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Refractory Installation Quality Control—

Inspection and Testing of Refractory

Brick Systems and Materials

API STANDARD 975

SECOND EDITION, ??? 2025

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Important Information Concerning Use of Asbestos or

Alternative Materials

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).

There are currently in use and under development several substitute materials to replace asbestos in certain applications. Manufacturers and users are encouraged to develop and use effective substitute materials that can meet the specifications for and the operating requirements of the equipment to which they would apply.

SAFETY AND HEALTH INFORMATION WITH RESPECT TO PARTICULAR PRODUCTS OR MATERIALS CAN BE OBTAINED FROM THE EMPLOYER, THE MANUFACTURER, OR SUPPLIER OF THAT PRODUCT OR MATERIAL, OR THE MATERIAL SAFETY DATASHEET.

1 Scope

This standard provides installation quality control (QC) procedures for aluminum silicate dense and insulating fire brick refractory systems 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 inspection personnel who monitor and direct the QC process are also defined (see 4.4).

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 936, *Refractory Installation Quality Control—Inspection and Testing Monolithic Refractory Lining and Materials*

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API 976, Refractory Installation Quality Control—Inspection and Testing AES/RCF Fiber Linings and Materials

ASTM C16,¹ Standard Test Method for Load Testing Refractory Shapes at High Temperatures

ASTM C27, Standard Classification of Fireclay and High-Alumina Refractory Brick

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

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

ASTM C134, Standard Test Methods for Size, Dimensional Measurements, and Bulk Density of Refractory Brick and Insulating Firebrick

ASTM C155, Standard Classification of Insulating Firebrick

ASTM C210, Standard Test Method for Reheat Change of Insulating Firebrick

ASTM C832, Standard Test Method of Measuring Thermal Expansion and Creep of Refractories Under Load

Harbison-Walker Refractories Company,² Modern Refractory Practice, Fifth Edition, Indresco, Pittsburgh, Pennsylvania

ISO 3187,³ Refractory Products—Determination of Creep in Compression

ISO 5017, Dense Shaped Refractory Products—Determination of Bulk Density, Apparent Porosity and True Porosity

ISO 10059-2, Dense, Shaped Refractory Products—Determination of Cold Compressive Strength—Part 2: Test with Packing

ISO 12677, Chemical Analysis of Refractory Products by X-ray Fluorescence (XRF)—Fused Cast-bead Method

SSPC SP 3,⁴ Power Tool Cleaning

SSPC SP 6/NACE No. 3, Commercial Blast Cleaning

3 Terms and Definitions

¹ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, Pennsylvania 19428-2959, www.astm.org.

²Harbison-Walker International, 1305 Cherrington Parkway, Suite 100, Pittsburgh, PA 15108, thinkhwi.com.

³International Organization for Standardization, ISO Central Secretariat, Chemin de Blandonnet 8, CP 401 - 1214 Vernier, Geneva, Switzerland, www.iso.org.

⁴Association for Materials Protection and Performance, 15835 Park Ten Place, Houston, Texas 77084, www.amp.org.

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

NOTE Annex A contains a short collection of refractory-related definitions not explicitly used within the document but provided as supplemental information related to understanding refractories and refractory systems.

3.1

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.

3.2

bulk density

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

3.3

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 and/or firing.

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

3.4

compliance data sheet

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

3.5

firebrick

Refractory brick of any type.

3.6

firebrick (dense high-alumina)

Firebrick that contains 45 % to 99 % alumina.

3.7

firebrick (insulating)

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

3.8

fireclay 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).

3.9

fireclay brick (medium-duty)

Fireclay brick that has a pyrometric cone equivalent (PCE) not lower than Cone 29 nor higher than 31 to 31½ (ASTM C27).

3.10

fireclay brick (high-duty)

Fireclay brick that has a pyrometric cone equivalent (PCE) not lower than Cone 31½ nor above 32½ to 33 (ASTM C27).

3.11

fireclay brick (super-duty)

Fireclay brick that has a pyrometric cone equivalent (PCE) not lower than Cone 33 and that meets certain other requirements, as outlined in ASTM C27.

3.12

heat setting mortar

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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.

3.13

independent laboratory

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

3.14

inspector

The party or individual whom the owner has contracted or otherwise designated to monitor refractory testing and installation work performed by the contractor and refractory material manufacturer(s).

3.15

installer (refractory)

An individual of a team responsible for installing refractory products.

3.16

installer qualification testing

Preinstallation 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.

3.17

key

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

3.18

manufacturer (refractory)

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 QC at the manufacturing site, and specific procedures such as those for product mixing, installation, and start-up.

3.19

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.

NOTE Brick testing is usually not required unless this is specified and/or agreed to by the contracting parties.

3.20

owner

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

3.21

phosphate bonded mortars

Mortar composition of ground refractory materials that includes a liquid or powdered phosphate binder.

3.22

product data sheet

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

3.23

production run (lot)

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

3.24

reheat change

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A measure of a refractory's permanent dimensional changes as a result of heating to a specific temperature.

3.25

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.

3.26

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.

4 Responsibilities

4.1 Owner

4.1.1 The owner shall provide a detailed specification. The specification shall include the following design details:

- a) lining products, brick thickness, method of installation, corrosion protection, and extent of coverage;
- b) anchor and/or support type and style/grade, layout and weld details;

4.1.2 The owner shall provide quality requirements covering the following:

- a) material property requirements to be used for material qualification and installation QC by specific product, installation procedures, and location where the product will be used (these requirements shall be in accordance with manufacturer's compliance data sheet (Annex B) unless amended by prior agreement with the owner;
- b) sampling frequency and testing requirements for QC as applicable for the product's intended use;
- c) required lining thickness tolerances.

4.1.3 The owner shall approve the engineering drawings and project execution plan prior to any installation activity.

4.1.4 The owner shall approve the inspection and test plan (ITP)

4.1.5 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.

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4.1.5 The owner should provide an inspector(s) for the refractory installation work who has minimum competencies that are appropriate for the required work scope.

4.1.6 The owner shall provide all the final approved engineering documentation to the installer.

4.2 Installer

4.2.1 The installer shall prepare a detailed execution and quality plan in accordance with this standard and the requirements of the owner's specification and quality standards. The execution and quality plan shall be prepared, submitted for the owner's approval, and agreed to in full before work starts. Execution and quality details shall include but not limited to:

- a) designation of responsible parties;
- b) develop and issue an ITP to the owner for approval prior to any work taking place.
- c) designation of inspection hold points and the required advance notification to be given to the inspector;
- d) surface preparation and welding procedures;
- e) procedures for material qualification, material storage, installer qualification, installation, and QC;
- f) ensure that the dry-out (if any) and the heat-up procedures for the completed lining system are performed per manufacturer recommended instructions [heat-up is the procedure of raising the particular process up to operation parameters (temperature, process flow, etc.)];
- g) submission to the owner of all exceptions to this standard and other referenced documents (owner's approval shall be secured before implementation of the changes);
- h) scheduling and execution of work to qualify all equipment (bricking support machine/props, mortar mixer, etc.) and personnel required to complete installation work, including documentation and verification by the inspector;
- i) advanced 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;
- j) execution of installation work.

4.2.2 Installer shall provide inspector verified documentation of installation records, including:

- a) product(s) being installed;
- b) traceable batch or lot code location where installed;
- c) mortar lot numbers;
- d) installation crew members' names and certifications;
- e) temperature during installation;
- f) accountability for installed refractories meeting specific standards, including lining thickness, tolerances as per owner specifications, and quality standards;
- g) procedure necessary for safe and healthy handling and installation of the bricks and mortar, as advised in the relevant safety standard.

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4.2.3 Installer shall:

- a) provide compliance data sheet in accordance with Annex B for each applicable product;
- b) provide compliance data sheets;
- c) provide installation instructions;
- d) provide safety data sheets (SDS) and procedures to ensure compliance with health and safety requirements;
- e) ensure that they are in possession of all the necessary drawings.

4.3 Refractory Manufacturer

The refractory manufacturer shall:

- a) provide recommended guidelines for weather protection and storage of products;
- b) prepare and identify all pre-shipment testing samples and timely deliver to the testing laboratory (as per contract);
- c) provide material production test certificates (MTC);
- d) provide a compliance data sheet to the owner in accordance with Annex B for each applicable product;
- e) provide the product data sheet and any other information pertaining to the selected material necessary for the implementation of installation activities;
- f) provide material that meets the approved compliance data sheet.

4.4 Inspector

4.4.1 Inspector Qualifications

4.4.1.1 The inspector shall have no commercial affiliations with the installer or manufacturer(s).

4.4.1.2 The inspector shall possess the latest version of the following documents: this standard (API 975) and related standards and recommended practices; the owner specifications; the project execution plan; the ITP. Other job-specific requirements may be outlined by the owner, installer, and/or manufacturer and are required to be readily available. The inspector shall have a working knowledge of these documents.

4.4.2 Inspector Responsibilities

The inspector shall:

- a) ensure that the material and applicator qualification tests are fully documented;

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- b) notify the owner/fabricator and the installer of any work deficiencies. Notification shall be made in accordance with the job-specific requirements outlined in the procedures and drawings. Notification shall take place as soon as possible, and shall occur within one working day after the discovery of the deficiency. Notifications to the owner shall be in writing;
- c) check the availability of the material production test certificates;
- d) monitor production work to ensure compliance with job specifications and agreed-to quality practices;
- e) verify style, lay-out, and composition of anchors/shelf support are installed in accordance with the project requirement;
- f) check and verify that accurate installation records are being documented by the contractor;
- g) monitor compliance with the approved ITP.

The inspector shall not make engineering decisions unless approved by owner. Conflicts between the specified execution plan and the actual installation procedures or installed refractory quality results shall be submitted to the owner for resolution.

5 Materials

5.1 General

Refractories applied in accordance with this standard shall be sampled and tested to verify that the physical attributes meet intended criteria. Acceptance/rejection criteria are determined by average physical attributes for each sample, which shall fully meet the criteria established for that material in 4.1.2 a).

5.2 Physical-chemical and Visual Property

Physical-chemical and visual property shall meet the following requirements:

- a) physical-chemical requirements are defined in 6.2;
- b) visual attributes requirements are defined in 6.3.

5.3 Packaging and Marking

5.3.1 Packages shall be marked to identify product, manufacturing date, expiry date (if applicable), and batch/lot number and hazard identification label.

5.3.2 Various qualities and shapes shall be clearly marked for identification.

5.3.3 Refractories shall be packaged and stored to prevent penetration by water or liquids that could physically damage the material due to physical and/or chemical contamination. Mechanical protection can be provided by cardboard, rigid plastic, or metal outside containers.

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5.3.4 Each alloy anchor shall be stamped or laser etched or supplied in sealed traceable packaging to identify alloy and forming manufacturer. Anchors that are being stored, delivered or installed from open packaging not stamped/etched or from an unmarked package shall have alloy confirmed with 100 % positive material identification (PMI) prior to installation.

5.3.5 The classification of all welding consumables (if any) shall be identified on the package and/or spool or welding rod.

5.4 Shipping

Brick shall be protected from mechanical damage during shipment and handling.

5.5 Storage and Weather Protection

5.5.1 Brick shall be packaged and stored to protect the refractory from inclement weather and from exposure to foreign chemicals that might penetrate the microstructure and affect properties in service. Refractory materials shall be stored in a weather-protected area.

5.5.2 Mortar shall be packaged and stored to protect the refractory from inclement weather with no freeze exposure (wet mortars).

5.6 Shelf Life—Mortars

The manufacturer shall supply shelf-life recommendations and define storage conditions.

5.7 Discarding Criteria

5.7.1 Materials that exceed the shelf life (dry and wet mortars) shall be discarded.

5.7.2 Packages with broken seals or that have become damp or wet (e.g. dry mortars) shall be subject to requalification or discard.

5.8 Regulations and SDS

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

5.8.2 The latest issue of the refractory manufacturer's compliance data sheets, application instructions, and SDS shall be available at the installation site and complied with during the installation.

5.9 Anchors

5.9.1 The anchor material shall be selected based on the maximum temperature an anchor and/or component tip will be exposed to and selection criteria listed in Table 1.

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Table 1—Maximum Temperature for Anchor Tips

Anchor Material	Maximum (°C)	Anchor Temperature (°F)
Carbon Steel	455	850
TP 304 stainless steel	760	1400
TP 316 stainless steel	760	1400
TP 309 stainless steel	815	1500
TP 310 stainless steel	927	1700
TP 330 stainless steel	1038	1900
Alloy 601 (UNS N06601)	1093	2000

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

5.9.3 All alloy components, including anchors, tiebacks and support shelves shall be subject to PMI. If components are marked and traceable, 5% of components shall be checked. For unmarked and non-traceable components, PMI shall be 100% as identified in 5.3.4.

5.9.4 Weld materials shall be compatible with anchor and base metal as specified in the approved weld procedure specification.

5.9.5 All anchor components shall be supplied with mill certifications and heat number identified on the package and/or anchor component.

5.9.6 The composition of the welding consumables shall be identified on the package and/or spool or welding rod.

5.9.7 All weld procedures and welder qualifications shall be approved by owner\.

5.9.8 Surfaces shall be cleaned to meet SSPC SP 6/NACE No. 3. For spot cleaning, SSPC SP 3 shall apply.

5.10 Expansion Materials

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See API 976 for fiber materials to use for expansion materials.

6 Refractory QA/QC, Examination, and Testing

6.1 General

Testing shall be in strict accordance with ASTM, ISO, and EN procedures as modified below. The laboratory conducting the test procedures shall be subject to audit and/or approval by the owner.

QC sampling and testing shall be as per the owner specification and ITP.

6.2 Physical Property

Options for physical property are as follows:

- a) density—ASTM C134 (ISO 5017); EN-993-1;
- b) strength—ASTM C133 (ISO 10059-2);
- c) reheat change (refractory brick)—ASTM C113;
- d) reheat change (IFB)—ASTM C210;
- e) reversible thermal expansion—ASTM E288;
- f) thermal conductivity—ASTM 111C-201, ASTM C182, ASTM C202, ASTM C1113/C1113M;
- g) hot load/creep deformation—ASTM C16, ASTM C832 (ISO 3187);
- h) pier test—ASTM C199;
- i) chemistry
 - 1) mineralogy—X-ray diffraction;
 - 2) chemical composition—inductively coupled plasma, X-ray fluorescence, atomic absorption (ICP/XRF/AA).

6.3 Physical Attributes

6.3.1 Physical attribute testing shall be completed by the manufacturer, prior to shipment.

Dimensions of manufactured bricks shall be taken at a sampling frequency of one brick per 100 using a caliper to an accuracy of ± 0.03 mm (0.001 in.) and reported to the nearest ± 0.5 mm (0.02 in.). Dimensional control shall be based on individual bricks (unless otherwise indicated as in the case of assemblies). Alternatively, measurements of lay-ups may be used to control a linear dimension (e.g. the height of bricks by a lay-up of 10 bricks) as well as the radius of curvature of an assembly of tapered bricks.

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6.3.2 Warpage shall be measured as following ASTM C134 procedure for concave and convex surfaces recording the maximum obtainable reading to the nearest 0.5 mm (0.02 in.) on each diagonal using appropriate measuring wedges (see Figure C.1).

Warpage tolerances and dimensional tolerances for high-alumina grades of brick are as follows.

- a) Length:
 - For high-alumina grades: $\pm 1.5\%$;
 - For fireclay grades: $\pm 2\%$;
- b) Thickness:
 - ± 1.5 mm (1/16 in.);
- c) Taper (< between largest and smallest measure):
 - ± 1 mm (0.04 in.) for tapered length < 155 mm (6 in.);
 - ± 1.5 mm (1/16 in.) for tapered length > 155 mm (6 in.);
- d) Warpage (Largest Δ from a straight edge across the diagonal of a brick face):
 - ± 1.5 mm (1/16 in.) for diagonal.

NOTE Tighter tolerances can be applied based on equipment specific requirements.

6.3.3 Defects are a part of the manufacturing process but manufacturers have specific tolerances that they shall meet to have an acceptable refractory brick product. Dense firebrick and insulating firebrick have different manufacturing requirements.

6.3.3.1 For dense firebrick shapes, defect criteria shall be as follows:

- a) Laminations: The bricks shall be free of internal laminations. On a cut surface of a representative brick, laminations if present must be clearly visible. The test can be used to indicate the possible occurrence of such laminations (see Figure C.2).
- b) Fins at corners and edges shall be no more than 3.0 mm (1/8 in.) high maximum (see Figure C.3).
- c) Cracks visible on the surface of the brick shall be no larger than 19 mm (3/4 in.) in length, deeper than 2 mm (1/16 in.), or wider than 0.25 mm (0.01 in.) (see Figures C.4 and C.7).
- d) Edge and Corner Damage: A brick shall have no more than two corner and/or edge defects for which the total dimensions of each defect is 19 mm (3/4 in.) maximum. Any bricks with more than three defects (corner or edge flaws), shall be rejected (see Figures C.5–C.7).

6.3.3.2 For insulating firebrick (IFB), defect criteria shall be as follows:

- a) Laminations: The bricks shall be free of internal laminations or voids (larger than >10 mm diameter). On a cut surface of a representative brick, laminations/voids if present shall be identified and measured to verify meeting this requirement (see Figure C.2).
- b) Cracks visible on the surface of the brick shall not be larger than 35 mm (1 3/8 in.) in length, deeper than 4 mm (5/32 in.), and wider than 1.5 mm (1/16 in.) (see Figures C.4 and C.7).

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- c) **Edge and Corner Damage:** A brick shall have no more than three corner and/or edge defects for which the total dimensions of each defect is 40 mm (1 5/8 in.) maximum (see Figures C.5–C.7).

6.3.4 Mortar will have its own set of attributes. The manufacturer shall provide mortar in conformance to the compliance datasheet. Mortar shall be tested in accordance with the end user, agreed upon compliance datasheet. In addition to the mortar test results, the refractory product name and manufacturer, batch number, date of manufacture, shelf life, pallet number, water content, mixing time, date of testing, and the name of the testing agency shall also be provided.

6.4 Pre-shipment Requirements

6.4.1 Refractory brick shall be tested to confirm that it conforms to compliance values provided by the manufacturer. Tested physical properties shall be density and strength [by modulus of rupture, and/or cold crushing strength (CCS)], and dimensional requirements identified in 6.3.1.

6.4.2 The physical property testing shall be conducted for each lot.

6.4.3 The physical attributes testing shall require a minimum AQL of 4 % (Table 2).

Table 2—Lot Size, Sample Size, and Rejection Levels for Physical Attributes

Lot Size (pcs.) ^a	Sample Size (pcs.)	Lot Re-test or Rejected (on Re-test) if Defective Number of Bricks from Sample
<50	8	2
51–90	13	3
91–150	20	4
151–280	32	6
281–500	50	8
501–1200	80	11
1201–10,000	125	15
>10,000	200	22
^a “Lot Size” is a group of hard bricks identified and produced under the same manufacturing process. Lots are pressed, fired, and finished (as required) at the same time.		

7 Installation/Execution

The execution plan shall include the following:

- a) Materials handling instructions;

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- b) Identification during re-palletization;
- c) Conveyance—physical handling;
- d) Quality plan;
- e) Qualification of crew/installers;
 - 1) Application qualification—craftsman certification as required.
 - 2) Prior to starting work, the installer to provide a list to the owner of all applicators that will be installing refractory brick and fired materials, listing previous project references available for contact, and verification as to where they have had similar installations.
 - 3) Workers that will be installing brick and fired shapes shall have work history for all types of brick construction defined in the work satisfactory to the owner and be trained in the safe handling of all brick, mortar, and equipment required for the installation.
 - 4) A mock-up of the installation shall be done if required by owner.
- f) Anchor and support preparation;
 - 1) Tie backs, shelves, bolts
 - i) Horizontal shelf supports shall support the firebrick load weight, and the shelf width shall support at least 1/3 of the hot-face lining thickness.
 - ii) Support shelves shall be spaced on vertical centers typically 1.8 m (6 ft) high, but not to exceed 3 m (10 ft), based on calculated loads, thermal expansions, and lining penetrations.
 - iii) Support shelves shall be slotted to provide differential thermal expansion. Shelf design, metallurgy and layout shall be approved by the Owner.
 - iv) For flat walls, >15 % of the bricks shall be tied back. This frequency may be reduced or eliminated for cylindrical walls when the radius of curvature of the casing keys the firebrick linings.
 - v) If required, tie-backs shall extend into at least 1/3 the thickness of the hot-face brick layer.
 - 2) Preparation of casing variations
 - i) Casings shall be checked for defects, distortions, and joint discontinuities.
 - ii) Minor variations in casings may be compensated for by varying the thickness of the backup layer (e.g. castable refractory, ceramic fiber, or block insulation). It is important there shall be no gap between the brick and casing/backup layer.
- g) Workmanship firebrick;
 - 1) Firebrick shall be handled without causing physical damage.
 - 2) Firebricks with signs of physical damage shall not be used without inspector approval.
 - 3) IFB that is wet or has had water damage shall not be used without approval by owner or inspector.

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- 4) Visual inspections shall be made to ensure bricks are laid plumb and "tapped" tight to back-up or shell with no overlapping (lipping). Maximum acceptable lipping tolerance, measured at the hot face, is $\pm 1.5\%$ or 1.5 mm (1/16 in.) of brick thickness.
 - 5) Metallic hammers shall not be used to tamp any type of brick into place.
 - 6) Firebricks shall be saw cut to size. They shall not be "hammer" cut or "chipped" into place.
 - 7) Excessive mortar on the face of firebricks shall be removed so that visual inspection of joints can be made.
 - 8) Any cut firebrick shall not be less than 50 % of the nominal dimensions in any direction.
 - 9) The last brick to be installed as the "key" or "ring closure brick" shall be a full dimensional brick. If the space adjacent to key or ring closure brick is less than one brick width or length, the brick shall require cutting. In such case, no key brick shall be cut less than 50.8 mm (2 in.) in any dimension. The space shall be adjusted with two cut bricks, if required.
 - 10) A cut brick shall not be in the 12 o'clock position as a ring closure brick. The ring closure brick shall be staggered from adjacent rings.
 - 11) Firebricks that are cracked or damaged during installation shall be replaced.
 - 12) All expansion joints shall be located and built in accordance with installation procedures, project specifications, and preapproved construction detail drawings. They shall be properly protected for size and cleanliness during construction and filled in accordance with installation procedures and project specifications.
 - 13) Firebrick ties or supports shall be installed through holes drilled in each supported firebrick without stress cracking,
- h) Firebrick layer lining and gravity wall construction;
- 1) All hot face firebrick linings on vertical flat casing shall be tied back to and supported by the structural steel framing members. All tie-back members shall be austenitic alloy material. It is not necessary for the firebrick lining on the cylindrical casing to be tied back if the radius of the curvature of the casing keys the firebricks in place.
 - 2) Radiant chamber walls of gravity construction shall not exceed 7.3 m (24 ft) in height and shall be at least high-duty fireclay brick. The base width shall be at least 8 % of the total wall height. The height-to-width ratio of each wall section shall not exceed five to one. The walls shall be self-supporting, and the base shall rest on the steel floor. Free-standing IFB walls of up to 10 ft high are acceptable.
 - 3) Gravity and vertical lined walls shall be bonded, mortared construction. The mortar shall be air setting and compatible with the firebrick.
 - 4) Vertical expansion joints shall be provided at gravity-wall ends and required intermediate locations. All expansion joints shall be kept open and free to move. If the joint is formed with lapped firebrick, no mortar shall be used; that is, it shall be a dry joint. In some cases involving those areas not to be covered by mortar, a visual proof material should be added to show that mortar was not installed in the joint. A common proof material is waxed paper.

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- 5) Target walls with flame impingement on both sides (free-standing) shall be constructed with the following:
 - i) super-duty fireclay bricks—minimum brick specification;
 - ii) mortar with a minimum rating of 1540 °C (2800 °F);
 - iii) mortared brick joints;
 - iv) expansion joints packed with ceramic fiber strips with a minimum rating of 1430 °C (2600 °F), minimum.
- i) Mortar workmanship;
 - 1) Mortar joint thickness shall be consistent and spread evenly as per design.
 - 2) Mortar for bricks shall be properly labeled if not in a manufacturer's supplied container.
 - 3) Once a bag or drum of mortar has been opened and/or mixed, it shall be used within the usable life, as specified by manufacturer. Only full bags or drums shall be mixed; splitting or mixing of partial bags shall not be permitted. Extra water shall not be used to extend useful life of mortar.
 - 4) Mixing of refractory mortar materials from one mortar manufacturer with those from other manufacturers shall not be permitted.
 - 5) Mortar shall be mixed using a mechanical mixer with a clean, dry, stirring paddle, using potable water.
 - 6) Containers of dry refractory mortar material containing hard lumps (i.e. that cannot be easily broken by hand) shall be discarded.
 - 7) Mortar shall be mixed to a uniform troweling or dipping consistency as applicable for the installation method, in accordance with the manufacturer's recommended and specified installation procedures.
 - 8) The mortar shall be capable of being spread uniformly over a brick surface without dragging, showing evidence of unmixed or foreign material, sagging, or running.
 - 9) Mortar shall be used as provided from the manufacturer. Water or other material shall only be added if approved by the mortar manufacturer. Any water used for mixing shall be potable water and contain less than 50 ppm chlorides.
 - 10) Mortar mixing shall be performed in accordance with mortar manufacturer's temperature recommendations for the specific material and placement conditions.
 - i) Mix temperature requirements shall be met by cooling or heating the material, cooling or heating the water, or providing a controlled environment for mixing.
 - ii) If the mortar manufacturer's mix temperature recommendation is not available, the temperature of the wet-mixed refractory mortar shall be maintained between 5 °C (40 °F) and 38 °C (100 °F).
 - 11) Mortar supplied dry shall be stored per manufacture recommendations to maximize effective life.

8 Repair

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8.1 All repairs shall be approved by the owner prior to the completion of those repairs.

8.2 The mechanical function of supports, tie-backs, and expansion joints must be taken into consideration when repairing firebrick linings.

9 Preparation for Shipment

9.1 Shop-installed brick lining shall be prepared for shipment in a manner that ensures delivery to the destination in the original lined and fired condition.

9.2 Equipment shall be reinforced using spiders, truing rings, braces, etc., to maintain the equipment shape and prevent damage to the linings during handling and shipment.

9.3 All openings shall be sealed and a means shall be provided to keep linings dry during shipping, storage, and post-erection before the start-up.

9.4 Proper supports, external bracing, rigging, and lifting techniques shall be used to prevent flexing of the equipment during handling, shipping, and erection.

9.5 Orientation of the equipment during shipment and storage shall maintain integrity of the lining.

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Annex A

(informative)

Glossary

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

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.

acid refractories: Refractories containing a substantial amount of silica, which is reactive with basic refractories, basic slags, or basic fluxes at high temperature.

alumina: Al_2O_3 , the oxide of aluminum; melting point 2050 °C (3720 °F); in combination with H_2O (water), alumina forms the minerals diaspore, bauxite, and gibbsite; in combination with SiO_2 and H_2O , alumina forms kaolinite and other clay minerals.

alumina-silica refractories: Refractories consisting essentially of alumina and silica, such as high-alumina, fireclay, and kaolin refractories.

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

anchor or tieback: Metallic or refractory device that retains the refractory or insulation in place.

apparent porosity (ASTM C 20): The relationship of the volume of the open pores in a refractory specimen to its exterior volume, expressed in percentage.

arch: A flat or sloped portion of a fired heater radiant section opposite the floor.

arch brick: A standard brick shape whose thickness tapers along its width.

arch, flat: In furnace construction, a flat structure spanning an opening and supported by abutments at its extremities; the arch is formed of a number of special tapered brick, 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 which usually spans an opening or space between two walls.

arch, suspended: A furnace roof consisting of brick shapes suspended from overhead supporting members.

breaching section (of furnace): Enclosure in a heat exchanger furnace in which flue gases are collected after the last convection coil for transmission to the stack or outlet ducting.

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 the dried or fired condition.

burn: The degree of heat treatment to which refractory brick is 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.

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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.

carbon deposition: The deposition of amorphous carbon, resulting from the decomposition of carbon monoxide gas into carbon dioxide and carbon within a critical temperature range. 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.

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.

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

convection: The transfer of heat by the circulation or movement of the heated parts 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.

corbel: A supporting projection of the face of a wall; an arrangement of brick in a wall in which each course projects beyond the one immediately below it to form a support, shelf, or baffle.

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

creep: Time-dependent deformation due to sustained load.

cristobalite: A mineral form of silica; stable from 1470 °C (2678 °F) to the melting point at 1723 °C (3133 °F). 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.

expansion joint: A separation between adjoining parts of a refractory lining which allows small expansive movements, such as those caused by thermal changes.

firing: The process of heating refractories to develop desired properties (see also burn).

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

fireclay brick: A refractory brick manufactured substantially or entirely from fireclay.

flux: A substance or mixture that promotes fusion of a solid material by chemical action.

fluxing: Fusion or melting of substance as a result of chemical action.

flux load (in welding): Addition of an alumina ball to enhance weldability during stud-welding metallic components such as anchors.

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

grout: A suspension of mortar material in water, that is of such consistency that when it is poured upon horizontal courses of brick masonry, it will flow into vertical open joints.

high-duty fireclay brick: Fireclay bricks that have a pyrometric cone equivalent (PCE) not lower than Cone 31½ nor above 32½–33.

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

independent laboratory: Refractory testing facility not affiliated with any manufacturer or contractor.

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

key brick: In furnace construction, the uppermost or the closing brick of a curved arch.

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

load subsidence: A refractory's load-bearing strength as determined by specimen dimensional changes under a compressive load at high a temperature, per ASTM C 16.

low-duty fireclay brick: Fireclay brick which has a PCE not lower than Cone 15, nor higher than 28–29.

medium-duty fireclay brick: A fireclay brick with a PCE value not lower than Cone 29 nor higher than 31–31½.

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.

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.

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.

heat set mortar: A refractory mortar that bonds to the firebrick at elevated temperatures to allow expansion movement of the brick lining before bonding.

air set mortar: A refractory mortar using silicate or similar air setting binders, which bonds to the firebrick at room temperature

phos-bonded mortars: A refractory mortar that uses phosphoric acid as the bonding binder.

nine-inch equivalent: A brick volume equal to that of a standard 9 in. x 4½ in. x 2½ in. straight brick; a unit of measurement of brick quantities in the refractory industry.

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

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

porosity of refractories: 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.

pyrometric cone: One of a series of pyramidal shaped pieces consisting of mineral mixtures and used for measuring time-temperature effect. A standard pyrometric cone is a three-sided truncated pyramid; and, approximately, is either 66 mm (2 ⅝ in.) high by 16 mm (⅝ in.) wide at base or 29 mm (1 ⅞ in.) high by 16 mm (⅝ in.) wide at the base. Each cone is of a definite mineral composition; it bends at a definite temperature.

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 pyrometric cone equivalent (PCE) of refractory materials (see ASTM C 24).

radiant section (of furnace): The hottest section of a heat exchanger furnace near the burners in which radiant heat transfer is dominant.

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

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538 °C (1000 °F). 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 property of resistance to melting, softening, or deformation at high temperatures. For fireclay and some high-alumina materials, the most commonly used index of refractoriness is that known as the pyrometric cone equivalent.

refractory (adj.): Chemically and physically stable at high temperatures.

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

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

semi-silica fireclay brick: A fireclay brick containing not less than 72 % silica.

shelf life: Maximum time interval during which a material may be stored under manufacturer's recommendations after which the guaranteed properties of the material could deteriorate.

spalling of refractories: The loss of fragments (spalls) from the face of a refractory structure, through cracking and rupture, with exposure of inner portions of the original refractory mass.

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.

super-duty fireclay brick: Fireclay brick that has a PCE not lower than Cone 33, and that meets certain other requirements as outlined in ASTM C 27.

suspended arch: A furnace roof consisting of brick shapes suspended from overhead supporting members.

thermal conductivity: The property of matter by virtue of which heat energy is transmitted through particles in contact.

thermal expansion: The increase in linear dimensions and volume that occurs when materials are heated and that is counterbalanced by contraction of equal amount when the materials are cooled.

thermal shock: The exposure of a material or body to a rapid change in temperature that may have deleterious effect.

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

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

warpage: The deviation of the surface of a refractory shape from that intended, caused by bending or bowing during manufacture.

wedge brick: A standard brick shape whose thickness tapers along its length.

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Young's modulus: In mechanics, the ratio of tensile stress to elongation within the elastic limit; the modulus of elasticity.

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Annex B

(normative)

Development of Refractory Compliance Data Sheet—Material Requirements

B.1 Scope

This annex describes the contents of and the requirements for compliance data sheets produced by refractory manufacturers.

B.2 Definition

A compliance data sheet lists 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.

B.3 Application

Compliance data sheets are applicable to certification and qualification testing of refractory materials. They may also be used as a part of laboratory and technician qualification procedures. Compliance data sheets are not applicable to testing of as-installed materials unless specified by the owner.

B.4 Requirements

B.4.1 Compliance data sheets are to 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 data sheet shall include a statement of identification as a compliance data sheet.

B.4.2 The refractory manufacturer shall provide compliance data sheets to the purchaser upon request.

B.4.3 Standard compliance data sheets shall include values for bulk density, CCS, reheat change, chemical analysis, and, for materials intended for erosive services, abrasion resistance.

The purchaser may request compliance data on the following additional properties: modulus of rupture, apparent porosity, and thermal conductivity. A note indicating that this information may be requested shall be included on each standard compliance data sheet, along with the test methods to be used.

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B.4.4 Values on the compliance data sheet 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 Tables B.2–B.5. The compliance data sheet shall include a listing of the test method used for each value listed. Samples shall not contain metal-reinforcing fibers.

B.4.5 If a test is not applicable to the specific material (e.g. abrasion resistance for a lightweight insulating brick), the words “not applicable” shall be entered into the appropriate place on the compliance data sheet.

B.5 Attachments

Figure B.1 and Figure B.2 are intended to illustrate the content of a typical compliance datasheet. The layout/form shown is not significant and may be altered to comply with the manufacturer's standard presentation. The information in the guideline is fictitious and is not intended to portray any actual material or category/class of material. The designation (***) in the guideline indicated a location that contains numeral values.

Table B.1—Test Methods for Compliance Data Sheets Property Listings

Property	Test Method	Comments
Bulk Density	ASTM C134 ISO 5017	Provide an upper and lower limit
Cold Crushing Strength	ASTM C133 ISO 10059–2	Provide a minimum value
Abrasion Resistance	ASTM C704 ISO 16349	Provide a maximum value
Reheat Change	ASTM C113 ASTM C210	Temperature range shall be mentioned. Provide % of change
Chemical Analysis	ASTM E1172, ASTM E1184, or ASTM E1479 ISO12677	Provide an upper and lower limit
Apparent Porosity	ASTM C20 ISO 5017	Provide upper and lower limit
Thermal Conductivity	ASTM C201 and C417 ISO 8834	Provide max and mean range for testing.
Cold Modulus of Rupture	ASTM C133 ISO 5014	Provide a minimum value
Hot Modulus of Rupture	ASTM C1099 ISO 5013	Provide a minimum value
Thermal Expansion under Load and Creep	ASTM C 832 ISO 3187	Provide a max temperature, load time, and percent deformation
NOTE Not all properties required for every product. Please refer to the compliance data sheets for		

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quality requirements. Testing shall be similar to what is completed on compliance data sheet.

Table B.2—Dense Refractory Requirements (Fireclay Brick)

High-duty Fireclay Brick—Required Properties			
Property	Test Method	Test Temperature	Reported value(s)
Bulk Density	ASTM C134	As manufactured	Min and max
CCS or MOR	ASTM C133	As manufactured	Min
Reheat change	ASTM C113 as modified by API 936	1400 °C (2550 °F)	Max shrinkage or expansion
Super-duty Fireclay Brick—Required Properties			
Bulk density	ASTM C134	As manufactured	Min and max
CCS or MOR	ASTM C133	As manufactured	Min
Reheat change	ASTM C113 as modified by API 936	1600 °C (2910 °F)	Max shrinkage or expansion

Table B.3—Dense Refractory Brick (High-alumina Brick)

Class 50 % to 85 % High-alumina Refractory Brick—Required Properties			
Property	Test Method	Test Temperature	Reported value(s)
Bulk density	ASTM C134	As manufactured	Min and max
CCS or MOR	ASTM C133	As manufactured	Min
Reheat change	ASTM C113 as modified by API 936	1600 °C (2910 °F)	Max shrinkage or expansion
Alumina chemical analysis	—	As manufactured	Min and max
Class 90 % to 99 % High-alumina Refractory Brick— Required Properties			
Bulk density	ASTM C134	As manufactured	Min and max
CCS or MOR	ASTM C133	As manufactured	Min
Reheat change	ASTM C113 as modified by API 936	1700 °C (3092 °F)	Max shrinkage or expansion
Alumina chemical analysis	—	As manufactured	Min and max
Dense Refractory Brick—High-alumina Brick—Required at Request of Owner			
Other chemical analysis	ASTM E1172, ASTM E1184, or ASTM E1479 XRF method ISO 12677	As manufactured	Typical or as specified by owner

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Thermal conductivity	ASTM C201 and ASTM C417 EN 993–15	As specified by owner	Typical
Load test at high temperatures	ASTM C16	As specified by owner or API standard	Max

Table B.4—Insulating Firebrick Requirements

Insulating Firebrick—Required Properties			
Property	Test Method	Test Temperature	Reported value(s)
Bulk density	—	As manufactured	Max
CCS or MOR	ASTM C133	As manufactured	Min
Reheat change	ASTM C210 as modified by API 936	ASTM C155 Group # 16: 845 °C (1550 °F) ASTM C155 Group # 20: 1065 °C (1950 °F) ASTM C155 Group # 23: 1230 °C (2250 °F) ASTM C155 Group # 26: 1400 °C (2550 °F) ASTM C155 Group # 28: 1510 °C (2750 °F) ASTM C155 Group # 30: 1620 °C (2950 °F) ASTM C155 Group # 32: 1730 °C (3150 °F) ASTM C155 Group # 33: 1790 °C (3250 °F)	Max shrinkage or expansion

Table B.5—Refractory Mortars Requirements

Refractory Mortars— Required Properties			
Property	Test Method	Test Temperature	Reported value(s)
Refractoriness test	ASTM C199	At or above expected operating temperature or maximum of 1700 °C (3092 °F)	Flow or no flow from joints
Cold bond strength via MOR	ASTM C133	—	—

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SUPERBRICK 99

Date

Bulk Density (ASTM C134)	(**) to (**) lb/ft ³
Cold Crushing Strength (ASTM C133)	(**) to (**) psi (minimum)
Permanent Linear Change (ASTM C113)	
2350F	(**) to (**) percent
2550F	(**) to (**) percent
2910F	(**) to (**) percent
3092F	(**) to (**) percent
Thermal Conductivity (ASTM ***)	(**) BTU.hr/in ² .F
Apparent Porosity (ASTM C20)	(**) percent
Creep Resistance (ASTM C832)	(**) percent at (**)°F for (**) hour soak
Chemical Analysis (Specify Test Method)	
Al ₂ O ₃	(**)%
SiO ₂	(**)%
Fe ₂ O ₃	(**)%
CaO	(**)%
P ₂ O ₅	(**)%
Others	(**)%

Additional information

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Figure B.1—Manufacturer's Product Compliance Data Sheet—Brick Materials (Sample)

MORTAR 99

Date

Mortar 99 is supplied dry and needs to be mixed with potable clean water prior to use. Mixing shall be performed in accordance with the mixing instructions.

Mortar 99 is air setting.

Water Additions/Liquid Binder Additions (l/100kg) (gal/100lb)	(***) min	(***) max
---	-----------	-----------

Workability	(***) %
-------------	---------

Min Usable Workability	(***) %
------------------------	---------

Cold Bonding Strength (MPa) (psi) 105°C (220°F)

Typical Data	(***) max	(***) min
--------------	-----------	-----------

Guaranteed Compliance Values	(***) max	(***) min
------------------------------	-----------	-----------

Screen Size (% Retained)

Typical Data	(***) max	(***) min
--------------	-----------	-----------

Guaranteed Compliance Values	(***) max	(***) min
------------------------------	-----------	-----------

Chemical Analysis (Specify Test Method)

Al ₂ O ₃	(***)%
--------------------------------	--------

SiO ₂	(***)%
------------------	--------

Fe ₂ O ₃	(***)%
--------------------------------	--------

CaO	(***)%
-----	--------

P ₂ O ₅	(***)%
-------------------------------	--------

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Others (***)%

Additional information

Figure B.2—Manufacturer's Product Compliance Data Sheet—Mortar Materials

BALLOT DRAFT

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Annex C

(informative)

Defects in Dense Fireclay and Insulating Firebrick

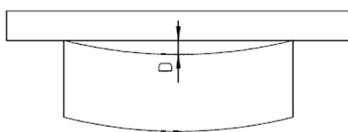
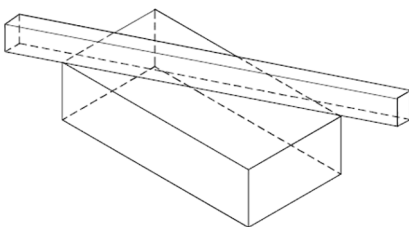


Figure C.1—Warpage

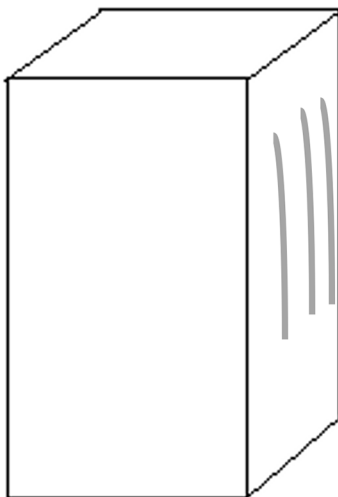


Figure C.2—Laminations

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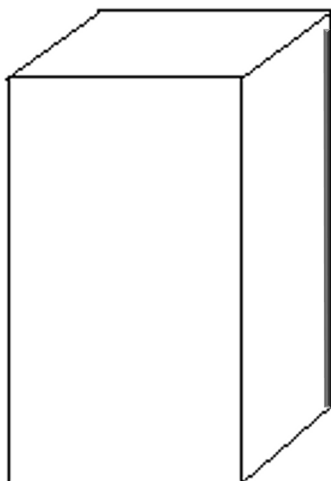


Figure C.3—Fins

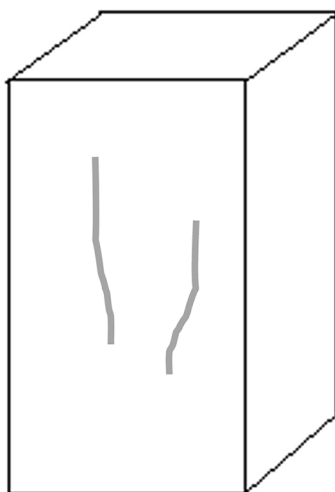


Figure C.4—External Cracks

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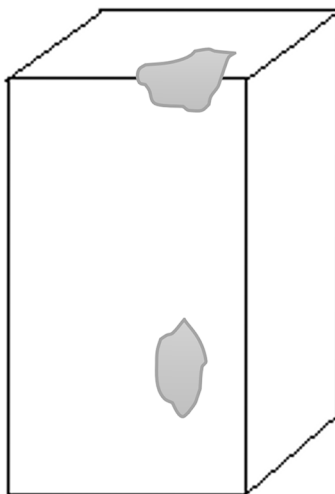


Figure C.5—Edge and Corner Damage

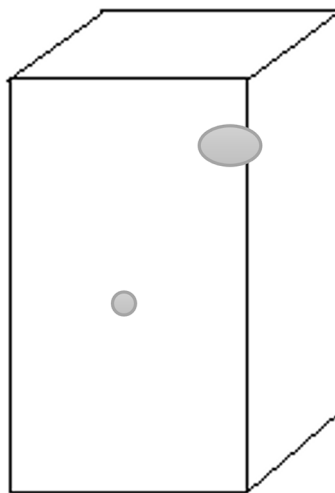


Figure C.6—Voids and Air Pockets

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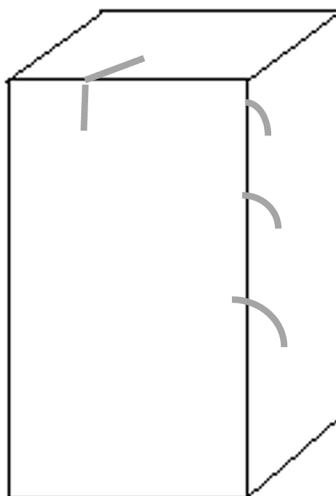


Figure C.7—Edge and Internal

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- [1] API 560, *Fired Heaters for General Refinery Service*
- [2] ASTM C71, *Standard Terminology Relating to Refractories*
- [3] ASTM C467, *Standard Classification of Mullite Refractories*
- [4] ASTM C680, *Standard Practice for Estimate of the Heat Gain or Loss and Surface Temperatures of Insulated Flat, Cylindrical, and Spherical Systems by Use of Computer Programs*