Refractory Installation Quality Control—Inspection and Testing of Refractory Brick Systems and Materials

API STANDARD 975
Proposed FIRST EDITION Ballot Draft
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 a number of 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 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.
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Refractory Installation Quality Control—Inspection and Testing of Refractory Brick Systems and Materials

1 Scope
This standard provides installation quality control procedures for 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 quality control process are also defined.

2 Normative References
The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Standard 560, Fired Heaters for General Refinery Services
API Standard 936, Refractory Installation Quality Control – Inspection and Testing Monolithic Refractory Linings and Materials
ASTM C27, Standard Classification of Fireclay and High Alumina Brick
ASTM C71, Standard Terminology Relating to Refractories
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 C155, Standard Classification of Insulating Firebrick
ASTM C201, Standard Test Method for Thermal Conductivity of Refractories
ASTM C210, Standard Test Method for Reheat Change of Insulating Firebrick
ASTM 832, Standard Test Method of Measuring Thermal Expansion and Creep of Refractories Under Load
ASTM C1113/C1113M, Standard Test Method for Thermal Conductivity of Refractories by Hot Wire (Platinum Resistance Thermometer Technique)
ISO 3187, Determination of Creep in Compression
ISO 1893, Determination of Refractoriness Under Load
Handbook of Refractory Practices
Handbook of Industrial Refractories Technology, Stephen C. Carniglia, Gordon Barna
Practical Refractories, J.D. Hancock
SSPC SP3, Power Tool Cleaning
SSPC SP 7/NACE No. 4, Brush-Off Blast Cleaning

1 ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org
2 International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211 Geneva, Switzerland, www.iso.org
3 Harbison-Walker Refractories Company, 400 Fairway Drive, Moon Township, PA15108, www.hwr.com
4 Published by Vulkan-Verlag
5 Published by Elsevier Science
6 Published by Cartworth Industries, 1988
7 The Society for Protective Coatings, 40 24th Street, 6th Floor, Pittsburgh, Pennsylvania 15222, www.sspc.org
3 Terms and Definitions

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

NOTE Annex A contains a glossary of refractory terms, not referenced in API 936, but are a collection of refractory definitions that will provide supplemental information related to understanding refractories and refractory systems.

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

3.2 contractor
The party or parties responsible for installing refractory in the Owner’s equipment.

3.3 firebrick
Refractory brick of any type. (see Normative References)

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

3.3.1.1 Medium duty firebrick, High Duty firebrick, Super Duty Firebrick

3.3.2 dense high alumina firebrick
Firebrick that contains 50% to 99% alumina.

3.3.3 Insulating firebrick
Firebrick manufactured from densities of 480 kg/m$^3$ to 1362 kg/m$^3$ (30 lbs/ft$^3$ to 85 lbs/ft$^3$) from use temperatures from ambient to 1787 °C (3250 °F).

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

3.5 inspector
The party or individual whom the owner has contracted or otherwise designated to monitor refractory installation work being conducted by the contractor and supplying material manufacturer(s).

3.6 manufacturer
The party or parties manufacturing the refractory lining materials to be installed in the equipment of the owner.

3.7 material qualification testing
Pre-installation 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.

3.8 owner
The proprietor of equipment who has engaged one or more parties to install or repair refractory in the equipment.
3.9 production run
The quantity of refractory having the same formulation that is prepared in an uninterrupted manufacturing operation.

3.10 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.

3.11 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.

3.12 cold crushing strength (CCS)
A measure of a refractories ability to resist failure under a compressive load as determined at room temperature after drying or firing. CCS is calculated by dividing the total compressive load by the specimen cross-sectional area.

3.13 Reheat Change
A measure of a refractory’s permanent dimensional changes as a result of heating to a specific temperature. A specific specimen dimension is measured before and after heating at room temperature. PLC is calculated by the percentage change in these measurements.

3.14 density
The mass of a unit volume of a substance. It is usually expressed either in grams per cubic centimeter or in pounds per cubic foot.

4 Responsibilities

4.1 Owner/EM(Equipment Manufacturer)

4.1.1 The Owner/EM shall provide a detailed specification. The specification shall include the following design details.

4.1.1.1 Lining products, construction, brick thickness, method of installation, corrosion protection and extent of coverage.

4.1.1.2 Anchor type and style/grade, layout and weld details

4.1.2 The Owner/EM shall provide quality requirements covering the following

4.1.2.1 Material property requirements to be used for material qualification and installation quality control by specific product, installation procedures, and location where the product will be utilized. These requirements shall be in accordance with the Manufacturer’s Compliance Data Sheet, (Annex B) unless amended by prior agreement with the owner.

4.1.2.2 Sampling frequency for quality control (QC) as applicable for the product’s intended use.

4.1.2.3 Required lining thickness tolerances.

4.1.3 The Owner/EM shall approve the engineering drawings and project execution plan prior to any installation activity.
4.1.4 The Owner/EM shall resolve the following:

4.1.4.1 Exceptions, substitutions, and deviations to the requirements of the execution plan, this standard, and other referenced documents;

4.1.4.2 Conflicts between the execution plan, this standard, and other referenced documents;

4.1.4.3 Actual or potential work deficiencies discovered and submitted by the inspector.

4.2 Installer

4.2.1 The installer shall prepare a detailed execution plan in accordance with this standard and the requirements of the Owner's/EM's specification and quality standards. The execution plan shall be submitted for the Owner's/EM's approval, and agreed to in full before work starts. Execution details shall include:

4.2.1.1 Designation of responsible parties;

4.2.1.2 Designation of inspection hold points and the required advance notification to be given to the inspector;

4.2.1.3 Surface preparation and welding procedures;

4.2.1.4 Procedures for material qualification, material storage, applicator qualification, installation and quality control;

4.2.1.5 Heat up procedures for the completed lining system.

4.2.1.6 Submission to the Owner/EM of all exceptions, substitutions, and deviations to the requirements of the execution plan, this standard and other referenced documents. Owner/EM approval shall be secured before implementation of the changes.

4.2.1.7 Scheduling and execution of work to qualify all equipment and personnel required to complete installation work, including documentation and verification by the inspector.

4.2.1.8 Advanced notification to the Owner/EM of the time and location where work will take place so that this information can be passed on to the inspector.

4.2.1.9 Execution of installation work.

4.2.2 Provide Inspector verified documentation of installation records, including:

4.2.2.1 Product(s) being installed;

4.2.2.2 Pallet code numbers and location where installed;

4.2.2.3 Mortar lot numbers;

4.2.2.4 Installation crew members;

4.2.2.5 Temperature;

4.2.2.6 Accountability for installed refractories meeting specific standards, including lining thickness, tolerances as per Owner/EM specifications and quality standards.

4.3 Refractory Manufacturer

The Manufacturer shall do the following.

4.3.1 Provide a Compliance Data Sheet in accordance with Annex B for each product.

4.3.2 Provide material that meets the approved Compliance Data Sheet.

4.3.3 Provide all documentation with Compliance Data Sheets, installation instructions and SDS to be available at the installation site and complied with during the installation of the refractory materials.

4.3.4 Provide recommended guidelines for weather protection and storage of products.

4.3.5 Prepare and identify all pre-shipment testing samples and make timely delivery to the testing laboratory (as per contract).
4.3.6 The Manufacturer is to provide a preservation program if there is a delay between construction and commissioning.

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 API Standard 975, Owner specifications, the project execution plan, the inspection and test plan, and other job-specific requirements outlined by the Owner, Installer, and/or Manufacturer. The Inspector shall have working knowledge of these documents.

4.4.2 The Inspector shall be responsible for the following:

4.4.2.1 Ensure that the material and applicator qualification tests are fully documented.

4.4.2.2 Notify the Owner/EM/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. Notify the Owner/EM/Fabricator in writing.

4.4.2.3 The Inspector shall make no engineering decisions unless approved by Owner/EM/Fabricator. Conflicts between the specified execution plan and the actual installation procedures or installed refractory quality results shall be submitted to the Owner/EM/Fabricator for resolution.

4.4.2.4 Check and verify that accurate installation records are being documented by the contractor.

5 Materials

5.1 General

Refractories applied in accordance with API Standard 975 shall be sampled and tested to verify that the physical properties meet intended criteria. Acceptance/rejection criteria are determined by average physical properties, which shall fully meet the criteria established for that material in 4.1.2.1

5.2 Physical Properties - Chemical and Visual Attributes Requirements

5.3 Packaging and Marking

5.3.1 Packages shall be marked to identify product, manufacturing date and batch/lot number.

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

5.4 Shipping

Brick must 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. Wet mortars shall be protected from freezing during shipment from the manufacturer and during storage before installation and from excessive heat during storage before installation.

5.6 Shelf Life of Mortars

5.6.1 The Manufacturer shall supply shelf life recommendations.

5.7 Discarding Criteria

5.7.1 Materials that exceed the shelf life shall be discarded.

5.7.2 Packages with broken seals or that have become damp or wet (e.g. dry mortars) shall be discarded.
5.8 Regulations and Safety Data Sheets (SDS)

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

5.8.1.2 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 Anchors are required to hold refractory linings in place. 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 3 for maximum temperature of studs.

5.9.2 Weld materials shall be compatible with anchor and base metal.

5.9.3 All anchor components shall be supplied with mill certifications and heat number identified on the package and/or anchor component. For Insulating Firebrick (IFB) tie-backs stress relieving is required.

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

5.9.5 All weld procedures and welders shall be approved by Owner/EM/Fabricator.

5.9.6 Surfaces shall be cleaned to meet SSPC SP-7. For spot cleaning SSPC SP-3 shall apply.

5.10 Expansion Materials

See API 976 for materials to use.

API Staff NOTE: API 976 is a proposed draft that has not been balloted. Documents cannot be cited as normative references until published.

6 Refractory QA/QC, Examination and Testing

6.1 General

Testing shall be in strict accordance with ASTM procedures listed below in 6.2. The laboratory conducting the test procedures shall be subject to audit and approval by the Owner. Quality control testing shall consist of agreed upon tests and procedures and other tests required by the Owner shall be defined in the Owner’s specifications.

6.2 Physical Properties

Test verification using agreed on tests for each quality of firebrick or mortar, as presented in the Compliance Data Sheets, consists of:

6.2.1 Density – ASTM C134 (ISO 5017)

6.2.2 Strength – ASTM C133

6.2.3 Reheat Change – ASTM C113

6.2.4 Volume Stability – ASTM C210

6.2.5 Reversible Thermal Expansion – ASTM E288

6.2.6 Thermal Conductivity – ASTM C201, ASTM C182, ASTM C202, ASTM C1113/C1113M

6.2.7 Hot Load/Creep Deformation – ASTM C16, ASTM C832, ISO 3187, ISO 1893

6.2.8 Pier Test – ASTM C199

6.2.9 Chemistry

6.2.9.1 Mineralogy – X-Ray Diffraction
6.2.9.2 Chemical Composition (ICP/XRF/AA)

6.3 Physical Attributes

After physical properties, bricks shall be inspected for dimensions and physical defects and acceptance/rejection shall be based on the following criteria.

6.3.1 Dimensions – At a sampling frequency of 1 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). See Table 6.1 for lot size and sampling frequency.

6.3.2 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.

<table>
<thead>
<tr>
<th>Lot Size (pcs.(^1))</th>
<th>Sample Size (pcs.)</th>
<th>Lot Retest or Rejected (on retest) if Defective number of brick from sample ≥</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;50</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>51 to 90</td>
<td>13</td>
<td>3</td>
</tr>
<tr>
<td>91 to 150</td>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td>151 to 280</td>
<td>32</td>
<td>6</td>
</tr>
<tr>
<td>281 to 500</td>
<td>50</td>
<td>8</td>
</tr>
<tr>
<td>501 to 1200</td>
<td>80</td>
<td>11</td>
</tr>
<tr>
<td>1201 to 10,000</td>
<td>125</td>
<td>15</td>
</tr>
<tr>
<td>&gt;10,000</td>
<td>200</td>
<td>22</td>
</tr>
</tbody>
</table>

NOTE 1 Lot is a group of hard bricks manufactured from same identified production batch pressed, fired and finished (as required) under same manufacturing process at same time.
Table 6.2—Warpage Tolerances for Firebrick

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length</strong></td>
<td>+/- 1.5%</td>
<td></td>
</tr>
<tr>
<td><strong>Thickness</strong></td>
<td>+/- 1.5 mm (1/16 in.)</td>
<td></td>
</tr>
<tr>
<td><strong>Taper</strong> (&lt; between largest and smallest measure)</td>
<td>± 1 mm (0.04 in.) for tapered length &lt; 155 mm (6 in.)</td>
<td>± 1.5 mm (1/16 in.) for tapered length &gt; 155 mm (6 in.)</td>
</tr>
<tr>
<td><strong>Warpage (largest Δ from a straight edge across the diagonal of a brick face)</strong></td>
<td>± 1.5 mm (1/16 in.) for diagonal</td>
<td></td>
</tr>
</tbody>
</table>

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

6.3.3 Warpage should 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.

6.3.3.1 Tolerance requirements for brick shall be:

6.3.4 Defects

6.3.4.1 For Dense Firebrick Shapes, defect criteria shall be as follows:

6.3.4.1.1 Laminations: The bricks shall be free of internal laminations. On a cut surface of a representative brick, laminations if present must be clearly visible.

6.3.4.1.2 Fins at corners and edges shall be no more than 3.0 mm (1/8 in.) high maximum.

6.3.4.1.3 Cracks visible on the surface of the brick shall be not larger than 19 mm (0.8 in.) in length, deeper than 2 mm (0.1 in.) and wider than 0.25 mm (0.01 in.).

6.3.4.1.4 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 28 mm (1 1/8 in.) maximum. Any bricks with more than 5 defects, corner or edge flaws, shall be rejected.

6.3.4.2 For IFB, defect criteria shall be as follows:

6.3.4.2.1 Laminations: The bricks shall be free of internal laminations or voids larger than 10 mm (0.40 in.) in diameter. On a cut internal surface of a representative brick, laminations/voids if present must be clearly visible.

6.3.4.2.2 Cracks visible on the surface of the brick shall not be larger than 35 mm (1.4 in.) in length, deeper than 4 mm (0.2 in.) and wider than 1.5 mm (1/16 in.).

6.3.4.2.3 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.

6.3.4.3 Warpage should 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 the appropriate measuring wedges. See Annex C.
6.3.5 Mortar

6.3.5.1 The Manufacturer shall provide mortar in conformance with the Compliance Data Sheet for the product per Annex B.

6.3.5.2 Mortar shall be tested in accordance with the requirements of Annex B, following the Manufacturer’s recommended procedures.

6.3.5.3 In addition to the test results, the refractory product name and manufacture, batch number, date of manufacture, pallet number, water content and mixing time (for dry mortars), date of testing and the name of the testing agency shall be provided.

6.3.5.4 Pre-formed Cast Fired Shapes

6.4 Pre-Shipment Requirement—Conformance to Compliance Data

6.4.1 AQL by Application

6.4.2 Physical Properties

6.4.3 Chemistry

6.4.4 Physical Attributes

7 Installation/Execution

7.1 The Execution Plan should include the following details:

7.1.1 Materials Handling

7.1.2 Identification During Re-palletization

7.1.3 Conveyance – Physical Handling

7.1.4 Quality Plan

7.1.5 Qualification of Crew/Installers

7.1.5.1 Application Qualification – Craftsman certification as required.

7.1.5.2 Prior to starting work the contractor 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

7.1.5.3 Workers that will be installing brick and fired shapes shall have personal safe 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.

7.1.5.4 A mock-up of the installation shall be done if required.

7.1.6 Anchor and Support Preparation

7.1.6.1 Tie backs, Shelves, and Bolts

7.1.6.1.1 Horizontal shelf supports shall not support more than 10 times the firebrick load weight, and the shelf width shall support 50% of the hot-face lining thickness.

7.1.6.1.2 Support shelves shall be regularly spaced on vertical centers typically 1.8 m (6 ft.) high, but not to exceed 3 m (10 ft.), based on calculated loads and thermal expansions.

7.1.6.1.3 Support shelves shall be slotted to provide differential thermal expansion. Shelf material is defined by the calculated service temperature at the hottest portion of the shelf and any corrosive agents it will be exposed to shelves. (See Table 3 for Maximum Temperature requirements.)

7.1.6.1.4 All tie-back members shall be austenitic alloy material stress relieved.
Table 7.1—Maximum Temperature for Anchor Tips

<table>
<thead>
<tr>
<th>Anchor material</th>
<th>Maximum anchor temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon steel</td>
<td>455 °C / 850 °F</td>
</tr>
<tr>
<td>TP 304 stainless steel</td>
<td>760 °C / 1400 °F</td>
</tr>
<tr>
<td>TP 316 stainless steel</td>
<td>760 °C / 1400 °F</td>
</tr>
<tr>
<td>TP 309 stainless steel</td>
<td>815 °C / 1500 °F</td>
</tr>
<tr>
<td>TP 310 stainless steel</td>
<td>927 °C / 1700 °F</td>
</tr>
<tr>
<td>TP 330 stainless steel</td>
<td>1038 °C / 1900 °F</td>
</tr>
<tr>
<td>Alloy 601 (UNS N06601)</td>
<td>1093 °C / 2000 °F</td>
</tr>
<tr>
<td>Ceramic studs and washers</td>
<td>&gt; 1093 °C / &gt; 2000 °F</td>
</tr>
</tbody>
</table>

7.1.6.1.5 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.

7.1.6.1.6 Tie-backs shall extend into at least \( \frac{1}{3} \) the thickness of the hot-face brick layer with a minimum of 2.5 in. to 3 in. engagement from the cold face of the brick.

7.1.6.2 Preparation of casing variations

7.1.6.2.1 Casings shall be checked for defects, distortions, and joint discontinuities.

7.1.6.2.2 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).

7.1.7 Firebrick Workmanship

7.1.7.1 Firebrick shall be handled without causing physical damage.

7.1.7.2 Firebricks with signs of physical damage shall not be used without Inspector approval.

7.1.7.3 IFB that have had water damage or are wet shall not be used without approval by Owner or Inspector.

7.1.7.4 Visual inspections shall be made to ensure bricks are laid plumb and “tapped” tight to back-up or shell with no overlapping (lipping).

7.1.7.5 Metallic hammers shall not be used to tamp any type brick into place.

7.1.7.6 Firebricks shall be saw cut to size. They shall not be “hammer” cut or “chipped” into place. Manual saws are acceptable for IFB.

7.1.7.7 Excessive mortar on the face of firebricks shall be removed so that visual inspection of joints can be made.

7.1.7.8 Firebrick shall not be less than 50% of the nominal dimensions in direction. This can be per the owner’s discretion by application.

7.1.7.9 Ring closure brick shall be a full dimensional brick.

7.1.7.10 Cut brick shall not be in the 12 o’clock position and shall be staggered from adjacent rings.
7.1.7.11 Firebricks that are cracked or damaged during installation shall be replaced.

7.1.7.12 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.

7.1.7.13 Firebrick tie-backs or supports shall be installed through holes drilled and not impaled in each supported firebrick without stress cracking. In some cases, like with marine boiler anchor bricks, that are pressed with grooves/slots for receiving and holding metallic anchors can be used in this application.

7.1.8 Mortar Workmanship

7.1.8.1 Mortar joint thickness shall be consistent and spread evenly as per design.

7.1.8.2 Mortar for bricks shall be properly labeled if not in a manufacturer’s supplied container.

7.1.8.3 Full contents of each bag or drum of refractory mortar material shall be used.

7.1.8.4 Mixing of refractory mortar materials from one mortar manufacturer with those from other manufacturer shall not be permitted.

7.1.8.5 Mortar shall be mixed using a mechanical mixer with a clean, dry, stirring paddle.

7.1.8.6 Containers of dry or wet refractory mortar material containing hard lumps (i.e., that cannot be easily broken by hand) or using a shear mixer for wet shall be discarded.

7.1.8.7 Mortar shall be mixed to a uniform troweling or dipping consistency as applicable for the installation method.

7.1.8.8 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.

7.1.8.9 Mortar shall be used as provided. Water or other material shall not be added unless approved by the mortar manufacturer.

7.1.8.10 Mortar mixing shall be performed in accordance with the mortar Manufacturer’s temperature recommendations for the specific material and placement conditions.

7.1.8.10.1 Mix temperature requirements shall be met by cooling or heating the material, cooling or heating the water, or providing a controlled environment for mixing.

7.1.8.10.2 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).

7.1.8.11 Mortar supplied dry shall be mixed in accordance with the Manufacturer’s recommended and specified installation procedures.

8 Repair and Preservation

8.1 Repair Procedures

8.1.1 The mechanical function of supports, tie-backs and expansion joints must be taken into consideration when repairing firebrick linings. Repairs are generally made by replacing or refurbishing entire structural units, such as the entire lift of firebricks on a support from expansion joint to expansion joint and/or several courses of firebricks at the top of a lift.

8.2 Preservation Procedures

8.2.1 The Refractory Manufacturer is to provide a preservation program if there is a delay between construction and commissioning.

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.
Annex A
(informative)

Glossary

This annex provides supplemental definitions related to refractories and refractory materials.

NOTE See footnotes at the end of this annex for the source of the definition. Additional definitions are contained in Section 3.

abrasion of refractories [1]: Wearing away of the surfaces of refractory bodies in service by the scouring action of moving solids.

acid-proof brick [2]: Brick having low porosity and permeability, and high resistance to chemical attack or penetration by most commercial acids and some corrosive chemicals.

acid refractories [3]: Refractories containing a substantial amount of silica, which is reactive with basic refractories, basic slags, or basic fluxes at high temperature.

alumina [2]: Al₂O₃, the oxide of aluminum; melting point 2050 °C (3720 °F); in combination with H₂O (water), alumina forms the minerals diaspore, bauxite, and gibbsite; in combination with SiO₂ and H₂O, alumina forms kaolinite and other clay minerals.

alumina-silica refractories [2]: 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 [4]: Metallic or refractory device that retains the refractory or insulation in place.

applicator qualification testing: A 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.

apparent porosity (ASTM C20) [3]: 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 [2]: 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 [2]: 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 [2]: 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) [2]: 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 (firing of refractories) [2]: The degree of heat treatment to which refractory brick are subjected in the firing process; also the degree to which desired physical and chemical changes have been developed in the firing of a refractory material. 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 [2]: 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. Sometimes referred to as “CO Disintegration.”

C-clip (anchors) [2]: A C-shaped metallic anchor used to attach ceramic anchors to the casing or shell of a process unit or fired heater.

cold face [3]: The surface of a refractory section not exposed to the source of heat.

convection [2]: The transfer of heat by the natural or forced 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 [2]: 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 [2]: A horizontal layer or row of brick in a structure.

creep [5]: Time-dependent deformation due to sustained load.

cristobalite [2]: A mineral form of crystalline 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 [2]: A furnace roof, especially one which is dome shaped; the highest point of an arch.

expansion joint [5]: A separation between adjoining parts of a refractory lining which allows small expansive movements, such as those caused by thermal changes.

firing [5]: The process of heating refractories to develop desired properties.

firebrick [2]: Refractory brick of any type.

fireclay [2]: An earthy or stony mineral aggregate which has as the essential constituent hydrous silicates of aluminum with or without free silica, plastic when sufficiently pulverized and wetted, rigid when subsequently dried, and of sufficient purity and refractoriness for use in commercial refractory products.

fireclay brick [2]: A refractory brick manufactured substantially or entirely from fireclay.

flux [2]: A substance or mixture that promotes fusion of a solid material by chemical action.

fluxing [2]: 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 [2]: Refractories formed by electrical fusion followed by casting and annealing.

gROUT [2]: A suspension of mortar material in water, 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 [2]: Fireclay bricks which have a pyrometric cone equivalent (PCE) not lower than Cone 31 1/2 nor above 32 1/2 to 33.

hot face [3]: The surface of a refractory section exposed to the source of heat.

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

insulating firebrick [1]: A refractory brick characterized by low thermal conductivity and low heat capacity with densities of 30 to 85 pcf (480 kg/m³ to 1362 kg/m³)

key [2]: In furnace construction, the uppermost or the closing brick of a curved arch.
key brick: A standard brick shape whose width tapers along its length.

K-factor $^2$: 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 C16.

low-duty fireclay brick $^2$: Fireclay brick which has a PCE not lower than Cone 15, nor higher than 28 to 29.

material qualification testing: Pre-installation testing of refractory materials in which production lots of refractories manufactured for an installation are sampled and tested to confirm that they meet specified physical property requirements.

medium-duty fireclay brick $^2$: A fireclay brick with a PCE value not lower than Cone 29 nor higher than 31 to 31 1/2.

modulus of elasticity (physics) $^1$: 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) $^2$: 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) $^1$: 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 using an air-set, heat set or chemical bond system.

nine-inch equivalent $^2$: A brick volume equal to that of a standard 230 mm x 115 mm x 115 mm (9 in. x 4 1/2 in. x 2 1/2 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 $^2$: 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 $^2$: 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.

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

pyrometric cone $^2$: 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 ($^{23}/8$ in.) high by 16 mm ($^{7}/8$ in.) wide at base or 29 mm ($^{1}/8$ in.) high by 16 mm ($^{3}/8$ in.) wide at the base. Each cone is of a definite mineral composition; it bends at a definite temperature.

pyrometric cone equivalent (PCE) $^2$: 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 C24).

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

refractories $^1$: 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 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 $^2$: 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.
refractoriness under load: (RUL) is a measure of the deformation behavior of refractory ceramic products subjected to a constant load and increasing temperature. RUL is a critical property for refractory bricks, which basically reflects the service temperature of the brick’s raw materials.

refractory (adj.) [2]: Chemically and physically stable at high temperatures.

rise of arches [2]: The vertical distance between the level of the spring lines and the highest point of the under surface of an arch. Good practice will have to determine both for a stable arch or dome.

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 [2]: A fireclay brick containing not less than 72% silica.

shelf life [5]: Maximum time interval during which a material may be stored.

spalling of refractories [2]: 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 [2]: 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 [2]: The quantity of heat required to raise the temperature of a unit mass of a substance one degree.

superduty fireclay brick [2]: Fireclay brick which have a PCE not lower than Cone 33, and which meet certain other requirements as outlined in ASTM C27.

suspended arch [2]: An arch in which the brick shapes are suspended from overhead supporting members.

thermal conductivity [2]: The property of matter by virtue of which heat energy is transmitted through particles in contact.

thermal expansion [2]: The increase in linear dimensions and volume which occurs when materials are heated and which is counterbalanced by contraction of equal amount when the materials are cooled.

thermal expansion and creep of refractories under load: Thermal expansion under load is used to measure rates of subsidence or creep over long hold periods. Many mineralogical reactions are time dependent, and creep test is run under load at a specific temperature over a period of many hours. Subsidence is generally caused by the formation of viscous glassy phases with increasing temperature. The crystalline phases present (such as mullite in high alumina products) can reduce the amount of glassy phases and thus increase creep resistance.

thermal shock [3]: The exposure of a material or body to a rapid change in temperature which may have deleterious effect.

thermal spalling [3]: Spalling which occurs as the result of stresses caused by non-uniform heating and/or cooling.

tolerance [2]: The permissible deviation in a dimension or property of a material from an established standard, or from an average value.

warpage [2]: 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.

Young’s modulus [2]: In mechanics, the ratio of tensile stress to elongation within the elastic limit; the modulus of elasticity.

3. Refractory Concrete ACI 547-79, American Concrete Institute, Detroit, Michigan, 1979.
5. Refractory Plastics and Ramming Mixes ACI 547.1R89, American Concrete Institute, Detroit, Michigan.
Annex B
(normative)

Development of Compliance Data Sheets

B.1 Scope
This Annex describes the contents of and the requirements for Compliance Data Sheets produced by refractory manufacturers.

B.2 Definition
Compliance Data Sheet – A form that 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. Standard Compliance Data Sheets containing the data agreed upon by the purchaser and refractory manufacturer shall be prepared in advance and retained on file for immediate transmission to the purchaser.

B.4.3 Standard Compliance Data Sheets shall include values for the key properties required by the purchaser. Each refractory used will have a Compliance Data Sheet based on the application area and agreement between purchaser and the refractory company.

B.5 Listed below are proposed guidelines for the various tests that could be a part of the Compliance Data Sheet. Each product type, Fireclay Brick, Dense High Alumina Brick, Insulating Firebrick and Air-Set, Heat-Setting and Chemically Bonded Mortars have a chart associated with the typical tests that might be required to meet purchaser’s requirements.

B.6 Due to the large number of product types and qualities within each of the Firebrick and Mortar families, along with the many different application areas in the refining and petrochemical industry, the typical properties for these materials can be found in various ASTM and ISO procedures, and therefore, are not included in this document. (See Normative References).

B.7 Compliance Data Sheets shall be developed in cooperation between the Refractory Manufacturer and End Users.
### Table B.1—Compliance Data Sheet Test Protocol for Dense Refractory Brick – Fireclay Brick

NOTE See ASTM C27 for Classifications and Typical Properties.

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Method</th>
<th>Temperature</th>
<th>Range</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk Density</td>
<td>ASTM/ISO 5017</td>
<td></td>
<td>Provide an lower limit</td>
<td></td>
</tr>
<tr>
<td>Cold Crushing Strength</td>
<td>ASTM C133 as modified by API 936, paragraph 6.2.1 (^b)</td>
<td></td>
<td>Provide a minimum value</td>
<td></td>
</tr>
<tr>
<td>Reheat Change</td>
<td>ASTM C113 as modified by API 936, paragraph 6.2.4</td>
<td>Temperature depending on quality</td>
<td>Provide a maximum value</td>
<td></td>
</tr>
<tr>
<td>Chemical Analysis</td>
<td>ASTM E1172, E1184, or E1479 XRF method ISO 12677</td>
<td></td>
<td>Provide an lower limit for Al(_2)O(_3) and upper for SiO(_2) and Fe(_2)O(_3)</td>
<td>Main components only</td>
</tr>
<tr>
<td>Apparent Porosity</td>
<td>ASTM C20 ISO 5017</td>
<td></td>
<td>Provide upper limit</td>
<td></td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>ASTM C201 and C417 EN 993-15</td>
<td>At 425 °C (800 °F) (Mean) At 537 °C (1000 °F) (Mean)</td>
<td>Only on special request</td>
<td></td>
</tr>
<tr>
<td>Cold Modulus of Rupture</td>
<td>ASTM C133 (^b)</td>
<td></td>
<td>Provide a minimum value</td>
<td></td>
</tr>
<tr>
<td>RUL/Creep Test</td>
<td>Creep ISO 3187 RUL ISO 1893</td>
<td>Temperature depending on quality</td>
<td>Provide a minimum value</td>
<td>Only on special request</td>
</tr>
</tbody>
</table>

**Notes**

- a. Tests shall be conducted at a laboratory that has been mutually agreed upon by the Owner, Contractor, and Manufacturer.
- b. Tests required and minimum/maximum values shall be determined by Application Requirements and Owner’s Specifications
<table>
<thead>
<tr>
<th>Classification</th>
<th>90%</th>
<th>94%</th>
<th>99%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Properties</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density, kg/m³ (lb./ft³)</td>
<td>2820 (176)</td>
<td>3060 (191)</td>
<td>3090 (193)</td>
</tr>
<tr>
<td>Apparent Porosity per ASTM C20</td>
<td>10 to 18%</td>
<td>12 to 18%</td>
<td>18 to 21%</td>
</tr>
<tr>
<td>Cold Crushing Strength, MPa (psi) per ASTM C133</td>
<td>103 (15,000)</td>
<td>62 (9000)</td>
<td>48 (7000)</td>
</tr>
<tr>
<td>Modulus of Rupture, MPa (psi) per ASTM C133</td>
<td>15.2 (2200)</td>
<td>16.5 (2400)</td>
<td>17.0 (2500)</td>
</tr>
<tr>
<td>Hot Load Test per ASTM C16 (Deformation at Temperature)</td>
<td>0.6 to + 0.2% @1700 °C (3100 °F)</td>
<td>0.6 to + 0.2% @1700 °C (3100 °F)</td>
<td>0.5 to 1.4% @1700 °C (3100 °F)</td>
</tr>
<tr>
<td>Reheat Permanent Linear Change, per ASTM C113 (at Temperature)</td>
<td>0 to 2.0% @1760 °C (3200 °F)</td>
<td>0 to 1.0% @1760 °C (3200 °F)</td>
<td>0.1 to 0.4% @1760 °C (3200 °F)</td>
</tr>
<tr>
<td>Thermal Conductivity – k, W/m °K (Btu-in/(h·ft·°F))</td>
<td>3.93 (27.3)</td>
<td>3.89 (27.0)</td>
<td>3.76 (26.1)</td>
</tr>
<tr>
<td>Al₂O₃ (wt. %)</td>
<td>90 ±2</td>
<td>93 Min</td>
<td>97 Min</td>
</tr>
<tr>
<td>SiO₂ (wt. %)</td>
<td>9 ± 2</td>
<td>&lt;7</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>Fe₂O₃ (wt. %)</td>
<td>0.5</td>
<td>0.4</td>
<td>&lt;0.5</td>
</tr>
</tbody>
</table>
Table B.3—Option Compliance Data Sheet Protocol Dense Refractory Brick Requirements – High Alumina Brick

<table>
<thead>
<tr>
<th>Property d</th>
<th>Test Method a,d</th>
<th>Temperature d</th>
<th>Range d</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk Density</td>
<td>ASTM/ISO 5017</td>
<td></td>
<td></td>
<td>Provide an lower limit</td>
</tr>
<tr>
<td>Cold Crushing Strength</td>
<td>ASTM C133 as modified by API 936, paragraph 6.2.1 b</td>
<td></td>
<td></td>
<td>Provide a minimum value</td>
</tr>
<tr>
<td>Abrasion Resistance</td>
<td>ASTM C704 as modified by API 936, paragraph 6.2.2</td>
<td></td>
<td></td>
<td>Provide a maximum value Only if need in application (for instance fluidized bed)</td>
</tr>
<tr>
<td>Reheat change</td>
<td>ASTM C113 As modified by API 936, paragraph 6.2.4</td>
<td>Temperature depending on quality</td>
<td></td>
<td>Provide a maximum value</td>
</tr>
<tr>
<td>Chemical Analysis</td>
<td>ASTM E1172, E1184, or E1479 b,j XRF method ISO 12677</td>
<td></td>
<td></td>
<td>Provide an lower limit for Al₂O₃ and upper for SiO₂ and Fe₂O₃ Main components only</td>
</tr>
<tr>
<td>Apparent Porosity</td>
<td>ASTM C20 e,f ISO 5017</td>
<td></td>
<td></td>
<td>Provide upper limit</td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>ASTM C201 and C417 g,h EN 993-15</td>
<td></td>
<td>At 425 °C (800 °F) (Mean) At 538 °C (1000 °F) (Mean)</td>
<td>Only on special request</td>
</tr>
<tr>
<td>Cold Modulus of Rupture</td>
<td>ASTM C133 b</td>
<td></td>
<td></td>
<td>Provide a minimum value</td>
</tr>
<tr>
<td>RUL/Creep Test</td>
<td>Creep ISO 3187 RUL ISO 1893</td>
<td>Temperature depending on quality</td>
<td></td>
<td>Provide a minimum value</td>
</tr>
</tbody>
</table>

Notes

a. Tests shall be conducted at a laboratory that has been mutually agreed upon by the Owner, Contractor, and Manufacturer.
b. Specimens shall be 50 mm x 50 mm x 50 mm (2 in. x 2 in. x 2 in.).
c. Specimens shall be 50 mm x 50 mm x 225 mm (2 in. x 2 in. x 9 in.).
d. Tests required and minimum/maximum values shall be determined by Application Requirements and Owner’s Specifications.
Table B.4—Insulating Firebrick Properties

<table>
<thead>
<tr>
<th>ASTM C155 Classification °F</th>
<th>Insulating Firebrick</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature Classification, °C</td>
<td>1260</td>
</tr>
<tr>
<td>Properties</td>
<td></td>
</tr>
<tr>
<td>Density, kg/m³ (lb/ft³)</td>
<td>Per ASTM C134 Minimum</td>
</tr>
<tr>
<td>500</td>
<td>480</td>
</tr>
<tr>
<td>(31.2)</td>
<td>(30)</td>
</tr>
<tr>
<td>Cold Crushing Strength, MPa (psi) per ASTM C133 Typical</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>12 (145)</td>
</tr>
<tr>
<td>Modulus of Rupture, MPa (psi) per ASTM C113 Typical</td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td>(102)</td>
</tr>
<tr>
<td>Reversible Linear Thermal Expansion, % per ASTM E228 (Maximum)</td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>0.5</td>
</tr>
<tr>
<td>Reheat Permanent Linear Change, per ASTM C113 (at Temperature)</td>
<td></td>
</tr>
<tr>
<td>0.2 @ 1230 °C (2246 °F)</td>
<td>0.2 @ 1230 °C (2246 °F)</td>
</tr>
<tr>
<td>Hot Load Test Per ASTM C16 (Deformation at Temperature)</td>
<td></td>
</tr>
<tr>
<td>0.1 @ 1100 °C @ 0.034 MPa (2012 °F @ 5 psi)</td>
<td>0.1 @ 1260 °C @ 0.034 MPa (2300 °F @ 5 psi)</td>
</tr>
<tr>
<td>0.1 @ 1320 °C @ 0.034 MPa (2408 °F @ 5 psi)</td>
<td></td>
</tr>
<tr>
<td>Thermal Conductivity →k, W/m °K (Btu/ft/(ft² °F)) Per ASTM C201 at 600 °C (1112 °F) Typical</td>
<td></td>
</tr>
<tr>
<td>0.22 (1.54)</td>
<td>0.16 (1.11)</td>
</tr>
<tr>
<td>Al₂O₃ (wt. %)</td>
<td>Typical</td>
</tr>
<tr>
<td>45</td>
<td>37</td>
</tr>
<tr>
<td>SiO₂ (wt. %)</td>
<td>48</td>
</tr>
<tr>
<td>Fe₂O₃ (wt. %) Typical</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>0.7</td>
</tr>
</tbody>
</table>
Table B.5—Refractory Mortar Typical Properties

<table>
<thead>
<tr>
<th>Classification</th>
<th>Fireclay Mortar</th>
<th></th>
<th>High Alumina Mortar</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Properties</strong></td>
<td>Medium Duty</td>
<td>High Duty</td>
<td>Super Duty</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>85% ( \text{Al}_2\text{O}_3 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>90% ( \text{Al}_2\text{O}_3 )</td>
</tr>
<tr>
<td>Refractoriness Test per ASTM C199</td>
<td>No Flow @1400 °C (2550 °F)</td>
<td>No Flow @1500 °C (2730 °F)</td>
<td>No Flow @1600 °C (2910 °F)</td>
</tr>
<tr>
<td>Cold Bonding Strength per ASTM C198 using Modulus of Rupture, MPa (psi) per ASTM C133</td>
<td>4.5 (650)</td>
<td>4.5 (650)</td>
<td>5.5 (800)</td>
</tr>
<tr>
<td>( \text{Al}_2\text{O}_3 ) (wt. %)</td>
<td>30</td>
<td>40</td>
<td>54</td>
</tr>
<tr>
<td>( \text{SiO}_2 ) (wt. %)</td>
<td>60</td>
<td>53</td>
<td>40</td>
</tr>
<tr>
<td>( \text{Fe}_2\text{O}_3 ) (wt. %) (Maximum)</td>
<td>1.4</td>
<td>1.2</td>
<td>1.1</td>
</tr>
</tbody>
</table>
Figure B.1—Manufacturer’s Product Compliance Data Sheet—Brick Materials

DATE SUBMITTED __________________

EQUIP. NO. _____________________________  EQUIP. NAME __________________________

REFRACTORY MATERIAL
REFRACTORY MANUFACTURER

____________________________________________________________________________

REFRACTORY SUPPLIER ______________________________________________

DENSITY (kg/m³) (lb/cu ft.)
Manufacturer’s Guarantee _______________ min. _______________ max.

COLD CRUSHING STRENGTH (MPa) (psi)
Manufacturer’s Guarantee _______________ min.

POROSITY (%)
Manufacturer’s Guarantee _______________ min.

THERMAL CONDUCTIVITY FACTOR “K” AT 538 °C (1000 °F) MEAN
Manufacturer’s Guarantee _______________ max.

CHEMICAL ANALYSIS (min/max)

Alumina (Al₂O₃) _______________ Silica (SiO₂) _______________
Iron Oxide (Fe₂O₃) _______________ Others _______________

NOTE  These are only suggested items and can be modified by the Purchaser and Refractory Manufacturer during negotiations.
Figure B.2—Manufacturer’s Product Compliance Data Sheet—Mortar Materials

DATE SUBMITTED

EQUIP. No. _____________________________  EQUIP. NAME _____________________________

REFRACTORY MATERIAL ____________________________________________________________

REFRACTORY MANUFACTURER ______________________________________________________

REFRACTORY SUPPLIER __________________________________________________________

WATER ADDITIONS

Total (L/100 kg) (gal/100 lb.)   min.   max.

WORKABILITY** (%)   Min. Usable Workability (%)   

COLD BONDING STRENGTH (MPa) (psi)* 105 °C (220 °F)

Manufacturer’s Data   max.   min.

Manufacturer’s Guarantee   max.   min.

SCREEN SIZE (% RETAINED)*

Manufacturer’s Data   max.   min.

Manufacturer’s Guarantee   max.   min.

CHEMICAL ANALYSIS (min/max)

Alumina (Al₂O₃)  Silica (SiO₂)  

Iron Oxide (Fe₂O₃)  Calcia (CaO)  

Phosphate (P₂O₅)  Others  

Annex C
(informative)

Defects in Dense Fireclay and Insulating Firebrick

Figures C.1 through C.7 depict the types of defects found in dense fireclay and insulating firebrick.

Figure C.1—Warpage

Figure C.2—Laminations

Figure C.3—Fins

Figure C.4—External Cracks

Figure C.5—Edge and Corner Damage

Figure C.6—Voids and Air Pockets

Figure C.7—Cracks – Edge and Internal