

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

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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.

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**density³**

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**firing⁴**

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.

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 $\frac{3}{4}$ 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.

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 $\pm 2\%$.

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 ($\pm \frac{1}{32}$ 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 $\times$ 75 mm $\times$ 1.5 mm (3 in. $\times$ 3 in. $\times$ $\frac{1}{16}$ 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/ft ³ (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 to 1600)	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 $\frac{1}{32}$ 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/cm³. 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 to