

# Monolithic Refractories: Installation and Dryout

API TECHNICAL REPORT 980  
FIRST EDITION, APRIL 2018



AMERICAN PETROLEUM INSTITUTE

## Special Notes

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

Neither API nor any of API's employees, subcontractors, consultants, committees, or other assignees make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any authorities having jurisdiction with which this publication may conflict.

API publications are published to facilitate the broad availability of proven, sound engineering and operating practices. These publications are not intended to obviate the need for applying sound engineering judgment regarding when and where these publications should be utilized. The formulation and publication of API publications is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

All rights reserved. No part of this work may be reproduced, translated, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher. Contact the Publisher, API Publishing Services, 1220 L Street, NW, Washington, DC 20005.

*Copyright © 2018 American Petroleum Institute*

## Foreword

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this publication or comments and questions concerning the procedures under which this publication was developed should be directed in writing to the Director of Standards, American Petroleum Institute, 1220 L Street, NW, Washington, DC 20005. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the director.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. A one-time extension of up to two years may be added to this review cycle. Status of the publication can be ascertained from the API Standards Department, telephone (202) 682-8000. A catalog of API publications and materials is published annually by API, 1220 L Street, NW, Washington, DC 20005.

Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, DC 20005, [standards@api.org](mailto:standards@api.org).



## Contents

|                                                      | Page |
|------------------------------------------------------|------|
| 1 Scope .....                                        | 1    |
| 2 Referenced Documents .....                         | 1    |
| 3 Terms and Definitions .....                        | 2    |
| 4 Installation .....                                 | 7    |
| 4.1 Introduction .....                               | 7    |
| 4.2 Refractory Concrete .....                        | 7    |
| 4.3 Plastic Refractories .....                       | 14   |
| 5 Construction Details for Refractory Concrete ..... | 29   |
| 5.1 Introduction .....                               | 29   |
| 5.2 Support Structure .....                          | 29   |
| 5.3 Forms .....                                      | 30   |
| 5.4 Anchors .....                                    | 30   |
| 5.5 Rebar and Metal Embedment .....                  | 38   |
| 5.6 Joints .....                                     | 38   |
| 6 Curing, Drying, and Firing .....                   | 38   |
| 6.1 General Drying/Firing Considerations .....       | 38   |
| 6.2 Modes of Drying/Firing .....                     | 40   |
| 6.3 Refractory Concretes .....                       | 40   |
| 6.4 Plastics and Ramming Mixes .....                 | 44   |
| 7 Repair .....                                       | 48   |
| 7.1 Introduction .....                               | 48   |
| 7.2 Failure Mechanisms .....                         | 48   |
| 7.3 Surface Preparation .....                        | 49   |
| 7.4 Anchoring and Bonding .....                      | 50   |
| 7.5 Repair Materials .....                           | 50   |
| 7.6 Repair Techniques .....                          | 51   |
| Bibliography .....                                   | 55   |

## Figures

|                                                                                                        |    |
|--------------------------------------------------------------------------------------------------------|----|
| 1 Hot Modulus Versus the Amount of Mixing Water for a Fireclay Castable with a Low-purity Cement ..... | 9  |
| 2 Flexural Strength of a Tabular Alumina, High-purity Cement Castable .....                            | 10 |
| 3 Typical Hand-held Reciprocating Rammer .....                                                         | 18 |
| 4 Short-handled Trimming Spade .....                                                                   | 18 |
| 5 Transmission of Force by the Rammer .....                                                            | 19 |
| 6 Trimming a Plastic Refractory .....                                                                  | 24 |
| 7 Construction Joints Being Added to Installed Plastic Refractory Lining .....                         | 25 |
| 8 Refractory Construction for Three-zone Pusher Furnace .....                                          | 27 |
| 9 Refractory Construction for Roof Anchor Design .....                                                 | 27 |
| 10 Refractory Construction for Roof Section in Reheat Furnace (1 in. = 25.4 mm) .....                  | 28 |
| 11 Refractory Construction for Typical Burner Port (1 in. = 25.4 mm) .....                             | 29 |
| 12 Typical V-clip Anchors .....                                                                        | 31 |
| 13 Typical Anchor Arrangement for V-clips .....                                                        | 32 |
| 14 Metal Roof Anchors .....                                                                            | 33 |

## Contents

|                                                                                                                             | Page |
|-----------------------------------------------------------------------------------------------------------------------------|------|
| 15 Flexible Rotary Kiln Anchor . . . . .                                                                                    | 33   |
| 16 Wall Anchors for Monolithic Construction . . . . .                                                                       | 35   |
| 17 Refractory Roof Anchors . . . . .                                                                                        | 36   |
| 18 Typical Wall Seat Attachment. . . . .                                                                                    | 37   |
| 19 Hydration Reaction Products of Calcium Aluminates . . . . .                                                              | 41   |
| 20 Graph Showing Maximum Drying Rate for Phosphoric Bonded Refractories Occurs<br>at Approximately 174 °F (80 °C) . . . . . | 47   |

### Tables

|                                                          |    |
|----------------------------------------------------------|----|
| 1 Dryout of Conventional Castable Refractories . . . . . | 43 |
|----------------------------------------------------------|----|



## Introduction

This report is the last in a series of three American Petroleum Institute (API) reports covering the use of refractory concrete (castables), plastics, and ramming mixes for applications for the hydrocarbon processing industry (HPI). Its content is complimented by the two other reports in this series:

- [API TR 978](#), *Monolithic Refractories: Manufacture, Properties and Selection*
- [API TR 979](#), *Applications of Refractory Lining Materials*

These API technical reports update and add to the original reports written by Committee 547 of the American Concrete Institute (ACI) in 1979 and 1989. The ACI reports are ACI 547.R-79, *State-of-the Art Report: Refractory Concrete* and ACI 547.1R-89, *State-of-the Art Report: Refractory Plastics and Ramming Mixes*. Many of the figures appearing in these three new API technical reports are scanned images from the two ACI 547 reports, and are used with ACI's written permission. Even though the native files are no longer available, these figures were not redrawn because of their historical significance.

ACI Committee 547 was organized in 1969 to provide a reliable and comprehensive source of information on monolithic refractory technology. In subsequent years, participation in the ACI refractory technical community waned. At the same time, participation increased on the API committee that was drafting refractory content. The API committee currently runs a certification program for refractory practitioners based on [API Standard 936](#), *Refractory Installation Quality Control—Inspection and Testing Monolithic Refractory Linings and Materials*. To facilitate use of the updated content in the API certification program, ACI allowed API to use the material in the two above-mentioned ACI publications, which are no longer maintained by ACI. This enabled API to create new technical reports by updating and adding to the material from the ACI reports.

API formed the Vessel Refractory Task Group in the late 1980s with the objective of providing a standard for the inspection and application of quality controls for monolithic refractories used in refining applications. In response to demands for greater reliability and cycle life objectives, refiners had already developed their own company specifications for refractory installations for the highest-value applications, where unit availability is critical. A cottage industry of supporting quality control experts and inspectors evolved that has helped owners reduce this gap in the last few decades. Up until that time, however, manufacturers and installers largely had little say in this development, and uniform industry standards were never developed or adopted.

To address this issue, a broad representation of all the stakeholders gathered as part of API's spring and fall Refining Equipment Standards Meetings. Addressing the standards gap and noting the many similarities in owner and equipment manufacturer-developed specifications, the API task force undertook the task of identifying useful industry practices and/or negotiating to agreement best fits for standards application. API's *Refractory Installation Quality Control Guidelines—Inspection and Testing Monolithic Linings and Material* was first issued in 1996 as a recommended practice. After a number of subsequent revisions, it was approved as [API Standard 936](#) in 2006, with a certification program that began in 2004.

In addition to maintaining [API Standard 936](#) and overseeing the certification program, the task force reorganized in 2014 under the API Committee on Refinery Equipment (CRE) and became the Refractory Project Group. As a project group, work expanded to writing ceramic fiber and brick quality control standards and unit-specific applications, such as sulfur recovery units and hydrogen furnaces, as well as drafting technical reports, such as this report. In response to this broadening recognition of the need to advance this technology for HPI applications, the API CRE reclassified the group as a full subcommittee in 2016, and it now works under the title of Subcommittee on Refractory Materials (SCRM).

# Monolithic Refractories—Installation and Dryout

## 1 Scope

This technical report covers the installation and dryout of monolithic refractory lining materials for hydrocarbon processing industry (HPI) applications. It discusses the best practice procedures and techniques used in the installation of refractory concrete, as well as those for air- and heat-setting plastics and ramming mixes. In addition, it discusses the need for curing and dryout, and procedures to achieve successful results. This instruction is consistent with [API Standard 936](#), which is the HPI industry standard for the installation quality control of monolithic refractories. It also serves as the body of knowledge document for the [API 936](#) Refractory Personnel certification program.

## 2 Referenced Documents

[API Standard 560](#), *Fired Heaters for General Refinery Services*

[API Standard 561](#), *Reforming Furnaces for Hydrogen and Syngas Production* <sup>1</sup>

[API Standard 565](#), *Thermal Reactors in Sulfur Recovery Units for General Refinery Service* <sup>1</sup>

[API Standard 936](#), *Refractory Installation Quality Control—Inspection and Testing Monolithic Refractory Linings and Materials*

[API Standard 975](#), *Refractory Installation Quality Control—Inspection and Testing of Refractory Brick Systems and Materials* <sup>2</sup>

[API Standard 976](#), *Refractory Installation Quality Control-Inspection and Testing AES/RCF Fiber Linings* <sup>2</sup>

[API Technical Report 978](#), *Monolithic Refractories: Manufacture, Properties and Selection* <sup>1</sup>

[API Technical Report 979](#), *Applications of Refractory Lining Materials* <sup>1</sup>

[ASTM C71](#) <sup>3</sup>, *Standard Terminology Relating to Refractories*

[ASTM C113](#), *Standard Test Method for Reheat Change of Refractory Brick*

[ASTM C181](#), *Standard Test Method for Workability Index of Fireclay and High-Alumina Refractory Plastics*

[ASTM C133](#), *Standard Test Methods for Cold Crushing Strength and Modulus of Rupture of Refractories*

[ASTM C704/C704M](#), *Standard Test Method for Abrasion Resistance of Refractory Materials at Room Temperature*

[ASTM C860](#), *Standard Test Method for Determining the Consistency of Refractory Castable Using the Ball-In-Hand Test*

---

<sup>1</sup> Expected to be published in 2018.

<sup>2</sup> Expected to be published in 2019.

<sup>3</sup> ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania, 19428, [www.astm.org](http://www.astm.org).

### 3 Terms and Definitions

For the purposes of this document, the following definitions apply.

#### 3.1

##### **abrasion resistance**<sup>4</sup>

The ability to withstand the effects of eroding particles for an extended period without significant loss of material or other damage.

#### 3.2

##### **aggregate**<sup>4</sup>

As applied to refractories, a ground mineral material consisting of particles of various sizes, used with much finer sizes for making formed or monolithic bodies.

#### 3.3

##### **air-setting refractories**<sup>4</sup>

Compositions of ground refractory materials that develop a strong bond at ambient temperatures by virtue of chemical reactions within the binder phase that are usually activated by the addition of water. These refractories include cement and phosphate-bonded castables.

#### 3.4

##### **anchor or tieback**<sup>4</sup>

A metallic or refractory device that retains the refractory or insulation in place.

#### 3.5

##### **bloating**<sup>4</sup>

A subsurface defect that can occur in plastic refractory lining systems caused by steam pockets entrapped in the pore structure of the refractory during initial heating due either to rapid heat-up or insufficient permeability in the refractory.

#### 3.6

##### **calcium aluminate cement**

The product obtained by pulverizing clinker, which consists of hydraulic calcium aluminates formed by fusing or sintering a suitably proportioned mixture of aluminous and calcareous materials.

#### 3.7

##### **castable**<sup>5</sup>

A combination of refractory grain and a suitable amount of bonding agent that, after the addition of a proper liquid, is generally poured into place to form a refractory shape or structure that becomes rigid because of chemical action.

#### 3.8

##### **casting**<sup>4</sup>

The application of wet mixed castable refractory by placing (possibly with the aid of vibration), pouring, or rodding.

#### 3.9

##### **chemical-setting**<sup>4</sup>

Refractory developing a strong bond by chemical reaction.

NOTE These refractories include phosphate-bonded plastics and ramming mixes.

---

<sup>4</sup> Definition from [API Standard 936](#), Fourth Edition.

<sup>5</sup> Definition from ACI CT-13, *ACI Concrete Terminology*.

**3.10****cold face<sup>4</sup>**

The surface of a refractory section not exposed to the heat source.

NOTE The cold face is commonly the surface furthest from the source of heat.

**3.11****cold-setting refractories**

A composition that develops a bond at normal ambient temperature prior to drying.

**3.12****construction joint**

See “joint.”

**3.13****compactability<sup>5</sup>**

The ease with which the volume of a freshly placed plastic refractory or ramming mix is reduced to a practical minimum, usually by ramming.

**3.14****conversion (of high alumina cement)**

The transformation of the hexagonal metastable hydrates (CARD or  $C_2AHg$ ) to the stable, cubic hydrate ( $C_3AH_6$ ). The cubic hydrate occupies less volume than the hexagonal hydrates; this results in an increase in matrix porosity and a possible reduction in concrete strength.

NOTE C = CaO; A =  $Al_2O_3$ ; and H =  $H_2O$ .

**3.15****curing<sup>4</sup>**

The process of bond formation in a newly installed monolithic refractory.

NOTE For hydraulic bonded castables, curing occurs at room temperature and is facilitated by an excess of water being present to react with the cement component. For phosphate-bonded plastic refractories, heating to 500 °F–700 °F (260 °C–370 °C) is required to form the bond.

**3.16****drying**

Removal of free moisture from a material.

**3.17****dryout<sup>4</sup>**

The initial heating of a newly installed castable lining in which heating rates and hold times are controlled to safely remove retained water without explosive spalling and to form a well-distributed network of shrinkage cracks in the lining.

**3.18****expansion joint<sup>4</sup>**

A separation between adjoining parts of a refractory lining to allow small, expansive movements, such as those caused by thermal changes.

**3.19****explosive spalling<sup>4</sup>**

A sudden fragmentation of the castable that occurs as the result of a buildup of steam pressure due to inappropriately rapid heating, generally on the first firing.

**3.20****field mix<sup>5</sup>**

A mix formulated at or near the job site.

**3.21****firing**

The process of heating refractories to develop desired properties.

**3.22****gun-casting**

A method of placing castables that uses a pneumatic gun as a conveyor of the material by reducing the velocity of the castable at the nozzle.

**3.23****gunning<sup>4</sup>**

The act of applying refractory, which is emplaced by projecting onto a surface via an air placement gun and using either the dry-mix or shotcreting (wet-mix) method.

NOTE There is a wide divergence of definitions for gunning in the industries where it is used. To minimize misunderstanding, API has developed consistent definitions for refractory applications that are in line with [ASTM C71](#) definitions, but are different than those endorsed by organizations such as the American Concrete Institute.

**3.24****gunning, dry-mix**

An application technique that uses a pneumatic means to transport a refractory material and the majority of the water is added by the nozzleman at the outlet nozzle.

NOTE There is a wide divergence of definitions for this type of gunning in the industries where it is used. To minimize misunderstanding, API has developed consistent definitions for refractory applications that are in line with [ASTM C71](#) definitions, but are different than those endorsed by organizations such as the American Concrete Institute.

**3.25****gunning mix<sup>5</sup>**

A refractory mix that is emplaced by projecting onto a surface via an air placement gun.

**3.26****heat-setting refractories<sup>4</sup>**

Compositions of ground refractory materials that require relatively high temperatures for the development of an adequate bond (commonly called the “ceramic bond”)

**3.27****hot face**

The surface of a refractory section exposed to the heat source.

**3.28****hydraulic cement**

A cement that sets and hardens by chemical interaction with water and that is capable of doing so under water.

**3.29****insulating castable<sup>4</sup>**

A castable with relatively low thermal conductivity that usually has a low in-place density [less than 100 lb/ft<sup>3</sup> (1.6 Mg/m<sup>3</sup>)].

**3.30****lamination<sup>6</sup>**

A plane of weakness within a monolithic refractory lining that is parallel to the hot face of the lining and permits separation into layers.

---

<sup>6</sup> Definition from [ASTM C71](#).

**3.31****lightweight castable**

See “insulating castable.”

**3.32****matrix<sup>4</sup>**

The continuous phase in the emplaced refractory.

**3.33****monolithic refractory<sup>4</sup>**

Castable or plastic refractories applied by casting, gunning, or hand/ram packing to form monolithic lining structures of any shape.

**3.34****normal-weight refractory concrete<sup>4</sup>**

Refractory concrete having a unit weight greater than 100 lb/ft<sup>3</sup> (1.5 Mg/m<sup>3</sup>) in place.

**3.35****plastic refractories<sup>4</sup>**

A moldable refractory material that can be extruded and has a level of workability that permits it to be pounded into place to form a monolithic structure.

**3.36****plasticity<sup>4</sup>**

A property of a material that allows it to be molded or shaped.

**3.37****punkiness**

A friable, spongy appearance.

**3.38****ramming mix<sup>6</sup>**

A refractory material, usually tempered with water, that cannot be extruded, but has suitable properties to permit ramming into place to form a monolithic structure.

**3.39****rapid fire technology**

Additives mixed with the castable to allow the installed lining to be fired safely (i.e. without explosive spalling) when the lining is exposed to faster firing rates.

NOTE This allows the installed lining to pass through the phase where the chemically combined water is released from the cement matrix.

**3.40****rebound<sup>4</sup>**

Aggregate and/or cement that bounces away from the surface against which refractory is being projected by gunning.

**3.41****refractory**

Materials resistant to high temperatures.

**3.42****refractory aggregate**

Materials having refractory properties that form a refractory body when bound into a conglomerate mass by a matrix.

**3.43****refractory concrete (castable)**

Concrete that is suitable for use at high temperatures and contains hydraulic cement as the binding agent.

**3.44****setting<sup>4</sup>**

The hardening that occurs with time and/or temperature.

**3.45****sheeting<sup>4</sup>**

Spalling of layers from the hot face of the refractory.

**3.46****shelf life<sup>4</sup>**

The maximum interval during which a material may be stored and remain in a usable condition.

**3.47****shotcreting**

An installation technique in which a pump is used to convey tempered refractory castable to a nozzle where an admixture and air pressure are injected, spraying the castable stream onto a substrate where the castable becomes sufficiently stiff to withstand the force of gravity.

NOTE There is a wide divergence of definitions for this term in the industries where it is used. To minimize misunderstanding, API has developed consistent definitions for refractory applications that are in line with [ASTM C71](#) definitions, but may be different than those endorsed by organizations such as the American Concrete Institute.

**3.48****spall**

A surface fragment, usually in the shape of a flake, detached from a larger mass by impact, the action of weather, pressure, or expansion within the larger mass.

**3.49****steam spalling**

See “explosive spalling.”

**3.50****thermal spalling<sup>4</sup>**

Spalling that occurs as a result of stresses caused by non-uniform heating and/or cooling.

**3.51****thixotropic<sup>4</sup>**

A mixture that flows when vibrated, but is stiff and unmoving otherwise.

NOTE Vibration cast refractories are an example.

**3.52****vent hole**

An opening into the hot face of the monolithic refractory to permit the escape of gas or steam during drying and firing.

**3.53****wall seat**

A support for a vertical element of refractory.

**3.54****weep hole**

An opening at the cold face to permit the escape of moisture.

## 4 Installation

### 4.1 Introduction

Proper installation is an essential prerequisite to maximize the service life of refractories used in many applications. While installation quality cannot reverse selection or product manufacturing deficiencies, installation quality is integral to placement of a monolithic refractory lining structure that is free of structural defects and that is applied in a manner that optimizes the physical properties of the constituent refractory. Quality control standards for monolithic refractories are covered separately in [API Standard 936](#), which also provides best-practice procedures for the dryout, as well as guideline heating rates and holding times for typical lining systems used in HPI applications.

There are several methods of applying refractory concretes. These include casting, gunning (by either wet or dry method), pumping and extruding, pneumatic gun casting, trowel placing, and dry packing. Each of these application modes is significantly different from the other. Selection of the proper application mode will depend upon several factors, including size of the job, geometry of the finished concrete, economics, and technology available to carry out the job. The most frequently used methods of installing refractory concretes are casting and gunning.

Plastic refractories are installed by ramming, gunning, hand-packing, and vibratory placement. Ramming mixes are generally installed with a pneumatic rammer, but are sometimes installed by gunning.

Construction details are more important to the successful application of plastics. For a high-quality, long-lasting lining, careful attention must be given to the temporary support and final anchoring system.

### 4.2 Refractory Concrete

#### 4.2.1 Casting

Casting is one of the most widely used methods of placing refractory concrete. It is particularly suitable for special shapes, such as burner blocks, and for large-volume horizontal installations. For a given refractory concrete mix, variables that can be controlled during casting of refractory concretes are:

- water content;
- material and concrete mixing temperatures;
- mixing (time and manner); and
- vibration (manner and extent).

The more closely these four variables are controlled, the less likely two additional variables, cure and heat-up rate, will be detrimental to the refractory concrete. The effects of the listed variables, and in particular, their influence on mechanical and physical properties, are discussed below.

##### 4.2.1.1 Mixing

Proper mixing of castables is of primary importance. Care should be taken to avoid mixing previously hydrated material into fresh refractory concrete. Mixers, tools, and transporting equipment used previously with Portland or other types of cement concretes must be cleaned prior to mixing. Adequate cleaning can be accomplished by sandblasting, chipping, or by extended mixing of coarse refractory aggregate in the drum to wear away the old materials. Remnants of lime, plaster, or Portland cement will induce flash set and will lower refractoriness.

All mixing must be performed with water of potable quality (water suitable for human consumption). Refractory concretes can be mixed in trowel boxes with a hoe or in paddle, screw, or barrel mixers. Ready-mix trucks are frequently used on large jobs. With such trucks, however, special precautions are

required, including thorough pre-cleaning of the truck mixer and careful control of water additions and mixing time. Thorough cleaning is especially important when Portland cement concrete has been used previously. All three of these requirements are essential with calcium aluminate cement.

When Portland cement concrete has been used previously in the mixer, a thorough cleaning is especially important. \*A recommended practice for cleaning ready-mix trucks <sup>[1]</sup> is to charge 2000 lb (907 kg) of coarse aggregate into the drum and rotate at mixing speed for 15 minutes to 20 minutes, or until the rinsing water runs clean. Aggregates and water used for cleaning the truck should be discarded. Generally, paddle mixers are best used for small- to medium-size jobs involving calcium aluminate cement concretes because of the ease in controlling water, mixing efficiency, and cleanliness of equipment.

In a paddle mixer, normal-weight refractory concretes should be mixed for about 4 minutes to 6 minutes. Refractory concretes of less than 60 lb/ft<sup>3</sup> (960 kg/m<sup>3</sup>) density should be mixed for no longer than necessary to ensure thorough wetting. This precaution is necessary because the lightweight aggregate may break up during the mixing action and reduce the effectiveness of the concrete as a heat insulator. Refractory concretes in the 75 lb/ft<sup>3</sup> (1200 kg/m<sup>3</sup>) to 90 lb/ft<sup>3</sup> (1400 kg/m<sup>3</sup>) density range should be mixed for approximately 2 minutes to 5 minutes. Because working time may be short, all castables should be cast immediately after mixing.

#### 4.2.1.2 Water Content

Water content is important and must be carefully controlled. The amount of water necessary for a given material will depend on a number of factors, including: material proportions, ambient temperature, water temperature, the type and speed of the mixer, and the size and shape to be cast. In general, the smallest amount of water necessary to consolidate the material into a solid concrete mass is recommended. Care should be taken, however, to use sufficient water, otherwise the concrete will be difficult to work and voids and/or laminations may occur.

The effect on representative physical and mechanical properties of a low-purity cement castable brought about by varying the mixing water is shown in Figure 1 <sup>[2]</sup>. In all cases, water additions above the required amount were detrimental to the physical properties measured. For lightweight refractory concretes, the effect of water content on physical properties is even more dramatic.

Conversely, if adequate water is not available to react with the cement, sufficient hydration will not take place. Problems can occur even if the proper amount of water is used for mixing. For example, water can be absorbed by wooden forms, aggregates, refractory anchors, etc. Pre-wetting refractory anchors and coating or sealing wooden forms are methods that are frequently used to overcome the water absorption problem. Water will also be lost through uncovered surfaces. Methods of sealing the forms include covering with plastic and coating with oil or paint. To protect the concrete surface and prevent water evaporation, methods such as covering with wet burlap or plastic (when heat dissipation is unnecessary) or coating with curing compounds are satisfactory. Curing should begin as soon as possible and continue for at least 24 hours (see Section 6).

\* References from this point forward are endnotes and indicate the source appearing in the Bibliography at the end of TR 980.

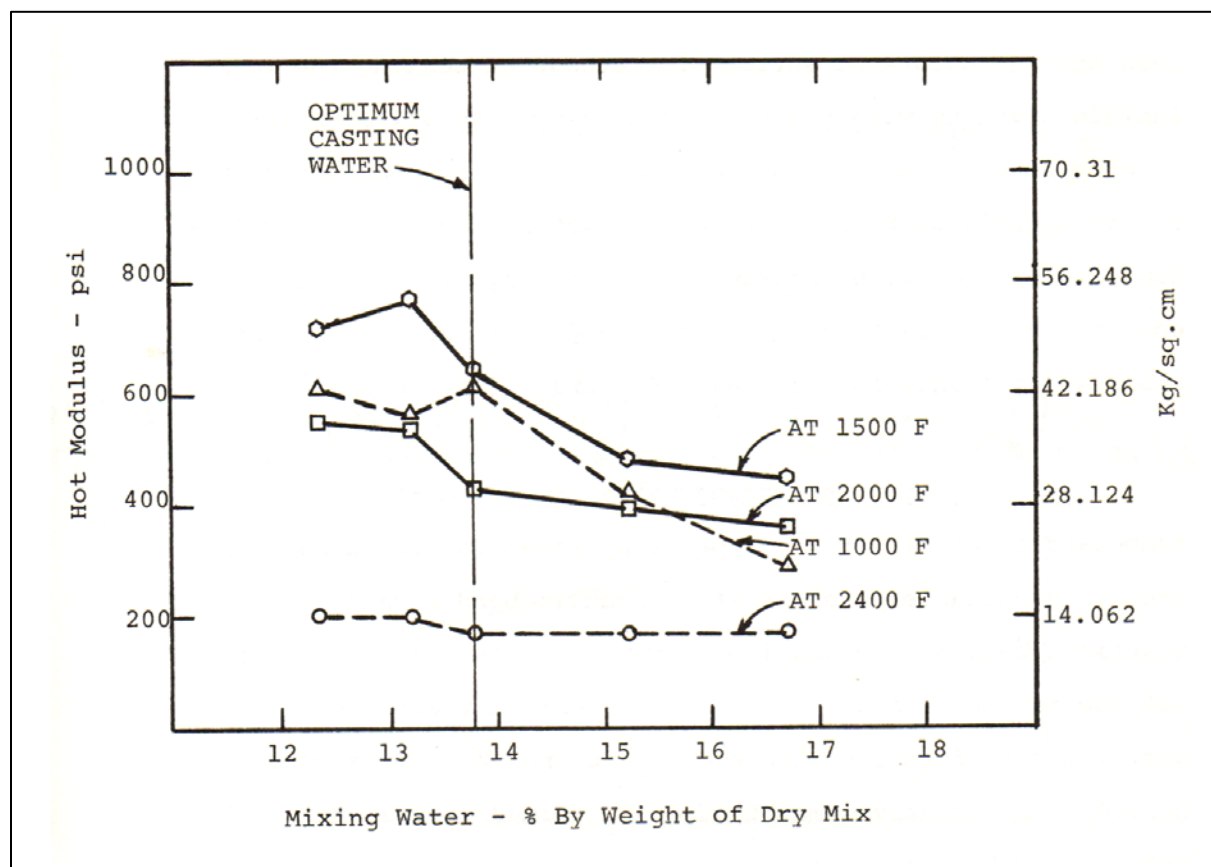


Figure 1—Hot Modulus Versus the Amount of Mixing Water for a Fireclay Castable with a Low-purity Cement

#### 4.2.1.3 Mixing and Curing Temperature

Mixing and curing temperatures can affect the type of hydrates formed in set concrete. A castable develops its hydraulic bond because of chemical reactions between the calcium aluminate cement and water. To get the maximum benefits from these chemical reactions, it is preferable to form the stable  $C_3AH_6$  during the initial curing period. The relative amount of  $C_3AH_6$  formed versus metastable  $CAH_{10}$  and  $C_2AH_8$  can be directly related to the temperature at which the chemical reactions take place.

Recent work illustrates the significant impact of mixing and curing temperatures on strength properties. Figure 2<sup>[3]</sup> shows the flexural strength of a tabular alumina, high-purity cement castable plotted as a function of mixing and curing temperatures. It can be seen that the strength developed after mixing and curing at 85 °F (30 °C) and drying at 230 °F (110 °C) is nearly twice that of the concrete mixed and cured at 60 °F (15 °C) and dried at 230 °F (110 °C). The reason for the reduced strength properties of the high-purity binder mixed at lower temperatures may be that the predominant hydrate formed after curing for 24 hours is  $CAH_{10}$ . This metastable compound must then convert in the set concrete to the stable  $C_3AH_6$  after drying at 230 °F (110 °C).

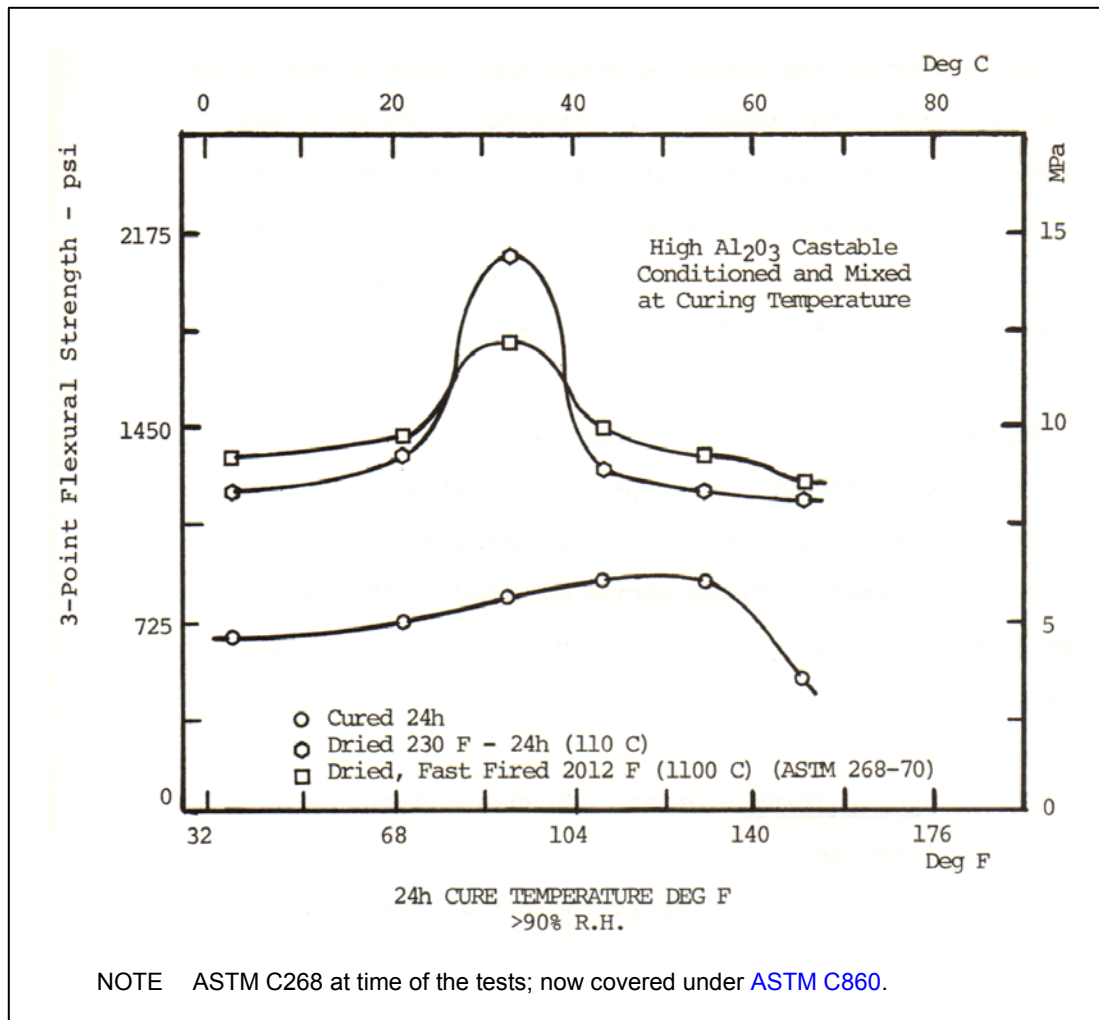


**Figure 2—Flexural Strength of a Tabular Alumina, High-purity Cement Castable**

Explosive spalling of high-purity cement concretes can occur when casting and curing temperatures below 50 °F (10 °C) are used. Thus, a refractory concrete containing a high-purity cement should be cast or cured above 70 °F (10 °C). This phenomenon is less likely to occur with low- or intermediate-purity cement binders.

#### 4.2.1.4 Transporting

Other than gunning and pumping, which will be discussed later, the techniques for transporting refractory concretes are similar to those used for Portland cement concrete. Some calcium aluminate cement binders have a shorter placing time available.

Movement and distribution of refractory concrete are determined primarily by jobsite location and access, size and frequency of batches, and mixer capacity and type. Typical handling equipment includes the 5-gallon (18.9-liter) bucket, wheelbarrow, cart, or buggy (hand and power), dumper, concrete bucket and crane, hoist, and conveyor. Precautions must be taken to avoid casting fresh concrete on partially hardened or dry material. Unless this precaution is observed, lamination planes may develop. Casting should be continuous and to the full design thickness.

#### 4.2.1.5 Vibrating

In-place vibration of refractory concrete generally increases the density and uniformity of the finished concrete. In some cases, it also serves to reduce the water requirement. Vibration is also used to move the material into corners and joints where it would not normally flow. The type of vibration to be used will depend

upon the job. A pencil-type (immersion) vibrator varying in diameter from  $\frac{3}{4}$  in. (1.9 cm) to 2 in. (5.1 cm) is the type most commonly used. Vibrators with 12,000 cycles/min to 14,000 cycles/min are preferred. Table vibrators are often used to cast many similar pieces, such as burner blocks.

Unfortunately, there are hazards associated with vibrating, especially with lightweight concretes. Over vibration can cause segregation between coarse and fine particles. This reduces density, and may also result in parts of the concrete having a lower cement content than specified. Under-vibration can lead to a poorly consolidated finished product. Currently, there are no specific guidelines for successful vibration of refractory concrete, and success or failure often depends on the experience of the installers. Where vibration is impractical, hand rodding can be used; however, it is a less desirable alternative.

#### 4.2.2 Gunning

Gunning of refractory concrete is particularly effective where:

- forms are impractical,
- access is difficult,
- thin layers and/or variable thicknesses are required, and/or
- normal casting techniques cannot be employed.

The same precautions regarding water purity and mixing temperatures apply to gunning as to casting.

##### 4.2.2.1 Equipment

There are two basic types of gunning methods: dry-mix and shotcrete (wet-mix). The dry-mix method (sometimes called “gunite”) conveys the aggregate and binder pneumatically to the nozzle in an essentially dry state where water is added in a spray nozzle. Shotcreting by the wet-mix method conveys the aggregate, binder, and a predetermined amount of water, either pneumatically or under pressure, to the nozzle, where compressed air is used to increase the velocity of impact. The dry method produces a greater rebound, but is the most suitable technique and is recommended for gunning insulating refractories. Shotcreting generally allows for better wetting of hot-patching and erosion-resistant refractories.

With either the dry-mix or shotcrete method, two types of guns may be used: the continuous-feed gun or the batch (single-charge) gun. The continuous-feed gun is usually the most practical for jobs requiring placement of a large volume of concrete. Various specially-designed nozzles are commercially available; however, differences in the end result are generally slight.

In the dry-mix method, proper mixing and pre-dampening of the refractory mix prior to feeding into the gun hopper is necessary in order to reduce dust and loss of binder and other fines, to minimize the amount of rebound, and to ensure the proper distribution of the fines, which may have segregated in the bag. The use of a paddle mixer is generally preferred. The choice of a mixer (paddle, mortar, auger, elevating screw, ribbon, or barrel) for pre-dampening and mixing depends on the gunning equipment, size, and type of the project, and on the volumes to be placed during specific time periods.

##### 4.2.2.2 Installation

When using the dry or shotcrete method, the refractory materials, gun, hoses, compressor, and mixer must be properly balanced and coordinated to achieve the best possible results. The most important factor in this operation, however, is the qualification and experience of personnel.

Gunning is an acquired skill that requires training and experience for best results. It is recommended that emphasis be placed on developing competent crews. A successful application usually requires three crew members: the foreman, the gun operator, and the nozzleman. The foreman must understand and be experienced in all phases of the operation, including surface preparation, anchor installation, equipment setup, gun operation, nozzle techniques, finishing, and curing. The gun operator oversees and controls the

speed of the mixing, and operates his gun to ensure a measured, steady, and non-pulsating rate of flow. To ensure a uniform covering free of laminations and with minimum rebound, the nozzleman should move the nozzle in a small, circular orbit and, where possible, maintain the flow from a 3 ft (0.9 m) to 4 ft (1.2 m) distance at right angles to the receiving surface <sup>[4]</sup>. The nozzle valve must be adjusted so that the proper amount of water is added to the mix in order to minimize rebound, rebound pockets, sloughing, and slumping.

The applied refractory should be left in its as-placed state immediately after gunning. If scraping or finishing is required, the absolute minimum should be done so as to avoid breaking the bond or creating surface cracks. Gunning refractory concretes can increase the in-place density and result in other changes in the physical properties. This effect is more pronounced in lower-density castables and must be taken into account when specifying thicknesses and material quantities for insulating applications. For additional information on gunning, refer to [API Standard 936](#).

#### 4.2.3 Pumping and Extruding

Although pumping is generally not used on a large scale, certain refractory concretes can be installed with positive displacement pumps in conjunction with rigid or flexible pipelines. The term “pumping” is usually associated with the following types of equipment:

- piston pumps—simplex and duplex,
- continuous flow—rotary and screw, and
- peristaltic-squeeze pumps.

The design of the mix is critical, and special attention must be given to the absorptive characteristics and sizing of the aggregate. Additional important factors to be considered in pumping are the pump mechanism, pipe size, distance, and height to which the material must be pumped, number of pipe bends, and rheology of the mix.

The concrete to be pumped is premixed, as in casting or shotcreting (wet-mix). The effect of water content on the efficiency of the pumping operation and on the final quality of the concrete cannot be overemphasized. The advantages and disadvantages of this technique are similar to those for gunning (discussed in Section 4.2.2).

Some applicators use the term “extruding” to describe the conveying and placing of refractory concrete at velocities that are very low or close to zero on exit from the pipeline. This placement technique is usually accomplished with pneumatic placers or “pressure bottles,” which are classified as single chamber (intermittent) or double chamber (continuous flow). When extruding, mixing of the refractory castable and water can be done internally or externally, depending on the type of extruding device. The conditions affecting the quality and efficacy of this technique are similar to those described above for pumping.

Since the terms “extruding” and “pumping” are similar in concept and apply to related techniques, the line dividing them is a very fine one. In fact, the words can be, and are, used interchangeably, depending on geographical location and practice.

#### 4.2.4 Dry Packing

Dry packing (also known as tamping or ramming), is used for placing refractory concrete on curved surfaces or when forming and casting are impractical. Dry packing is never used when a suitable alternative is available. A tamping mix uses a minimum amount of water, which is determined by adding water until a compact ball can be formed without a moisture film on its surface. Final placement compacting is done with heavy tampers or pneumatic rammers utilizing an oversized ramming plate. Care must be taken to avoid vibrating or disturbing previously placed sections that have achieved an initial set.