Refractory Installation Quality Control—Inspection and Testing Monolithic Refractory Linings and Materials

API STANDARD 936
FIFTH EDITION, MARCH 2024

American
Petroleum
Institute

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Asbestos is specified or referenced for certain components of the equipment described in some API standards. It has been of extreme usefulness in minimizing fire hazards associated with petroleum processing. It has also been a universal sealing material, compatible with most refining fluid services.

Certain serious adverse health effects are associated with asbestos, among them the serious and often fatal diseases of lung cancer, asbestosis, and mesothelioma (a cancer of the chest and abdominal linings). The degree of exposure to asbestos varies with the product and the work practices involved.

Consult the most recent edition of the Occupational Safety and Health Administration (OSHA), U.S. Department of Labor, Occupational Safety and Health Standard for Asbestos, Tremolite, Anthophyllite, and Actinolite, 29 Code of Federal Regulations Section 1910.1001; the U.S. Environmental Protection Agency, National Emission Standard for Asbestos, 40 Code of Federal Regulations Sections 61.140 through 61.156; and the U.S. Environmental Protection Agency (EPA) rule on labeling requirements and phased banning of asbestos products (Sections 763.160–179).

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Introduction

The purpose of this standard is to define the minimum requirements for the installation of monolithic refractory linings and to provide guidance for the establishment of quality control elements necessary to achieve the defined requirements.

Refractory Installation Quality Control—Inspection and Testing Monolithic Refractory Linings and Materials

1 Scope

This standard provides installation quality control procedures for monolithic refractory linings and may be used to supplement owner specifications. Materials, equipment, and personnel are qualified by the methods described, and applied refractory quality is closely monitored, based on defined procedures and acceptance criteria. The responsibilities of all parties involved in the quality control process are also defined.

2 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any addenda) applies.

API Standard 560, *Fired Heaters for General Refinery Service*

ASTM C113, *Standard Test Method for Reheat Change of Refractory Brick*

ASTM C133, *Standard Test Methods for Cold Crushing Strength and Modulus of Rupture of Refractories*

ASTM C181, *Standard Test Method for Workability Index of Fireclay and High-Alumina Plastic Refractories*

ASTM C704/C704M, *Standard Test Method for Abrasion Resistance of Refractory Materials at Room Temperature*

ASTM C1054, *Standard Practice for Pressing and Drying Refractory Plastic and Ramming Mix Specimens*

SSPC SP 3, *Power Tool Cleaning SSPC SP 7/NACE No. 4, Brush-Off Blast Cleaning*

3 Terms and Definitions

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

NOTE See Annex A for a glossary of additional refractory terms that are not referenced in this standard.

3.1
abrasion resistance
The ability to withstand the effects of eroding particles for an extended period without significant loss of material or other damage.

EXAMPLE A vapor stream containing solid particles.

NOTE For refractory materials, abrasion resistance is measured in the form of eroded volume loss in accordance with ASTM C704/C704M.

3.2
acceptance quality limit
The acceptable limit of defect samples in a lot or batch, expressed as a percentage or ratio.

3.3
applicator qualification testing
Preinstallation simulation of production work that is visually inspected, sampled, and tested to verify that application equipment and personnel are capable of meeting specified quality standards.

3.4
as-installed testing
Testing of refractory materials sampled from the installation to confirm that they meet specified physical property standards.

3.5
biscuit
[cookie]
A refractory piece formed within an area completely enclosed by the anchoring system.

EXAMPLE A hexmetal or flexmesh cell.

NOTE The biscuit has the shape of the enclosed area and the thickness of the lining. Biscuits are normally independent of each other except for limited connections through perforations in the anchoring system.

3.6
castable (refractory) [1]
A combination of refractory grain (aggregate) and suitable bonding agent that, after the addition of a proper liquid, is installed into place to form a structure that becomes rigid due to a thermal or chemical reaction.

3.7
casting
Castable installation technique whereby refractory is mixed with an appropriate liquid and placed in a formed enclosure with the aid of vibration that causes the refractory to become “fluid-like” and thereby flow and consolidate to the shape of the formed enclosure.

3.8
chemical-setting [2]
[chemical bond]
Developing a strong bond by chemical reaction. These refractories include phosphate-bonded plastics and ramming mixes.

3.9
cold crushing strength
CCS
A measure of a refractory’s ability to resist failure under a compressive load as determined at room temperature after drying or firing, or a combination thereof.

NOTE CCS is calculated by dividing the total compressive load at failure by the specimen cross-sectional area. (ASTM C133)

3.10
cold wall
An insulating refractory lining system with a metal shell temperature generally less than 500 °F (260 °C).

3.11
compliance datasheet
A list of mechanical and chemical properties for a specified refractory material that are warranted by the manufacturer to be met if and when the product is tested by the listed procedure in accordance with the given standard.

3.12
Conventional monolithic refractories
Castable refractories containing greater than 2.5 % CaO as classified in ASTM C401.

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1 ASTM C71-88, *Standard Terminology Relating to Refractory*.

2 API Technical Report 979, *Applications for Refractory Lining Materials*.

3.13
curing
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 from 500 °F to 700 °F (260 °C to 370 °C) is required to form the permanent bond.

3.14
cutback
Unset refractory trimmed from the lining surface via a cutting action to give the final lining thickness dimension, usually in a gunning installation.

3.15
density [3]
The mass of a unit volume of a substance. It is usually expressed either in kilogram per cubic meter, grams per cubic centimeter, or in pounds per cubic foot.

3.16
dryout fibers
Low-melting-point fibers such as polypropylene or polyethylene are added to refractory to enhance moisture release by burning out during initial dryout, increasing the permeability by leaving tiny, interconnected voids.

3.17
dry gunning
Pneumatic placement of gunning mixes where water is added at the nozzle.

NOTE See 3.25 for the definition of gunning.

3.18
erosion service
Refractory application in which erosion resistance is a determining feature of lining service life.

EXAMPLE Transfer lines, overhead lines, cyclone linings, and deflector shields of fluid solids units.

3.19
erosion-resistant lining
Refractory lining system whose purpose is to withstand the effects of an eroding material for an extended period without significant loss of material or other damage.

3.20
execution plan
A written document prepared by the refractory contractor that is submitted to and approved by the owner before work starts detailing how the refractory contractor intends to perform the job and meet the objectives and quality standards set for the job in the owner's specifications and drawings.

3.21
firing [4]
The process of heating refractories to develop desired properties.

3.22
flocculating agent
A chemical additive that causes rapid stiffening of a fluid refractory castable, mortar, or similar material.

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3 *Harbison-Walker Handbook of Refractory Practices.*

4 ASTM C71-88, *Standard Terminology Relating to Refractory*.

3.23
green refractory (monolithic linings)
A newly installed refractory before it is exposed to dryout or initial heating.

3.24
gun operator
Individual in a dry gun operation who controls material charging, flow rate, and air flow of the gunning machine.

3.25
gunning [7]
The application of monolithic refractories by means of air placement guns.

3.26
hammer test (of refractory lining)
A subjective test of green or fired refractories in which the lining is impacted with a hammer to gauge soundness and uniformity via audible resonance.

3.27
hand packing
Castable installation technique whereby refractory is placed by packing successive handfuls of material to the desired shape. Refractory is mixed at a consistency that is stiff enough for the placed refractory to hold its shape and is wet and sticky enough so that the lining formed is structurally homogenous.

3.28
hexalt anchors
Individual metallic anchors that are used as an alternative to hexmetal in thin-layer, erosion-resistant linings.

3.29
hexmetal
NOTE A metallic anchoring system constructed of metal strips, also known as ribbons, joined together to form hexagonal shaped enclosures where erosion-resistant refractory is packed after welding to the base plate steel. The thickness is usually $^{3}/_{4}$ in. or 1 in. (19 mm or 25 mm) but can be up to 2 in. (50 mm).

3.30
hot wall
A thin refractory lining system with a metal shell temperature greater than 500 °F (260 °C).

3.31
hydraulic-setting (bonded) refractories [5]
Monolithic refractory materials that contain binder such as aluminate cement which imparts hydraulic setting properties when mixed with water. These materials are installed by casting and are also known as castables.

3.32
independent laboratory
A refractory testing facility not affiliated with the refractory manufacturer or refractory contractor.

3.33
inspection and test plan (ITP)
A written inspection plan summarized into a checklist format that lists identifiable steps where each step requires acceptance by the refractory inspector. As the refractory contractor completes each step, a signature approval is required by the refractory inspector before continuing to the next step.

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5 ASTM C71-88, *Standard Terminology Relating to Refractory*.

3.34
material qualification testing
Preinstallation testing of refractory materials in which production lots of refractories manufactured for a specific installation are sampled and tested to confirm that they meet specified physical property requirements.

3.35
membrane curing compound
A nonreactive coating applied to freshly installed cementitious materials that aids the hydration process by retarding moisture loss.

3.36
metal fiber reinforcement
Metal fibers dispersed in refractory to improve applied lining toughness and shrinkage crack distribution.

NOTE Metal fibers are usually made of austenitic stainless steel 3/4 in. to 1 in. (19 mm to 25 mm) in length and 0.010 in. to 0.022 in. (0.3 mm to 0.6 mm) in effective diameter. They are blended into castable refractory, typically during the mixing operation, at a quantity of up to 1 weight percent to 4 weight percent (1 wt % to 4 wt %) of the refractory.

3.37
monolithic lining
A refractory lining formed of material that is rammed, cast, gunned, or sintered into place.

3.38
monolithic refractory
Unshaped refractories that are placed to form structures or linings of any shape. See also “castable refractory”.

3.39
nozzleman
Individual at the point of application in a gunning operation who controls material build up via maneuvering and positioning of the outlet nozzle. In a dry gunning operation, the nozzleman controls water addition via a water valve. In a wet gunning operation, the nozzleman controls flocculant and possibly air via a valve.

3.40
other service
Refractory installed in locations where erosion resistance is not a required feature of the lining service as included in API Standard 936.

3.41
owner
The proprietor of equipment who has engaged one or more parties to install or repair refractory.

3.42
permanent linear change
PLC
A measure of a refractory’s physical property that defines the change in dimension because of initial heating to a specific temperature for a specified period.

NOTE A specific specimen dimension is measured at room temperature before and after heating. PLC is calculated as the percentage change in the dimension.

3.43
physical properties
Properties of a refractory such as density, strength, erosion resistance, and linear change.

3.44
planetary mixer
A high energy mixer with a rotating paddle on a vertical orbiting mixer shaft.

3.45
plastic refractory [6]
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.

3.46
potable water
Water quality that is considered safe for human consumption.

3.47
Positive Material Identification (PMI)
Non-destructive test which detects the chemical composition of a metallic alloy.

3.48
prewetting or predampening (gunning)
A technique used with dry gunning machines where a small quantity of water is mixed into the dry refractory before charging into the gun to reduce rebound and dust and to improve wetting of the cement in the gunning operation.

3.49
production run
The quantity of refractory having the same formulation that is prepared in an uninterrupted manufacturing operation.

3.50
pump casting
Castable installation technique in which refractory material designed for this application, is mixed with an appropriate liquid and pumped through piping or hoses, or a combination thereof to the installation site, where it is poured from the outlet nozzle directly into a formed enclosure.

3.51
ramming
The use of compressive force or impact to deform a stiff refractory mix, causing it to completely fill the intended volume (e.g. a hexmetal cell) or fully bond or join to previously placed refractory (e.g. thick plastic linings), or a combination thereof.

3.52
rebound
Aggregate or cement, or a combination thereof not adhering to the gunned or shotcreted surface during the gunning process.

3.53
refractory contractor
The party or parties responsible for installing refractory in the owner's equipment.

3.54
refractory dryout
The initial heating of a newly installed monolithic lining in which heating rates and hold times are used to control and remove retained water without spalling and to form a well distributed network of shrinkage cracks in the lining.

[6] ASTM C71-88, *Standard Terminology Relating to Refractory*.

3.55
refractory inspector
The party or individual whom the owner has contracted or otherwise designated to monitor refractory testing and installation work performed by the refractory contractor and refractory material manufacturer(s). The Refractory Inspector shall meet the minimum requirements identified in Annex C.2.

3.56
refractory Installer
An individual of a team responsible for installing refractory product

3.57
refractory manufacturer
The party that manufactures the refractory products or ancillaries, or a combination thereof.

NOTE The refractory manufacturer has primary responsibility for material design properties, manufacturing quality control at the manufacturing site and specific procedures such as those for product mixing, installation, and start-up.

3.58
refractory practitioner
An individual who has demonstrated knowledge of the refractory quality control and assurance process.

3.59
sample
The quantity of randomly selected refractory taken from a single container or installation sequence that represents that batch or installation. It is used to make a complete set of test specimens to determine physical properties of the whole.

3.60
shelf life [7]
Maximum manufacturer recommended time interval under given conditions, during which a material may be stored and remain in a usable condition.

3.61
shotboard
Temporary containments used in gunning that are set up and secured to provide a firm surface on which to make perpendicular cold joints at the termination of work areas.

3.62
specimen
A piece or portion of a sample (cube, bar, plate, or other test pieces) selected and prepared for performing a test.

3.63
submersion vibrator
A cylindrical mechanical shaft driven device immersed into cast refractory to assist in consolidation, de-airing, and promotion of flow by vibration.

3.64
supplier
The party supplying the refractory and other materials.

NOTE The supplier may (or may not) be the manufacturer.

[7] ASTM C71-88, *Standard Terminology Relating to Refractory*.

3.65
vibration casting
Castable installation technique whereby refractory is mixed with an appropriate liquid and placed in a formed enclosure with the aid of vibration that causes the refractory to become "fluid-like" and thereby flow and consolidate to the shape of the formed enclosure.

3.66
wet gunning
Hydraulic placement of premixed castables (including liquid) where activating agents and placement air are added at the nozzle. Also known as shotcreting.

3.67
workability index
A measure of the moldability of plastic refractories as determined in accordance with ASTM C181. The workability index is commonly used to control consistency of plastic refractories during manufacture and serves as a measure of the facility with which it is rammed, gunned, or vibrated into place.

4 Quality Control Elements

Key quality control elements related to this standard are listed in Table 1. The table lists the key elements in work chronology and identifies the objectives of each element. Also indicated are the sections of this standard in which detailed requirements for each of the elements are defined. Quality control is dependent upon proper execution of the elements in Table 1. Timely planning is vital to the success of the quality control program.

Table 1—Quality Control—Key Elements

Elements	Actions	Objectives
Documentation (see 5.1.1 and 5.2.1)	Owner specification or refractory contractor execution plan, or both.	Define job-specific work scope.
Material qualification (see 8.2)	Testing at independent or manufacturer's laboratory. Inspector directs sampling, monitors specimen preparation and witnesses testing.	Confirm that materials manufactured for the job meet the specified physical property standards.
Applicator qualification (see 8.3)	Refractory installer demonstration of capabilities in simulated installation which is witnessed and inspected by the inspector.	Confirm that equipment and personnel are capable of installing qualified materials to specified standards.
Installation monitoring (see Section 9)	Inspector monitors refractory installer work and test sample preparation.	Confirm that specifications, good practice and installation procedures are followed.
As-installed testing (see 8.4)	Inspector coordinates sampling and testing of as-installed materials.	Confirm that installed materials meet specified physical property standards.
Pre-dryout inspection [see 5.3 f)]	Inspector performs visual/hammer test inspection of applied linings.	Confirm that installed linings meet specification standards.
Dryout monitoring (see Section 10)	For dryout prior to normal startup of equipment, the inspector monitors heating rates and hold times.	Confirm that agreed upon procedure is followed.
Post dryout inspection [see 5.3 f)]	Inspector performs visual/hammer test inspection of applied linings.	Confirm that installed linings meet specification standards.
NOTE When an independent laboratory is used or the refractory contractor assumes complete accountability for as-installed testing results, inspector participation may be waived or reduced by the owner.		

5 Responsibilities

5.1 Owner

5.1.1 The owner shall prepare a detailed specification. The specification shall include the following design details.

a) Lining products, thickness, method of application, and extent of coverage.

b) Anchor materials, geometry, layout, and welding details.

c) When used, details of metal fiber reinforcement include dimensions, concentration, type, and metallurgy.

d) Constraints on curing and dryout heating (e.g. design temperature limits or maximum differential temperatures or both that shall be maintained to avoid damaging the unit or components, or both).

5.1.2 The owner shall provide quality requirements covering the following:

a) Physical property requirements to be used for refractory material selection by specific product, installation method or location, or a combination thereof where the product will be used.

b) Preshipment sampling frequency as applicable for the product's intended use in either erosion service or other service (see 8.2.1.6).

c) Production (as-installed) sampling frequency in excess of the minimums outlined in 8.4.

d) Required lining thickness tolerances.

e) Criteria for hammer testing and the extent of cracking and surface voids permitted.

5.1.3 The owner shall approve the engineering drawings, execution plan, and dryout procedure prior to any installation activity.

5.1.4 The owner shall resolve the following:

a) exceptions, substitutions, and deviations to the requirements of the execution plan, this standard, and other referenced documents;

b) conflicts between the execution plan, this standard, and other referenced documents;

c) actual or potential work deficiencies discovered and submitted by the inspector.

5.2 Refractory Contractor

5.2.1 The refractory contractor shall prepare a detailed execution plan, including an inspection test plan (ITP), for the construction activities assigned to the refractory contractor in accordance with this standard and the requirements of the owner's specification and quality standards. The execution plan shall be prepared, submitted for the owner's approval, and agreed to in full before work starts. Execution details shall include:

a) designation of responsible parties;

b) designation of inspection hold points and the required advance notification to be given to the inspector;

c) surface preparation and welding procedures;

d) procedures for material qualification, material storage, applicator qualification, installation, and quality control;

e) curing (including the curing compound, if any, to be used) and dryout procedures for the completed lining system.

5.2.2 The refractory contractor shall submit to the owner of all exceptions, substitutions, and deviations to the requirements of the execution plan, this standard, and other referenced documents including manufacturer's compliance datasheets. Owner's approval shall be secured before implementation of the changes.

5.2.3 The refractory contractor shall schedule the material qualification tests and delivery of those materials and test results.

5.2.4 The refractory contractor shall schedule and execute the work to qualify all equipment and personnel required to complete installation work, including documentation and verification by the inspector.

5.2.5 The refractory contractor shall prepare and identify all testing samples (pre-shipment, applicator qualification, and production/installation) and timely delivery to the testing laboratory.

5.2.6 The refractory contractor shall provide advance notification to the owner of the time and location where work will take place so that this information can be passed on to the inspector.

5.2.7 The refractory contractor shall review and accept that installed anchor materials, geometry, layout, and weld details have been accepted by the owner or inspector.

5.2.8 The refractory contractor shall execute the installation work, including preparation of as-installed samples in accordance with 5.1.2 b) and 8.4.

5.2.9 The refractory contractor shall provide inspector verified documentation of installation records, including:

a) product(s) being applied;

b) pallet code numbers and location where applied;

c) installation crew members (designating nozzleman and gun operator when gunning);

d) mixing or gunning, or both equipment used;

e) fiber and water percentages;

f) mixing details including time, temperature, and aging time (if gunned);

g) location and identity of samples taken for installation quality control;

h) shell temperatures;

i) weather conditions and any other unusual conditions or occurrences;

j) dryout records.

5.2.10 The refractory contractor shall be accountable for installed refractories meeting specified standards, including as-installed testing results as defined in 8.4.4 and lining thickness tolerance limits as defined by 5.1.2 c).

5.3 Inspector

The inspector shall:

a) ensure that material and applicator qualification test results are fully documented prior to installation;

b) monitor qualification, production work, and dryout (when applicable) conducted by the manufacturer(s) and refractory installer to ensure compliance with job specifications and agreed-to quality practices;

c) request production refractory samples based on installation observations as indicated in 8.4.1.1, 8.4.2.1, and 8.4.3.1; notify the owner and the refractory contractor of any work deficiencies, potential deficiencies, or need for additional sampling. Notification shall be made according to the job-specific requirements outlined in the procedures. Notification shall take place as soon as possible and shall occur within one working day after discovery of the deficiency;

d) make no engineering decisions unless approved by the owner;

e) conflicts between the specified execution plan and the actual installation procedures or installed refractory quality results shall be communicated with the refractory contractor and submitted to the owner for resolution

f) inspect and hammer test installed linings before dryout and after dryout (when possible), and report any anomalies to the owner;

g) check and verify that accurate installation and dryout records are being documented in accordance with 5.2.8;

Record all nonconformances or potential problems, or both to which the inspector has alerted the refractory contractor and owner.

5.4 Manufacturer

The manufacturer shall:

a) provide a compliance datasheet in accordance with Annex B for each product;

b) provide material that meets the approved compliance datasheet;

c) provide all documentation required in 7.3.2.2;

d) for plastic refractories, provide the minimum acceptable workability index (per ASTM C181) for successful refractory application.

e) provide installation instructions and dry out schedule for each product

f) provide manufacturing quality plan that includes test methods, frequency, and sampling procedures during manufacturing at manufacturer's plant.

6 Inspector Qualifications

6.1 The inspector shall possess an active API 936 Refractory Personnel Certification.

6.2 The inspector shall have no commercial affiliations with the refractory contractor or manufacturer(s).

6.3 The inspector shall possess this standard, owner specifications, the project execution plan, the inspection and test plan, and other job-specific requirements outlined by the owner, refractory contractor, or manufacturer, or a combination thereof. The inspector shall have a working knowledge of these documents.

6.4 Refer to Annex C.2 for additional inspector competencies.

7 Materials

7.1 Physical Property Requirements

7.1.1 Refractories applied in accordance with this standard shall be sampled and tested to verify that the physical properties meet intended criteria. As defined in 5.1.2 a), product-specific physical property requirements shall be determined by agreement prior to material qualification. Qualification shall be based upon the sampling/testing procedures described in this standard.

7.1.2 The acceptance/rejection criteria for both material and applicator qualification testing are determined by average physical properties for each sample, which shall fully meet the criteria established for that material in 5.1.2 a).

7.1.3 Acceptance/rejection criteria for as-installed testing shall be based upon criteria and procedures agreed to prior to work start. The physical properties criteria of 5.1.2 a) shall be extended to account for field conditions as shown in Table 3.

7.2 Storage

7.2.1 General

Refractory materials are affected by moisture, humidity and elevated ambient temperatures. Proper storage of these materials is critical to the development of optimal physical properties. Shelf life is also affected by the ambient conditions. Storing refractory in the proper conditions will maintain shelf life.

7.2.2 Weather Protection

Refractory materials shall be stored in a weather protected area. The storage facility shall prevent moisture contact with the refractory. Storage shall be on an elevated, ventilated platform. Moisture shall be directed away from the refractory.

7.2.3 Temperature

Refractory materials shall be stored per the manufacturer's instructions. If manufacturer's instructions are not available, then refractory materials shall be stored at a temperature of 5 °C to 38 °C (40 °F to 100 °F). Refractory materials can be stored outside of this temperature range so long as the manufacturer allows it, and the temperature is returned to the proper temperature range prior to installation.

7.2.4 Shelf Life

The shelf life of any refractory material shall be set by the manufacturer. Shelf life set by the manufacturer is only valid if manufacturer storage requirements are complied with. Failure to store material properly will result in shorter shelf life. The shelf life of any monolithic refractory shall not exceed 12 months without the owner's approval. With the manufacturers and owners' approval, materials deemed beyond shelf life may be requalified following guidelines set in 8.2. Shelf life will be extended an additional three months after requalification of material.

7.2.5 Discarding Criteria

Packages with broken seals or that have become damp or wet (see 9.3) or for plastics only, refractory with a workability index below the manufacturer's minimum required value (see 5.4 d), 8.3.3.6 and 8.3.4.6) shall be subject to requalification or discard (see 8.2.3). The concerned manufacturer shall be involved to assess and gauge the usability of the material for re-evaluation. If approved by the owner, damaged material may be recertified following the guidelines in 8.2, otherwise they shall be discarded. Shelf life may be extended an additional three months after requalification of material.

7.3 Packaging and Marking

7.3.1 General

Packaging of refractory is important to preserving the integrity of the material. Markings provide valuable information to determine the age of material, assist in establishing water content requirements and track the placement of material.

7.3.2 Regulations and Safety Datasheets (SDS)

7.3.2.1 Refractory materials shall comply with all applicable federal, state, and local codes and regulations on storage, handling, safety, and environmental requirements.

7.3.2.2 The latest issue of the refractory manufacturer's compliance datasheets, application instructions, and SDS shall be available at the installation site and complied with during the installation of monolithic refractory linings.

7.3.3 Packaging

7.3.3.1 Hydraulic bonded castable refractories shall be packaged in sealed, moisture-proof bags.

7.3.3.2 Chemical-setting refractories shall be packaged in heat-sealed plastic to assure vapor-tight enclosure. Mechanical protection shall be provided by cardboard, rigid plastic, or metal outside containers.

7.3.4 Marking

7.3.4.1 Refractory bags or containers shall be marked with the product name, batch number, hazards identification label, and date of manufacture clearly shown.

7.3.4.2 Refractory bags or containers shall be marked with the contained refractory weight. The actual weight shall not deviate from the marked weight by more than ± 2 %.

7.3.4.4 Each pallet shall be uniquely identified by pallet number and code date.

7.4 Anchors

7.4.1 Each alloy anchor shall be stamped, or laser etched or supplied in sealed traceable packaging to identify metallic and forming manufacturer. Anchors from unmarked and/or packaging not stamped/etched or being installed from a freshly opened package shall be confirmed by 100 % positive material identification (PMI) before installation. For hexmetal installations, the same stamping/etching or sealed packaging shall apply. Each unmarked sheet shall be confirmed by PMI before installation.

7.4.2 Selection, installation, inspection, and testing of anchors shall be in accordance with the design drawings and specifications.

8 Qualification and Testing

8.1 Testing and Test Procedures

8.1.1 General

Testing shall be in strict accordance with ASTM procedures as modified below. The laboratory conducting the test procedures shall be subject to audit and approval by the owner and shall not be affiliated with the refractory contractor. Quality control testing shall consist of density, cold crushing strength (CCS), permanent linear change (PLC), abrasion loss (when applicable), and workability index (plastics only). Other tests required by the owner shall be as defined in the owner’s specifications. The test results report should be shared with the manufacturer to provide historical data for creating compliance datasheets. Testing reports should contain applicable manufacturer compliance values to compare against.

8.1.2 Cold Crushing Strength

Testing shall be in accordance with ASTM C133, and the following:

a) Cube loading surfaces shall be parallel to within a tolerance of ± 0.8 mm (± $^{1}/_{32}$ in.) and perpendicular to within a tolerance of ± 1 degree, whether cast or gunned.

b) Cold crushing strength shall be determined on samples that have been fired to 815 °C (1500 °F) in accordance with 8.5.4.

c) The loading head of the test machine shall have a spherical bearing block.

d) For cast or hand packed specimens, the load shall be applied to either or both pair of faces cast against the side of the molds. For specimens cut from a larger cast panel, an open face shall not be used for the top or bottom (i.e. load application faces) during the test. For gunned specimens, load shall be applied perpendicular to the gunning direction, in other words, on cut faces perpendicular to the face of the panel.

e) Bedding material shall be noncorrugated cardboard shims, placed between the test specimen and the loading surfaces. New shims shall be used for each test cube. Shim dimensions shall be ~75 mm × 75 mm × 1.5 mm (3 in. × 3 in. × $^{1}/_{16}$ in.) thick. Two thinner shims making up the same total thickness may be used in place of a single shim.

f) Testing machine minimum sensitivity and maximum loading rate shall be as in Table 2.

Table 2—Testing Machine Sensitivity and Loading Rate

Castable Density lb/ft3 (kg/m^3)	Testing Machine	
	Sensitivity [a] lbf (N)	Loading Rate [b] psi/min (kPa/s)
>100 (1600)	500 (2222)	2500 (290) [c]
60 to 100 (960 to1600)	100 (444)	300 (35) [c]
<60 (960)	25 (111)	250 (29) [c]

[a] If load is registered on a dial, the dial calibration shall permit reading to the nearest load value specified. Readings made within $^{1}/_{32}$ in. (0.8 mm) along the arc described by the end of the pointer are acceptable.

[b] Loading rate shall be based on the nominal cross-sectional area of the test specimen.

[c] Fifty percent of the expected load may be applied initially at any convenient rate.

8.1.3 Abrasion (Erosion) Resistance

Testing shall be in accordance with ASTM C704/C704M, supplementary requirements, and the following:

a) Fire to 815 °C (1500 °F) in accordance with 8.5.4. Weigh the specimens to the nearest 0.1 g.

b) Abrasion surface shall be the surface most representative of the hot face. (e.g. original free surface for rammed/hand packed linings, formed surface for cast linings, and screeded exposed surface for gunned). Prequalification and production samples may use a cut surface if the representative hot face surface is not acceptable.

c) Use the silicon carbide only once before discarding.

d) From the initial weight and volume, calculate the initial bulk density to the nearest 0.1 g/cm^3. Calculate and report the amount of refractory lost by abrasion in cubic centimeters to the nearest 0.1 cc.

e) The apparatus shall not be used if calibration was last performed more than seven days prior to the test, as described in ASTM C704M §S1.4.

Density shall be determined at room temperature on specimens that have been fired in accordance with 8.5.4. Testing procedure shall be as follows:

a) Measure specimen dimensions to the nearest 0.5 mm (0.02 in.) and determine the specimen volume. Weigh the specimen to the nearest 1.0 g (0.002 lb).

b) Calculate density by dividing weight by volume and report in units of pounds per cubic foot or kilograms per cubic meter.

8.1.4 Permanent Linear Change (PLC)

8.1.4.1 General

Testing shall be in accordance with ASTM C113 and the following:

a) The length of each test specimen shall be measured to the nearest 0.025 mm (0.001 in.) along the 230 mm (9 in.) dimension at each of the four edges of the specimen.

b) At room temperature, determine the green refractory dimension by measuring the length of the specimen. For heat-setting plastic refractories, the green dimension shall be determined from the form dimensions. Oven-dry the specimens in accordance with 8.5.4 a).

c) After cooling to room temperature, measure the dried length of the specimen and then fire in accordance with 8.5.4 b).

d) After cooling to room temperature, measure the fired length of specimen.

8.1.4.2 Green-to-Dried and Dried-to-Fired PLC

8.1.4.2.1 General

Determine the green-to-dried and dried-to-fired PLC as follows. Report the PLC as an average percent shrinkage in length for each specimen to ± 0.05 %.

8.1.4.2.2 Green to Dried

Determine the green-to-dried length change of each of the four edges of the specimen [see 8.1.4.1 b) and c)]. Divide each change by the green length of that edge. Average the four values to obtain the green to dried PLC of the specimen.

8.1.4.2.3 Dried-to-Fired

Determine the dried-to-fired length change of each of the four edges of the specimen [see 8.1.4.1 c) and d)]. Divide each change by the dried length of that edge. Average the four values to obtain the dried to fired PLC of the specimen.

8.1.5 Workability Index

Testing shall be in accordance with ASTM C181. Each sample shall consist of five specimens.

8.2 Pre-shipment Refractory Qualification Testing

8.2.1 General

8.2.1.1 Refractories to be installed by gunning, casting, or hand/ram packing shall be tested to ensure that they comply with specified physical property requirements as described in 5.1.2 a). Tested physical properties shall be density; PLC; CCS or abrasion resistance (for abrasion-resistant refractory); and workability index (for plastic refractory), in accordance with 8.1 and 8.5.

8.2.1.2 Subject to owner's approval, the refractory contractor shall arrange for testing at either an independent laboratory or the manufacturer's plant and direct the work to assure that mixing techniques, water quality and content, ambient temperatures, and mix temperatures represent those needed for production installation. The testing party is responsible for conducting sampling, specimen preparation, testing, and documentation of results.

8.2.1.3 For plastic refractories, the manufacturer shall provide the actual workability index determined seven days after manufacture in accordance with 8.1.5 and the minimum acceptable workability index for suitable installation of each plastic refractory supplied.

8.2.1.4 Anchoring components, including metallic anchors, ceramic anchor attachments and ceramic components including ceramic anchors, and tubesheet ferrules shall be certified according to owner's criteria.

8.2.1.5 The refractory contractor shall inform the owner of testing arrangements and timing so that the owner may notify the inspector to witness, or spot check the testing. When engaged as a witness, the inspector shall select the container to be tested and observe all sampling, specimen preparation, and testing. In cases where an independent laboratory is used or the refractory contractor assumes complete accountability for testing results, inspector participation may be waived or reduced by the owner.

8.2.1.6 Test results shall be shared with the Owner or Owner's representative for approval prior to shipping of the corresponding refractory material.

8.2.1.7 Based upon the service designation, minimum testing frequency shall be as follows:

a) erosion service—one sample per pallet or partial pallet from each production run,

b) other service—one sample per three pallets or less from each production run.

When the refractory is packaged in bags or another similar container, the sampled bag shall be randomly selected.

8.2.2 Forming of Refractory Test Specimens

8.2.2.1 As directed by the refractory contractor and subject to approval by the owner, the entire selected container of refractory shall be mixed, and test specimens formed using metal or plastic forms of the required specimen dimensions. Alternatively, samples may be made to larger dimensions and then cut to the required dimensions after 24-h cure. See 8.5 for details of specimen preparation.

NOTE When the refractory is packaged in supersacks or other similar bulk containers, a representative sample of appropriate size shall be collected from each container at the time of packaging of the production run.

8.2.2.2 For cast installations, refractory shall be cast in the same manner as the installation. For vibration cast installations, vibration shall be used in the forming of the test specimens.

8.2.2.3 For pump cast installations, refractory shall be poured into forms.

8.2.2.4 For hand packed installations, refractory shall be hand packed.

8.2.2.6 For gunned installations, refractory shall be gunned. Gunned samples shall be made into a large panel with specimens cut from the central portion of the panel (i.e. away from the edges). Specimens may be cast or hand packed subject to owner approval Plastic and other ramming refractories shall be formed using a mallet or handheld pneumatic rammer. Specimen formation using a pneumatic or ramming press, as described by ASTM C1054, is not permitted.

8.2.3 Retesting

In the event a sample fails to meet specified requirements, it may be retested once. The retest shall be conducted using a new sample representing the same pallet(s) of the same batch of refractory as the failed sample. Use the same testing facility, testing procedure, inspector, and inspection methods. A different facility may be used, subject to the owner's approval. If the retest is unsuccessful, the refractory represented by the sample(s) shall not be used.

8.3 Qualification of Installation Procedure and Crew/Installers

Prior to installation, the refractory installer shall demonstrate that the specified quality standards will be met using the material qualified for the job, including metal and dryout fibers as applicable, and the installation method, equipment, and personnel to be used for the installation work. This shall be done by simulating the installation and sampling and testing the applied materials as follows.

8.3.1 Gunning (Wet or Dry)

8.3.1.1 A test panel shall be prepared by each nozzleman/gun operator team for each refractory being installed. The panel and test specimens shall be inspected and tested prior to commencing the actual installation. Preparation and examination shall be in accordance with 8.3.1.2 through 8.3.1.6.

8.3.1.2 A test panel measuring a minimum of 600 mm × 600 mm (24 in. × 24 in.) shall be fabricated. The panel thickness, anchors and anchor pattern shall be in accordance with the actual installation job.

8.3.1.3 The test panel forms shall be constructed with a removable back and sides to permit visual inspection of the installed castable. The method of anchor attachment shall permit removal of the forms without damage to the refractory or the anchors (e.g. use a bolt through the form). Interior surfaces of the forms shall be coated with a manufacturer approved releasing agent to facilitate removal from the refractory.

8.3.1.4 The test panel shall be inclined 45 degrees above the horizontal and supported on a frame so that the panel's midpoint is ~1.8 m (6 ft) above grade. The nozzleman/gun operator team shall demonstrate their abilities by gunning the test panel in this inclined position. During the test panel installation, samples shall be created in a wire basket as described in 8.4.1. Apply a manufacturer approved membrane-type (nonreactive) curing compound to all exposed surfaces before the surface is dry to the touch. At least 24 h after completion of the panel, remove the forms and inspect the panel for voids, laminations, nonuniformities, entrapped rebound, or other flaws. The panel shall then be sectioned or broken, and the exposed surfaces inspected for voids, laminations, nonuniformities, and rebound entrapment.

8.3.1.5 Test specimens (number and type in accordance with 8.5) shall be cut from the center of each sample and tested in accordance with 8.1 for compliance to 5.1.2 a) physical property requirements for density; PLC; and CCS or, where applicable, abrasion resistance (see Table 4). Alternatively, with the owner's approval, full testing may be waived, and measurements of the panel dimensions and weight used to determine the green density, which is then compared with a previously approved manufacturer supplied value.

8.3.1.6 Satisfactory examination and test results in accordance with 8.3.1.5 and 8.3.1.6, shall serve to qualify the mixing and installation procedures and the nozzleman/gun operator teams. The nozzleman and gun operator shall not gun refractory materials until they are qualified.

8.3.2 Casting

8.3.2.1 A mock-up shall be prepared by each applicator for each mixing/installation procedure and for each refractory being installed. The mock-up shall simulate the most difficult piece of the installation work for which the subject refractory and mixing/installation procedure will be used, or it shall be of the size/shape agreed to in the documentation phase (see 5.2.1). The mock-up and test specimens shall be inspected and tested prior to commencing the actual installation. Preparation and examination shall be in accordance with 8.3.2.2 through 8.3.2.9.

8.3.2.2 The mock-up shall simulate forming and general installation procedures, including mixing, handling/delivery to the lining cavity, and associated quality control requirements. Installation of refractory shall be in the same orientation to be used for the actual installation and shall simulate installation obstacles (e.g. around nozzle protrusions and beneath overhangs), and fit-up tolerances if work involves lining of sections to be fit-up later.

8.3.2.3 The refractory thickness, anchors, and anchor pattern shall be in accordance with the actual installation job.

8.3.2.4 For vibration cast installations, the mock-up shall demonstrate the adequacy of the vibration method, equipment, and means of vibrator attachment.

8.3.2.5 For pouring and pump cast installations, only vibration that will be used in the actual installation shall be allowed in the mock-up.

8.3.2.6 The forms shall be constructed to permit removal for visual inspection of the refractory. The method of anchor attachment shall permit removal of the forms without damage to the anchors or the refractory. Interior surfaces of the forms shall be coated with a manufacturer approved release agent to facilitate removal from the applied refractory.

8.3.2.7 Test specimens (number, type, and preparation in accordance with 8.5) shall be prepared using material sampled from the mixes prepared for casting the mock-up. Specimens shall be formed in molds using the same level of agitation as the mock-up or may be sampled and cut from the mock-up after material has set. Specimens shall be tested in accordance with 8.1 for compliance with 5.1.2 a) physical property requirements for density; PLC; and CCS or, where applicable, abrasion resistance (see Table 4).

8.3.2.8 Refractory cast in the mock-up shall be cured for a 12 h minimum prior to stripping the forms. Remove the forms and visually inspect the refractory. The applied lining shall be homogeneous and free of voids or segregations and shall meet specified tolerances.

8.3.2.9 Satisfactory examination and test results in accordance with 8.3.2.7 and 8.3.2.8 shall serve to qualify the applicators and the mixing and installation procedures as well as the mixed water levels. The applicator(s) shall not cast refractory linings until they are qualified.

8.3.3 Thin-layer Abrasion (Erosion) Resistant Refractories

8.3.3.1 A test panel 300 mm × 300 mm × 19 mm (12 in. × 12 in. × $^{3}/_{4}$ in.) or 25 mm (1 in.), shall be packed by each applicator for each anchoring system and refractory being installed by the applicator. The test panel and test specimens shall be inspected and tested prior to commencing the actual installation. Preparation and examination shall be in accordance with 8.3.3.2 through 8.3.3.7.

8.3.3.2 Panel thickness shall be the same as the lining to be installed. Mixing and application techniques (e.g. pneumatic ramming, hand packing), orientation (sidewall or overhead), shall be in accordance with the actual installation job.

8.3.3.3 The hexmetal or hexalt anchoring system(s) (as used for the actual installation) shall be attached to a backing plate in such a manner that the backing plate may be removed without damaging the refractory or the anchoring system. For hexalt systems, perimeter forms shall also be used to contain the refractory. The backing plate (and forms, if required) shall be coated with a manufacturer approved release agent to facilitate removal from the applied refractory.

8.3.3.4 Examination of the panel may be performed immediately after ramming, or within 24 h, as directed by the owner. Remove the backing plate and examine the panel from the backside. The lining shall be free of voids, incomplete filling of the anchoring system and inadequate compaction of the refractory.

8.3.3.5 Test specimens shall be prepared using materials sampled from the mixes applied. Specimens shall be formed in molds (see 8.5), using the same placement method as the test panel. Specimens shall be tested in accordance with 8.1 for density, PLC, and abrasion resistance. The results shall be in compliance with 5.1.2 a).

8.3.3.6 For each batch of plastic refractories the workability index shall be determined and shall exceed the minimum acceptable value for installation [see 5.4 d) and 8.1.5].

8.3.3.7 Satisfactory examination and test results in accordance with 8.3.3.4 through 8.3.3.6 shall serve to qualify the applicator(s) and the mixing and installation procedures, as well as the mix water levels. The applicator(s) shall not apply refractory linings until they are qualified.

8.3.4 Thick-layer Plastic Installations [Greater than 2 in. (50 mm)]

8.3.4.1 A test panel shall be pneumatically ram packed by each applicator and for each refractory being installed. The test panel shall be inspected and tested prior to commencing the actual installation. Preparation and examination shall be in accordance with 8.3.4.2 through 8.3.4.8.

8.3.4.2 The test panel shall be 600 mm × 300 mm (24 in. × 12 in.) with an applied lining thickness, anchors and anchor pattern in accordance with the actual installation job. In the event ceramic anchors are to be used in the construction, panel shall be large enough to properly demonstrate setting one entire ceramic anchor assembly.

8.3.4.3 The test panel shall be constructed with removable back and sides to permit visual inspection of the installed refractory. Anchors shall be attached to the form in a manner that permits removal of the backing plate without damage to the refractory or the anchoring system. Interior surfaces of the backing plate and forms shall be coated with a manufacturer approved releasing agent to facilitate removal from the applied refractory.

8.3.4.4 Test panel refractory shall be installed by pneumatic ramming in a manner and orientation (e.g. sidewall or overhead) simulating the actual installation.

8.3.4.5 After refractory installation is completed, the test panel forms and backing plate shall be removed immediately and the refractory examined from the backside. The refractory shall be free of inadequate consolidation and voids. The sample shall be sectioned and examined to confirm that the refractory plastic is free of inadequate consolidation or voids around the anchors, or both.

8.3.4.6 For plastic refractories the workability index shall be determined and shall exceed the minimum acceptable value for installation [see 5.4 d) and 8.1.5].

8.3.4.7 Except as noted in 8.3.4.6, test specimens and testing are not required.

8.3.4.8 Satisfactory results in accordance with 8.3.4.5 and 8.3.4.6 shall serve to qualify the equipment, techniques, and applicator. The applicator(s) shall not ram pack refractory materials until they are qualified.

8.4 Production (As-installed) Refractory Sampling and Testing

During the installation of refractory products, the refractory contractor is responsible for samples taken in accordance with 5.2.5 and the execution plan.

8.4.1 Gunning (Wet or Dry Gun)

8.4.1.1 A minimum of one sample of applied refractory shall be gunned by each gunning crew per material per shift using a "wire mesh basket." At least one sample shall be prepared for each lined item at the completion of the installation, shift, or as directed by the inspector or owner's representative.

8.4.1.2 The basket shall be ~300 mm × 300 mm (12 in. × 12 in.) and at least 100 mm (4 in.) deep but no greater than the installed refractory thickness. The basket shall be constructed of wire mesh with $^{1}/_{2}$ in. (13 mm) square openings.

8.4.1.3 The basket shall be supported on the wall where the lining application is proceeding, filled, and immediately removed. All loose refractory or rebound material shall be removed from the area where the basket was placed during sample preparation. Production samples shall remain in the same environment as actual production installation for the first 24 h.

8.4.1.4 The required test specimens (number and preparation in accordance with 8.5) shall be diamond saw-cut from the refractory applied in the basket. Testing shall be in accordance with 8.1 for density; PLC; and CCS or, where applicable, abrasion resistance.

8.4.1.5 Alternatively, panels with enclosed sides may be used in place of the wire baskets if the panel dimensions are at least 450 mm × 450 mm × 100 mm (18 in. × 18 in. × 4 in.) but no deeper than the installed refractory. Test specimens shall be cut from the center of the panels to avoid inclusion of rebound possibly trapped along the sides of the panels.

8.4.2 Casting

8.4.2.1 A minimum of one sample of the material being installed shall be cast by each mixing crew per material per shift. At least one sample shall be prepared for each lined item at the completion of the installation, shift, or as directed by the inspector or owner's representative.

8.4.2.2 Test specimens may be formed by casting directly into molds or by casting into larger forms and diamond saw cutting to the required specimen dimensions after curing. Production samples shall remain in the same environment as actual production installation for the first 24 h.

8.4.2.3 Vibration shall be used in casting samples as applicable to simulate installation work.

8.4.2.4 The specimen requirements and preparation shall be in accordance with 8.5. Testing shall be in accordance with 8.1 for density; PLC; and CCS or, where applicable, abrasion resistance.

8.4.3 Plastics and Thin-layer, Erosion-resistant Linings

8.4.3.1 A minimum of one sample shall be packed by each applicator per material per shift. At least one sample shall be prepared for each lined item at the completion of the installation, shift, or as directed by the inspector or owner's representative.

8.4.3.2 Test specimens shall be formed directly from the refractory being installed using the ramming technique used for the installation.

8.4.3.3 The specimen requirements and preparation shall be in accordance with 8.5, and testing shall be in accordance with 8.1.

8.4.4 Testing Frequency Requirements

8.4.4.1 Testing of applicator samples shall conform to a minimum acceptance quality limit (AQL) of 1.5 % as shown in Table 3. Samples tested shall be randomly selected by the inspector or approved owner representative and are separately accounted from samples tested for specific quality concerns.

8.4.4.2 Defects are defined as any sample that meets the rejection criteria described in 8.4.5.1.

8.4.4.3 If the total number of defects is outside of the AQL limit, then all samples shall be tested to identify the areas where additional rework may be needed.

Table 3—Minimum AQL Requirements for Testing Frequency and Allowable Defects of Production Samples

AQL %	Number of Total Samples Prepared	Testing Frequency	Allowable Defects
1.5	1–90	8	0
	91–280	32	1
	281–500	50	2
	501–1200	80	3

8.4.5 Acceptance/Rejection Criteria

8.4.5.1 The average physical properties of each sample of the as-installed refractory shall meet the criteria defined in Table 4. Table 4 describes modifications to the evaluation criteria defined in 5.1.2 a).

8.4.5.2 Inspector verified records shall be kept by the refractory contractor to identify the samples and the areas of the installed lining that they represent.

8.4.5.3 Failure to meet the criteria described in Table 4 shall be cause for rejection of the area of the refractory lining that the sample represents.

8.4.5.4 In the event of disagreement over the installed refractory quality, samples may be taken from the questionable area of the applied lining and retested using the same test procedure and evaluation criteria. If the retest is unsuccessful, the area of the lining represented by the sample shall be replaced.

8.4.5.5 The refractory contractor shall prepare records identifying and locating all areas of rejected and replaced lining (e.g. a map), the reason for the rejection, the means of repair, and the refractory used.

Table 4—Physical Properties and Acceptable Results for Testing of As-installed Refractories

Physical Property	Range of Acceptable Results [a]	
		Maximum [b]
Abrasion loss	None	110 %
Cold crushing strength	90 %	None
Density	–80 kg/m^3 (–5 lb/ft^3)	+80 kg/m^3 (+5 lb/ft^3)
Permanent linear change	Zero [c]	110 %

[a] Average of all specimen test results per sample. The minimum and maximum values are based upon the physical property value(s) listed on the manufacturer's compliance datasheet or other value in accordance with 5.1.2 a).

[b] When the manufacturer's compliance datasheet indicates a range for the physical property, the applicable limits shall apply to the upper and lower values of the compliance datasheet range.

[c] Zero means 0.00 % shrinkage. Products that have a positive PLC tested after 1500 °F shall not be used unless approved by the owner.

8.5 Test Specimen Preparation

8.5.1 Based on the use designation determined in accordance with 5.1.2 b), the minimum number of refractory specimens for each sample shall be in accordance with Table 5.

Table 5—Required Number of Test Specimens per Sample

Type of Test		Number of Specimens	Size of Specimens
For erosion service	Abrasion resistance	2	114 mm × 114 mm × 25 mm (4 1/2 in. × 4 1/2 in. × 1 in.)
	Permanent linear change	1	2 in. × 2 in. × 9 in. (50 mm × 50 mm × 230 mm)
	Density	—	Use specimens above
For other service	Cold crushing strength	3	50 mm × 50 mm × 50 mm (2 in. × 2 in. × 2 in.)
	Permanent linear change	1	50 mm × 50 mm × 230 mm (2 in. × 2 in. × 9 in.)
	Density	—	Use specimens above.

8.5.2 The specimens shall be cured in accordance with 9.13.

8.5.2.1 Hydraulic bonded castable refractories shall be cured for a minimum of 24 h after placement. During this period, the exposed surfaces of the refractory shall be covered or sealed with an impermeable coating or material.

8.5.2.2 Air-setting, phosphate-bonded castable refractories shall be air cured, uncovered, for a minimum of 24 h after forming. During this period, the refractory shall be protected from moisture.

8.5.2.3 Heat-setting, plastic refractories shall be allowed to air dry for a minimum of 24 h followed by oven drying [see 8.5.4 a)] in a form suitable for drying temperatures.

8.5.3 Once refractory specimens have been fully cured, they shall be removed from the forms or cut to required dimensions or both. The specimens shall be marked for identification with temperature-resistant paint (to prevent burn-off during firing).

8.5.4 Specimens shall be dried and fired as required by the testing procedure (see 8.1). Oven drying and firing shall be as follows.

a) Oven dry: hold for 12 h minimum at 104 °C to 110 °C (220 °F to 230 °F) in a forced air, convection dryer. Heat-setting plastics shall be oven-dried in the forms.

b) Oven fire: heat at 170 °C/h (300 °F/h) maximum to 815 °C (1500 °F), hold for 5 h at 815 °C (1500 °F); cool at 280 °C/h (500 °F/h) maximum to ambient. Remove heat-setting plastics from the molds after oven drying and before oven firing.

c) For heat-setting plastic refractories, see ASTM C1054 for procedures to remove from steel forms, drying and firing to avoid handling damage, skinning, bloating, and surface tears.

9 Installation/Execution

9.1 Surface Preparation

9.1.1 Immediately before refractory installation, all surfaces to be lined shall be cleaned to meet SSPC SP-7/ NACE No. 4, or better, standards for grit blasting if rust, weld slag, oil, dirt, or other foreign materials are present on the surface to be lined.

9.1.2 If grit blast cleaning is required, anchor leg coverings (if present) shall be removed before the grit blast cleaning. After grit blast cleaning, the surfaces to be lined shall be vacuum cleaned to remove all debris and new anchor leg coverings shall be installed. Water shall not be used for washing unless it contains a suitable inhibitor.

9.1.3 Surface cleaning in accordance with SSPC SP-3 shall be acceptable only for limited areas such as spot grinding for repairs.

9.2 Water Quality

Water used for mixing in the refractory shall be potable. The pH shall be between 6.5 and 8.5. The chloride content of the water shall not exceed 200 ppm. When refractory is installed on stainless steel surfaces the chloride content shall not exceed 50 ppm.

NOTE The 50-ppm limit does not apply when stainless steel is limited to the anchoring system or metal reinforcing fibers.

9.3 Water-contaminated Refractory

9.3.1 Containers of refractory exhibiting evidence of water contamination shall be discarded.

9.3.2 Any individual container of refractory material containing hard lumps (i.e. cannot be easily broken by hand) shall be discarded.

9.4 Preparation for Lining Installation

9.4.1 Timing

9.4.1.1 Refractory installation shall not begin until completion of welding, postweld heat treatment, and pressure testing.

9.4.1.2 If the refractory installation takes place before pressure testing, all pressure retaining weld seams shall remain unlined, i.e. exposed to the testing medium.

9.4.2 Lining Penetrations

Structural members, nozzle extensions, and other items within the limits of the lining shall be wrapped with 3 mm ($^{1}/_{8}$ in.) thick material, or alternative thickness as specified by the Owner/Designer, for expansion relief. The wrapping shall be impermeable, nonabsorbent, and taped smoothly into place to prevent moisture absorption from, or bonding to, the refractory lining.

9.4.3 Openings

9.4.3.1 Openings shall be closed by means of sealed wood or metal-jacketed plugs, slightly tapered (smaller toward the shell), and of such dimensions to fit snuggly into the openings.

9.4.3.2 Surfaces of the plugs shall be lightly coated with a manufacturer approved release agent or covered with plastic to prevent bonding to the refractory.

9.4.3.3 Plugs shall not be removed from the openings or disturbed until at least 24 h after the refractory installation.

9.4.4 Obstructions

Obstructions (e.g. scaffolding) that could interfere with the satisfactory and continuous application of the refractory lining shall be avoided.

9.4.5 Nozzle Necks

9.4.5.1 Insulating refractory in the nozzle neck shall be cast or hand packed to within 25 mm (1 in.) of the inside of the shell or head to which it is attached. The remaining 25 mm (1 in.) shall be installed monolithically with the shell lining. The objective is to prevent a cold joint that is flush with the shell of the vessel where process gases may penetrate the lining more easily.

9.4.5.2 Voids or spaces to be packed with ceramic fiber blanket insulation (e.g. annular space in nozzles equipped with inner sleeves) shall be completed before the installation of refractory. Nozzles shall be packed to a point flush with the inside face of the shell. After nozzle packing, the ceramic fiber density shall be at least 128 kg/m^3 (8 lb/ft^3). Ceramic fiber blanket insulation shall be used only where specifically shown on the approved drawings.

9.4.6 Anchor Preparation

9.4.6.1 Anchors shall be cleaned of spatter and foreign materials before refractory is installed.

9.4.6.2 For multilayer linings, anchors for the hot-face layer shall be protected and kept free of all backup refractory and foreign material before application of the hot-face layer.

9.4.6.3 If anchor leg coverings are required, placement of the coverings shall be confirmed immediately before refractory placement.

9.4.7 Equipment Cleaning

9.4.7.1 Mixers, guns, conveyors, hoses, and all other equipment shall be thoroughly cleaned before use.

9.4.7.2 Equipment shall be cleaned at each material change, shift change, and more often if buildup of castable takes place.

9.4.7.3 Cleaning is required between each mix of phosphate-bonded refractory.

9.4.7.4 For non-phosphate-bonded refractories, the cleaning interval shall be such as to prevent buildup of refractory materials on the mixer internals (including the drum). For low-moisture (low-cement) mixes and other refractories sensitive to water content, excess water shall be removed after each batch.

9.4.7.5 All tools used in mixing, transporting, and applying the refractory lining shall be cleaned after each batch and kept free of all deleterious materials.

9.4.7.6 For refractory which is mixed with chemical activator fluid rather than water, tools and equipment shall only be cleaned with a compatible fluid.

9.4.8 Site

9.4.8.1 The work area shall be kept clean and protected to ensure that lining installation can proceed in an orderly manner without incorporating dirt, debris, rain, or other deleterious material into the lining.

9.4.8.2 Porous surfaces in contact with a new monolithic lining shall be covered in advance with an impermeable layer (i.e. plastic sheet, wax paper) or dampened with water to avoid absorbing moisture from the new refractory.

9.5 Application Temperature

9.5.1 The temperature of the air and shell at the installation site shall be between 10 °C and 32 °C (50 °F and 90 °F) during refractory installation and for 24 h thereafter. Shading and enclosure shall be used to protect against extremes in temperature, sun exposure, and weather (e.g. wind and rain).

9.5.2 For cold weather conditions, heating or external insulation, or both may be used to maintain temperatures above the minimum requirement.

9.5.3 For hot weather conditions, shading, water spraying the unlined surface or air conditioning, or both may be used to maintain temperatures below the maximum requirement.

9.5.4 Temperature limits for refractory and mix water shall be in accordance with the manufacturer's requirements. In the absence of manufacturer's mix temperature limits, mix temperature shall be between 16 °C and 27 °C

(60 °F and 80 °F). This may require the heating or cooling of refractory material and mix water to achieve the required mix temperature range.

9.6 Gunning

9.6.1 Dry Gunning

9.6.1.1 Prewet the refractory by mixing with water prior to charging into the gun. Prewetting reduces dusting and segregation and helps avoid plugging in the feed hose. Optimum water addition, mixing time, and aging of the prewetted material shall be in accordance with the manufacturer's recommendations and the applicator qualification testing.

9.6.1.2 Gunning equipment shall provide a smooth and continuous supply of water and material to the nozzle and shall not contribute to laminations, voids, rebound entrapment, or other deleterious effects in the installed lining. Shotboards or perpendicular edge cuts shall be used to terminate work areas. When stoppages greater than 20 minutes are encountered, or initial set is determined by the inspector, only full thickness lining shall be retained.

9.6.1.3 Begin gunning at the lowest elevation, building up the lining thickness gradually over an area. Work in an upward direction to minimize the inclusion of rebound. Rebound material shall not be reused.

9.6.1.4 Gunning where rebound entrapment is likely is prohibited. Downhand gunning 30 degrees below horizontal shall be reviewed prior to installation. Where rebound entrapment is likely the refractory shall be placed by an alternative placement technique such as casting, hand packing, or repositioning to avoid downhand gunning.

9.6.1.5 Shotboard height or depth gauges or both shall be used for thickness measurement. After gunning and confirmation of sufficient coverage, the refractory shall be trimmed (cut back) in a timely manner with a serrated trowel or currycomb. Cutback shall be performed when the surface is not damaged by the cutback techniques (15 to 20 minutes after placement is typical), and before initial set occurs. Interrupted buildup of lining thickness is not permitted after the initial set, defined as either the surface being exposed for more than 20 minutes or becoming dry to the touch, whichever occurs first.

9.6.2 Wet Gunning

9.6.2.1 Wet gunning (also known as shotcreting) is an installation procedure that requires specialized equipment and a different skill set than is common for a refractory gunning installation. When wet gunning is established as the more suitable installation technique, the refractory contractor, in conjunction with the refractory manufacturer, shall prepare a detailed installation procedure and present it to the owner for approval. All quality control elements defined in this standard shall apply to the application of refractory by wet gunning.

9.6.2.2 Optimum water addition at the mixer, mixing time, and the rate of activating agent addition shall be in accordance with the manufacturer's recommendations and the applicator qualification testing.

9.6.2.3 Wet gunning equipment shall provide a smooth and continuous supply of material and flocculating agent to the nozzle and shall not contribute to laminations, voids, or other deleterious effects in the installed lining. Shotboards or perpendicular edge cuts shall be used to terminate work areas. When stoppages greater than 20 minutes are encountered, or initial set is determined by the inspector, only full thickness lining shall be retained.

9.6.2.4 Begin gunning at the lowest elevation, building up the lining thickness gradually over an area. Work in an upward direction.

9.6.2.5 Shotboard height or depth gauges or both shall be used for thickness measurement. After gunning and confirmation of sufficient coverage, the refractory shall be trimmed (cut back) in a timely manner with a serrated trowel or currycomb. Cutback shall be performed when the surface is not damaged by the cutback techniques (15 to 20 minutes after placement is typical), and before initial set occurs. Interrupted buildup of lining thickness is not permitted after the initial set, defined as either the surface being exposed for more than 20 minutes or becoming dry to the touch, whichever occurs first.

9.7 Casting

9.7.1 Forming shall be sufficiently strong to support the hydraulic head of wet refractory that will be retained and to resist any imposed mechanical loads, such as vibration. The forms shall be waterproof and leak free. Dimensional tolerances shall meet specified requirements. A manufacturer approved release agent shall be used to facilitate stripping of the forms.

9.7.2 Refractory shall be mixed using the procedures, equipment, and water levels demonstrated in the material and applicator qualification tests. For casting and vibration casting, the mixer capacity shall be sufficient to facilitate placement with no more than 10 minutes delay between successive mix batches. For pump casting, mixer capacity shall be sufficient to allow for continuous pump operation without stops and starts to wait for material.

9.7.3 For vibration casting, two or more vibrators shall be mounted externally on the equipment or component to be lined. Vibrators shall be attached by strapping or a similar method; do not attach vibrators to nozzles, welded lugs, or other components. Vibrators shall have adequate force to move and consolidate the material being vibrated. Each vibrator shall be independently controlled to focus the vibration and prevent segregation due to over vibration. Vibrator selection, number, placement, and method of attachment shall be included in the installation procedure and approved by the owner.

9.7.4 For pouring or pump casting, submersion vibrators or rodding may be used to aid refractory flow and filling of the formed enclosure. Self-leveling castables shall not be vibrated.

9.8 Thin-layer Abrasion (Erosion) Resistant Linings

9.8.1 General

9.8.1.1 Chemical-setting, erosion-resistant refractories shall be mixed in a planetary mixer, such as those manufactured by Hobart. The mixer shall have stainless steel paddles and bowls. Tools shall also be stainless steel. Mixing shall be in strict accordance with the manufacturer's recommended procedures, using water – and/or other required liquid – levels determined during material and applicator qualification testing.

9.8.1.2 Refractory shall be compacted using a handheld reciprocating pneumatic rammer, or a rubber mallet, or wood block, or a combination thereof as demonstrated in the applicator qualification tests. During placement, refractory shall be fully compacted in and around the anchor supports and, for hexalt anchoring systems, into the previously installed lining before it begins to set up, to form a homogeneous lining structure free of voids and laminations. The initially placed thickness shall be greater than the desired thickness. The full depth of the refractory lining shall be placed in one continuous operation (e.g. the initial placement shall completely fill the hexmetal biscuit).

9.8.1.3 After refractory consolidation, overfill shall be removed flush with the tops of the hexmetal or hexalt anchors using a trowel or curry comb and discarded. The surface shall be tamped, as necessary, to remove imperfections such as surface tearing and pull away defects.

9.8.1.4 Water slicking of the lining surface is not permitted. Water used to clean tools shall be dried off prior to use of the tools on the refractory.

9.8.2 Plastic Refractories

9.8.2.1 Plastic refractories shall be installed at the manufacturer's recommended consistency. Field water addition or reconditioning is not permitted. Reconditioning shall be performed by the manufacturer under controlled plant conditions, and the reconditioned material shall be fully requalified in accordance with 8.2.

9.8.2.2 Plastic refractory shall be removed from the container/plastic wrap only when ready for application. Contents shall be placed on a clean surface for cutting and/or separating precut slices. The work surface shall be cleaned and maintained to avoid contaminating fresh refractory with dried-out material from previous cutting or separating operations.

9.8.2.3 Under no circumstances shall dry or crumbly material be installed.

9.8.2.4 Installation shall be in accordance with 9.8.1.2, 9.8.1.3, and 9.8.1.4.

9.9 Thick-layer Plastic Linings

9.9.1 Plastic refractories shall be installed at the manufactured consistency. Field water addition or reconditioning is not permitted. Reconditioning shall be performed by the manufacturer under controlled plant conditions, and the reconditioned material shall be fully requalified in accordance with 8.2.

9.9.2 Plastic refractory shall be removed from the container/plastic wrap only when ready for application. Contents shall be placed on a clean surface for cutting or separating precut slices or both. The work surface shall be cleaned and maintained to avoid contaminating fresh refractory with dried-out material from previous cutting or separating operations.

9.9.3 Under no circumstances shall dry or crumbly material be installed.

9.9.4 Refractory shall be ram packed in successive layers of undensified slabs laid perpendicular to the hot face with broken joints using a reciprocating pneumatic rammer. Each slab shall be fully consolidated into a uniform mass with the previously placed slab, compacting the material in and around the anchor supports to form a homogeneous lining structure free of voids and laminations. The initially placed thickness shall be greater than the desired lining thickness.

9.9.5 After refractory consolidation, the lining shall be trimmed to the desired lining thickness using a trowel or currycomb. Cutback material may be reused if the material has not been contaminated and if workability characteristics are not diminished. The trimmed surface shall be tamped, as necessary, to remove imperfections such as surface tearing and pull away defects.

9.9.6 Water slicking of the lining surface is not permitted. Water used to clean tools shall be dried off prior to use of the tools on the refractory.

9.9.7 After plastic lining has been trimmed to proper thickness venting shall be performed with a pointed rod.

9.9.8 Shrinkage cracking shall be accommodated using cut or formed control joints at a spacing recommended by the manufacturer.

9.10 Metal Fiber Reinforcement

9.10.1 Metal fiber reinforcement shall be used only when specified by the owner. Fiber additions shall be uniformly dispersed in the castable, without agglomeration.

9.10.2 Details of fiber dimensions, concentration, and metallurgy shall be specified in the documentation in accordance with 5.1.1 c).

9.10.3 If metal fiber is added during installation mixing the procedure shall be as follows:

a) load castable into mixer and premix;

b) add prewet or mixing water;

c) using a dispersing device, such as $^1/_2$ in. (13 mm) hardware mesh, sieve the fibers into the castable with the mixer operating.

9.11 Dryout Fibers

Dryout fibers to facilitate moisture removal from refractory linings during the dry out shall be used, unless otherwise directed by the owner. Fiber addition shall be performed during manufacture of the castable or plastic refractory.

9.12 Interruption of Application

9.12.1 If application of hydraulic bonded or chemical-setting refractory is interrupted, the refractory lining shall immediately be cut back to the shell between anchors with a steel trowel.

9.12.2 Cutback shall be made at a right angle to the shell or in accordance with other construction joint configuration as indicated on detail drawings and at a location where the full refractory thickness has already been applied.

9.12.3 Discard all material beyond the cut and material left in the gun, hose, containers, or mixer or a combination thereof for more than 20 minutes.

9.12.4 Plate surfaces shall be cleaned of all refractory lining materials.

9.12.5 Dislodged anchor leg coverings shall be replaced.

9.12.6 During the period of interruption in application, curing of the refractory lining already applied shall be in accordance with 9.13.

9.12.7 If installation is halted for the day, all openings in the item being lined shall be covered, closed, and sealed.

9.12.8 Immediately before resuming refractory application, the exposed surface of the refractory lining to which a bond must be made shall be cleaned of all loose refractory material, roughened, and thoroughly wetted with water or coated with a manufacturer approved membrane curing compound [see 9.13.3 a)]. Alternatively, a bonding agent such as a weak phosphoric acid solution or phosphate-bonded mortar may be used.

9.12.9 If application of heat-setting plastic refractory is interrupted for less than 8 h, premoistened cloth or burlap shall be used to keep the mating surface hydrated until work can progress.

9.13 Curing

9.13.1 Curing shall be in accordance with the manufacturer's recommendation, or for a minimum of 24 h at 16 °C to 32 °C (60 °F to 90 °F), before moving the piece, stripping the forms, or heating.

9.13.2 For chemical-setting refractories, the lining surface shall remain uncovered and free from contact with moisture during the curing period.

9.13.3 For hydraulic bonded castables, sealing or excess moisture or a combination thereof shall be provided in accordance with one of the following methods.

a) Apply a manufacturer approved membrane-type (nonreactive) curing compound to all exposed surfaces before the surface is dry to the touch. No part of the lining shall be allowed to air dry more than 1 h prior to the application of curing compound. The curing compound shall be nonflammable, nontoxic, and contain pigmentation that allows for complete visual inspection of coverage. The compound shall burn off at a temperature of 65 °C to 95 °C (150 °F to 200 °F).

b) Wetting the exposed surfaces with a fine mist of water spray within 1 h of installation and then at approximately 2-h intervals, such that all surfaces shall be maintained wet to the touch throughout the curing period. Ensure that refractory components are not washed out or dislodged.

c) Covering the exposed surfaces with polyethylene or a damp cloth within 1 h of installation. The covering shall be in contact with, but not sticking to, the refractory surface. If a damp cloth is used, it shall be maintained damp throughout the curing period.

d) No coverage is required on formed surfaces if the forms are retained for the full 24-h curing period.

9.13.4 For climates where it is anticipated that freeze/thaw conditions will occur and a delay is expected after curing, refractories may be allowed to freeze, excluding plastic refractories. However, the following steps shall be taken.

a) All openings shall be sealed to prevent accumulation of water on the lining

b) The full thickness of the lining shall be raised to at least 32 °F (0 °C), with a recommendation to at least 60 °F (16 °C) prior to dryout.

9.13.5 Plastic refractories do not require air curing. They shall be kept dry and protected from freezing conditions prior to the dryout.

9.13.6 Manufacturers recommendations shall be used to properly protect phosphate-bonded plastics that will be allowed to remain unfired to bond maturity for prolonged periods of time after placement.

9.14 Repairs

9.14.1 General

9.14.1.1 Areas deemed defective [see 5.1.2 d)] shall be repaired.

9.14.1.2 Sections of the lining below the minimum thickness shall be cut out entirely and replaced.

9.14.1.3 Additional material shall not be placed over previously applied material to build up to the required thickness.

9.14.1.4 In a multilayer lining, the hot face shall be removed without removing or disturbing the backup lining.

9.14.1.5 The refractory contractor shall prepare records identifying and locating all repaired areas and field joints (e.g. a map). The record shall include the reason for all repairs and the means of repair along with the refractory used.

NOTE If the refractory used for repair differs from the refractory of the adjacent lining, the installation procedure, curing, and dryout requirements also may differ.

9.14.2 Repair Procedures

9.14.2.1 General

9.14.2.1.1 All proposed materials and methods of repair shall be approved by the owner before the repair is made.

9.14.2.1.2 Immediately before placement of the new refractory, the sound refractory material adjacent to the repair area shall be cleaned of debris, roughened, and completely prewetted with potable water (enough to dampen thoroughly, but not run down or puddle), membrane curing compound, phosphate-bonded mortar, or a weak phosphoric acid.

9.14.2.1.3 Anchors and shell shall be cleaned of refractory or other debris and new anchor leg coverings installed on the anchors where applicable.

9.14.2.1.4 If the anchors or the attachment weld are damaged, the anchor shall be replaced in accordance with the original installation.

9.14.2.2 Monolithic Lining

9.14.2.2.1 With the exception of surface bubble defects (see 9.14.2.2.3) unacceptable refractory lining shall be cut at a right angle to the shell and laterally to the acceptable lining and removed. The shell shall not be damaged.

9.14.2.2.2 Areas removed for repair shall have at least one anchor completely exposed. If not, a new anchor shall be installed. The area to be removed for repair shall be sufficient to expose three noncontinuous anchors.

9.14.2.2.3 When repair of surface bubble defects is required, they shall be repaired by packing with a phosphate-bonded castable. Metal fibers shall not be used in this type of repair. The surface shall be screeding flush with the adjacent refractory surface.

9.14.2.3 Thin Erosion-resistant Lining

9.14.2.3.1 Defective refractory in hexmetal lining shall require complete removal and replacement of all affected biscuits.

9.14.2.3.2 Repair of defective areas of hexalt lining shall comply with 9.14.2.2.

10 Dryout

10.1 Dryout Procedure

10.1.1 The refractory contractor shall submit a dryout procedure to the owner for approval. The dryout procedure shall accommodate the refractory manufacturer's dryout requirements and the requirements of this standard. In the absence of refractory manufacturer requirements, the minimum dryout schedules in accordance with Table 6 shall apply. The dryout procedure shall include heat-up/cooldown rates for all control temperature indicators, location of and maximum temperature difference between temperature indicators, ensure adequate flow of heated air over the entire refractory surface, and include guidelines in case of interruptions in the schedule.

10.1.2 The dryout plan for complex vessels or vessel/duct/pipe systems that involve more than one burner, more than two flue gas exit points, or eight or more thermocouples shall be reviewed by an engineer experienced in dryout of complex systems.

10.1.3 Initial heating of refractory linings shall be performed by temporary equipment such as portable burners or electric heating elements. When temporary heating devices are not practical, process heating devices are an acceptable alternative. Flame impingement and radiant heating shall be avoided.

10.1.4 Cold wall refractory lined components shall be dried out by heating from the refractory hot face only, in accordance with the approved dryout procedures.

10.1.5 Hot wall refractory lined components shall be dried out by application of heat from either the inside or outside surface or by placement within an oven and heating from both sides, in accordance with the approved dryout procedures.

10.1.6 Heating shall be controlled using temporary thermocouples to monitor gas temperatures throughout the lined area(s). Thermocouples shall be located within 13 mm ($^1/_2$ in.) of the refractory surface. Place thermocouples to detect any stagnant area(s) and the hottest and coldest area(s). When temporary thermocouples are not practical (e.g. dryout performed as part of startup), process thermocouples may be an acceptable alternative if they are capable of low temperature accuracy and located in an appropriate area.

10.1.7 Heating rates shall be monitored by the hottest thermocouples. The hold temperatures and durations shall be achieved to at least 90 % of the dryout plan at all thermocouples, including those at gas exits of the installed refractory. Thermocouples shall also be provided to protect design temperature limits of the unit or components, or both as defined in 5.1.1 d).

10.1.8 When cooldown is included in the dryout work scope, cooling rates shall not exceed 56 °C/h (100 °F/h).

10.2 Dryout Schedule

10.2.1 General

This section describes provisions for determining safe dryout schedules for conventional cement bonded castables. Dryout is the initial heating of castable refractory linings to remove retained water from within the refractory without adversely affecting its structure or mechanical properties. The procedure shall be efficient and provide execution with minimal impact on the service factor of the process unit in which the refractory is installed.

10.2.2 Dryout Index

10.2.2.1 Dryout is described in schedules or procedures by heating rates, target temperatures, and hold times. For the purpose of this standard, these requirements are based upon gas temperatures at the surface of the lining that will see the greatest heat during service. Heat sources and monitoring of gas temperatures affecting the dryout shall be in accordance with 10.1.

10.2.2.2 Table 6 describes typical dryout schedules for conventional castable refractories with a density of 2240 kg/m^3 (140 lb/ft^3) or less.

Table 6—Dryout of Conventional Castable Refractories [a, b, c]

Heating Stage	Refractory Density		
	Less than 1200 kg/m^3 (75 lb/ft^3)	1200 kg/m^3 to 1600 kg/m^3 (75 lb/ft^3 to 100 lb/ft^3)	1601 kg/m^3 to 2240 kg/m^3 [a] (101 lb/ft^3 to 140 lb/ft^3)
Initial temperature to first hold e	Heat at 56 °C/h (100 °F/h) Hold at120 °C to 150 °C (250 °F to 300 °F) Hold 1 h/25 mm (1 h/in.) of refractory thickness	Heat at 42 °C/h (75 °F/h) Hold at 120 °C to 150 °C (250 °F to 300 °F) Hold 1 h/25 mm (1 h/in.) of refractory thickness	Heat at 28 °C/h (50 °F/h) Hold at 120 °C to 150 °C (250 °F to 300 °F) Hold 1 h/25 mm (1 h/in.) of refractory thickness
Ramp to next hold	Heat at 56 °C/h (100 °F/h) Hold at 315 °C to 370 °C (600 °F to 700 °F) Hold 1 h/25 mm (1 h/in.) of refractory thickness	Heat at 42 °C/h (75 °F/h) Hold at 315 °C to 370 °C (600 °F to 700 °F) Hold 1 h/25 mm (1 h/in.) of refractory thickness	Heat at 28 °C/h (50 °F/h) Hold at 315 °C to 370 °C (600 °F to 700 °F) Hold 1 h/25 mm (1 h/in.) of refractory thickness
Ramp to next hold	Heat at 56 °C/h (100 °F/h) to operating temperature	Heat at 42 °C/h (75 °F/h) Hold at 540 °C to 565 °C (1000 °F to 1050 °F) Hold 1 h/25 mm (1 h/in.) of refractory thickness	Heat at 28 °C/h (50 °F/h) Hold at 540 °C to 565 °C (1000 °F to 1050 °F) Hold 1 h/25 mm (1 h/in.) of refractory thickness
Ramp to next hold		Heat at 42 °C/h (75 °F/h) to operating temperature	Heat at 42 °C/h (75 °F/h) to operating temperature
Dryout Index [c]	23 h	31 h	40 h

NOTE See 10.1.1. These rates only apply when the curing temperature is between 10 °C (50 °F) and 32 °C (90 °F). Conventional castable refractories having a "normal" cement content, i.e. greater than 2.5 % CaO.

[a] For refractories with densities higher than 2240 kg/m^3 (140 lb/ft^3), consult manufacturer.

[b] Initial temperature does not exceed 94 °C (200 °F).

[c] The Dryout Index is based on a refractory thickness of 127 mm (5 in.), an operating temperature of 705 °C (1300 °F), and heating from the refractory side only. It is further based on standard accepted dry out practice in a well exhausted configuration.

10.2.2.3 Refractory products with dryout requirements differing from those defined by Table 6 shall be rated by the Dryout Index. To provide a comparative basis, the Dryout Index shall be defined as the duration time in hours that is required for initial heating from 10 °C to 705 °C (50 °F to 1300 °F), including recommended heating rates and holding times. The index shall be based on single-layer linings 127 mm (5 in.) thick, applied and dried out in accordance with this standard.

10.2.2.4 Details of actual heating rates and holding times within the overall duration defined by the Dryout Index shall be determined prior to installation work in accordance with 10.1.1. Modifications to account for greater thickness or dual-layer designs or both shall be resolved at that time. When drying out a unit or vessel that has multiple refractories, schedules shall be based on the refractory or lining system that has the longest duration requirement for the maximum thickness at each stage of the dryout.

Annex A
(informative)

Glossary

This annex provides supplemental information related to refractories and refractory installations.

NOTE Additional definitions are contained in Section 3.

abrasion—Removal of the surface of a solid by rubbing, scouring, or friction action of other solids, including fluid solids.

abrasion of refractories—Wearing away of the surfaces of refractory bodies in service by the scouring action of moving solids.

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

NOTE For refractory materials, abrasion resistance is measured in the form of eroded volume loss in accordance with ASTM C704.

acceptance quality limit—The acceptable limit of defect samples in a lot or batch, expressed as a percentage or ratio.

acid refractories—Refractories containing a substantial amount of silica, which may react with basic refractories, basic slags, or basic fluxes at high temperature. Acid refractories tend to resist acid slags better than basic slags.

acid-proof brick—Brick having low porosity and permeability, and high resistance to chemical attack or penetration by most commercial acids and some corrosive chemicals.

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

air pressure gauges—Control devices used in an ASTM C704/C704M test to measure and allow for better control of the pressure of the motive air used to accelerate the blasting particles to create the test conditions.

air set mortar—Mortar that requires only air to gain a significant green strength, which is suitable for laying refractory brick and bonding them strongly prior to heating at furnace temperatures.

air-ramming/pneumatic ramming—A method of forming refractory shapes, furnace hearths, or other furnace parts by means of pneumatic hammers.

air-setting refractories—Compositions of refractory materials that develop a strong bond at ambient temperatures by virtue of chemical reactions within the binder. The bond maintains strength up to a point where ceramic bonding takes effect.

NOTE These refractories include various cement and phosphate-bonded castables.

alkali hydrolysis (refractory)—A potentially destructive, naturally occurring reaction between unfired hydraulic setting refractory concrete, carbon dioxide, alkaline compounds, and water.

alkaline earth silicate fiber (AES)—Manmade vitreous fiber (MMVF) composed of at least 18 % alkali earth oxides developed to meet the fiber exemption requirements spelled out in 97/69/EC of the Dangerous Substances Initiative in the European Union (EU). These fibers are exonerated from the EU carcinogen classification based on their low bio- persistence. They also may be known as bio-fiber, bio-soluble, or low bio-persistence fiber.

alkali earth oxides—The oxides of alkali earth metals. Magnesium oxide and calcium oxide are the most used in refractories.

alumina—An oxide of aluminum, commonly described as Al_2O_3. Has a melting point of 3720 °F (2050 °C). In the presence of SiO_2 and H_2O will form various clay compositions. In the presence of H_2O will form various aluminum oxide hydroxide mineral compositions including bauxite and gibbsite.

alumina-silica refractories—Refractories mainly consisting essentially of alumina (Al_2O_3) and silica (SiO_2), such as high-alumina, mullite, fireclay, and semi-acidic refractories.

alumina-zirconia-silica refractories (AZS)—Refractories containing alumina-zirconia-silica as a fusion cast, sintered body or as an aggregate used in erosion-resistant castables, precast special shapes, and bricks.

amorphous—Solid bodies lacking crystalline structure or definite molecular arrangement; without definite external form.

anchor—A metallic or ceramic device, embedded in the refractory, which holds the refractory or insulation in place.

anchor shadowing—when a defect/void occurs immediately behind the leg(s) of anchors(s) during pneumatic gunning or shotcreting installation due to the inability of material to be flow all around the anchor leg, correct manipulation of the nozzle around the anchor is required to prevent this defect.

anchor system—comprises of the anchors, attachment welds, clips, support hardware and other components which retain the refractory in place.

apparent porosity (ASTM C20)—The relationship of the volume of the open pores in a refractory specimen to its exterior volume, expressed in percentage.

applicator qualification testing—Preinstallation simulation of production work that is visually inspected, sampled, and tested to verify that application equipment and personnel are capable of meeting specified quality standards.

arch—For fired heaters, a flat or sloped portion of the radiant section opposite the floor; A section of refractory, normally brickwork, which provides self-spanning support across a vessel or vessel opening.

arch (brick)—A standard brick shape whose thickness tapers along its width. Can also be known as a side arch.

arch (flat)—In furnace construction, a flat structure spanning an opening and supported by abutments at its extremities; the arch is formed on a few special tapered bricks, and the brick assembly is held in place by their keying action. Also called a jack arch.

arch (sprung)—In furnace construction, a bowed or curved structure that is supported by abutments at the sides or ends only and that usually spans an opening or space between two walls.

arch (suspended)—A furnace roof consisting of brick shapes suspended from overhead supporting members.

ash—The non-combustible residue that remains after burning a fuel or other combustible material. This residue is a foulant that can foul the exterior of heater tubes.

NOTE Ash may be corrosive to steel or the refractory lining, depending on the composition and metals content of the fuel.

as-installed testing—Testing of refractory materials sampled from the installation to confirm that they meet specified physical property standards.

ASTM C704 testing machine—ASTM-specified machine where a refractory sample is eroded by a controlled grit blasting using No. 36 silicon carbide (SiC) grit at a specified feed rate, duration, and calibrated air pressure, using the specified machined block nozzle at 8 in. (203 mm) from nozzle tip to sample surface.

attrition—Loss of refractory material by friction; abrasion.

average heat flux density—Heat absorbed divided by the exposed heating surface of the coil section.

NOTE Average flux density for an extended-surface tube is indicated on a bare surface basis with extension ratio noted.

backup layer—Refractory layer behind the hot-face layer.

basic refractories—Refractories whose major constituent is lime, magnesia, or both; that may react chemically with acid refractories, acid slags, or acid fluxes at a high temperature.

batch—Quantity of monolithic castable refractory produced by a single blending or mixing operation either during production or field mixing.

batten strip—A single or folded layer of fiber blanket placed and compressed between courses of fiber modules.

bauxite—A mineral that contains at least 65% alumina (Al_2O_3) on a calcined basis, which processed into sized refractory aggregates and commonly used in refractory products. Bauxites and their component minerals boehmite, diaspore, and gibbsite (hydrated aluminas) are common occurring natural minerals.

bedding—Layer of refractory that serves the purpose of leveling a surface before placing additional refractories.

bend test (of anchors)—Inspection technique where metal anchors (e.g. anchor legs or tines) are physically bent at the weld point to verify the weld integrity to the shell or casing.

binder—A substance added to a granular material to give it workability and green or dry strength.

biscuit—A refractory piece formed within an area completely enclosed by the anchoring system.

EXAMPLE A hexmetal or flexmesh cell.

NOTE The biscuit has the shape of the enclosed area and the thickness of the lining. Biscuits are normally independent of each other except for limited connections through perforations in the anchoring system.

bloating—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.

block insulation—Lightweight rigid block used as a backup layer because of its high insulating properties and its limited temperature resistance.

breeching—Heater section where flue gases are collected after the last convection coil for transmission to the stack or the outlet ductwork.

brick ledge—A support for a vertical element of refractory. Also known as a brick support or wall seat.

bridgewall (gravity wall)—Wall that separates two adjacent furnace zones. (usually fabricated with refractory brick)

British thermal unit (BTU)—The amount of heat required to raise the temperature of one pound of water one-degree Fahrenheit at standard barometric pressure and at a standard temperature.

bulk density—The ratio of weight (or mass) to volume in a specific condition.

burn—The degree of heat treatment to which refractory bricks are subjected in the firing process; also, the degree to which desired physical and chemical changes have been developed in the firing of a refractory material.

burner—Device that introduces fuel and air/Oxygen into a heater at the desired velocities, turbulence, and concentration to establish and maintain proper ignition and combustion.

NOTE Burners are classified by the type of fuel fired, such as oil, gas, or a combination of gas and oil, which may be designated as “dual fuel” or “combination.”

burner tile/brick/block—High temperature refractory that surrounds the burner. It forms the burner’s acid gas; fuel gas or air flow opening and helps stabilize the flame and protects the burner components. Also referred to as a muffle block or quarl.

burning (firing) of refractories—The final heat treatment in a kiln to which refractory brick are subjected in the process of manufacture, for the purpose of developing bond and other necessary physical and chemical properties. Burning usually occurs above 1000 °C (1830 °F).

carbon deposition—The deposition of carbon, which may be the result of the decomposition of carbon monoxide gas into carbon dioxide and carbon within a critical temperature range or may be directly from carbon within the process environment. When deposited within the pores of a refractory, the carbon may build up such pressure that it destroys the bond and causes the refractory to disintegrate.

carbon monoxide (CO) resistance—Refractory materials resistant to attack in an atmosphere of carbon monoxide (CO). The CO resistance is determined according to ASTM C288.

casing—Metal plate used to enclose the fired heater.

castable (refractory)—A combination of refractory grain (aggregate) and suitable bonding agent that, after the addition of a proper liquid, is installed into place to form a monolithic shape or structure that becomes rigid because of thermal or chemical action.

casting—Castable installation technique whereby refractory is mixed with an appropriate liquid and placed in a formed enclosure with the aid of vibration that causes the refractory to become “fluid-like” and thereby flow and consolidate to the shape of the formed enclosure.

catalyst—A substance that enables or accelerates a chemical reaction, without itself being chemically altered or consumed by the reaction.

C-clip (anchors)—A C-shaped metallic anchor used to attach ceramic anchors to the casing or shell of a process unit or fired heater.

cement (refractory)—A powdery substance that is mixed with water and will harden by itself hydraulically and generally bind larger aggregates into a refractory system. Refractory cements are higher temperature materials and generally are based on calcium aluminates but can include other materials such as hydrated alumina.

ceramic anchor—Fired refractory device that retains the refractory lining in place. Often used when temperatures exceed the useful limit of metal anchors.

ceramic fiber—Fibrous refractory insulation that can be in the form of refractory ceramic fiber or man-made vitreous fiber (MMVF).

NOTE Applicable forms include bulk, blanket, board, modules, paper, coatings, pumpables, and vacuum-formed shapes.

ceramics—“Products made of inorganic materials by first shaping them and later hardening them by fire”.—F. Singer.

"The art and science of making and using solid articles which have as their essential component, and are composed in large part of, inorganic, non-metallic materials. This includes materials such as pottery, porcelain, refractories, cements, structural clay products, abrasives, and glass but also nonmetallic magnetic materials, ferroelectrics, and a variety of other products".—W. Kingery.

ceramic bond—Designates the condition caused by phase reaction of the components of a ceramic body during firing. It is usually achieved by sintering.

checker wall—A fixed or free-standing wall of either cylindrical, hexagonal, or rectangular brick shapes made from high alumina refractory material, stacked, or mortared installed between the main burner and steam generator inlet tubesheet intended to disrupt gas flow for improvement in process gas mixing.

NOTE 1 The checker wall is also intended to protect the steam generator tubesheet from direct heat radiation.

NOTE 2 Also commonly referred to as a baffle wall.

chemically-bonded brick—Brick manufactured by processes in which mechanical strength is imparted by chemical bonding agents instead of by firing.

chemical-setting or chemical bond—Refractory developing a strong bond by chemical reaction.

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

choke ring—A structure in the thermal reactor, made from refractory materials, which locally reduces the diameter of the thermal reactor to promote mixing. Can also be called an orifice ring.

classification temperature (of man-made vitreous fiber)—The temperature at which man-made vitreous fiber has a linear shrinkage (measured as per ASTM C892) not exceeding 4 % (for blanket, paper) and 2 % (for vacuum form, boards) after 24-h heat treatment and in a neutral (not oxidizing or reducing) atmosphere.

NOTE 1 In the field, the continuous application temperature is typically 167 °C (300 °F) below the classification temperature. Above that temperature, increased crystallization can occur, and shrinkage increases. Polycrystalline PCW fiber can generally be used up to classification temperature.

NOTE 2 Fiber materials are available in three types (classification temperature):

— Alkaline Earth Silicate (AES) Fiber up to 1450 °C (2642 °F)

— Refractory Ceramic (RCF) Fiber up to 1426 °C (2600 °F)

— Polycrystalline Wool (PCW) Fiber > 1426 °C (2600 °F)

clay—Clay minerals are fine particle size hydrous aluminum silicates which develop plasticity when mixed with water. They are used in the forming of refractories due to their plastic nature and sintering characteristics over wide temperature ranges. (Also see "fireclay".)

clinch—In Hexmetal, the location where the two ribbons are joined in the formation of a sheet.

clinker—A partially fused product or by product of a high temperature process such as cement from a kiln or slag from a fired boiler.

coke impregnation—Deposition of coke within a refractory lining.

coke jacking—Separation of hexmetal or hexalt anchors from the steel substrate caused by coke buildup between the refractory and the steel substrate.

coke ratcheting—Permanent deformation of steel substrate caused by coke buildup between the biscuits and surrounding anchors.

cold crushing strength (CCS)—A measure of a refractory’s ability to resist failure under a compressive load as determined at room temperature after drying or firing, or both.

NOTE CCS is calculated by dividing the total compressive load at failure by the specimen cross-sectional area. (ASTM C133)

cold face—The surface of a refractory lining against the metal casing surface, not directly exposed to the heat source.

cold joint (refractory)—A joint formed in an otherwise monolithic refractory due to design considerations or from work stoppage during refractory installation.

cold wall refractory design—An internal insulating refractory lining system which results in a temperature gradient from the hot internal surface to cold wall temperature less than 500 °F (260 °C).

cold-face temperature (refractory)—Temperature at the casing calculated using the thermal conductivity of the lining and hot-face temperature.

colloidal—A substance that consists of particles dispersed throughout another substance, liquid, or gas and which are too small for resolution with an ordinary light microscope.

comminution—Reduction of materials to fine particles.

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

compliance datasheet—A list of mechanical and chemical properties for a specified refractory material that are warranted by the manufacturer to be met when the product is tested by the listed procedure in accordance with the given standard.

congruent melting—The change of a substance, when heated from a solid to a liquid of the same composition (e.g. melting of ice to water).

construction joint (refractory)—A joint formed in a lining to mechanically decouple refractory components.

contractor—The party or parties responsible for installing refractory in the owner's equipment.

convection—The transfer of thermal energy by the forced or natural movement of a liquid or gas.

convection section (of furnace)—The section of a heat exchanger furnace downstream of the radiant section that is closely packed with tubes for optimum convective heat transfer.

conventional refractories—Castable refractories containing greater than 2.5 % CaO.

conversion (of high alumina cement)—The transformation of the hexagonal metastable hydrates (CAH_{10} or C_2AH_8) to the stable, cubic hydrate (C_3AH_6). The cubic hydrate occupies less volume than the hexagonal hydrates, and 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.

corrosion—Disintegration or deterioration by chemical attack, including electrolysis.

corrosion of refractories—Destruction of refractory surfaces by the chemical action of external agencies.

corundum—A natural or synthetic mineral theoretically consisting solely of alumina (Al_2O_3). Specific gravity 4.00 to 4.02. Melting point 3720 °F (2050 °C). Hardness 8.8 Mohs.

course—A horizontal layer or row of brick in a structure.

creep—Time-dependent deformation of a material due to sustained load, at a temperature below its melting point.

cristobalite—A mineral form of silica; stable from 2678 °F (1470 °C) to the melting point at 3133 °F (1723 °C). Specific gravity is 2.32. Cristobalite is an important constituent of silica brick.

crown—A furnace roof, especially one which is dome-shaped, the highest point of an arch.

crystal—A chemically homogenous solid body having a definite internal molecular structure, and if developed under favorable conditions, having a characteristic external form, bounded by plane surfaces.

crystalline—Product having the structure or composed of crystals.

crystallite—A small mineral form that marks the beginning of crystallization. It is formed when a melt solidifies. Consequentially, they are usually not surrounded or limited by smooth surfaces.

curing—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 from 500 °F to 700 °F (260 °C to 370 °C) is required to form the bond.

cutback—Unset refractory trimmed from the lining surface via a cutting action to give the final lining thickness dimension, usually in a gunning installation.

cyclones (of FCCU or fluid coking unit)—Components, usually internal, used for inertial (momentum) separation of particulate solids from flue or product gas.

deflection/target wall (refractory)—A refractory wall used to redirect flames or shield portions of a fired heater from gas or radiant heat.

dense high alumina firebrick—Firebrick that contains 45 % to 99 % alumina.

density—The mass of a unit volume of a substance, usually expressed in kilograms per cubic meter (kg/m^3), grams per cubic centimeter (gm/cm^3), or pounds per cubic foot (lb/ft^3).

design temperature (refractory)—The maximum continuous use temperature of the hot face or interface, plus a design margin of 165 °C (300 °F).

NOTE The refractory design temperature is used to select refractory material.

devitrification—A change in formation from a glassy to a crystalline condition.

dew point—The temperature (varying according to pressure and water content) below which liquid droplets begin to condense from an atmosphere.

dry gunning—Pneumatic placement of gunning mixes where water is added at the nozzle.

drying—The removal of free moisture from a material.

dryout—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.

dual layer—Refractory construction comprised of two refractory materials wherein each material performs a separate function (e.g. a dense monolithic over insulating monolithic).

dual-layer lining—As compared to a "one-shot lining," a refractory lining consisting of two different types of monoliths. Typically, this would consist of a low-density insulating refractory behind a stronger, medium-, or high-density refractory.

dusting—Conversion of a refractory material either wholly or in part into fine powder or dust. Dusting usually results from:

a) chemical reactions such as hydration; or

b) from mineral inversion accompanied by large and abrupt change in volume, such as the inversion of beta to gamma dicalcium silicate upon cooling.

equipment manufacturer (EM)—Original equipment manufacturer or equipment supplier with overall responsibility for design, fabrication, and delivery of a finished product.

emissivity, thermal—The capacity of a material for radiating heat; commonly expressed as a fraction or percentage of the ideal "black body" radiation of heat, which is the maximum theoretically possible.

endothermic—Reaction where energy is absorbed. The opposite of Exothermic.

erosion—Progressive disintegration of a solid by the abrasion or cavitation action of gases, liquids or solids in motion.

erosion of refractories—Mechanical wearing away of the surfaces of refractory bodies in service by the washing action of moving liquids or gasses, such as molten slags or high-velocity particles.

NOTE In the case of moving solid particles, this is more correctly termed "abrasion."

erosion resistance (as it applies to ASTM C704/C704M test results)—Volume of refractory loss, measured in cubic centimeters, after abrading the surface of a test specimen with 2.2 lb (1000 g) of silicon carbide (SiC) grit, in accordance with ASTM C704/C704M.

NOTE The lower the number of cubic centimeters (cm^3) lost, the higher the erosion (abrasion) resistance of the refractory.

erosion service—Refractory application in which erosion resistance is a determining feature of lining service life.

EXAMPLE Applications include transfer lines, overhead lines, cyclone linings, and deflector shields of fluid solids units.

erosion-resistant lining—Refractory lining system whose purpose is to withstand the effects of an eroding material for an extended period without significant loss of material or other damage.

execution plan—A written document prepared by the refractory contractor that is submitted to and approved by the owner before work starts detailing how the refractory contractor intends to perform the job and meet the objectives and quality standards set for the job in the owner's specifications and drawings.

eutectic point—Temperature of the lowest melting point possible in a multiple material or multiple phase system in which the compounds or phase of the original compositions have higher melting points and their solid material components do not mix with one another without gaps.

EXAMPLE SiO_2- Al_2O_3 system—One eutectic point consists between mullite and pure silica at a composition of 94.5 % SiO_2 and 5.5 % Al_2O_3 and a eutectic melting point of 1,595 °C.

expansion joint (refractory)—A non-bonded joint in a lining system with a gap designed to accommodate thermal expansion of adjoining materials; commonly packed with a temperature-resistant, compressible material, such as ceramic fiber.

explosive spalling—A sudden fragmentation of a castable, gunite or similar material that occurs as the result of a buildup of steam pressure. It is generally associated with faster firing rates than recommended and on the initial curing/firing.

exothermic—A reaction where heat energy is given off. The opposite of endothermic.

extrude—To force a plastic refractory through a die by the application of pressure.

extrusion—A process in which plastic material is forced through a die by the application of pressure.

fabricator—Company responsible for the overall construct sections of the equipment in which refractory is installed.

ferrule—A tube insert used at the tube and tubesheet area designed to limit heat transfer and protect against corrosion. Ceramics materials are used for higher temperature applications while metals can be used for lower temperature applications.

fiber component fabricator—A third-party separate from the refractory manufacturer and the refractory contractor engaged in a business of purchasing fiber and anchor materials that are fabricated into modular lining components. These components are then purchased and installed by the refractory contractor.

fiberboard—Rigidized fiber blanket manufactured and supplied in a rigid board form.

field mix—A refractory concrete mix that is designed and formulated at or near a particular job site.

firebrick—Refractory brick of any type.

fireclay—An earthy or stony mineral aggregate that has as the essential constituent hydrous silicates of aluminum with or without free silica, plastic when sufficiently pulverized and wetted, rigid when subsequently dried, and of sufficient purity and refractoriness for use in commercial refractory products.

fire-clay brick—A refractory brick manufactured substantially or entirely from fireclay.

EXAMPLE Medium duty firebrick, High Duty firebrick, Super Duty Firebrick (As defined in ASTM C27).

fired heater (furnace)—An insulated enclosure where the heat liberated by the combustion of fuels is transferred to fluids contained in tubular coils.

firing—The process of heating refractories to develop desired properties.

flash coat—A layer coat of refractory, usually gunned, which is applied over refractory that has already been applied and allowed to set up.

flexmesh—A longitudinally hinged version of mesh supplied in flexible rolls for easy access through vessel openings to the installation area and ready fit to curved surfaces. The enclosed cells are normally trapezoidal.

float glass—Glass made by allowing it to solidify on molten metal with soda-lime silicate being the most common type and used, as a calibration standard for ASTM C704/C704M requirements.

flocculating agent—A chemical additive causing rapid stiffening of a fluid refractory castable, mortar or similar material.

fluid catalytic cracking unit (FCCU)—Complex refining processing equipment consisting of reactor and regenerator vessels and interconnecting piping in which particulate catalyst is fluidized and circulated at elevated temperatures to upgrade low-value feedstock to high-value products, such as heating oil, gasoline components, and chemical feedstocks.

NOTE Also known as a “cat cracker.”

fluid coking unit—A thermal cracking process where feed is injected directly into the reactor, forming hydrocarbon products that are generally heavier than those produced by catalyst cracking and particulate coke similar in size and flow characteristics to FCCU catalysts. The unit consists of two major vessels with transfer lines circulating fluidized coke particles between the reactor [operating at 900 °F (480 °C)] and the burner [operating at 1300 °F to 1350 °F (700 °C to 730 °C)].

flux (fluxing)—A substance or mixture that promotes fusion of a solid material by chemical action.

flux load (in welding)—Addition of an aluminum tip to enhance weldability during stud-welding metallic components such as anchors.

footed anchor—Metallic anchor, usually a V-stud, which has a foot-shaped configuration at the base to aid proper orientation and welding attachment to the shell.

fractionator (of FCCU or fluid coking unit)—Vessel downstream of the reactor used to separate different product fractions.

friable—Easily reduced to a granular or powdery condition. For refractory materials this is generally due to high temperature degradation or chemical attack.

fuels fired (refractory)—The type of fuels fired in the heater. Corrosive ash and impurities in the fuel (e.g. sulfur, alkali, and heavy metals) will guide selection of the type or form of refractory and the method of construction for refractory linings.

fused silica—Silica in a fused or vitreous state produced by arc melting of sand. Castables containing fused silica aggregate have low thermal conductivity and low thermal expansion, which is useful in thermal shock applications such as seal pots. Refractories based on fused silica can also have improved acid resistance for certain applications.

fused-cast refractories—Refractories formed by electrical fusion followed by casting and annealing.

fusion—A state of fluidity or flowing, in consequence of heat; the softening of a solid body, either through heat alone or through heat and the action of a flux, to such a degree that it will no longer support its own weight but will slump or flow. Also, the union or blending of materials, such as metals, with the formation of alloys.

fusion point—The temperature at which melting takes place. Most refractory materials have no definite melting points but soften gradually over a range of temperatures.

glass—The non-crystalline part of ceramic materials that has cooled to a rigid condition without crystallizing.

grain size—As applied to ground refractory materials, the relative proportions of particles of different sizes; usually determined by separation into a series of fractions by screening.

green refractory (monolithic linings)—A newly installed refractory before it is exposed to dryout or initial heating.

green strength—Strength of ceramic bodies after curing and before drying or firing.

grog—A type of aggregate, typically crushed ceramic or brick, used as an additive to control shrinkage or impart other properties. Recycled refractory is a typical grog material.

grout—A suspension of mortar or fine-grained material in water or other liquid, of such consistency that when it is poured upon horizontal courses of brick masonry, it will flow into vertical open joints. Some grouts are made to be pressure pumped.

gun operator—Individual in a dry gun operation who controls material charging, flow rate, and air flow of the gunning machine.

gun-casting—A method of placing castables using a pneumatic gun as a conveyor of the material by reducing the velocity of the castable at the nozzle (see "gunning").

gunning—The application of monolithic refractories by means of air placement guns. (See also "dry gunning".)

gunning (dry-mix)—An application technique that uses a pneumatic means to transport a refractory material and most of the water is added by the nozzleman at the outlet nozzle.

gunning mix—A refractory mix that is designed to be installed using the gunning application.

hammer test (of refractory lining)—A subjective test of refractories in which the lining is impacted with a hammer to gauge soundness and uniformity via audible resonance.

hand packing—Castable installation technique whereby refractory is placed by packing successive handfuls of material to the desired shape. Refractory is mixed at a consistency that is stiff enough for the placed refractory to hold its shape and is wet and sticky enough so that the lining formed is structurally homogenous.

hand-shaped brick—Brick shapes made by hand with the help of tools/forms. These bricks are generally made when the shape cannot be pressed on a press or a small number are required, or both. The physical properties usually differ from those manufactured on a press.

heat curing—Process of heating used to develop bonding in refractories such as phosphate-bonded refractories. With these refractories, heat curing is concurrent with dryout but not necessarily interchangeable with use of the term, as dryout refers only to the elimination of retained water within the lining system.

heat resistant concrete/refractory concrete—Any concrete which will not disintegrate when exposed to constant or cyclical heating at any temperature below which a ceramic bond is formed.

heating contractor/dryout contractor—Contractor or subcontractor who specializes in the dryout of monolithic refractory linings.

heat-setting refractories—Compositions of ground refractory materials that require relatively high temperatures for the development of an adequate bond, commonly called the ceramic bond.

heat setting mortar—Mortar that requires heat to gain a significant strength, which is suitable for laying refractory brick. Joints are usually thin, and bricks are in compressive rings.

heat up curve—A graphical illustration of the temperature progression of how to heat up refractory linings, new and old.

heavy weight castable—Castable refractory with a density roughly greater than 150 lb/ft^3 (2400 kg/m^3).

hexalt anchors—Individual metallic anchors used as an alternative to hexmetal in thin-layer, erosion-resistant linings.

hexmetal—A metallic anchoring system constructed of metal strips, also known as ribbons, joined together to form hexagonal shaped enclosures where erosion-resistant refractory is packed after welding to the base plate steel.

NOTE Thickness is usually $^3/_4$ in. or 1 in. (19 mm or 25 mm) but can be up to 2 in. (50 mm).

hex metal rolled the "easy way"—Roll is perpendicular to the ribbons/strips. That is, the clinches become deformed to create the required diameter.

hex metal rolled the "hard way"—Hex metal sheet which has been rolled parallel to the ribbons/strips. That is, the ribbons become deformed to create the required diameter.

high duty firebrick (HDFB)—Fireclay brick which has a pyrometric cone equivalent (PCE) not lower than Cone 31 $^1/_2$ nor above 32 $^1/_2$ to 33. (ASTM C27).

high-alumina refractories—Alumina-silica refractories containing 45 % or more alumina. The materials used in their production include diaspore, bauxite, gibbsite, kyanite, sillimanite, andalusite, and fused alumina (artificial corundum).

high-temperature insulating wool—An accumulation of fibers of different lengths and diameters, produced synthetically from mineral raw materials. This group of fibers includes alkaline earth silicate (AES), refractory ceramic fiber (RCF), (et. al) as well as polycrystalline (PCW) with a classification temperature >1000 °C (1832 °F).

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

hot-face layer—In a multilayer or multicomponent lining, the refractory layer exposed to the highest temperatures.

hot-face temperature—Temperature of the refractory surface in contact with the flue gas or heated combustion air. This is the temperature used for thermal calculations for operating cold-face temperature and heat loss.

hot modulus of rupture (hot MOR)—Rupture strength of refractory materials at specific temperatures when subjected to a load. ASTM C583.

hot wall refractory design—A refractory lining system which provides low thermal insulation value, and results in a shell temperature greater than 500 °F (260 °C).

hydrate/hydration—Chemical reactions between refractory cement components and water that cause the applied lining to develop green strength.

hydraulic cement—A cement that sets and hardens by chemical interaction with water.

hydraulic-setting (bonded) refractories—Monolithic refractory materials that contain binders such as aluminate cement which impart hydraulic setting properties when mixed with water. These materials are installed by casting and are also known as castables.

hydrostatic pressure—Pressure in a resting fluid. For refractory castables that have not been set, the hydrostatic pressure is dependent on the density and height of the casting which is an important consideration for engineering forms and molds.

hydroscopic—Materials that absorb water out of gases. (i.e. absorbs water via humidity from the air)

incongruent melting—Dissociation of a compound on heating, with the formation of another compound and a liquid each having a different composition from the original compound.

independent laboratory—A refractory testing facility not affiliated with the refractory manufacturer or refractory contractor.

inspection and test plan (ITP)—a written inspection plan summarized into a checklist format that lists identifiable steps where each step requires acceptance by the refractory inspector. As the refractory contractor completes each step, a signature approval is required by the refractory inspector before continuing to the next step.

installer (refractory)—An individual of a team responsible for installing refractory products.

installer qualification testing—Pre-installation simulation of production work that is sampled and tested as well as visually inspected to verify that application equipment and personnel are capable of meeting specified quality standards of installation.

insulating castable (insulating refractory concrete)—A castable refractory with a relatively low thermal conductivity; it usually has an in-place density of less than 100 lb/ft^3 (1600 kg/m^3).

insulating firebrick—A refractory brick characterized by low thermal conductivity and low heat capacity.

interface temperature—Calculated temperature between any two adjacent layers of a multi-layer or multicomponent refractory construction.

inversion—A change in crystal form without change in chemical composition; as for example, the change from low- quartz to high-quartz, or the change from quartz to cristobalite.

iron oxide—Any of several oxides of iron such as FeO, Fe_2O_3, Fe_3O_4 in various valence stages transformed by oxidation or reduction. Iron oxides combined with silicates form low melting compounds and thus decrease the refractoriness of the materials.

isomorphous mixture—A type of solid solution, in which mineral compounds of analogous chemical composition and closely related crystal habit crystallize together in various proportions.

joint (also construction joint)—A separation between adjacent parts of a refractory construction.

kaolin—A white-burning clay having kaolinite as its chief constituent. The specific gravity is 2.4 to 2.6. The PCE of most commercial kaolins ranges from Cone 33 to Cone 35.

kaolinite—a clay mineral, part of the group of industrial minerals with the chemical composition $Al_2Si_2O_4$. It is a layered silicate mineral, with one tetrahedral sheet of silica linked through oxygen atoms to one octahedral sheet of alumina octahedra.

key—In furnace construction or rotary kiln lining, the uppermost or the closing brick of a curved arch or ring.

key brick—A standard brick shape whose width tapers along its length.

K-factor—The thermal conductivity of a material, expressed in standard units.

lamination (defect)—A plane of weakness or defective material within a monolithic refractory lining that is approximately parallel to the hot face of the lining and permits separation into layers.

lance tabs—Metallic projections into the refractory biscuits in a hexmetal lining. The purpose is to provide mechanical anchorage to the refractory and prevent the biscuit from falling out of the hex. The tabs are punched from the metal strips making up the hexmetal.

lightweight refractory castables—See insulating refractory.

load subsidence—A refractory's load-bearing response as determined by specimen dimensional changes under a compressive load at high temperature, in accordance with ASTM C16.

loss on ignition—As applied to chemical analyses, the loss in weight which results from heating a sample of material to a high temperature, after preliminary drying at a temperature just above the boiling point of water. The loss in weight upon drying is called free moisture; that which occurs above the boiling point, loss on ignition.

low bio-persistence (refractory)—Materials having solubility in body fluids and designed to be cleared from the lungs very quickly if they are inhaled. Clearance occurs through the body's natural defense mechanisms.

low-duty fireclay brick—Fireclay brick which has a pyrometric cone equivalent (PCE) not lower than 15, nor higher than 28 to 29. (ASTM C27)

machined block nozzle—A new nozzle design for ASTM C704, including a change to stainless steel, that replaces the aluminum body grit blasting nozzle used in previous revisions and other applications outside of HPI.

NOTE This design is less prone to leaks, dimensional imprecision, and rapid wear that adversely affect the test precision, while retaining the same internal dimensions to allow comparison to historical results.

manmade vitreous fiber (MMVF)—A class of insulating materials made primarily from glass, rock, slag, clay or high purity oxides. The four general categories included as MMVF are fiberglass, mineral wool, alkali or alkaline earth silicate fiber and refractory ceramic fiber.

NOTE MMVF is also referred to as synthetic vitreous fibers (SVF).

manufacturer—In refractory, the manufacturer is the party that manufactures the refractory products or ancillaries, or both.

NOTE The refractory manufacturer has primary responsibility for material design properties, manufacturing quality control at the manufacturing site and specific procedures such as those for product mixing, installation, and start-up.

material qualification testing—Preinstallation testing of refractory materials in which production lots of refractories manufactured for a specific installation are sampled and tested to confirm that they meet specified physical property requirements.

matrix—The continuous phase in an emplaced refractory.

maximum continuous use temperature (refractory)—Maximum temperature to which a refractory may be continuously exposed without excessive shrinkage or mechanical breakdown. It is also sometimes referred to as the “recommended use limit” or “continuous-use temperature”.

NOTE This may not be the same as the “Maximum Service Temperature” quoted on the manufacturer’s product data sheet.

medium weight castables—Castable refractories with densities roughly between 100 lb/ft^3 and 150 lb/ft^3 (1600 kg/m^3 and 2400 kg/m^3). (general terminology, no industry standard).

medium-duty fireclay brick—Fireclay brick which has a pyrometric cone equivalent (PCE) not lower than Cone 29 nor higher than 31 to 31 $^1/_2$. (ASTM C27).

melting point—The temperature at which crystalline and liquid phases having the same composition coexist in equilibrium. Metals and most pure crystalline materials have sharp melting points, in other words, they change abruptly from solid to liquid at definite temperatures (see “congruent melting”). However, most refractory materials have no true melting points but melt progressively over a relatively wide range of temperatures (see “incongruent melting”).

membrane curing compound—A nonreactive coating applied to freshly installed cementitious materials that aids the hydration process by retarding moisture loss.

metal fiber reinforcement—Metal fibers dispersed in refractory to improve applied lining toughness and shrinkage crack distribution.

NOTE Metal fibers are usually made of austenitic stainless steel $^{3}/_{4}$ in. to 1 in. (19 mm to 25 mm) in length and 0.010 in. to 0.022 in. (0.3 mm to 0.6 mm) in effective diameter. They are blended into castable refractory, typically during the mixing operation, at a quantity of up to 1 weight percent to 4 weight percent (1 wt % to 4 wt %) of the refractory.

mica—A group of rock minerals having nearly perfect cleavage in one direction and consisting of thin elastic plates. The most common varieties are muscovite and biotite.

micron—The one-thousandth part of a millimeter (0.001 mm); a unit of measurement used in microscopy and to define the particle size of FCCU catalysts.

microporous—Smallest and finest distribution of pores (pore diameters are usually less than 2 mm in size).

mineral—A natural inorganic substance, which is both definite in chemical composition and physical characteristics or varies in these respects within definite natural limits. Most minerals have a definite crystalline structure; a few are amorphous.

mineralogical reactions—Chemical reactions which occur and alter the mineral composition of the refractory, which may include phase changes, bonding reactions or chemical attack, or a combination thereof of the refractory.

mineral wool—Mineral wool is any fibrous material formed by spinning or drawing molten mineral or rock materials such as slag and ceramics. Applications of mineral wool include thermal insulation (as both structural insulation and pipe insulation, though it is not as fire-resistant as high-temperature insulation wool), filtration, soundproofing, refractories, and hydroponic growth medium.

mineral wool block—Block insulation composed of mineral wool fiber and an organic binder.

module (refractory)—Construction of fibrous refractory insulation in stacked/folded blankets or monolithic form, commonly with an integrated attachment system.

modulus of elasticity (physics)—A measure of the elasticity of a solid body; the ratio of stress (force) to strain (deformation) within the elastic limit. Also see “Young’s Modulus”.

modulus of rupture (MOR)—A measure of the transverse or “cross-breaking” strength of a solid body. MOR is calculated using the total load at which the specimen failed, the span between the supports, and the dimensions of the specimen.

mono-aluminum phosphate—Refractory bonding agent in most phosphate-bonded plastic refractory, mortar, and some castables. Made by prereacting phosphoric acid with aluminum hydroxide at temperatures between 200 °F to 400 °F (90 °C to 200 °C).

monolithic lining—A refractory lining formed of material that is rammed, cast, gunned, or sintered into place.

monolithic refractories—Collective term for castable or plastic refractories used to form structures of any shape. Also referred to as “monolithics”.

monolithic refractory construction—A refractory installation utilizing monolithic refractories.

mortar (refractory)—A finely ground preparation which becomes plastic and trowelable when mixed with water and is suitable for use in laying and bonding refractory bricks together.

multicomponent lining—Refractory system consisting of two or more distinct types of refractory materials.

NOTE Examples of refractory types are castable, insulating firebrick, firebrick, block, board, and ceramic fiber.

multi-layer lining—Lining consisting of more than one distinct layer of refractory material.

needled (refractory)—A knitted structure of fibers to enhance handling and mechanical strength.

neutral refractories—Refractories that are resistant to chemical attack by either acidic and basic slags, refractories, or fluxes at high temperatures.

nine-inch (9") equivalent—A brick volume equal to that of a standard 9 in. × 4 $^{1}/_{2}$ in. × 2 $^{1}/_{2}$ in. (101.25 in.^{3}) straight brick; a unit of measurement of brick quantities in the manufacturing process and refractory industry.

nozzleman—Individual at the point of application in a gunning operation who controls material build up via maneuvering and positioning of the outlet nozzle. In a dry gunning operation, the nozzleman controls water addition via a water valve. In a wet gunning operation, the nozzleman controls flocculants and possibly air via a valve.

off-set lance—Hexmetal manufactured with lance tabs off center.

one-shot lining—A lining composed of a single layer of one type of castable refractory.

dryout fibers—Low-melting-point fibers such as polypropylene or polyethylene added to refractory to enhance moisture release by burning out during initial dryout, increasing the permeability by leaving tiny, interconnected voids.

other service—Refractory installed in locations where erosion resistance is not a required feature of the lining service as included in API Standard 936.

overlay—A layer coat of refractory, usually troweled on, which is applied to an existing lining to extend the lining life.

overspray—A cement-rich layer of refractory that deposits on exposed surfaces around a gunning installation site from airborne, wetted refractory dust generated by the gunning operation. Installation of a gunite material beyond its intended/designed thickness. This can lead to spalling/sheet spalling.

owner—The proprietor of equipment who has engaged one or more parties to install or repair refractory.

oxides—Chemical compounds formed with one or more oxygen atoms. Most common compounds in refractories are silica (SiO_2), and alumina (Al_2O_3.)

oxidizing atmosphere—An atmosphere that, at high temperature, raises the state of oxidation of exposed materials. It typically refers to an O_2 rich atmosphere.

pallet—Quantity of refractory described by amount contained on a shipping pallet.

parquet—A module lining design where module support anchoring is aligned perpendicular for each adjacent module.

peep door plugs—A castable or fibrous insert to thermally shield the peep door during operation.

peep door surrounds—A refractory frame enclosing the perimeter of the peep door.

perlite—A siliceous glassy rock composed of small spheroids, varying in size from small shot to peas; combined with water content, 3 % to 4 %. When heated to a suitable temperature, perlite expands to form a lightweight glassy material with a cellular structure. Perlite is a common light weight aggregate used in refractory materials.

permanent linear change (PLC)—A measure of a refractory's physical property that defines the change in dimension because of initial heating to a specific temperature for a specified period.

permeability—The property of porous materials that permits the passage of gases and liquids under pressure. The permeability of a body is largely dependent upon the number, size, and shape of the open connecting pores and is measured by the rate of flow of a standard fluid under definite pressure.

pH value—A scale used to determine how acidic/basic (alkaline) a solution is. The range goes from 0 to 14, with 7 being neutral. pHs of less than 7 indicates acidity, whereas a pH of greater than 7 indicates a base (alkaline).

phosphate bonded mortars—Mortar composition of ground refractory materials which includes a liquid or powdered phosphate binder.

physical properties—Properties of a refractory such as density, strength, erosion resistance, and linear change.

pinch spalling—Spalling of refractory where the hot face breaks off, but remainder of the thickness stays in place. Pinch spalling may occur due to inadequate expansion allowance or mechanical stresses, or both exerted on the refractory.

planetary mixer—A high energy mixer with a rotating paddle on a vertical orbiting mixer shaft.

plastic refractories—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.

plasticity—That property of a material that enables it to be molded into desired forms, which are retained after the pressure of molding has been released.

plenum (of FCCU or fluid coking unit)—Enclosure inside a reactor or regenerator vessel where gases are collected. Mainly found in the top head of a reactor or regenerator connected to the cyclones. Some air distributors also have a plenum that collects air prior to distribution into regen.

polycrystalline—A solid composed of a multitude of crystallites in varying size and variously oriented.

polycrystalline wool (PCW) fiber—Fibers containing greater than 70 wt % Al_2O_3 that are produced by a “sol-gel method” from aqueous spinning solutions.

NOTE Generally used at application temperatures greater than 1426 °C (2600 °F) or in critical chemical and physical application conditions.

pores—As applied to refractories, the small voids between solid particles. Pores are described as “open” if permeable to fluids; “sealed” if impermeable.

porosity (refractories)—The property related to the ratio of the volume of the pores or voids in a body to the total volume, usually expressed as a percentage. The “true porosity” is based upon the total pore-volume; the “apparent porosity” upon the open pore-volume only.

positive material identification (PMI)—Non-destructive test which detects the chemical composition of a metallic alloy.

pot life—Time span in which a refractory material can be applied before setting/hardening makes the application difficult or produces unfavorable results.

potable water—Water quality that is considered safe for human consumption.

precast—A monolithic refractory which has been formed into a specific shape, then dried/fired before delivery to the job site.

pre-wetting/pre-dampening (gunning)—A technique used with dry gunning machines where a small quantity of water is mixed into the dry refractory before charging into the gun to reduce rebound and dust and to improve wetting of the cement in the gunning operation.

product data sheet—The list of mechanical and physical properties defining each product (physical appearance, chemical composition, thermal conductivity, density, and shrinkage) with related reference codes.

production run—The quantity of refractory having the same formulation that is prepared in an uninterrupted manufacturing operation.

protective coating—Corrosion-resistant material applied to a metal surface.

EXAMPLE Coating on casing plates behind porous refractory materials to protect against sulfur in flue gases.

pump casting—Castable installation technique in which refractory material designed for this application, is mixed with an appropriate liquid and pumped through piping or hoses, or both to the installation site, where it is poured from the outlet nozzle directly into a formed enclosure.

punky (punkiness)—A refractory lining that is abnormally soft and friable. Having a friable or spongey appearance

purchaser (refractory)—Party responsible for purchasing the refractory component from the refractory manufacturer.

pyrometric cone—Elongated triagonal pyramids made from specified mixtures of ceramic materials which when heated under stated conditions, may be used for measuring time-temperature effect.

pyrometric cone equivalent (PCE)—The number of that standard pyrometric cone whose tip would touch the supporting plaque simultaneously with a cone of the refractory material being investigated, when tested in accordance with the method of test for PCE of refractory materials (see ASTM C24).

qualification test (refractory)—Pre-installation evaluation of materials or applicators, or both to verify that materials purchased and equipment/personnel that will be installing the refractory material/s are capable of meeting specified quality standards.

quality Assurance (QA)—to monitor the effectiveness of the quality control, to audit, and to spot-check the installation quality of the refractory in compliance with the required installation standards, typically by a third-party representative, independent of the refractory contractor.

quality control (QC)—to monitor the quality of the refractory installation to ensure compliance with the required installation standards, typically by the Refractory Contractor QC representative.

ramming—The use of compressive force or impact to deform a stiff refractory mix, causing it to completely fill the intended volume (e.g. a hexmetal cell) and/or fully bond or join to previously placed refractory (e.g. thick plastic linings).

ramming mix—A refractory material, usually tempered with water or other liquid that has suitable properties to permit ramming into place to form a monolithic structure.

rapid fire technology—Additives mixed with the castable to allow the installed lining to be fired with less risk of explosive spalling and damage, when the lining is exposed to faster firing rates than conventional refractory firing schedules. Faster firing rates can be considered when compared to conventional refractory firing schedules when this technology is used.

NOTE This allows the installed lining to pass through the temperature phase where the chemically combined water is released from the cement matrix without expended holds.

reactor (of FCCU or fluid coking unit)—The vessel in which cracking reaction occurs or is completed and product gases are separated from coke or catalyst particulate, or both. Usually operates at 900 °F to 1000 °F (480 °C to 540 °C).

rebound—Aggregate and/or cement not adhering to the gunned or shotcreted surface during the gunning process.

reducing atmosphere—An atmosphere that, at high temperature, lowers the state of oxidation of exposed materials. (typically discussing atmosphere with low or no O_2).

refractories—Nonmetallic materials having those chemical and physical properties that make them applicable for structures, or as components of systems, that are exposed to environments above 1000 °F (538 °C). While their primary function is resistance to high temperature, they are usually called upon to resist other destructive influences also, such as abrasion, pressure, chemical attack, and rapid changes in temperature.

refractoriness—In ceramics, the capability of maintaining a desired degree of chemical and physical identity at high temperatures and in the environment and conditions of use. For fireclay and some high-alumina materials, the most used index of refractoriness is that known as the pyrometric cone equivalent.

refractory (adjective)—Chemically and physically resistant at high temperatures.

refractory ceramic fibers (RCF)—Manmade vitreous fibers (MMVF) whose chemical constituents are predominantly alumina and silica.

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

refractory contractor—The party or parties responsible for installing refractory in the owner's equipment.

refractory cure—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 from 500 °F to 700 °F (260 °C to 370 °C) is required to form the bond.

refractory dryout—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.

refractory inspector—The party or individual whom the owner has contracted or otherwise designated to monitor refractory testing and installation work performed by the refractory contractor and refractory material manufacturer(s). The Refractory Inspector shall meet the minimum requirements identified in C.2.

refractory manufacturer—The party that manufactures the refractory products and/or ancillaries.

NOTE The refractory manufacturer has primary responsibility for material design properties, manufacturing quality control at the manufacturing site and specific procedures such as those for product mixing, installation, and start-up.

regenerator (of FCCU)—Vessel in which coke and residual hydrocarbons are burned off the catalyst and the flue gas is then separated from the catalyst. Usually operates at 1200 °F to 1400 °F (650 °C to 760 °C).

reheat change—A measure of a refractory’s permanent dimensional changes because of heating to a specific temperature.

ribbon—In the formation of hex, it is a single strip of punches, clinches and tabs. Also, used as retaining or edging bar in some locations.

rigidizer—A liquid applied to AES/RCF that produces a rigid lining surface when dried. Rigidizer can be used to form shapes with fiber or used with pumpable fiber products.

rise of arches—The vertical distance between the level of the spring lines and the highest point under the surface of an arch.

riser (of FCCU or fluid coking unit)—Section of transfer line in which flow is in an upward direction.

sample—The quantity of randomly selected refractory taken from a single container or installation sequence that represents that batch or installation. It is used to make a complete set of test specimens to determine physical properties of the whole.

screen analysis—The size distribution of noncohering particles as determined by screening through a series of standard screens.

secondary expansion—The property exhibited by some fireclay and high-alumina refractories of developing permanent expansion at temperatures within their useful range.

self-levelling castable—Castable which flows into a form without vibration or significant manipulation. Minor rodding may be required. Also known as free-flowing castables.

semi-silica fireclay brick—A fireclay brick containing not less than 72 % silica (ASTM C27).

setting—The hardening of a refractory that occurs with time and/or temperature.

sheet spalling/sheeting—Spalling of layers from the hot face of a refractory lining.

shelf life—Maximum manufacturer recommended time interval under given conditions, during which a material may be stored and remain in a usable condition.

shimming—The use of a discontinuous wedge or plate to level a brick or brick course.

shot—Un-fiberized, sphere-shaped material in MMVF fibers that does not contribute to the insulating capability of fibrous insulation.

shotboard—Temporary containments used in gunning that are set up and secured to provide a firm surface on which to make perpendicular cold joints at the termination of work areas.

shotcrete refractory—A refractory castble material designed to be pumped and installed by wet gunning shotcreting.

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 See also “wet gunning”. 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.

silica—SiO_2, the oxide of silicon. Common materials include quartz and chalcedony.

silica volatilization—The loss of silica from refractory materials via transformation into gaseous phase.

silicon carbide (SiC) grit—Abrading medium of the correct particle size used in the ASTM C704/C704M test that is loaded into the testing apparatus at a controlled rate to the proper total quantity to meet the test requirements.

single component lining system (single-layer)—One layer of refractory with or without an anchoring system.

sintering—A heat treatment that causes adjacent particles of material to cohere, at a temperature below that of complete melting.

slag—A glass-like byproduct formed in any one of several ways by chemical action and fusion at furnace operating temperatures. Slag is usually a mixture of metal oxides and silicon dioxide—

a) in smelting operations, through the combination of a flux, such as limestone, with the gangue or waste portion of the ore;

b) in the refining of metals, by substances such as lime added for the purpose of affecting or aiding the refining;

c) by chemical reaction between refractories and fluxing agents such as coal ash, or between two different types of refractories.

slagging of refractories—Destructive chemical reaction between refractories and external agencies at high temperatures, resulting in the formation of a liquid.

slide valve (of FCCU or fluid coking unit)—A refractory lined valve used to control process flow of gases and particles through the valve, typically a gate design with refractory on the gate, orifice, and body portions exposed to process flow and may be either hot or cold wall design.

slumping—Condition of preset refractory in which gravitational forces cause it to lose its desired shape.

softening temperature—The temperature at which a refractory material begins to undergo permanent deformation under specified conditions.

NOTE This term is more appropriately applied to glasses than refractory materials.

soldier course—a) A module lining design where module support anchoring is aligned (parallel) similarly for all modules in a row; b) A course of brick set on end with the narrow side visible.

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.

spalling of refractories—The loss of fragments (spalls) from the face of a refractory structure, through the cracking or rupturing of a refractory unit, which usually results in the detachment or exposure of inner portions of the original refractory mass. Spalling can occur on refractory linings due to thermal shock, pressure/stress, or effects caused by chemical attack.

specific gravity—The ratio between the weight of a unit volume of a substance and that of some other standard substance, under standard conditions of temperature and pressure. For solids and liquids, the specific gravity is based upon water as the standard. The “true specific gravity” of a body is based on the volume of solid material, excluding all pores. The bulk or volume-specific gravity is based upon the volume as a whole, that is, the solid material with all included pores. The apparent specific gravity is based upon the volume of the solid material plus the volume of the sealed pores.

specific heat—The quantity of heat required to raise the temperature of a unit mass of a substance one degree.

specific thermal heat capacity—Property of materials to store energy dependent on temperature. This is defined as the heat needed to raise the temperature of 1kg of a substance by 1K (J/kg K).

specimen—A piece or portion of a sample (cube, bar, plate, or other test pieces) selected and prepared for performing a test.

sprayable/pumpable fibers (refractory)—Mixture of bulk fiber and wet binder suitable for pumping or spraying.

sprung arch—See arch, sprung.

standpipe (of FCCU or fluid coking unit)—Section of transfer line which holds a level of dense-phase catalyst during normal operation. Flow is in a downward direction.

staples—Anchor hooks to secure the batten strip to the module (mandatory in arches).

steam spalling—See “explosive spalling.”

stud weld (of anchors)—Welding method utilizing a resistance arc-welding machine in conjunction with a timer and a gun.

submersion vibrator—A cylindrical mechanical shaft driven device immersed into cast refractory to assist in consolidation, de-airing, and promotion of flow by vibration.

super-duty fireclay brick—Fireclay brick which has a pyrometric cone equivalent (PCE) not lower than Cone 33, and which meet certain other requirements, as outlined in ASTM C27.

supplier—The party supplying the refractory and other materials.

NOTE The supplier may (or may not) be the manufacturer.

suspended arch—See “arch (suspended)”.

target wall—Wall that receives direct flame or flow for the purpose of diverting or spreading over a wider area.

target wall reradiating wall—Vertical refractory firebrick wall that is exposed to direct flame impingement on one or both sides.

temperature gradient—The amount of temperature change over a specific period and refractory lining thickness. During heating-up and cooling-down procedures the temperature gradient is the rise of the temperature curve dependent on time. In a furnace wall or material layer, the temperature gradient is the stretch-dependent rise of the temperature curve. That is the first derivative of the temperature for that stretch.

termination strip—Steel bar or ring that is attached to the edge of hexmetal, or hexalt anchors, at terminations and sharp bends to retain refractory in partial cells. Termination bars/strips can also be used with cold wall refractory linings to terminate and secure the refractory. Can also be called a “retainer ring”.

test sample—That quantity of refractory taken from a single pallet or installation sequence that is used to make a complete set of test specimens to determine compressive strength, erosion resistance, density, linear change, and/or any other physical property determinations.

test specimen—Individual brick or test pieces used for physical property testing. Physical property test results for a sample are usually expressed as the average of two or more specimens made up from the same sample.

thermal conductivity—The thermal conductivity of a material is a measure of its ability to conduct heat. The property of matter by virtue of which heat energy is transmitted through particles in contact and is expressed as K-factor or coefficient of thermal conductivity.

thermal expansion—The increase in linear dimensions and volume that occurs when materials are heated. This is counterbalanced by contraction when the materials are cooled. For refractory materials, one differentiates between reversible and irreversible thermal expansion.

thermal resistance (refractory)—The ability of an insulation to resist heat flow from the hot-face to the cold face. A wide range of thermal resistances are possible by the selection of refractories with different thermal conductivities and/or lining thicknesses.

thermal shock—The exposure of a material to one or more rapid changes in temperature which may have a deleterious effect on the integrity of the refractory.

thermal shock resistance—Property of a refractory material to resist sudden thermal shock.

thermal spalling—Spalling that occurs as the result of stresses caused by nonuniform heating and/or cooling.

thixotropic—A mixture that flows when vibrated but is stiff and unmoving otherwise. Vibration cast refractories are an example.

tie-backs (refractory)—A metallic or refractory device that retains refractory or insulation materials in place while permitting the lining to thermally expand and contract. Used mainly in precast shapes and brick in position.

tolerance—The permissible deviation in a dimension or property of a material from an established standard or from an average value.

transfer line (of FCCU or fluid coking unit)—Refractory lined pipe used for the transport of hot particulate medium and gases between process vessels.

tubesheet—The process inlet and outlet endplates of a thermal reactor steam generator (TRSG) each consisting of a flat perforated metallic plate connected by tubes in a precisely arranged pattern (pitch) that convey process gases through the steam generator.

NOTE 1 The tube to tubesheet joints are designed in accordance with the pressure design code and in the case of a TRSG in sulfur recovery units, the inlet tube sheet and tube to tubesheet joint should be protected against high temperature sulfidation with high temperature insulating system, typically including ceramic ferrules.

NOTE 2 Refer to API Recommended Practice 669 for information and guidance on TRSG design.

tubesheet protection system—The refractory lining systems that retain process heat and protect the steel tube sheet from excessive temperatures which can cause corrosion and thermomechanical damage.

tunnel covers—Pre-cast or extruded refractory part that spans a single tunnel. Also known as coffin covers.

tunnel wall—Typical in top fired reformers, these are free standing walls located between tube rows. Their function is to channel flue gas flow out of the radiant box with minimal bypass of the total heat transfer surface of the radiant tubes. Also known as coffins.

turnaround—A planned outage of a refining process unit to conduct inspections and repairs of internal components, typically lasting multiple weeks.

vacuum formed—A manufacturing process combining fibers and binder components and using a vacuum to form a rigid, densified shape when dried.

vacuum formed (refractory)—A wet manufacturing process combining fibers and binder components and using vacuum to remove said liquid forming a rigid, densified shape when dried.

V-anchor—Metallic anchor made from rod or bar stock that is configured in a V shape.

vapor barrier—Metallic foil or special high temperature cloth, placed between layers of refractory as a barrier to flue gas flow. This barrier protects the steel shell from corrosion caused by condensing acids.

vendor—The vendor is the party that provides engineered products, sub-components, or services for the project work.

NOTE The vendor, whether they directly produce the materials or are agents in supply of such components, have responsibility for the quality of the product to either recognized industry or other standards as directed by the purchaser, whomever they may be. Vendors typically supply sub-components such as burners, fans, dampers, instrumentation, pipe hangers, castings, refractory, pipe / tubes, and fittings. A vendor may also provide specialty engineering services such as finite element analysis (FEA). Within the context of this standard, the supplier has prime responsibility for the products and services provided by the vendor.

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

vibration casting—Castable installation technique whereby refractory is mixed with an appropriate liquid and placed in a formed enclosure with the aid of vibration that causes the refractory to become “fluid-like” and thereby flow and consolidate to the shape of the formed enclosure.

vitrification—A process of permanent chemical and physical change at high temperatures in a ceramic body, such as fireclay, with the development of a substantial proportion of glass.

voids—The hollow space that forms in the core of ceramic parts (bodies) during consolidation or solidification. Voids can greatly impair the strength and other properties.

volume stability—Property of refractory materials after being subjected to a given temperature for a specific period to maintain the original dimensions/size after having cooled again. Any increase or decrease of the original dimension/size is defined as expansion or shrinkage.

warpage—The deviation of the surface of a refractory shape from that intended, caused by bending or bowing during manufacture.

water glass—Alkaline, inorganic chemical binder for refractory mortars and other unshaped refractory materials (monolithics). It is soluble in water and hardens at room temperature. Typically made with various grades of sodium silicate

wedge brick—A standard brick shape whose thickness tapers along its length. Can also be known as an “end arch brick”.

weep hole—An opening at the cold face of a refractory lining to permit the escape of moisture.

wet blanket (refractory)—Flexible, formable, RCF blanket saturated with wet binder that sets on heat exposure, forming a rigid, durable structure.

wet gunning—Hydraulic placement of premixed castables (including an appropriate liquid) where activating agents and placement air are added at the nozzle. Also known as “shotcreting”.

NOTE See also “shotcreting”.

wetting—The adherence of a film of liquid to the surface of a solid.

workability index—A measure of the moldability of plastic refractories as determined in accordance with ASTM C181. The workability index is commonly used to control consistency of plastic refractories during manufacture and serves as a measure of the facility with which it is rammed, gunned, or vibrated into place.

Y-anchor—Metallic anchor made from rod or bar stock that is configured in a Y shape, usually used for dual-layer linings.

Young’s modulus (Modulus of Elasticity)—In mechanics, the ratio of tensile stress to elongation within the elastic limit.

Annex B
(normative)

Refractory Compliance Datasheet

B.1 Scope

This annex describes the contents of and the requirements for compliance datasheets [8] produced by refractory manufacturers.

B.2 Definition

Compliance datasheet—lists physical and chemical properties for a specified refractory material that are warranted by the manufacturer to be met when the product is tested by the listed procedure.

B.3 Application

Compliance datasheets are applicable to material qualification, certification, and qualification testing of refractory materials. They may also be used as a part of laboratory and technician qualification procedures. For as-installed testing, the compliance datasheet values may be modified in accordance with 8.4.4.1 and Table 3.

B.4 Requirements

B.4.1 Compliance datasheets shall be developed for any refractory material commonly used in or marketed to the refining and petrochemical Industry. They may be developed for any refractory material. Each compliance datasheet shall include a statement of identification as a compliance datasheet.

B.4.2 The refractory manufacturer shall provide compliance datasheets to the purchaser upon request. Standard compliance datasheets containing the data listed in B.4.3 shall be prepared in advance and retained on file for immediate transmission to the purchaser. Additional compliance data, as listed in B.4.3, shall be delivered to the purchaser within three weeks of the request.

B.4.3 Standard compliance datasheets shall include values for bulk density (dried and fired), CCS, PLC, and for materials intended for erosive services, abrasion resistance. For plastic refractories, the workability index shall also be included.

The purchaser may request compliance data on the following additional properties—chemical analysis, modulus of rupture, apparent porosity, and thermal conductivity. A note indicating that this information may be requested shall be included on each standard compliance datasheet, along with the test methods to be used.

B.4.4 Values on the compliance datasheet shall be based upon the test method listed in Table B.1 for the applicable property. Values shall be given for each temperature or range described in Table B.1. The compliance datasheet shall include a listing of the test method, edition (date), and the edition of this standard (API 936) used for each value listed. Samples shall not contain metal reinforcing fibers.

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[8] Users of datasheets should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein. Where applicable, authorities having jurisdiction should be consulted. Work sites and equipment operations may differ. Users are solely responsible for assessing their specific equipment and premises in determining the appropriateness of applying the instructions. At all times users should employ sound business, scientific, engineering, and judgment safety when using this standard.

B.4.5 Compliance datasheets shall include a statement like the following, "Dry gunned samples of <<Insert product name>> will meet the following values for the listed properties when tested in accordance with the specified method(s). All tests and listed properties conform to the requirements of API Standard 936, Annex B, and are based upon samples without metal reinforcing fibers unless otherwise noted. The property values are valid whenever the total water content is within the listed range."

Table B.1—Compliance Datasheet Property Listings

Property	Test Method [a]	Temperature	Range
Bulk density	See 8.1.3	After drying at 105 °C (220 °F) and after firing to 815 °C (1500 °F)	Provide an upper and/or lower limit
Cold crushing strength	ASTM C133 as modified by 8.1.2 [b]	After firing to 815 °C (1500 °F)	Provide a minimum value
Abrasion resistance [c]	ASTM C704 as modified by 8.1.3	After firing to 815 °C (1500 °F)	Provide a maximum value
Permanent linear change	ASTM C113 as modified by 8.1.4	After drying at 105 °C (220 °F) and after firing to 815 °C (1500 °F)	Provide an upper and lower limit of green-to-dried and dried-to-fired values
Chemical analysis	ASTM E1172, ASTM E1184, or ASTM E1479 [d], [e]		Provide an upper and/or lower limit
Apparent porosity	ASTM C20 [f]	After drying at 105 °C (220 °F) [g] and after firing to 815 °C (1500 °F)	Provide an upper and lower limit
Thermal conductivity	ASTM C201 and ASTM C417 [h]	At 425 °C (800 °F) (mean) and at 540 °C (1000 °F) (mean)	Provide a maximum value
Cold modulus of rupture	ASTM C133 [i]	After firing to 815 °C (1500 °F)	Provide a minimum value
Workability index	ASTM C181	18 °C to 24 °C (65 °F to 75 °F)	Provide a minimum value

[a] Tests shall be conducted at a laboratory that has been mutually agreed upon by the owner, refractory contractor, and manufacturer.

[b] Specimens shall be 2 in. × 2 in. × 2 in. (50 mm × 50 mm × 50 mm).

[c] Applicable only to materials intended for abrasive service.

[d] The test method is selected by the refractory manufacturer and noted on the compliance datasheet.

[e] Perform analysis on blended and cast as formed samples of the finished product (not on the raw materials).

[f] Specimens shall be one-half of the specimen used for permanent linear change testing, i.e. Two in. × 2 in. × 4.5 in. (50 mm × 50 mm × 112 mm).

[g] Determination of the apparent porosity at 220 °F (105 °C) does not apply to phosbonded or plastic materials.

[h] Specimens to be dried but not fired. Data to be from the ascending curve.

[i] Specimens shall be 2 in. × 2 in. × 9 in. (50 mm × 50 mm × 225 mm). Ensure that opposing surfaces are parallel. In the tested position, a nonformed, noncut face shall be on the bottom. For gunned properties, specimens shall be cut from the center (i.e. not the perimeter) of a gunned panel. One 2 in. × 9 in. (50 mm × 225 mm) face shall be the surface of the gunned panel.

B.4.6 For applications involving water addition, compliance datasheets shall include a water range (variation in the amount of mixing water used) within which the property values listed for density, CCS, PLC, and abrasion resistance (when applicable) are valid. For dry gunning installations, this applies to predamping water only. The same water range shall be used when an optional property is requested. The refractory manufacturer shall determine the water range. A range of ± 10 % of the optimum water content is suggested.

B.4.7 The compliance datasheet shall include the installation method for which the data are valid (e.g. casting, dry gunning, and wet gunning). The compliance data shall be based upon specimens prepared by the listed method.

B.4.8 If a test is not applicable to the specific material (e.g. abrasion resistance for a lightweight insulating material), the words "not applicable" shall be entered into the appropriate place on the compliance datasheet.

B.4.9 The compliance datasheet shall include a manufacturer defined shelf life for the refractory.

B.5 Sample Compliance Datasheet

Figure B.1 is intended to illustrate the content of a typical compliance datasheet. The layout/format shown is not significant and may be altered to comply with the manufacturer's standard presentation. The information in the figure is fictitious and is not intended to portray any actual material or category/class of material. The designation (***) in the figure indicates a location that contains numerical values.

IMPERVIUM 519

Compliance Datasheet—Dry Gunned Installation

Impervium RP519 was developed to address all refining and petrochemical applications with a single product. It has excellent abrasion resistance and thermal insulating properties. It is also inert to all atmospheres found in refining and petrochemical processes. It may be installed by casting, vibracasting, or gunning.

Dry gunned samples of Impervium 519 will meet the following values for the listed properties when tested in accordance with the specified method(s). All tests and listed properties conform to the requirements of API Standard 936, Annex B, and are based upon samples without metal reinforcing fibers unless otherwise noted. The property values are valid whenever the total water content is within the listed range.

Water Content	(***) to (***) weight percent
Bulk Density	Dried density (***) to (***) pcf
(API Standard 936, Fourth Edition)	Density after firing (***) to (***) pcf
Cold Crushing Strength	(***) psi (minimum)
(ASTM C133-97—as modified by API Standard 936, Fourth Edition)	
Permanent Linear Change	(***) to (***) percent (green to dried)
(ASTM C113-02—as modified by API Standard 936, Fourth Edition)	(***) to (***) percent (dried to fired)
Abrasion Resistance	(***) cc (maximum)
(ASTM C704-01—as modified by API Standard 936, Fourth Edition)	
Workability Index	(***) (minimum)
(ASTM C181-03—as modified by API Standard 936, Fourth Edition)	(***) months
Shelf Life	

Chemical Analysis

[ASTM E1172-87(2003) X-Ray Florescence Spectroscopy]

Al_2O_3	SiO_2	Fe_2O_3	Imp_2O_3	Misc.
(***) to (***)	(***) to (***)	(***) to (***)	(***) to (***)	(***) to (***)

Additional Properties

Compliance values for the following properties are available upon request: modulus of rupture (in accordance with ASTM C133-97), apparent porosity (in accordance with ASTM C20-00), and thermal conductivity (in accordance with ASTM C201-93 and ASTM C417-05).

Figure B.1—Sample Compliance Datasheet

Annex C
(informative)

API Certification for Refractory Personnel

C.1 API Certification for Refractory Personnel

API's 936 Certification Program is based on this standard as well as other relevant bodies of knowledge. This program targets all refractory personnel. Applicants must pass a written examination to obtain certification. No experience verification is conducted at the time of the application. Certification term is three years and individuals must recertify to continue their certification.

C.2 Refractory Inspectors

Individuals wishing to be qualified as refractory inspectors must achieve and demonstrate the minimum competency obtained in inspection activities, in addition to being certified to the 936 Refractory Personnel Program by API. Completion of the API 936 Practitioner exam does not, by itself, qualify an individual to be a refractory inspector.

C.2.1 General Competencies

For inspectors to qualify per Annex C.2 their minimum competency including education and experience, when combined, shall be equal to at least one of the following in Table C.1.

Table C.1—Minimum Inspector Competencies

Level of Education	General Refractory Experience [a]	Specific Experience in Refractory Inspection Activities [b]	Total Minimum Experience Needed
Bachelor of Science Degree in engineering or technology	0 years	1 year	1 year
Two-year degree or certificate in engineering or technology	1 year	1 year	2 years
High school diploma or equivalent	2 years	3 years	5 years
No high school diploma or equivalent	3 years	3 years	6 years

[a] General Refractory Experience—Refers to installation activities related to refractory work. This may include, but is not limited to, hands-on experience and engineering design.

[b] Specific Experience in Refractory Inspection Activities—Refers to the quality control elements related to refractory workmanship and/or materials.

C.2.2 Examples of Types of Competency Experience

The following are examples of general competency experience:

a) safety,

b) teamwork,

c) technical knowledge,

d) communication,

e) report writing,

f) supervision.

The following are examples of specific experience in refractory inspection activities:

a) ceramic fiber,

b) design,

c) brick,

d) gunite,

e) laboratory experience,

f) shotcrete,

g) ramming,

h) vibratory casting,

i) pump casting,

j) self-leveling castables.

Annex D
(informative)

Carbonation Reaction of Calcium Aluminate Cements—Alkali Hydrolysis

D.1 Background

In the late 1960s, there was a large push to convert refractory linings for Process Heaters from traditional insulating firebrick to lower cost insulating monolithic ceramic materials (castables) containing calcium aluminate cement (CAC). Many castable linings exhibited rapid deterioration within two to four weeks of initial placement. Lining deterioration ceased once the castable lining was fired. The rapid deterioration of the insulating castable was determined to be the result of uncontrolled alkali hydrolysis/carbonation (AH/C) reactions occurring within the calcium aluminate binder system. Storage of the process heaters, in the presence of moisture, permits time for AH/C reactions to occur damaging the insulating castable.

Alkali hydrolysis is a form of attack specific to CAC that is typically seen as a general breakdown of the refractory surface to a depth of 2.5 mm (0.1 in.) to 10 mm (0.4 in.). AH/C is most often observed in the form of a soft powdery surface, or in some cases, as a thin sheet of castable separating from the surface. For AH/C to occur, water, soluble alkalis, and carbon dioxide are needed. These ingredients are most easily combined in CAC castable with high porosity. History has shown that lightweight castables have the most occurrences with this method of failure. As castable density increases, the occurrence of AH/C has decreased, but occasionally are still observed. It should be noted that API Standard 560 recommended partial dry out to 260 °C (500 °F) is helpful but not a guarantee as instances of AH/C have been reported to have been observed emanating from within the partially dried castable lining.

The deterioration of concretes due to alkalis has also been observed with Portland cement concrete or calcium silicate hydrates (CSH). This form of attack, known as alkali-aggregate reaction (AAR), was first recognized in concrete structures in the 1940s. This technical document will only consider AH/C reactions that occur with CAC concretes or refractories.

D.2 Carbonation Reactions

D.2.1 Types Found in Insulating Castables

There are several reactions that occur which are classified as carbonation reactions. There are three different reactions that can occur.

1) Sodium efflorescence.

2) Direct carbonation of the calcium aluminate hydrate bond.

3) Carbonation catalyzed by Alkalis–Alkali hydrolysis.

Of these three, sodium efflorescence and direct carbonation can happen with lightweight and dense castables. Carbonation catalyzed by alkalis is primarily observed in lightweight castables but in rare instances and conditions can occur in higher density castables.

D.2.2 Sodium Efflorescence of Castables

Sodium efflorescence has two different results as it reacts in the castable. One reaction is a purely a surface effect where sodium carbonate monohydrate percolates to the surface and is deposited on the surface of the castable as fine crystals. These can be easily removed with a slight brushing of the surface and the original castable surface is not changed and still retains its original properties. The other sodium carbonate hydrates, because of the larger size of the formed crystals, can result in rupture and bursting, damaging the castable from within [43, 50]. These phases are destructive and generally form below the surface of the castable. The resulting damage can be interior laminations causing sections of castable to separate through the thickness.

— Na_2CO_3. H_2O—Surface efflorescence only

— Na_2CO_3. $7H_2O$—Rupture and bursting from within castable

— Na_2CO_3. $10H_2O$—Rupture and bursting from within castable

D.2.3 Direct Carbonation (In the Absence of Alkalis)

In this reaction, dissolved CO_2 in solution (CO_3^{2-}) reacts with the calcium aluminate cements (CxAHy) hydrates and forms monocarbo-aluminate C_3ACaCO_3 [48]. H_2O as a reaction product as well as calcium carbonate as vaterite and calcite. This direct carbonation forms within the porosity of the castable and increases the mechanical strength of the concrete and has a surface hardening effect. Analysis of carbonated samples has led to the hypothesis that the C3AH6 hydrate is more resistant to alkali hydrolysis mechanisms. Since there is no degradation of the surface in this process, this reaction is considered beneficial for the refractory concrete. However, for direct carbonation reaction to take place, alkalis must be absent. Because alkalis are readily abundant in refractories, this reaction is limited.

D.2.3.1 Carbonation Catalyzed by Alkalis–Alkali Hydrolysis

The beginning of this reaction sequence starts with the dissolving of alkali ions (sodium and potassium) into solution along with the solution of CO_2 as CO_3^{2-} in the water present in the castable [50]. These ions entering the solution starts the reaction with the calcium aluminate hydrate. From the initial reaction of Na+ and CO_3^{2-}, the calcium aluminate hydrate is consumed and replaced by calcium carbonate and alumina gel. Calcium carbonate is found as mineral forms of aragonite, vaterite and calcite [51]. The alumina gel is found as mineral forms of bayerite, nordstrandite and gibbsite. While these phases are not harmful, the disruption of the CAC bond system is harmful to the refractory system.

The presence of Na+ increases the solubility of the CO_2 in solution, (CO_3^{2-}), which accelerates the destruction of the CA hydrate phases [52]. This carbonation reaction destroys the calcium aluminate hydrates. The higher the porosity of the castable, the faster the reaction of the AH/C can occur. Higher porosity allows penetration of the CO_2 into the castable and movement of the alkalis via moisture to the CA phases. The hydrolysis rate does not appear to be a function of the alkali content. Early reaction kinetics is independent of the concentration of Na+. In fact, the reaction kinetics are extremely variable and unpredictable with cases seen occurring over days or months.

D.3 Current Methods of Inhibiting or Minimizing Alkali Hydrolysis/Carbonation Reactions in Castables

Various methods have been tried to minimize AH/C reactions in insulating castable. These methods include:

a) Partial Dryout

b) Surface Coatings

c) Refractory Material Modifications

d) Inert Gas Purge

D.3.1 Partial Dry Out

One of those methods is to dryout the lining to 500 °F (260 °C) within 45 days of installation. The partial dryout delays the reaction only if the castable can be kept dry while waiting for complete dryout during unit start-up. If humidity is not controlled, even ambient moisture can penetrate the lining and reactivate AH/C reactions. The partial dryout procedure removes most of the mechanical moisture and a portion of the calcium aluminate hydrate moisture. The partially dehydroxylation of the calcium aluminate hydrate phases, leaves the calcium aluminate hydrate phases unstable and will start to react with moisture. For the dryout to effectively work in stopping the AH/C reactions, the surface of the lining must be fully fired to temperatures greater than 649 °C (1200 °F) to completely sinter the CAH phases and prevent AH/C reactions from occurring. The Thermal Decomposition Temperatures for calcium aluminate hydrate phases are shown in Figure D.1, provided by Kerneos. Typical partial dry out of 260 °C (500 °F), would provide the internal lining temperatures as shown in Table D.1. At the 260 °C (500 °F) hot face temperature most of the calcium aluminate hydrates are still present throughout the lining for AH/C reactions to occur. (See Figure D.1).

An example heat flow through a hypothetical 6-in. 2300 LI lining with a hot face of 260 °C (500 °F), provides the interface temperatures as shown in Table D.1. Two inches below the hot face of a 6-in. lining, the interface temperature, (assuming steady state conditions are reached), is 193 °C (379 °F). This is where most of the hydrate phases have not been affected by the temperature and still contain most of the hydrate crystalline water. At 4 in. below the hot face assuming steady state conditions the interface has a temperature of 124 °C (256 °F). Just below the 4-in. thickness there is mechanical water present which can be drawn into the partially dehydroxylated sections and the AH/C can be re-started within the castable and not just on the surface. When dehydroxylated calcium aluminate hydrates are present, all that is needed is moisture, CO_3^{2-} in the moisture and CO_2 present in the ambient air. The desiccant effect of the dehydroxylated calcium aluminate hydrates will draw the moisture to the reaction area and promote continued AH/C reaction on the surface and within the castable lining.

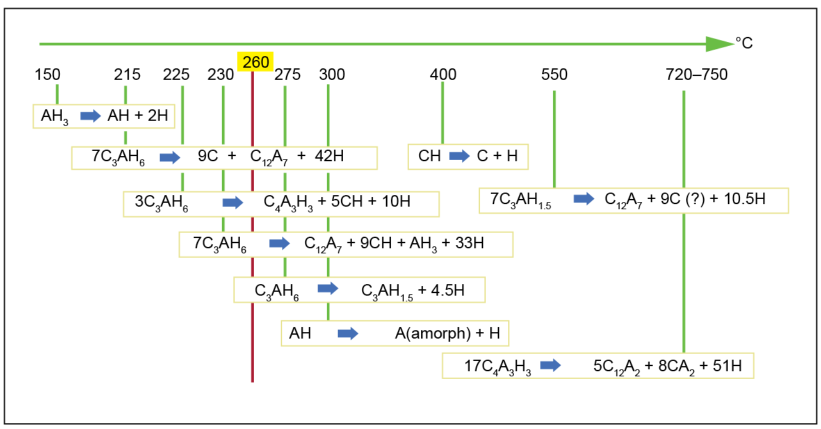

Figure D.1—Thermal Decomposition Temperatures for Calcium Aluminate Hydrates (Kerneos)

Table D.1—Theoretical Heat Flow at 500 °F Hot Face—6 in.-Thick Lining of 2300 LI Lightweight Castable

Product Casing Condition Wall	Refractory Depth	Interfaces Temperatures
2300 LI Castable (k = 2.4)	Hot Face	260 °C (500 °F)
2300 LI Castable	Interface 2 in. Below Hot Face	193 °C (379 °F)
2300 LI Castable	Interface 4 in. Below Hot Face	124 °C (256 °F)
	Cold Face	132 °F
Emissivity = 0.90	Ambient Temperature = 80 °F (27 °C)	Wind Velocity = 0.0 mph (0 m/s)
NOTE The k-value listed is for calculations only not a guaranteed value for that product.		

D.3.2 Preservation Measures Employed to Reduce AH/C in Calcium Aluminate Lightweight Castables

1) To reduce the possibility of alkali hydrolysis, linings with castable hot faces shall be dried out to a minimum of 260 °C (500 °F) hot temperature (heating from hot face) for 8 h within 45 days of installation. Heating/cooling rates for this dry out shall be 56 °C/h (100 °F/h), maximum.

2) Before dryout, castable linings shall be inspected for alkali hydrolysis. Affected material shall be removed and possibly replaced prior to the dryout. Alternate methods for minimizing alkali hydrolysis and remediation shall be approved by the owner.

3) Once dried out, linings shall be protected from moisture and mechanical damage.

4) To do this requires humidity control using silica gel desiccants with routine inspections and possibly additional dryout to remove the moisture from the surface of the lining.

5) Another option that has been used, is to provide circulation of dry or warmed air across the castable after the partial dryout and until unit start-up can be completed. This must consider the ambient air humidity with discontinuation during periods of high humidity.

D.3.3 Surface Coatings

Refractory manufacturers have created coatings that create a membrane over the exposed refractory. When these coatings are applied correctly, they will inhibit the reaction by creating a barrier that prevents the CO_2 and moisture from contacting the refractory surface.

D.3.4 Refractory Material Modifications

a) Alternate methods have focused on castable compositions that reduce the number of alkalis that are available for the reaction.

b) These castable are designed to minimize/eliminate alkali hydrolysis and remediation requirements. These alternative methods are available on the market as “AH Resistant”/“AH Proof” solutions from refractory suppliers.

c) Use of other bonding systems in lieu of or in combination with CA cement can reduce AH. The cement is what carbonates and eventually undergoes AH, so when it is reduced, the carbonation/AH reaction is significantly reduced.

d) Extensive testing has been completed by these manufacturers and the available data show great improvement in the reduction of the Alkali Hydrolysis reaction.

D.3.5 Inert Gas Purge

An inert gas blanket over the refractory will remove CO_2 from the environment and prevent alkali hydrolysis from forming.

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