements of the calcium aluminate type called high alumina cements with the content of Al_2O_3 over 40 % /Table 3/,

/b/ Cements of calcium silicate type called Portland cements /Table 4/.

The cements of the calcium aluminate type are divided according to the content of major component into current high alumina cements with the content of 40 - 60 % of Al_2O_3 and white high alumina cements with the content of 68 - 80 % of Al_2O_3./2/. The latter cements are of the best quality and are used for the castables exposed to temperatures up to 1900°C.

The Portland cements are suitable for the castables exposed to the temperature of 1150°C at most. As to their utilization, it is important to stabilize free CaO formed by hydratation by means of a fine admixture - microfiller. A material of equal composition as the granular aggregate in castable is used as a microfiller. The granulerity of the

Table 3. Typical high alumina cements for castables

	High alumina cement				
	a	b	c	d	e
Chemical composition /%/					
Al_2O_3	82.5	73.4	66.9	50.0	41.9
CaO	16.5	26.1	25.7	40.0	38.1
Fe_2O_3	0.1	0.1	2.2	2.5	16.4
SiO_2	0.1	0.1	5.0	7.0	3.0
Specific gravity /$g.cm^{-3}$/	3.3	2.9	2.7	2.7	3.1
max. service temperature /°C/	1900	1800	1550	1500	1400

Table 4. Typical calcium silicate cements for castables

	Calcium silicate cement	
	350	450
Chemical composition /%/		
Al_2O_3	6.5	5.5
CaO	62.0	62.0
Fe_2O_3	2.4	2.1
SiO_2	20.5	19.0
Specific gravity /g.cm^{-3}/	2.9	3.0
Max. service temperature /^{o}C/	1150	1150

microfiller must be under 0.09 mm. The amount of microfiller is governed by the content of slag in the Portland cement and varies within the range from 20 % to 100 % of cement weight.

The production process and processing of blends into castables is illustrated in Figure I. The production of blends is not complicated. The ground granular refractory aggregates sorted into individual fractions of different particle sizes are stowed into storage bins. By means of an automatic balance the individual fractions of granular aggregate and cement are weighed and subsequently homogenized in a periodically operating homogenization device. The process of homogenization takes usually 5 minutes. The homogenized blends are usually weighed by 50 kg into moistureproof bags.

The composition of typical blends and properties of castables are given in Table 5 and Table 6. Besides the optimum granularity of granular aggregate it is necessary to keep the optimum amount of hydraulic binder. At a low content of hydraulic binder the necessary strength of monolith is not achieved while an excess amount of cement reduces the maximum temperature for the use of castables.

The processing of castables is carried out right on the place of use. The blend in a concrete mixer with forced circulation is moistened with a definite amount of water. The amount of water is chosen according to the kind of processing of the castable into monolith which may consist in casting, vibrating, ramming or gunning. The kind of processing is determined by the demands on the quality of monolith.

Castables processed by ramming achieve the highest density and strength. For this procedure the lowest possible content of water is used. The water - cement ratio is equal to 0.4 or 0.6 . The mass is rammed by electric or pneumatic rams and in some cases by hand, too.

Figure I. Scheme of the line for the production and processing of castables

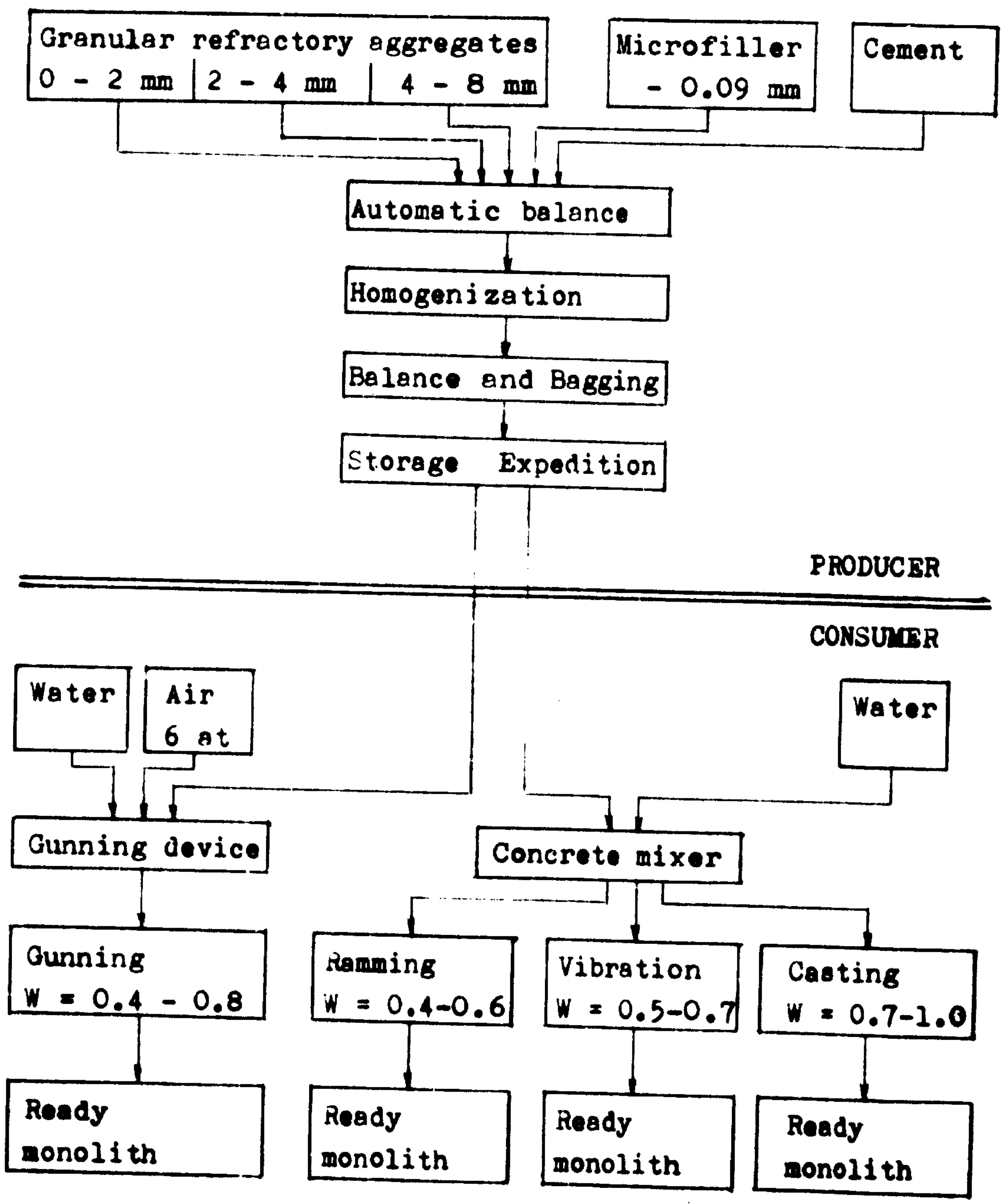


Table 5. Composition of typical blends and properties of heavy castables

Granular aggregate	Cement Kind /Tab. 3-4/	Recom. content /%/	Max. service tempera-ture/°C/	Recom. water content /%/	Cold crushing strength /kp.cm^{-2}/	Bulk density /g.cm^{-3}/
fused alumina	a	17-20	1900	9-10	600	2.9
fused alumina	b	17-20	1800	10-12	600	2.8
sillima-nite	c	18-20	1550	10-13	500	2.5
fireclay	d	17-19	1450	12-14	400	2.1
fireclay	e	20-22	1350	13-14	350	2.1
fireclay	350	20-25	1150	14-16	250	1.9
fireclay	450	20-25	1150	14-16	300	1.9

Table 6. Composition of typical blends and properties of lightweight castables

Granular aggregate	Cement Kind /Tab. 3-4/	Recom. content /%/	Max. service temperature/°C/	Recom. water content /%/	Cold crushing strength /kp.cm^{-2}/	Bulk density /g.cm^{-3}/
bubble alumina	b	39	1700	17	150	1.3
lightweight high-alumina grog	b	40	1400	30	100	1.7
vermiculite	e	34	1050	65	30	0.7
expanded perlite	e	59	900	60	10	0.4
expanded perlite	450	57	800	60	10	0.4

The width of one rammed layer ought not exceed 10 cm. In order to bind perfectly individual layers it is necessary to roughen the surface of a rammed layer before supplying futher material.

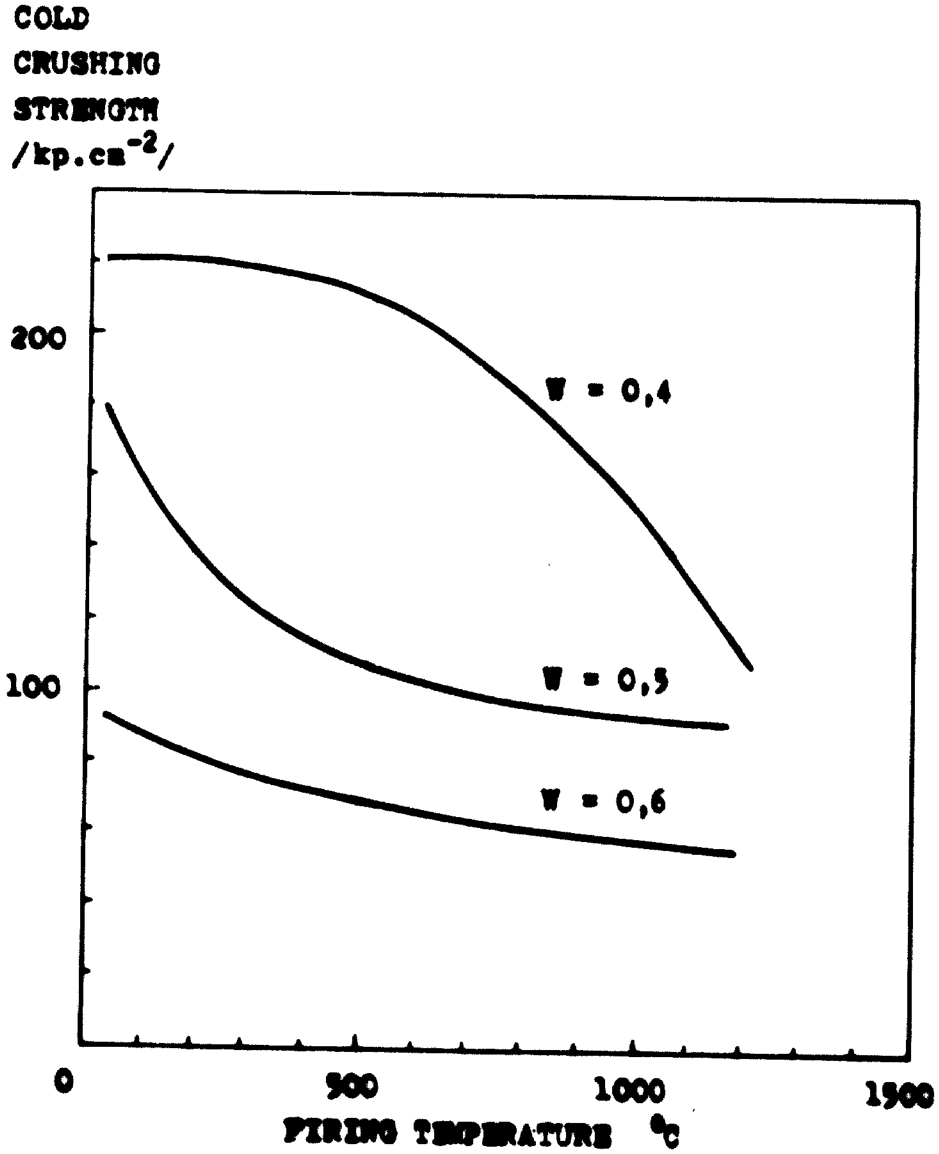
The blend processed by vibration must show a higher moisture content than the rammed mass. The water - cement ratio varies within the range from 0.5 to 0.7. The cement mortar is liquified by vibration and the granular aggregates take the position providing a dense filling of space. The resulting strength of castables is lower than in the case of processing the material by ramming.

Castable refractories can be also installed by casting in the same way as structural concretes. However, the casting is used only if the demands on the density and strength of castables are not too great and the monolith is not subjected to very high temperatures. Perfect packing of monolith cannot be achieved by casting and an undesirable shrinkage of monolithic lining can occur at high temperatures. This method of monolith formation is used especially for processing insulating castables. At casting the water - cement ratio varies in the range from 0.7 to 1.0. The effect of the water - cement ratio on the strength of castables is presented in Figure II.

Recently, the installation of castables by gunning has spread considerably. Using this technique the material is thrown against a wall by compressed air. The gun application began to be used first for patching and later for complete linings. With improved guns and better application techniques it was found possible to achieve equal or as much as by 5 % higher densities than the densities of cast material. The strength, too, was higher by 50 % or even 100 % than the strength of cast material.

The gun used may be of the dry or wet type, as shown

Figure II. Dependence of cold crushing strength of castables at different water-cement ratios /W/ on firing temperature



diagrammatically in Figure III and Figure IV. The use of dry gun requires moistening of the mix prior to adding it to the gun chamber. Water in the amount equal to as much as one-fifth of the batch weight may be added and the mix still remains flowable. The remainder water is added at the nozzle and is controlled by the operator. The dry gun gives a very dense concrete with low water - cement ratio. At the same time, it is possible to put a layer of a 5 to 8 cm width.

Less used is the wet-type gun where a slurry is formed by mixing a controlled amount of water with the dry material and then forcing it through the nozzle. The castable placed with a wet gun is less dense than that placed with a dry gun. The applied layer of castable must be thinner than it is in the case of dry gunning.

The green monolith made of castable has to be protected against heat and desiccation during setting and hardening. In this period of time it must not to be expoced neither to chemical influences nor mechanical shocks. The most convenient temperature of setting and hardening of the monolith is between +15^{o} and +25^{o}C. During setting the ready monolith has to be moistened. Castables with Portland cement are moistened for 4 - 6 days, castables with high alumina cement for 1 - 3 days. Instead of moistening the monolith another kind of protection against desiccation is used. This protection consist in spraying the surface of the completed monolith immediately with an impermeable membrane of resin solution or special asphalt. The formwork is usually removed 2 - 6 days after making the monolith and in the case of statically stressed construction it is left until the final strengths have been achieved.

During drying and tempering the monolithic lining of castable requires a greater attention than a lining of bricks. The drying and tempering of ready monolith starts when the demanded strengths of castables have been reached.

Figure III. Dry gun - schematic chart

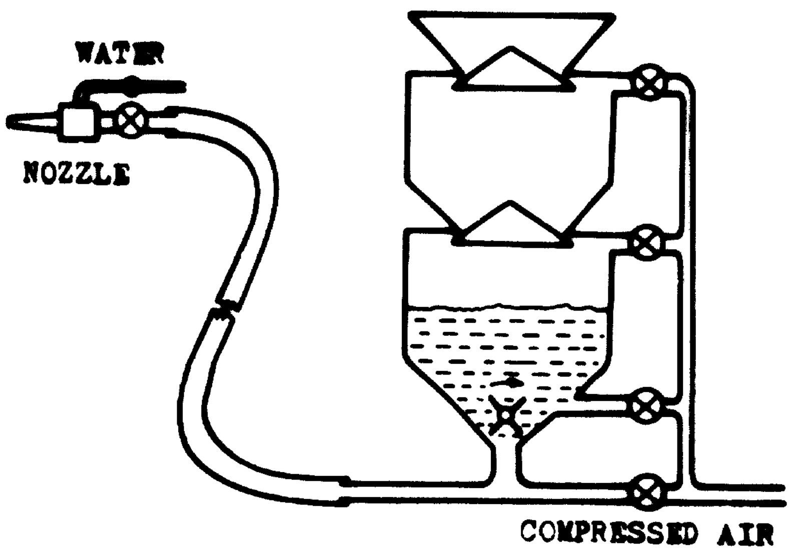
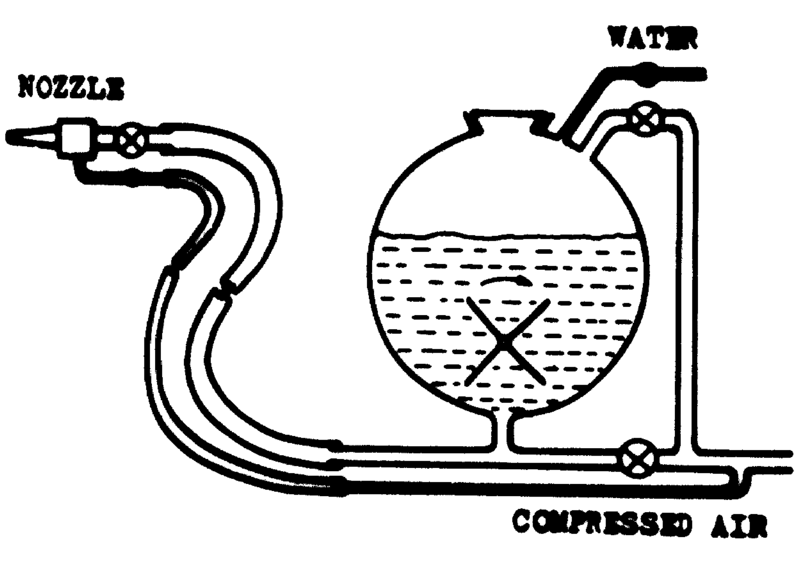


Figure IV. Wet-mix gun - schematic chart



For castables with Portland cement it is in about 14 days while for castables with alumina cement it is in about 6 days.

The proper drying and tempering takes place in following stages:

/a/ Beginning of drying - heating to 110° - 120°C at the rate of 5°C per hour.

/b/ Drying at 110° - 120°C. The evaporation of the substantial amount of water takes place. The maintenance at this temperature depends on the width of lining and varies approximately between 24 and 72 hours.

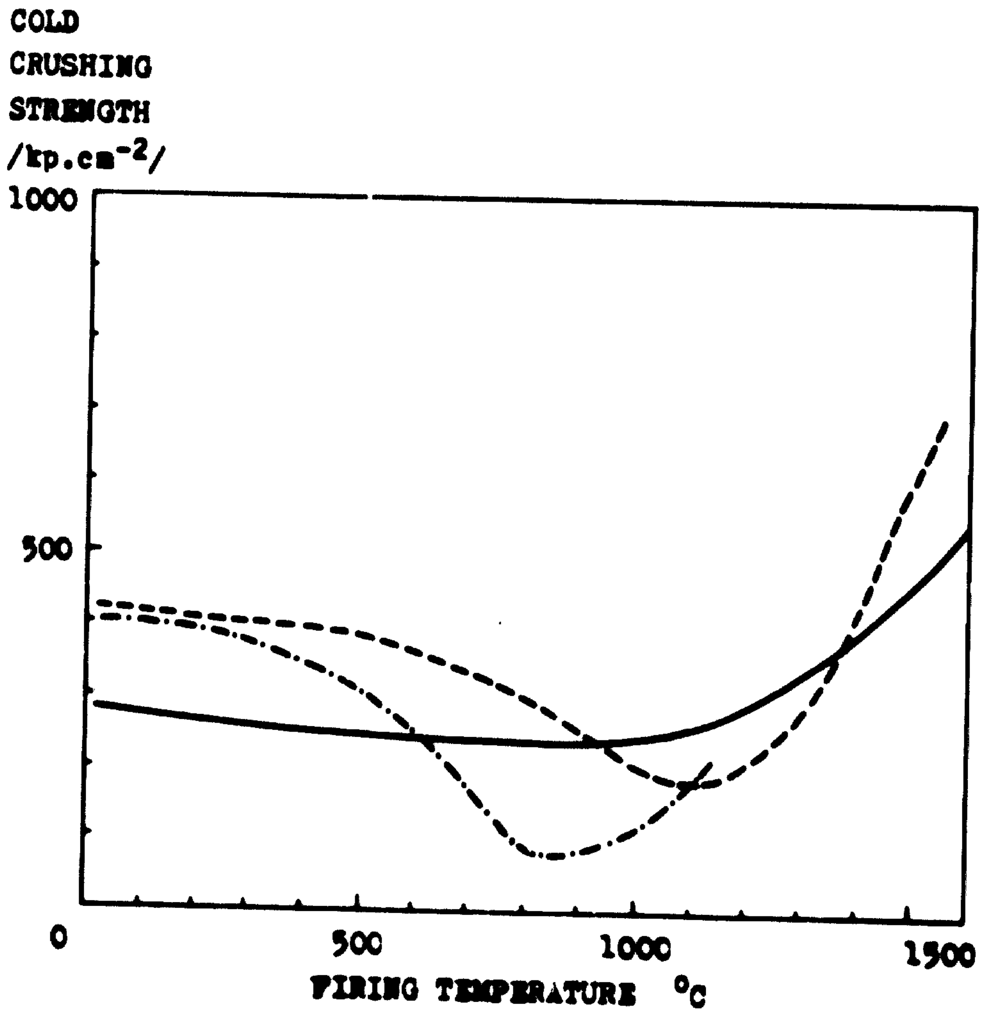
/c/ Heating from 120° to 600°C - expulsion of the last residues of water - the rate of heating about 50°C per hour. The drying and heating to 600°C is carried out only by means of combustion gases and no direct flame is used. A good exhaust of waste gases must be provided for.

/d/ Heating to the working temperature at the rate of about 50° - 100°C per hour.

On heating, castable refractories lose some strength with the loss of water of hydratation until all combinated water is expelled. As the temperature increases, some degree of vitrification takes place forming a ceramic bond which gives increasing strength to the castables. Figure V shows the variation of the cold crushing strengths of different monolithic materials with the firing temperature. If the working temperature of a monolith of castable is in the region of its decreased strength, it is convenient to heat the monolith at tempering up to the temperature of ceramic bond formation, i. e. about 1200°C and keep it for four hours. Thus the surface of monolithic lining gets hardened.

The conditions of drying and tempering must be determined separately for every furnace with respect to the castable used, width of lining, maximum operating temperature and

Figure V. Dependence of cold crushing strength of various monolithic refractories on firing temperature



——— cold-setting mouldable with phosphate bond

----- castable with high-alumina cement

-·-·-· castable with portland cement

local conditions /air temperature, humidity, etc./.

The manipulation and drying of the monolith of castable requires much time and brings about a considerable prolongation of furnace building or reparation. This shortcoming is removed by assembling the furnace lining from prefabricated refractory concrete blocks. These blocks of castables weighing often even a few tons are made in advance by the producer of monolithic refractories. From these blocks the linings are completed in a very short time by using assembly cranes.

As to the mass production of refractory prefabs, there is a chance of achieving a better quality of monolith right at the producers than processing castables on the site of furnace construction. The prefabricated blocks are often made in the form of products consisting of two or several layers which have been manufactured by using the castables of graduated quality or by combining heavy castables with insulating castables.

C. Mouldable refractories and ramming mixes

Mouldable and ramming refractories consist of granular refractory aggregate together with a suitable clay type binder. Mouldables are furnished in the form of solid plastic whereas ramming mixes are loose because of lower moisture content. Both sorts of materials are, however, supplied with such moisture content to be processed into monolithic lining without further modification or moistening. The sorts of the granular aggregates used are presented in Table 3.

Mouldables and ramming mixes which contain only granular aggregate and bond clay but no other substances forming chemical bonds are heat-setting which means that they obtain the strength at firing by sintering of the bond clay.

The volume stability at drying and firing as well as good workability of mouldables is achieved if the granular aggregate shows the optimum granularity providing a dense filling of space and if the mouldable contains the optimum amount of the right sort of bond clay. A refractory clay with a high plasticity has to be used. Very fine-grained kaolinitic clays are most frequently used. Typical properties of a bond clay are presented in Figure 7.

In order to prevent the shrinkage of monolith, the content of clay in mass must be relatively low. Therefore, ramming mixes usually contain less then 15 % of clay while the content of clay in mouldables does not exceed 20 - 25 %.

Some of the mouldables and ramming mixes are cold-setting i. e. they develop strength on drying. The setting during drying is achieved by the addition of various chemical substances which react at increased temperature and form the so-called chemical bonds in the mass. Some typical substances which are used for the formation of chemical bond in monolithic refractory materials are given in Table 8.

The bond which are most frequently effective in mouldables are phosphate bonds which give a monolith of relatively high strength, the main reaction product being a high temperature resistent aluminium orthophosphate with the melting point of 2050°C /3, 4/. The arising aluminium orthophosphate also contributes to the volume stability of monoliths at high temperatures. By combining the substances, it is possible to affect the temperature at which the chemical bond occurs. By the use of orthophosphoric acid and aluminium hydrate the reaction between these substances sets in already at room temperature. On the other hand, orthophosphoric acid reacts with aluminium oxide only at increased temperature. The monolith with phosphate bond still hardens at ordinary drying, but it is desiderable to dry it at about 400°C because the intermediates of the reaction of orthophosphoric acid

Table 7. Typical properties of a bond clay for the production of mouldables and mortars

Chemical composition /%/	
Loss by ignition	13.6
SiO_2	49.6
$Al_2O_3 + TiO_2$	32.8
Fe_2O_3	1.8
CaO	0.6
MgO	0.4
$Na_2O + K_2O$	1.2
Grading /%/	
+ 20 µm	8
1 - 20 µm	27
- 1 µm	65
Refractoriness /°C/	1720
Sintering temperature /°C/	1250

Table 8. Compounds most frequently used for the formation of chemical bond in cold-setting mouldables and ramming mixes

Compounds	Recommended amount	Hardening	Product responsible for setting
H_3PO_4 + + $Al/OH/_3$	2-5 % P_2O_5 5-10 %	at room temperature	$/AlPO_4/_x$
H_3PO_4 + + Al_2O_3	2-5 % P_2O_5 5-10 %	by drying	$/AlPO_4/_x$
$Al/H_2PO_4/_3$ solution	2-5 % P_2O_5	by drying	$/AlPO_4/_x$
Aluminium oxichloride	10 %	by drying	α-Al_2O_3
Na_2SiO_3 solution	2 - 20 %	by drying	$/Si/OH/_4/_x$
Na_2SiF_6 + + Na_2SiO_3	1 - 2 % 2 - 20 %	at room temperature	$/Si/OH/_4/_x$
$Al/OH/_3$ + + Na_2SiO_3	10 % 15-20 %	by drying	alkaline aluminates

with aluminium component are hygroscopic. Some furnishers of the mouldables with phosphate bond encountered difficulties since the chemical reaction took place already at the transport and storing of the mass which got hard and inapplicable. The premature hardening may be prevented by introducing an inhibitor with the phosphoric acid, for instance acetyl aceton or sulphosalicylic acid /5/.

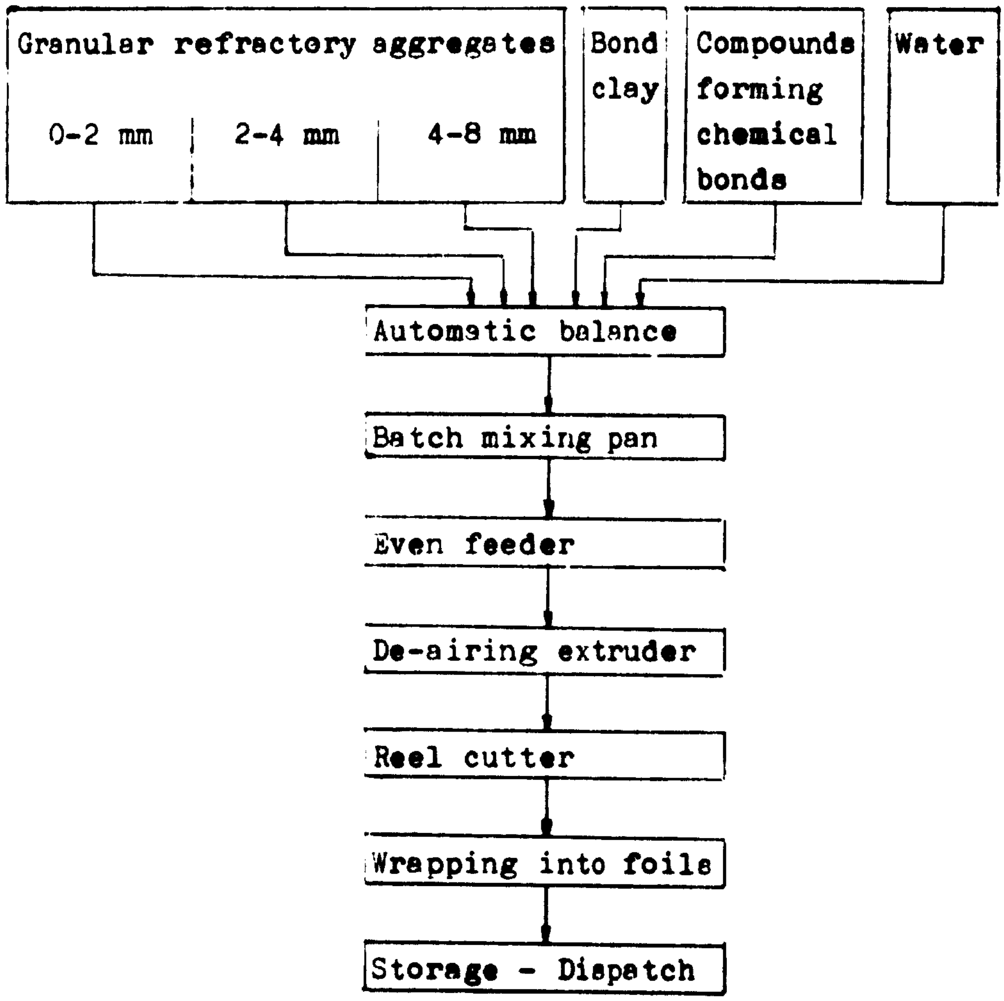
The so-called inorganic polymers /aluminium oxychloride/ are applied to the bond formation especially if very pure granular aggregates are used. The strengths of monoliths attained are not so high as they are in the case of phosphate bonds.

The majority of other compounds forming a chemical bond contains melting agents the presence of which decreases the temperature of the use of monoliths.

The production of mouldables is illustrated in Figure VI. The crushed granular refractory aggregate of convenient granularity is fed into a batch mixing pan together with the necessary amount of bond clay, eventually with the admixtures for the forming of chemical bonds. In the batch mixing pan the homogenization and plastification of the mix takes place. The time of the mixing is about 20 minutes. From the batch mixing pan the plastified material is discharged into a feeder from where it is continuously fed into a de-airing screw extruder. The solid plastic which is discharged from the extruder in the form of a continuous band is cut in a reel cutter in plates of the width of 5 - 10 cm. These plates are wrapped automatically into plastic foils and put into cardbords in which they are delivered to the user.

In the production of ramming mixes the mass is also homogenized and plastified in batch mixing mills. These masses contain a lower moisture content and therefore they go out of mixing mills in a loose form. Subsequently they are wrapped into moistureproof bags.

Figure VI. Scheme of a line for the production of mouldables



The composition and properties of some typical mouldables and ramming mixes are presented in Table 9.

Previously the use of mouldables was limited only to the repairs of refractory linings. The manufacturing of whole monolithic linings was enabled by the development of lining construction, especially by the anchoring system. For the monolithic linings subjected to the temperatures over 800°C only the ceramic anchor bricks from a refractory material of corresponding quality are used at present. The anchor system in a monolithic lining is obvious from Figure VII. The distances among individual anchor bricks are equal to about 400 mm. The installation of mouldables in the anchoring system is carried out by pounding with pneumatic rammers or hand hammers. The ramming is performed in layer of about 50 mm width. The ramming finished, the ready monolith is perforated in regular distances of 100 - 150 mm and the perforations serve for carrying eway vapour during the drying of lining. The finishing of green monolithic lining consists in making dilatation joints in the form of cuts which are about 50 mm deep and distant approximately 1 m from each other.

A special method of the formation of monolith is slinging which is used for the making the linings of steel-plant ladles. The principle of slinging is obvious from Figure VIII. By means of a belt conveyor the slinging mass is transported into a slinger unit where it falls onto a short high speed conveyor. This belt conveyor transports the material to the slinger head which follows the periphery of the ladle and revolves about a central point throwing the material down between the former and the ladle shell. The slinging material is thrown with the speed up to 30 m/s and when it falls down, it is compacted and a monolithic lining is formed. Various acid slinging materials on the base of quartz sand with a granularity from 0 to 2 mm are

Table 9. Composition and typical properties of mouldables and ramming mixes

Material	Components	Recommended content /%/	Moisture /%/	Hardening	Max. service temperature/^{o}C/
Ramming mix	Fused alumina alumina power aluminium oxychloride	80 10 10	3	by drying	1900
Ramming mix	Tabular alumina alumina power bond clay $Al/H_2PO_4/_3$	76 6 10 8	6	by drying	1800
Mouldable	Sintered mullite alumina power bond clay H_3PO_4	70 5 20 5	10	by drying	1600
Slinging mix	Quartz sand bond clay	85 15	8	by firing	1600
Mouldable	Fireclay grog bond clay	80 20	12	by firing	1400
Ramming mix	Fireclay grog $Al/OH/_3$ bond clay Na_2SiO_3	65 10 10 15	8	by drying	1200
Ramming mix	Fireclay grog bond clay Na_2SiO_3 Na_2SiF_6	80 10 9 1	10	at room temperature	1100

Figure VII. Detail of wall and roof construction of the continuous reheating-furnace lined completely with monolithic refractories

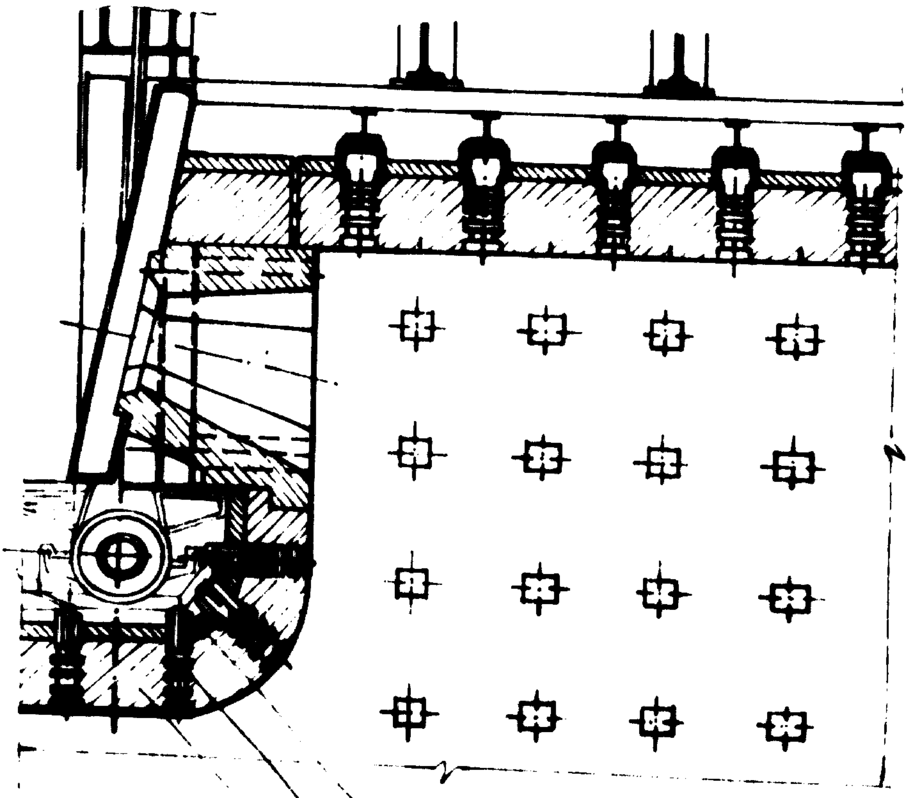
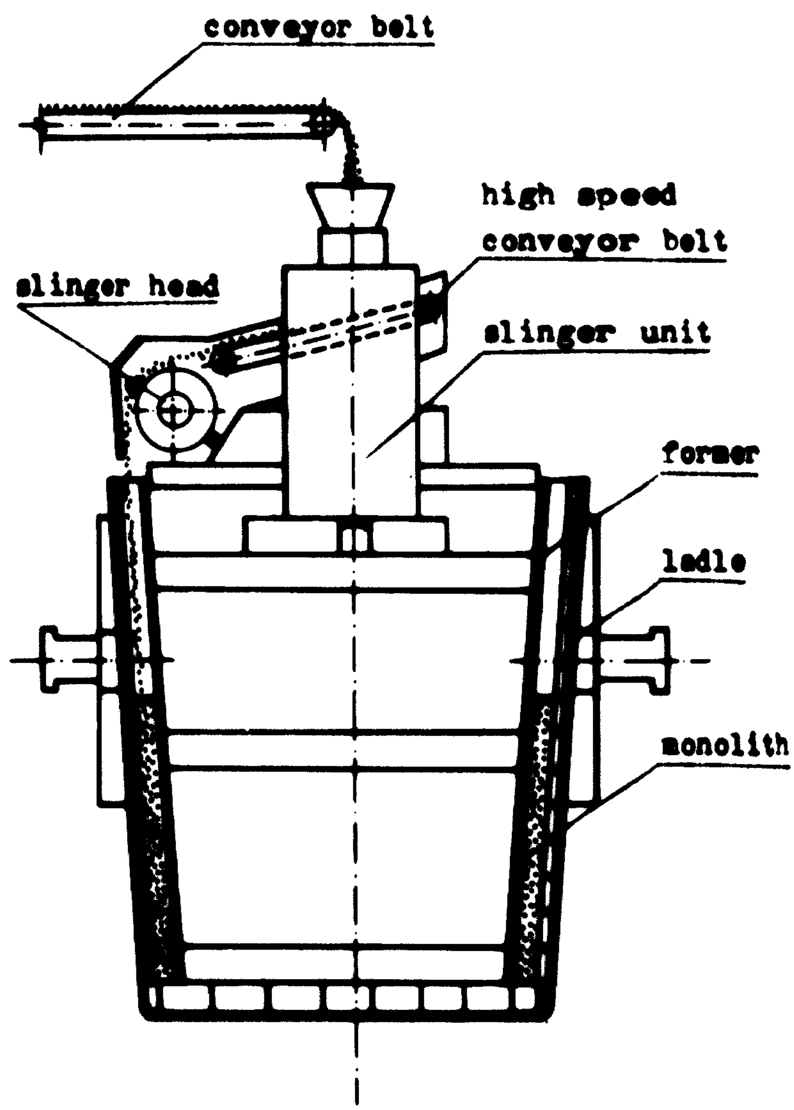


Figure VIII. Schematic chart of slinging the monolithic lining of steelplant ladle



used. An exemple of the composition of such material is presented in Table 9.

A monolithic lining made of mouldables or ramming mixes may be dried and heated immediately after its preparation. At first the lining is heated approximately to 200°C. Provided this temperature is kept some time, all mechanically bound water is removed. According to the size of lining this period of drying usually takes 6 - 24 hours. Then the temperature of the working side of lining is raised to 600°C at the rate of about 50°C per hour. In the period of about 6 hours the chemically bonded water is removed. This water escapes from the bond clay present in the mass. Subsequently the temperature is raised again up to the maximum working temperature at the rate of about 50°C per hour. The exact conditions of drying and tempering a monolithic lining must be fixed individually for every furnace with respect to the kind of material used, size of the furnace, size and complicacy of lining and conditions of operation.

II. REFRACTORY MORTARS

The refractory mortars are fine grained mixes of raw materials which are used for joining refractory bricks and thus for making linings. They are generally composed of a grog and bond clay. Some of the dense and fine grained refractory aggregates listed in Table 1 are used as grog. The properties of a typical bond clay are presented in Table 7.

They are heat-setting mortars which set at heat and air-setting or cold-setting mortars which set at room temperature or on drying. The setting of heat-setting mortars is due to the sintering of the bond clay while various substances forming hydraulic bonds listed in Table 3 and Table 4 or substances forming chemical bonds listed in Table 8 must be added for the setting of air-setting and cold-setting mortars.

From this point of view, the air-setting mortars are similar to castables by their composition while the cold-setting mortars are similar to mouldables. Mortars are very fine grained materials which cannot be used for the construction of monolithic linings while castables and mouldables are not suited for joining the bricks in lining because they are coarse grained.

The ordinary mortars are furnished in the granularity up to about 1 mm while the granularity of special mortars is predominately under 0.2 mm.

The technology of mortar production is very simple and consists in feeding the individual raw materials, milling them to a required granularity, weighing and wrapping them into moisture proof bags. The blends of raw materials for ordinary mortars are usually milled in dry pan mills while the special mortars are milled in ball mills. The mortars are usually furnished in the form of dry mixes which are watered either with pure water or a certain solution until a pasty consistency is attained. Merely some special mortars are furnished in barrels right in the consistency suited for use. Typical compositions and properties of mortars are given in Table 10.

The chemical and mineralogical composition of the mortars used for making walls is similar to that of joined bricks. If the lining is not exposed to the corrosion by melts, the main function of mortar is to form a uniform lining. If the brick lining is subjected to the corrosion by melts, the mortar is usually a "bottleneck" which means that the lining gets more worn in joints. The higher wear of mortar in joints with respect to the neighbouring bricks is due to its higher porosity and lower strength. In order to level the corrosion of bricks and mortar in joints, it is necessary tc construct brick walls with close joints /under 1 mm/ which

Table 10. Typical composition and properties of mortars

Mortar for	Bond	Components	%	Grading /mm/	Max. service tempera-ture/°C/
Fireclay bricks	Heat-setting	Fireclay grog bond clay	80 20	-1	1500
Fireclay bricks	Cold-setting	Fireclay grog bond clay Al/OH/$_3$ Na_2SiO_3	70 10 10 10	-0.5	1400
High alumina bricks	Heat-setting	High alumina grog bond clay Na_2CO_3 sulphite lye	90 9.8 0.1 0.1	-0.2	1600
High alumina bricks	Cold setting	High alumina grog bond clay alumina power H_3PO_4	80 10 5 5	-0.2	1700
Silica bricks	Heat-setting	Silica grog bond clay	95 5	-1	1600
Zircon bricks	Heat-setting	Zircon sand bond clay	85 15	-0.2	1600

requires the use of bricks with exact dimensions and fine grained mortar. Furthermore, the density of mortar has to be raised which is achieved especially by the addition of surface active substances which enable us to water the mortar with a small amount of water. Such mortars are called plastified ones. A decrease in corrosion of the mortar in joints with respect to the corrosion of bricks may be also achieved by using a mortar which is chemically more resistent than the bricks. For instance, high alumina mortar may be used for laying fireclay bricks.

For making a wall the expected consumption of mortar corresponds to 3 - 5 % of the weight of bricks.

III. TECHNICAL AND ECONOMICAL VIRTUES OF MONOLITHIC REFRACTORIES

The rapid increase in the production of monolithic refractories ensues from the technical and economical preference due to the introduction of monolithic linings in various industrial lines. These virtues may be characterized as follows /6/:

/a/ Easy construction especially of complex linings and the possibility of excluding expensive and complicated fired shapes.

/b/ Speedy installation of monolithic linings by using various moulding methods or prefabricated blocks. For instance, by using the slinging technique it is possible to make a monolithic lining in a steelplant ladle within 25 minutes while the use of shaped bricks demands the working time of several shifts /7/. Another illustrative example is the complete installation of a 75 ton soaking pit lining made of prefabricated refractory concrete blocks within 17 minutes /8/. Instead of whole days only minutes were necessary.

/c/ The installation of monolithic linings requires less skilled work. According to Nekrasov /9/ by the use of monoliths the productivity of work increases twice on the average, the price of lining decreases by 20 - 30 % and the period of time necessary for the construction of lining gets shorter by 50 % or even 75 %.

/d/ Excellent resistence of monolithic linings to thermal shock. It should be noted that the monolithic material in a lining fires hard only on the hot face and has a weaker and more flexible zone on the cooler side.

/e/ Lower thermal conductivity of monolithic lining in comparison with a brick lining improves thermal efficiency or permits thinner lining.

/f/ The use of monolithic lining frequently brings about an increased service life of linings or a reduced and simplified furnace maintenance.

It may be stated that the monolithic refractories have opened up new fields for technique and economy in the construction and maintenance of furnaces.

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