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Refractory ~~Castable~~ Compliance Data Sheet Development and Use Guidelines

API RECOMMENDED PRACTICE 986
FIRST EDITION, ~~FOR BALLOT~~

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Special Notes

Users of this recommended practice should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

Where applicable, authorities having jurisdiction should be consulted.

Work sites and equipment operations may differ. Users are solely responsible for assessing their specific equipment and premises in determining the appropriateness of applying the recommended practice.

At all times users should employ sound business, scientific, engineering, and judgment safety when using this recommended practice.

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Introduction

Compliance data sheets (CDSs) were introduced in the third edition of API 936, published November 2008. CDSs are documents produced by refractory manufacturers that are intended to list physical, ~~and~~ chemical and thermal properties of refractory materials that are “*warranted by the manufacturer to be met when the product is tested by the listed procedure*”.

CDSs have similarities to manufacturers’ technical data sheets (TDSs), however with different purposes. TDSs are sales documents that describe the general intended use and typical average properties of refractory products. CDSs are intended to specify allowable property limits that will be confirmed during quality control testing.

Since 2008, CDSs and material testing protocols have been implemented into refractory projects and usage of CDSs has generally worked as intended. When test results fall outside of CDS limits, this causes concerns and may cause investigations, ~~project delays~~ and rework. Further investigation has found that there are multiple reasons that test results fall outside of CDS limits:

a) API 936 testing protocols have prevented:

1) ~~shipment of defective castable to a project site, and~~

2) Defective production run of castable from being placed into operation: There have been cases when a purchased production run of castable was rejected after initial material qualification testing

4)3) Refractory contractor not following the manufacturer’s mixing and installation procedures: There have been cases of field collected samples not meeting CDS properties due to improper mixing and installation procedures and these lining areas were rejected.

2) ~~Defective production run of castable: There have been cases when a purchased production run of castable was rejected after initial material qualification testing.~~

– ~~Refractory contractor not following the manufacturer’s mixing and installation procedures: There have been cases of field collected samples not meeting CDS properties due to improper mixing and installation procedures and these lining areas were rejected.~~

b) There have been cases when the contractor followed mixing and installation procedures correctly and then the field collected test results were outside CDS limits.

c) There ~~was a case~~ are known cases when material qualification samples were tested and results confirmed that the batch of castable was acceptable. This castable was shipped to the job site. The contractor installed the castable by gunning while following procedures correctly, however the installed castable was unacceptable and field collected test results were outside CDS limits.

d) ~~CDS property limits may not have included the actual range of properties from field collected samples.~~

e)d) Project guidelines and standards are typically set to TDS properties values, not CDS. TDSs often include a disclaimer that the properties are not guaranteed and could change without notice. There are no existing guidelines or standards for manufacturers to set TDS property values. Property values are listed on TDSs however it is common for TDSs to include disclaimers describing that properties are not guaranteed, and properties may change without notice.

f)e) New refractory products may not have sufficient field collected test results to compare against preliminary manufacturer’s product development testing.

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g)f) It is not common for field test results to be shared with manufacturers to check field properties against CDS limits.

h)g) CDS limits are based on castables with no metallic fibers added. However, it is common in petrochemical equipment to add metallic fibers to field mixes. Metallic fiber addition may require additional water/liquid to meet the desired consistency and may reduce the workability of a mixed castable.

i)h) CDS limits may be based on cast samples and there can be wider ranges of properties when preparing samples by gunning, pump casting or wet gunning (shotcreting). CDS limits may only be applicable to cast samples while the range of properties from other processes may be unknown.

j)i) Refractory testing lab bias may be a causal factor to a wider range of test results however lab bias is unknown. There have been no general studies or comparison tests to confirm by the API subcommittee on refractory materials (SCRM), although some studies for laboratory precision and bias have been completed by ASTM. An improvement to consistency of ASTM C704 abrasion testing was developed in 2018 (API 977) when round-robin abrasion tests were performed. API 977 implemented several improvements to ASTM C704 tests that have resulted in more consistent measurements between labs. For other CDS properties such as density, cold crushing strength (CCS) and permanent linear change (PLC), there have been no round-robin studies of refractory test lab bias by the API SCRM.

These refractory test results and CDS limits are important to refractory contractors because contractors are held accountable for as installed properties. The following requirement has been in place since the first edition of API 936:

[CONTRACTOR RESPONSIBILITIES]: “Accountability for installed refractory meeting specified standards, including as installed testing results....”

Refractory testing practices introduced by API standards have generally improved the quality of refractory installation by providing several extra checks of purchased castables. However, improvements are needed to the process of CDS development and CDS management as more field data is shared with manufacturers. The benefits of improved sharing field as-installed data with manufacturers, and improved CDS practices will be to provide more realistic representation of field collected properties ~~and to avoid unnecessary concern, project delays and re-work.~~

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1 Scope

1.1 General

This document discusses compliance data sheets (CDSs) for several different types of castable refractories, with data from test results to support the discussion on how refractory manufacturers, contractors, inspectors and owners set, interpret, and understand the test results when compared to compliance data sheet values.

Guidance is also provided for manufacturers, contractors, inspectors, test laboratories and owners to help ensure quality refractory installation is achieved while understanding the potential pitfalls and issues that may be encountered when applying compliance data sheet value limits to refractory installations. This document is intended to provide guidelines for manufacturers to develop and maintain CDSs with property limits that accurately report the range of field collected properties. Procedures for sending test data to manufacturers and updating the material acceptability limits will be provided. Test data from field collected samples is encouraged to be collected in the data set to validate CDS limits.

1.2 Limitations

This document will focus on castable CDSs since only castable (vibration castables, gunned castables, rammed castables) data was collected and analyzed. The general principles described in this document may also apply to other refractory standards that require CDSs (e.g., brick, fiber, plastic).

2 Normative References

~~A list of documents associated with API 986 are included in the bibliography~~

~~ASTM C704 Abrasion Resistance of Refractory Materials at Room Temperature.~~

~~API 982 Inspection and Assessment of Refractory Linings.~~

~~API Standard 936, –Refractory Installation and Quality Control – Inspection and Testing Monolithic Refractory Linings and Materials.~~

~~ASTM C20, Standard Test Methods for Apparent Porosity, Water Absorption, Apparent Specific Gravity, and Bulk Density of Burned Refractory Brick and Shapes by Boiling Water~~

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

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

~~ASTM C181, Standard Test Method for Workability Index of Fireclay and High-Alumina Refractory Plastics~~

~~ASTM C201, Standard Test Method for Thermal Conductivity of Refractories~~

~~ASTM C417, Standard Test Method for Thermal Conductivity of Unfired Monolithic Refractories~~

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

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ASTM E1172, Standard Practice for Describing and Specifying a Wavelength Dispersive X-Ray Spectrometer

ASTM E1184, Standard Practice for Determination of Elements by Graphite Furnace Atomic Absorption Spectrometry

ASTM E1479, Standard Practice for Describing and Specifying Inductively Coupled Plasma Atomic Emission Spectrometers

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3 Terms, Definitions, Abbreviations, and Acronyms

3.1 Terms and Definitions

3.1.1 abrasion resistance

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

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

3.1.2 applicator qualification testing

Preinstallation simulation of production work that is visually inspected, sampled, and tested to verify that the refractory material, application equipment and personnel are capable of meeting specified quality standards.

3.1.3 as-installed testing

Testing of refractory materials sampled from the installation to confirm that they meet specified physical property standards.

3.1.4 bar (sample mold)

Castable specimen typically used to measure permanent linear change (PLC).

3.1.5 castable (refractory)

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

3.1.6 casting

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

3.1.7 chain of custody

What party is under the “care, custody and control” of a product between purchasing, shipping and handling, and ultimately the end-user.

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3.1.8 compliance datasheet

Lists physical 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.

3.1.83.1.9 cube (sample mold)

Castable specimen typically used to measure cold crushing strength (CCS) in accordance with ASTM C133. Sample size is 50.8mm (2" in.) x 50.8mm (2" in.) x 50.8mm (2" in.)

3.1.93.1.10 density

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

3.1.103.1.11 fluid catalytic cracking unit **FCCU**

A refining process consisting of reactor and regenerator vessels and interconnecting piping in which particulate catalyst is circulated at elevated temperatures to upgrade low-value feedstock to high-value products, such as heating oil, gasoline components, and chemical feedstocks.

NOTE: Also known as a "cat cracker".

3.1.113.1.12 green refractory (monolithic linings)

A newly installed refractory before it is exposed to dryout or initial heating.

3.1.123.1.13 hand packing

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

3.1.133.1.14 independent laboratory

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

3.1.143.1.15 licensor

The entity that holds the technology and or patents for a particular process or design.

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3.1.153.1.16 material qualification testing

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

3.1.163.1.17 metal fiber reinforcement

Metal fibers dispersed in refractory to improve applied lining toughness and shrinkage crack distribution.

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

NOTE Metal fibers can also negatively impact some refractory properties.

3.1.173.1.18 mock-up

Prequalification of the refractory installation, where the contractor executes a trial installation using the equipment, materials and installation method that is intended to be used for the job. The mockup sample is typically destructively tested to confirm condition of the refractory.

3.1.183.1.19 owner

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

3.1.193.1.20 physical properties

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

3.1.203.1.21 plate (sample mold)

Castable specimen typically used to measure abrasion resistance. Sample size is 114mm (4.5" in.) x 114mm (4.5" in.) x 25.4mm (1" in.).

3.1.213.1.22 production run

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

3.1.223.1.23 production sample

Castable sample collected during the installation of refractory products. Also called "as-installed" sample.

3.1.233.1.24 project authorities

Individuals or a group that is separate from the owner and has decision making responsibilities regarding project scope of work, scheduling and design specifications.

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3.1.243.1.25 pump casting

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

3.1.253.1.26 purchaser (refractory)

Party responsible for purchasing the refractory component from the refractory manufacturer.

3.1.27 quality Control

~~(QC):-~~

~~†To monitor the quality of the refractory installation to ensure compliance with the required installation standards, typically by the Refractory Contractor QC representative.~~

3.1.263.1.28 rebound

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

3.1.273.1.29 ramming

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

3.1.283.1.30 refractories

Nonmetallic materials having those chemical and physical properties that make them applicable for structures, or as components of systems, that are exposed to environments above 1000 °F (538 °C).

NOTE 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.

3.1.293.1.31 refractory contractor

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

3.1.303.1.32 refractory Installer

An individual of a team responsible for installing refractory product.

3.1.313.1.33 refractory manufacturer

The party that manufactures the refractory products or ancillaries, or both.

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

3.1.323.1.34 sample

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

3.1.333.1.35 shelf life

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

3.1.343.1.36 shotcreting

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

NOTE See also “wet gunning”.

3.1.353.1.37 specimen

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

3.1.363.1.38 supplier

The party supplying the refractory and other materials.

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

3.1.373.1.39 test lab bias

The difference in measurements of an independent lab compared to a reference standardized laboratory when both labs measured the same item while following the same measuring standard.

3.1.40 Wwater curve

(liquid curve)

A series of tests performed on the same batch of refractory when mixed with various water / liquid ratios. The curve shows how properties deteriorate with higher or lower water / liquid content.

3.1.383.1.41 wire mesh basket (gunned sample)

Gunned samples are typically collected by gunning into a “wire mesh basket”.

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3.2 Abbreviations and Acronyms

CCS	cold crushing strength
CDS	compliance data sheet
MOR	modulus of rupture
PLC	permanent linear change
QC	quality control
TDS	technical data sheet

4 Background

4.1 History of refractory castable property testing

Refractory castable property testing during several phases of a refractory project was introduced by API 936 First Edition, published October 1996. Castable samples are either prepared in a test lab, a mockup, qualification, or ~~prepared~~ during field installation. These samples are sent to a lab where physical properties are measured following API 936 test protocols and these properties are compared to CDS limits. The sources of acceptable range of properties and extensions for field collected samples have evolved (Table 1) since API 936 First Edition:

Table 1 – Evolution of acceptable range of refractory castable properties

API 936 Edition, date of publication	Brief description of allowed refractory castable property limits
API RP 936 First Edition, October 1996	API RP 936 used the manufacturer's TDS as the basis for acceptable castable property limits. Some extensions to field collected properties allowed.
API RP 936 Second Edition, February 2004	API RP 936 used the manufacturer's TDS as the basis for acceptable castable property limits. Some extensions to field collected properties allowed.
API Standard 936, Third Edition, November 2008	TDS no longer used as the basis for acceptable property limits. CDSs were introduced with Annex C providing an example CDS format and guidelines for manufacturers to prepare CDS. Third Edition expanded CDSs to be applicable for <i>"any refractory material commonly used in or marketed to the refining and petrochemical industry."</i> Some extensions to field collected properties allowed.
API Standard 936, Fourth Edition, June 2014	Fourth Edition added expanded CDS guidelines in Annex B. Extensions to field collected properties generally revised to more stringent property limits.

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API Standard 936, Fifth Edition, March 2024	Extensions to field collected properties which is unchanged from Fourth Edition (Annex B).
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4.2 TDS Properties versus CDS Properties

Refractory castable TDSs are sales documents that describe a product's intended use and includes typical average properties and typical chemical composition. TDSs are not intended to be used for specification purposes.

CDSs, however are intended to be used for specification purposes. The property limits on CDSs are the critical limits that determine whether a refractory is acceptable or rejectable.

~~Existing API Standards require rejecting refractory castable in cases when quality control lab test results are outside compliance data sheet (CDS) limits. Rejecting castable or an already installed refractory lining can cause major problems such as project delays and re-work. API Standards do not offer other options to consider during these cases.~~

~~A group of SCRIM members collected castable test data from multiple sources including a variety of projects spanning over several years. The collected test data was compared to TDS advertised properties and CDS limits. One of the observations from this review is there are no existing guidelines or standards for setting CDS limits.~~

A comparison of TDS to CDS is shown in Table 2.

Table 2 - Comparison of TDS to CDS

Technical Data Sheet (TDS)	Compliance Data Sheet (CDS)
Properties on TDS are to be considered as typical AVERAGES	Properties on CDS intended to be "LIMITS"
Not intended for specification purposes	Intended for specification purposes
Typical disclaimers on TDS's: <ul style="list-style-type: none">– properties should not be used for specification purposes– properties should not be considered as guaranteed values– properties are not to be considered as a warranty or a guarantee– properties are subject to normal manufacturing variations– properties are subject to change without notice	Some manufacturers mention CDS limits based on "normal distribution with 95% confidence level"
Properties listed on TDS do not include metal fibers	Properties listed on CDS do not include metal fibers

4.3 Typical practice of castable lab testing and CDS usage

4.3.1 General

~~Castables and test samples shall be protected and not damaged during shipping and storage. As samples and materials are transferred from one party to another, they should be protected from damage, water, vibration and other detrimental factors. are usually not selected by the refractory contractor and may or may not be purchased by the refractory contractor. The chain of custody of a castable starts with the manufacturer and then custody is transferred to other parties between the manufacturing plant to the~~

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~~project site. Chain of custody is important to consider because the final product can be affected during manufacturing, packaging, shipping, handling and storage. Castables are typically packaged in moisture-proof bags that require careful handling and environmental controls during shipment and storage to prevent degradation. Also castables are labelled with date of manufacture because there is a limited shelf life of the castable.~~

4.3.2 Selection of refractory castable

It is common that the owner selects refractory materials however in some cases a Licensor or a separate entity can select the refractory. The owner may also have a list of pre-approved refractory products to allow some flexibility on the choice of castables for a specific location. If the refractory contractor selects a castable, then these selections typically require approval by the owner, project authorities, or licensor.

4.3.3 Purchaser Procurement of refractory castable

The purchaser responsibility for procurement of refractory castable is decided by the owner or by the project agreement. The refractory contractor may be designated as the purchaser however in some cases castable is purchased and shipped to the project site by other parties such as the owner, licensor or separate entity.

4.3.4 Refractory contractor installation

The castable eventually becomes under the custody and control of the refractory contractor, who mixes and installs the castable. API 936 assigns the refractory contractor as “accountable” for the final as-installed properties:

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

4.3.5 Material qualification testing

Material qualification testing is also called known as “Pre-Shipment Refractory Qualification Testing”. This step is intended to verify that the manufactured ~~batch (also called a~~ “production run”) of castable-refractory properties are within the allowable CDS limits before the castable-refractory is shipped to the project site. A portion of the manufactured batch is tested and then results sent to the purchaser and owner for review. This pre-shipment review allows either acceptance or rejection of the batch based on lab test results. The manufacturer should ensure that CDS data are based on as-manufactured material at manufacturer's shop.

Test labs for material qualification testing are either the manufacturer's test lab or an independent approved and qualified refractory material test lab. API 936 requires that lab mixed material qualification samples are prepared by following the procedures described in the Section “Forming of Refractory Test Specimens”.

Since publication of API 936, First Edition, refractory test labs have provided equipment and qualified personnel to mix castables in small batches and to either cast or ram samples into sample molds. API 936 has always required lab samples for gun castables to be gunned but allows casting or hand packing samples with approval by the owner. Gunned, ~~shotcreted and pumped lab-~~ prepared samples is are not common in labs due to complex equipment setup and skilled installers available in the lab. Qualification of pumped and shotcrete mockups and samples have always required a refractory contractor to provide equipment and skilled personnel to prepare samples.

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The process of material qualification testing has evolved since API 936 First Edition. Table 3 lists a summary of changes to lab sample preparation. API 936, Third edition changed the batch size mixed in the lab to require mixing "...*the entire selected container of refractory*". The purpose of mixing the entire container is ensure that the sample contains the fines and aggregate that will match the same fines/aggregate ratio of the production run. Larger gunned samples also require additional preparation and cutting for testing in the lab.

Reference API 936 for detailed qualification requirements, including the required number frequency of tests for each pallet of material.

Table 3 - Evolution of lab-prepared sample sizes and lab-prepared gunned samples

API 936 Edition, date of publication	Lab sample size	Lab prepared castables for gunning
API RP 936 First Edition, October 1996	No lab sample size requirements.	<i>"For gunned installations, refractory should be gunned or, alternatively, specimens may be hand packed subject to Owner's approval by the Owner of a suitable, product-specific correlation to gunned properties."</i>
API RP 936 Second Edition, February 2004	Same as First Edition	<i>"For gunned installations, refractory should be gunned or cast, alternatively specimens may be hand packed subject to prior approval by the Owner."</i>
API Standard 936, Third Edition, November 2008	<i>"the entire selected container of refractory should be mixed [in the lab]..."</i>	<i>"For gunned installations, refractory shallshould be gunned to produce a large panel. Specimens should be cut from the central portion of the panel (i.e. away from the edges). Alternatively, specimens may be cast or hand packed subject to Owner approval of a suitable, product specific correlation on the submitted product compliance datasheet to gunned properties supplied by the manufacturer."</i>
API Standard 936, Fourth Edition, June 2014	Same as the Third Edition	Same as the Third Edition
API Standard 936, Fifth Edition, March 2024	Same as the Third Edition	<i>"For gunned installations, refractory should-shall be gunned. Gunned samples should be made into a large panel with specimens cut from the central portion of the panel (i.e. away from the edges). Specimens may be cast or hand packed subject to Owner approval."</i>

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4.3.6 “As-installed” Production sample testing

The process of collecting samples at the job site (also referred to “as-installed” or “production samples”) and testing these samples has generally remained unchanged since API 936 First Edition.

The allowance for extending properties to account for field conditions has evolved since API 936, First Edition. API 936, Fourth Edition generally tightened the extended properties (See Table 7).

Table 4 shows how minimum acceptable refractory property values have evolved over several editions of API 936.

Table 4 - Evolution of API 936 extended minimum properties to account for as-installed field conditions

Physical property	First Edition, October 1996, Table 2 (Properties based to TDS)	Second Edition, February 2004, Table 2 (Properties based to TDS)	Third Edition, November 2008, Table 3 (Properties based to CDS)	Fourth Edition, June 2014, Table 3 (Properties based to CDS)	Fifth Edition, March 2024, Table 4 (Properties based to CDS)
Abrasion Loss Maximum	120%	120%	120%	110%	110%
CCS Minimum	80%	80%	80%	90%	90%
Density Maximum	+5 lb/ft ³ (+80 kg/m ³)	+5 lb/ft ³ (+80 kg/m ³)	+5 lb/ft ³ (+80 kg/m ³)	+5 lb/ft ³ (+80 kg/m ³)	+5 lb/ft ³ (+80 kg/m ³)
Density Minimum	-5 lb/ft ³ (-80 kg/m ³)	-5 lb/ft ³ (-80 kg/m ³)	-5 lb/ft ³ (-80 kg/m ³)	-5 lb/ft ³ (-80 kg/m ³)	-5 lb/ft ³ (-80 kg/m ³)
PLC Maximum	120%	120%	120%	110%	110%

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4.3.7 Comparison of lab-prepared samples to field collected samples

Extending property limits for production samples is necessary to account for differences between lab-prepared samples and field collected samples. A lab-prepared sample represents ideal and controlled conditions versus a project site where the castable is mixed in larger batch sizes, the job site installation process may be different than the lab process, and environmental conditions at the job site may be near the acceptable limits. Table 5 shows a side-by-side comparison of lab-prepared samples to field collected samples.

Table 5 – Comparison of lab-prepared samples to field collected samples

Material qualification samples prepared in test lab	Field collected “production” samples prepared at project site
Individual containers shipped to lab	Bags or supersacks shipped to a project site in pallet and truckload quantities
Labs are climate-controlled	Project site storage and climate control can be challenging, especially during extreme weather and in some cases storage, mixing and installation temperatures may be close to the upper or lower limit of acceptable range if achieved.
Dry material and water/liquid temperature easily controlled in a lab environment	Dry material and water/liquid temperature is challenging to control during extreme weather. During extreme weather, temperatures may be close to the upper or lower limit of acceptable range if achieved.
Dry material and water/liquid quantity accurately measured	Dry material bag weights are labeled on bags however dry material weights not consistently checked using scales. Water/Liquid quantity not measured during gunning.
Samples mixed in small batches using planetary mixers	Job site batches can be large such as 1,000 lb (454 kg) to 1,500 lb (680 kg) each using a variety of mixers.
Sample mixes are immediately cast or rammed into molds	Field mixed batches can take several minutes to place after mixing
Majority of lab mixed samples are cast or rammed	Samples are prepared via casting, ramming, gunning, pumping and shotcrete
Stainless steel fibers are rarely added to lab-prepared mixes	Common in petrochemical projects to add stainless steel fibers to mixes
Samples are tested immediately after ambient cure	Can be several days to several weeks between sample ambient curing and sample testing. Samples shall be stored, packaged and shipped to lab.
Ambient curing of sample in climate-controlled lab	Ambient cure conditions can be challenging during extreme weather and in some cases ambient curing conditions at project site may be close to the upper or lower limit of acceptable range.

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4.3.8 Acceptance/Rejection Criteria

If any of the properties measured from a production sample falls outside of the CDS limits and outside of the Table 4 with extended properties, then the area that the sample represents “~~shall~~~~should~~ be cause for rejection”.

API 936 Acceptance/Rejection Criteria: *For each [production] sample, the average physical properties of as-installed tests ~~should~~~~shall~~ meet the criteria defined in [Table with extended properties]. Failure to meet the preceding criteria ~~should~~~~shall~~ be cause for rejection of the area of the lining that the [production] sample represents.*

4.3.9 Acceptance Criteria at Each Stage of Work

Test results shall meet the following criteria at each stage of the work.

- a) PresShipment Testing = compliance data values with no tolerance.
- b) Applicator Prequalification testing = compliance data values with no tolerance.
- c) Mockup = compliance data values with no tolerance.
- d) Production Samples = compliance data values with acceptable tolerance per API 936, Table 4.

4.4 Factors Affecting Production Sample Results

The following is a list of factors which have been known to affect the properties of refractories. This list is not intended to cover every possible variable that can affect refractory properties but is intended to help identify where quality checks could be performed if a sample does not meet CDS values.

- a) Refractory material issues – such as cement problems, contamination in the manufacturer facility, raw material issues, maldistribution from pallet to pallet or bag to bag.
- b) Material which has been exposed to weather, rain, cold prior to mixing and has been inadvertently wetted or damaged.
- c) Quality of mixing water; contamination, temperature, pH, dissolved solids, hydrocarbon, and other contaminants.
- d) Ambient conditions during mixing and curing, too hot, too cold, humidity, rain, temperature of the equipment.
- e) Contamination during mixing from previous mixing – partially set refractory, other refractory
- f) Mixing setup, mixer type, mixing effectiveness, paddle wear, mixing speed, mix size vs mixer capacity.
- g) Gunning setup when pneumatic or wet gunning, air pressures, air flow rates, air humidity, water/liquid pressures, mixing, line size, nozzle type, valve type.
- h) Skill of the installer(s), including mixing, vibration, ramming, nozzleman performance, water / liquid addition control, mixing times.
- i) Time between mixing completed (material leaving the mixer) and installation completed.
- j) Location and access during installation; for example, restricted access during gunning, casting large sections in one pour, gunning overhead.

5 Castable Test Data Review

~~A group of SCRM members collected castable~~ Castable test data (included in Annex A) ~~was collected from multiple sources including a variety of projects spanning over several years. -with the purpose of comparing qualification tests with production tests. The collected test data was compared to TDS advertised properties and CDS limits. One of the observations from this review is there are no existing guidelines or standards for setting CDS limits. A large set of castable test data (test data listed in Annex A) from a variety of sources was reviewed by a volunteer group of SCRM members.~~ More than 500 results across a range of material categories and manufacturers were reviewed. All manufacturer brand names, test lab, and project details were omitted from the data set. Castables were separated into five categories (see Table 6).

Table 6 - Castable test data collected to review against CDS and TDS properties

Castable Category	Density of castable after firing to 1500 °F (815 °C)	
	US Customary	SI
Lightweight [LWC]	50-95 lb/ft ³	801 – 1522 kg/m ³
Medium weight [MWC]	95-125 lb/ft ³	1522 – 2002 kg/m ³
Medium weight erosion-resistant [MWERC]	100-150 lb/ft ³	1602 – 2403 kg/m ³
Dense [DC]	150-185 lb/ft ³	2403 – 2963 kg/m ³
Extreme erosion-resistant (typically rammed) [ERC]	greater than 175 lb/ft ³	>2803 kg/m ³

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6 Results

6.1 General

The results of property data collected was analyzed for variability and inconsistency between qualification testing and production sample testing, and in some cases also compared to the “Acceptable Results for Testing of As-Installed Refractories” values listed in Table 4 of API 936 5th edition. Table 4 of API 936 is hereafter copied as Table 7. The results of property data collected will be compared to the “Range of Acceptable Results” values listed in Table 7. API 936 requires that the average properties of each sample “*should-shall* meet the criteria defined in Table 4”.

Table 8 and Figure 1 show abrasion test results. Table 9 and Figure 2 show cold crushing strength test results. Table 10 and Figure 3 show density test results. Table 11 and Figure 4 show permanent linear change test results. These tables and figures show variability that is produced when testing the various classification types of refractory materials. Thus, if the mean or average value of the test data is used as a basis for the material, the range or variation above or below the average is shown.

Table 7 – Physical Properties and Acceptable Results for Testing of As-installed Refractories

Physical Property	Range of Acceptable Results ^a	
	Minimum	Maximum ^b
Abrasion loss	None	110 %
Cold crushing strength	90 %	None
Density	–80 kg/m ³ (–5 lb/ft ³)	+80 kg/m ³ (+5 lb/ft ³)
Permanent linear change	Zero ^c	110 %
<p>a Average of all specimen test results per sample. The minimum and maximum values are based upon the physical property value(s) listed on the manufacturer’s compliance datasheet or other value in accordance with 5.1.2</p> <p>b When the manufacturer’s compliance datasheet indicates a range for the physical property, the applicable limits <i>should-shall</i> apply to the upper and lower values of the compliance datasheet range.</p> <p>c Zero means 0.00 % shrinkage. Products that have a positive PLC tested after 1500 °F <i>shall</i> not be used unless approved by the owner.</p>		

6.2 Abrasion loss

6.2.1 General

Table 8 shows the summary of abrasion data by castable category and Figure 1 shows this data in chart form.

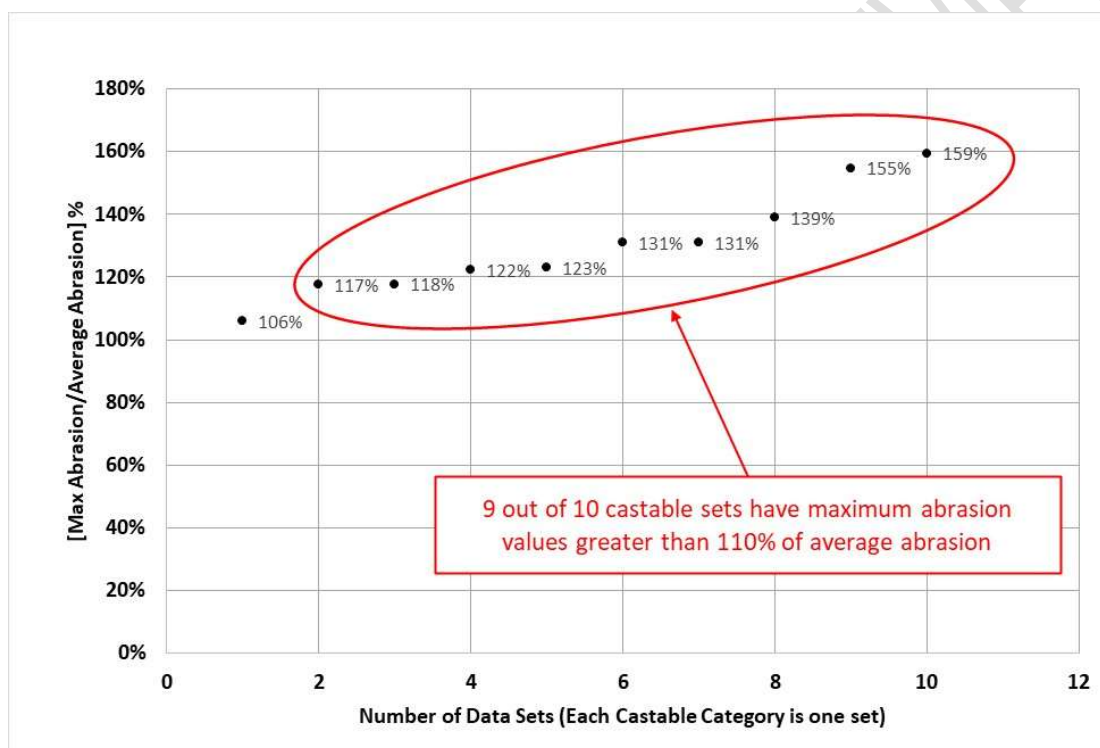
Table 8 – Summary of Abrasion loss by Category

Abrasion loss after firing to 1500°F (cc)					
Castable Category	Min Abrasion	Average Abrasion	Max Abrasion	Abrasion Range (Max-Min)	Max Abrasion/Average Abrasion (%)
(ERC1) Material Qualification	2.0	2.3	2.5	0.5	106%
(ERC1) Production	2.0	2.6	4.2	2.2	159%
(MWERC1) Material Qualification	6.5	8.8	10.3	3.8	118%
(MWERC1) Production	6.5	8.5	10.5	4.0	123%
(MWERC2) Material Qualification	4.3	6.3	8.3	4.0	131%
(MWERC2) Production	8.8	9.7	11.4	2.6	117%

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(MWERC3) Material Qualification CAST ONLY	6.7	8.6	11.2	4.5	131%
(MWERC3) Production	8.8	12.9	20.0	11.2	155%
(MWERC4) Material Qualification	7.3	9.4	11.5	4.2	122%
(MWERC4) Production	8.5	10.6	14.7	6.2	139%

Figure 1 – Chart showing maximum abrasion/average abrasion by category



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6.2.2 Observations

6.2.2.1 The range of abrasion test results for medium weight erosion resistant castable material qualification is 6.7cc to 12.7cc, which is a range of 7.0cc.

6.2.2.2 The range of abrasion test results for medium weight erosion resistant castable material production samples is 8.8cc to 20.0cc, which is a range of 11.2cc.

6.2.2.3 The range of results is 11.2cc for production sample testing, and only 7.0cc for qualification test results.

6.2.2.4 The highest loss is 12.7cc for prequalification versus 20.0cc for production sample test results.

6.2.2.5 Most of the castable categories (9 out of 10 refractory materials) have abrasion values that exceed the criteria of "maximum abrasion within 110% of the average". API 936 has limited the "range of acceptable results" to within 110% of the average since the Fourth Edition have a variability of more than 110% of the average.

6.2.2.6 Most of the castable categories (7 out of 10) have abrasion values that exceed the criteria of "maximum abrasion within 120% of the average". API 936 limited the "range of acceptable results" to within 120% of the average during the First through Third Editions have a variability of more than 120% of the average.

6.3 Cold Crushing Strength (CCS)

6.3.1 General

Table 9 shows the summary of CCS data by category and Figure 2 shows this data in chart form.

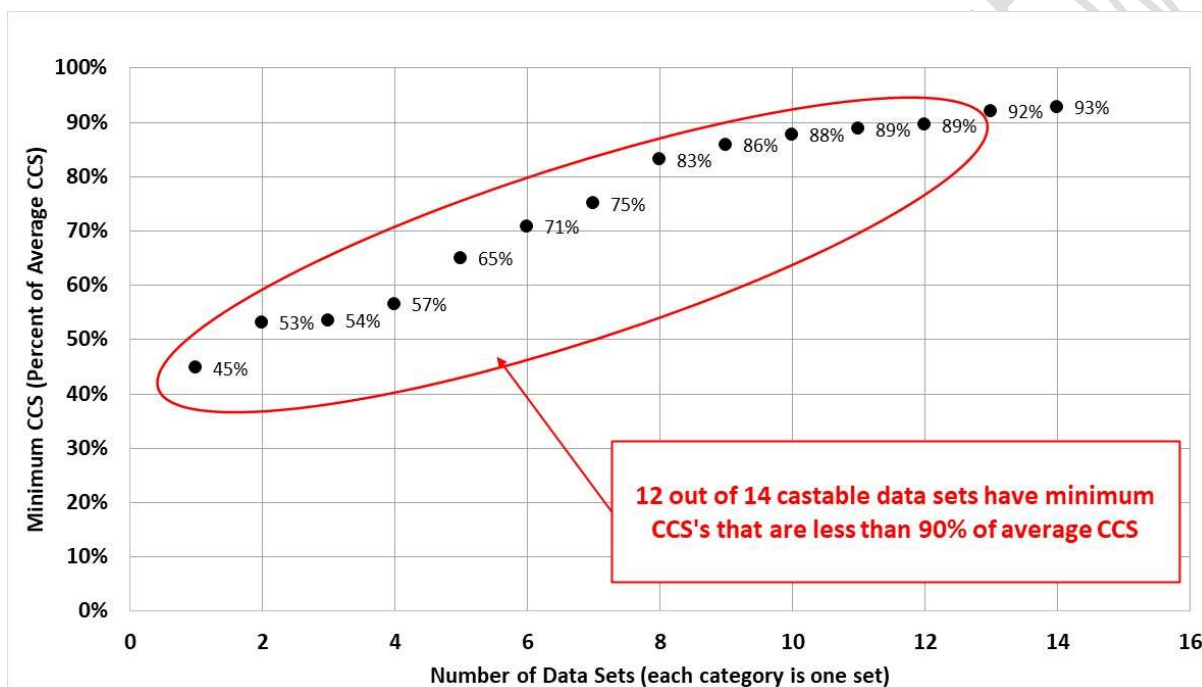
Table 9 – Summary of Cold Crushing Strength by category

Cold Crushing Strength (psi) after firing to 1500°F					
Castable Category	Min CCS	Average CCS	Max CCS	Minimum CCS Percent of average	CCS Range (Max-Min)
(MWC1) Material Qualification	2798	3042	3202	92%	404
(MWC1) Production	1613	3605	5628	45%	4015
(DC1) Material Qualification	6506	12,244	15,641	53%	9135
(DC1) Production	5036	8905	14,087	57%	9051
(LWC1) Material Qualification	1254	2343	4830	54%	3576
(LWC1) Production	1704	2407	3351	71%	1647
(MWERC3) Material Qualification	10,537	12,683	14,884	83%	4347
(MWERC3) Production	6371	8496	11,322	75%	4951
(ERC1) Material Qualification	21,576	24,113	25,000	89%	3424
(ERC1) Production	14,767	22,737	29,621	65%	14854
(MWERC4) Material Qualification	8603	10,030	11,706	86%	3103

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(MWERC1) Material Qualification	8160	9195	10,846	89%	2686
(MWERC2) Material Qualification	10,484	11,952	14,076	88%	3592
(MWERC2) Production	9209	9920	12,721	93%	3512

Figure 2 – [Minimum Cold Crushing Strength (CCS)/Average CCS] Percent



6.3.2 Observations

6.3.2.1 ~~Most of the castable categories (12 out of 14) have minimum CCS values that fall below the criteria of “minimum CCS above 90% of the average”. API 936 requires CCS values to be at least 90% of the average since the Fourth Edition have variability of greater than -10% from the average.~~

6.3.2.2 ~~Half of the castable categories (7 out of 14) have minimum CCS values that fall below the criteria of “minimum CCS above 80% of the average”. API 936 has required CCS values to be at least 80% of the average during the First through Third Editions have variability of greater than -20% from the average.~~

6.4 Density

6.4.1 General

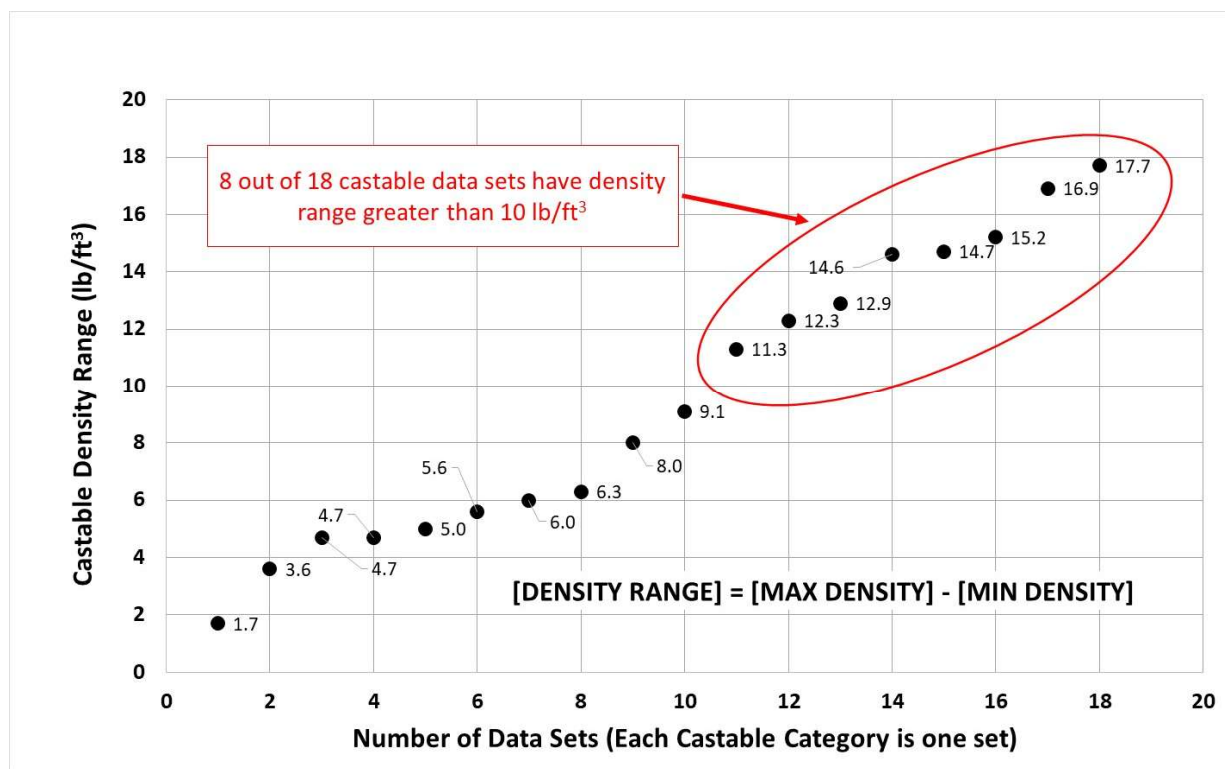
Table 10 shows the summary of density values by category. Figure 3 shows density range data in chart form.

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Table 10 - Summary of Density by category

Density* (lb/ft³) after firing to 1500°F						
Castable Category	Min Density	Average Density	Max Density	CDS Limit Min or Max Density	CDS Limit - Average Density	Density Range (Max-Min)
(ERC1) Material Qualification	180.4	181.0	182.1	186	5.0	1.7
(ERC1) Production	171.5	180.8	184.4	186	5.3	12.9
(MWC1) Material Qualification	99.7	103.0	104.4	105	2.0	4.7
(MWC1) Production	96.2	105.8	111.4	105	-0.8	15.2
(MWERC2) Material Qualification	129.0	130.5	132.6	136	5.5	3.6
(MWERC2) Production	127.3	128.7	132.0	136	7.3	4.7
(DC1) Material Qualification	160.0	162.9	165.6	180	17.1	5.6
(DC1) Production	147.3	155.5	165.0	180	24.5	17.7
(LWC2) Material Qualification	80.0	82.2	85.0	98	15.8	5.0
(LWC2) Production	77.0	83.7	91.7	98	14.3	14.7
(MWERC1) Material Qualification	137.7	139.9	144.0	125	14.9	6.3
(MWERC1) Production	133.1	138.6	142.2	136	2.6	9.1
(MWERC3) Material Qualification CAST only	110.0	114.0	118	117	3.0	8.0
(MWERC3) Production	105.0	107.6	111.0	117	9.4	6.0
(LWC1) Material Qualification	71.0	76.3	85.6	78	1.7	14.6
(LWC1) Production	72.6	79.4	84.9	80	0.6	12.3
(MWERC4) Material Qualification	107.2	112.9	124.1	114	1.1	16.9
(MWERC4) Production	104.1	107.4	115.4	114	6.6	11.3
*NOTE: For castable samples containing stainless steel fibers, the density was adjusted to the "no-fibers" density						

Figure 3 - Chart of Density ranges (Max Density – Min Density)



6.4.2 Observation

API 936 Table 4, Note (a) shows that density shall be within ± 5 lb/ft³ (± 80 kg/m³) of the “average of all specimen test results per sample”, and this has been the case for every edition of API936. Therefore, the maximum allowable range of allowable densities ~~should be~~ 10 lb/ft³ (160 kg/m³). Summary of the density data shows that 8 out of 18 categories do not meet a density range limit of 10 lb/ft³ (160 kg/m³).

6.5 Permanent Linear Change (PLC)

6.5.1 General

Table 11 shows the summary of PLC values by category. Figure 4 shows PLC data in chart form.

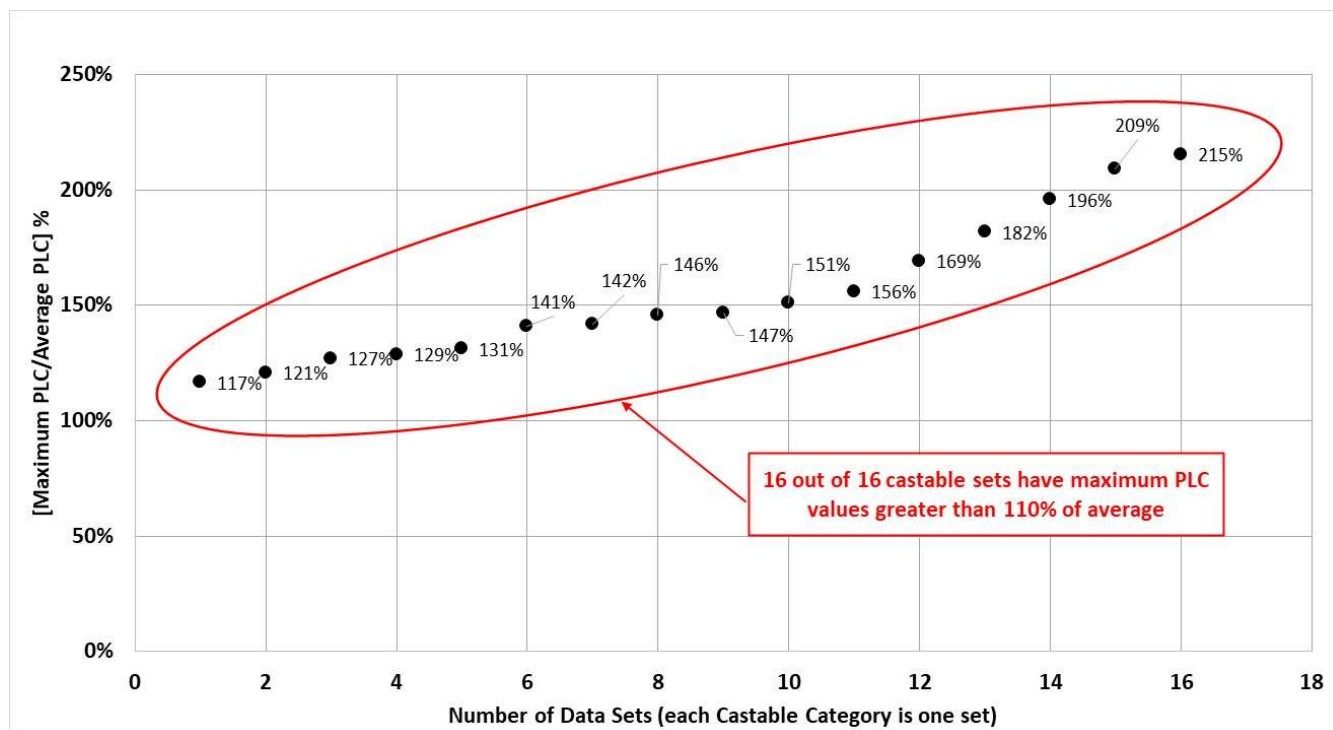
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Table 11 – PLC by category

Permanent Linear Change (%) Green-to-Fired¹					
Castable Category	Min PLC	Average PLC	Max PLC	PLC Range (Max-Min)	Maximum PLC/Average PLC
(MWERC4) Material Qualification	-0.12	-0.20	-0.33	-0.21	169%
(MWERC4) Production	-0.14	-0.17	-0.20	-0.06	117%
(ERC1) Material Qualification	-0.30	-0.36	-0.43	-0.13	121%
(ERC1) Production	-0.29	-0.38	-0.50	-0.21	131%
(MWC1) Material Qualification	-0.12	-0.14	-0.18	-0.06	129%
(MWC1) Production	-0.17	-0.25	-0.53	-0.36	209%
(MWERC1) Material Qualification	-0.21	-0.33	-0.48	-0.27	146%
(MWERC1) Production	-0.23	-0.30	-0.42	-0.19	142%
(MWERC2) Material Qualification	-0.15	-0.20	-0.30	-0.15	147%
(MWERC2) Production	-0.13	-0.23	-0.29	-0.16	127%
(LWC1) Material Qualification	-0.08	-0.18	-0.32	-0.24	182%
(LWC1) Production	-0.10	-0.22	-0.34	-0.24	156%
(MWERC3) Material Qualification	-0.07	-0.19	-0.40	-0.33	215%
(MWERC3) Production	-0.18	-0.28	-0.39	-0.21	141%
(DC1) Material Qualification	-0.05	-0.12	-0.24	-0.19	196%
(DC1) Production	-0.04	-0.13	-0.20	-0.16	151%
¹ Green-to-Fired: Percent change in length of refractory specimen after firing to 1500°F and cooling to room temperature while following API 936 5 th Edition Section 8.1.4 PLC testing protocol.					

Figure 4 – Chart [maximum PLC/Average PLC] Percent

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6.5.2 Observations

6.5.2.1 All of the castable categories (16 out of 16) have maximum PLC values that ~~are above the criteria~~ “maximum PLC below 110% of the average have variability of greater than 10% of the average”. API 936 has required PLC values to be 110% of the average or lower since the Fourth Edition.

6.5.2.2 Most of the castable categories (15 out of 16) have maximum PLC values that ~~are above the criteria of~~ “maximum PLC below 120% of the average have variability of greater than 20% of the average”. API 936 required PLC values to be 120% of the average or lower during the First through Third Editions.

6.6 Other observations of collected data

For some castables there were differences observed between cast properties and gunned properties for the same product. It is common that castables intended for gunning are typically cast in a test lab during material qualification testing.

Figure 5 shows that castable medium weight erosion resistant castable 3 (MWERC3), the gunned abrasion loss was generally greater than the cast abrasion loss.

Figure 5 – MWERC3 Gunned abrasion loss compared to cast abrasion loss

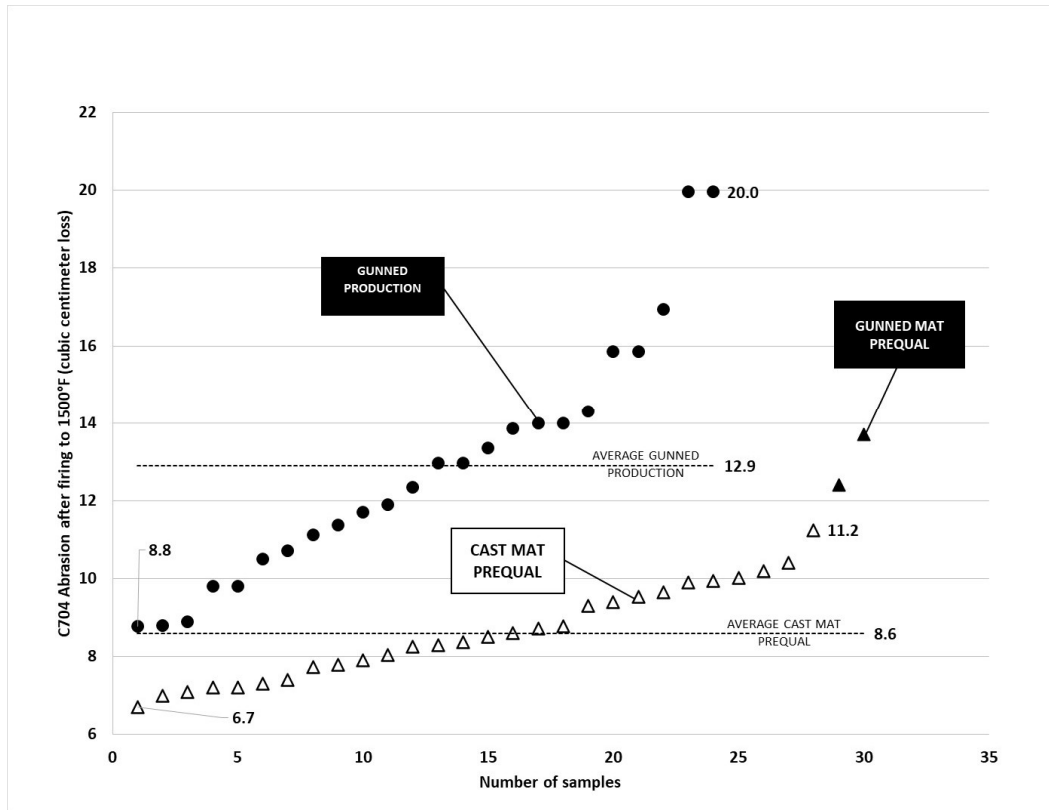


Figure 6 shows that castable MWERC3, the gunned CCS was generally lower than the cast CCS.

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Figure 6 – MWERC3 Gunned CCS compared to cast CCS

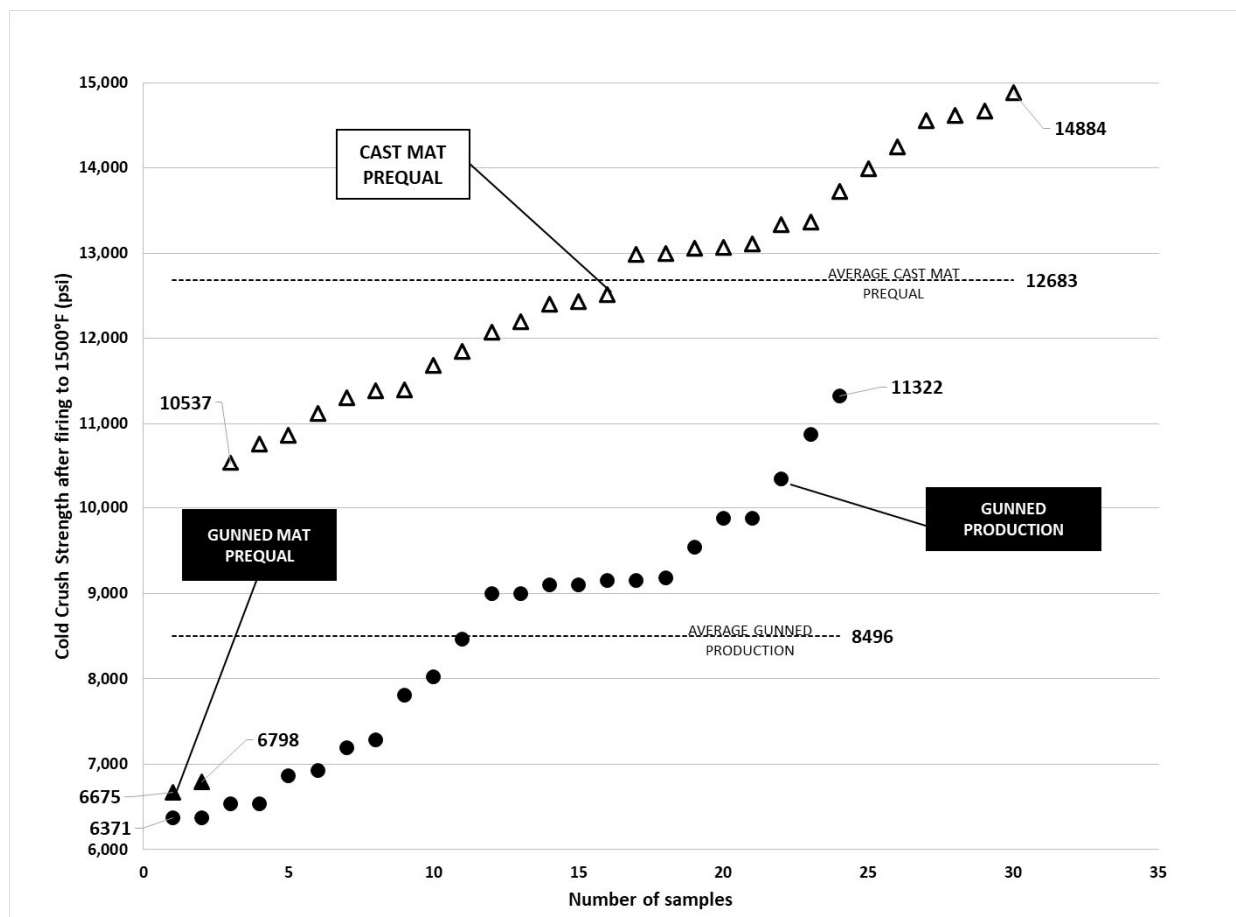
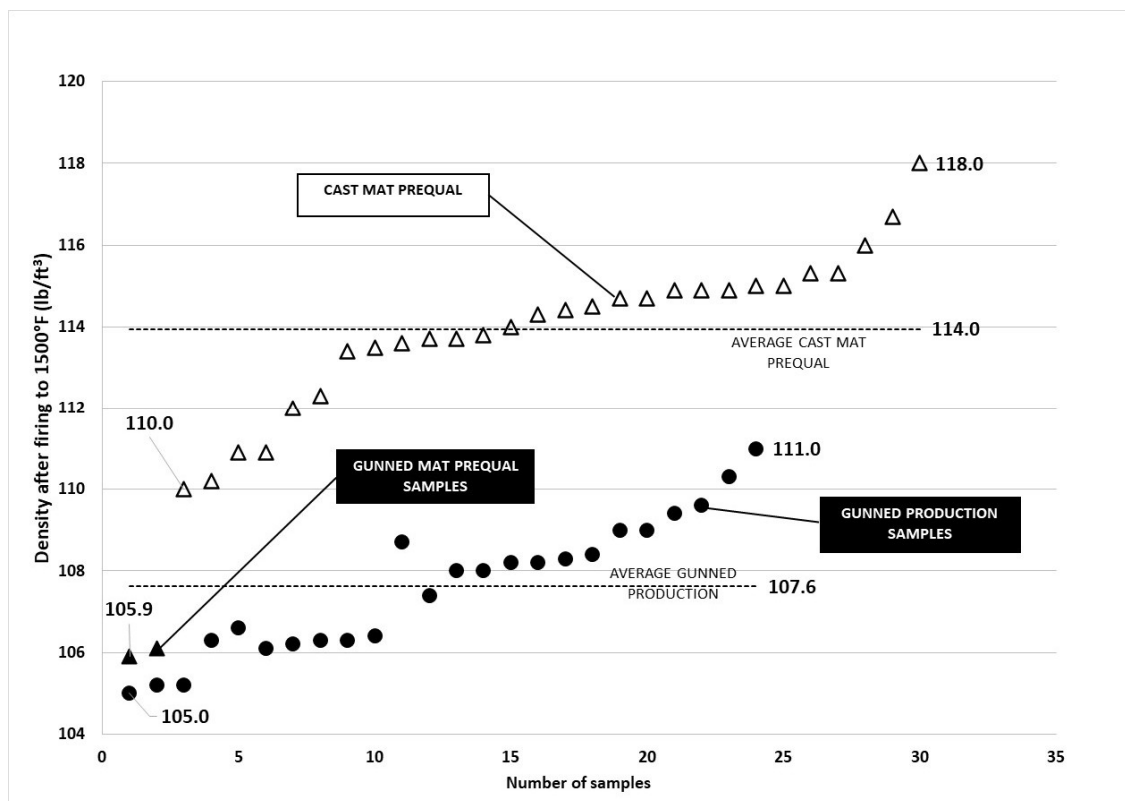


Figure 7 shows that castable MWERC3, the gunned density was generally lower than the cast density.

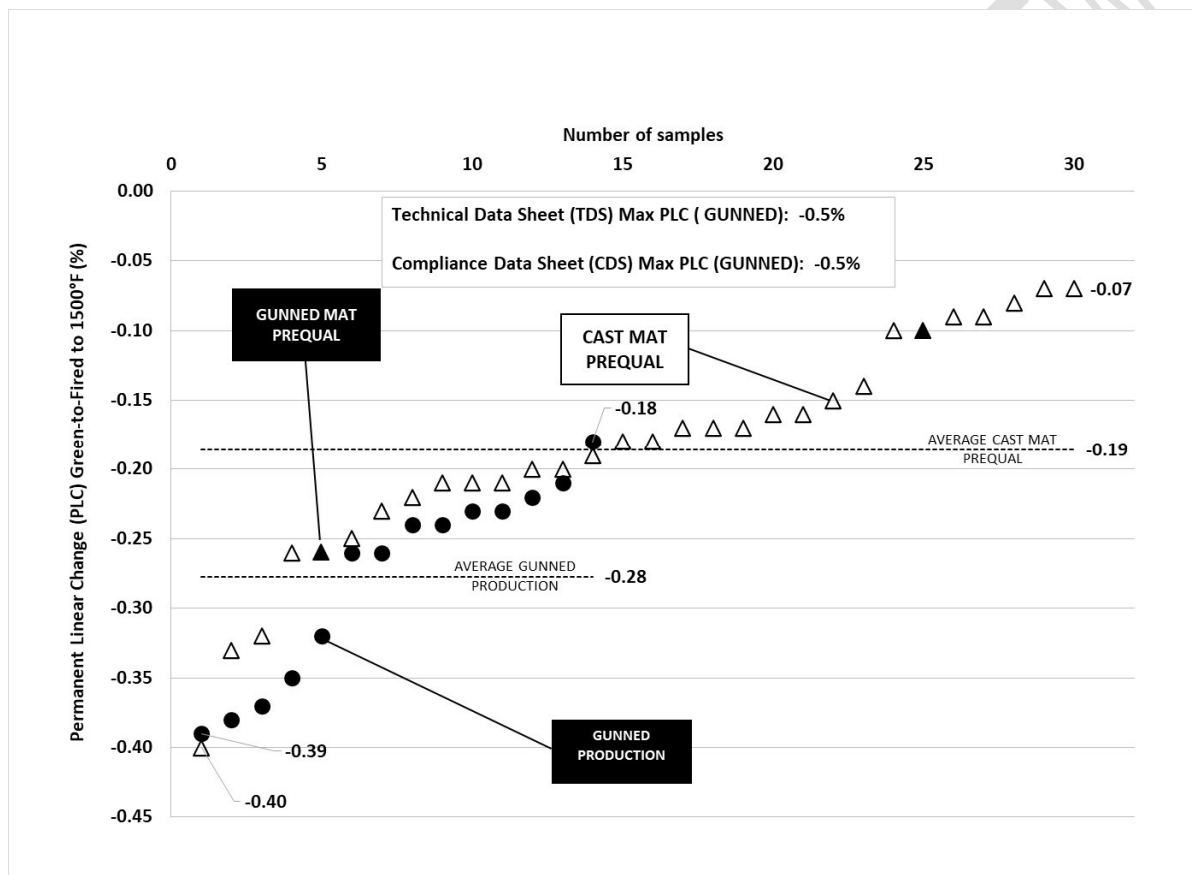
Figure 7 – MWERC3 Gunned density compared to cast density



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Figure 8 shows that castable MWERC3, the gunned PLC was generally greater than the cast PLC.

Figure 8 – MWERC3 Gunned PLC compared to cast PLC



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7 Guidelines for Refractory Manufacturers

7.1 API 936 requires refractory manufacturers to develop and manage CDSs for their products. The following guidelines are recommended for refractory manufacturers:

7.2 Once a batch of material has been shipped and CDS has been issued, the CDS should ~~should~~ **shall** not be changed.

7.3 If properties do not meet the CDS, investigation should ~~should~~ **shall** be performed to understand the cause.

~~API 936 requires refractory manufacturers to develop and manage CDSs for their products. The following guidelines are recommended for refractory manufacturers:~~

7.17.4 Each CDS should include the date of issue, the revision number and if production data are considered or not. Each CDS should include the date of issue with revision number.

7.5 If a CDS is issued for a specific project or time frame, this should be stated on the CDS.

7.27.6 If a refractory formulation, raw material, manufacturing process or other critical parameter is changed, ensure that the properties are still in compliance with the CDS. If properties change, issue a revised CDS for review and approval by the owner prior to manufacturing a batch of material that does not have the properties that the owner and contractor are expecting to receive.

7.37.7 Water ~~/-Liquid~~ curves range should be developed for materials and water range clearly specified on the CDS.

7.47.8 If any special specimen preparation instructions are necessary, manufacturers should provide these instructions to the installation contractor and refractory test lab. For example, some castables intended for gunning or shotcrete may require special instructions for preparing smaller lab-sized samples. Some rammed castables may require special instructions to provide the proper finished surface of the specimens.

7.5 API 936 Table 4 should not be used to initially develop CDS limits. Per Section 6 of this document, the range of actual properties collected exceeded the "range of acceptable limits" currently shown in API 936 Table 4.

7.67.9 If an existing project or owner specification has castable property limits, these limits should be sent to the manufacturer for review. ~~to confirm that the selected castables range of properties will not exceed specified limits.~~

7.77.10 CDS limits set by manufacturers that include test result data and properties measured from field collected samples (production samples) should be kept separate from as-manufactured test

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~~result data. CDS limits set by manufacturers should include test result data and properties measured from field collected samples (production samples) when this data is available.~~

~~7.8 A data set of field collected test results for each product should be stored and summarized in a table and available for review upon request.~~

~~7.9.7.11 If field-collected data falls outside installation as installed CDS limits, then further review is necessary to determine if the castable material was packed, shipped, transported, stored, installed, dried-out and tested following manufacturer's instructions properly. If this review concludes that there were no deviations from manufacturer's instructions, then the material shall be discarded unless the owner approves that the revised properties are acceptable. If this review concludes that there were no deviations from manufacturer's instructions, then it is possible that installation CDS limits were set too narrow.~~

~~7.12 Any non-conforming material shall only be accepted with explicit review and approval from the owner.~~

~~7.407.13 Manufacturers are encouraged to request and receive field collected test data from and only retain the minimum information needed to track properties. The project location, installation contractor, and test lab should not be tracked.~~ Minimum test data information is listed in Table 12.

~~7.14 If any specific sample preparation or curing conditions are required, identify these on the CDS.~~

~~7.417.15 If any test results are time-sensitive for the material, for example PLC should be tested with a specified period of time after the sample has been made, the manufacturer should include this information on the CDS. Once a batch of material has been shipped and CDS has been issued, the CDS should not be changed. If properties do not meet the CDS, investigation should be performed to understand the cause.~~

Table 12 - Minimum refractory castable test data information required

Refractory castable test data information required (each sample)
Product Name
Date sample prepared
Type of sample (lab prepared material qualification/applicator qualification/production)
Installation process: casting, gunning, ramming, shotcrete, hand packing, pumping
<u>Equipment type (mixer – paddle, planetary), (gun – pressure chamber, open top)</u>
Product date of manufacture, batch number or lot number, pallet number
Metallic Fiber addition, % added by weight <u>if specified</u>
Water (or liquid) mixed, %
Temperatures: dry material, water <u>/ liquid</u> , mix temperature, ambient temperature
Mixing time

Test results (Density, PLC, abrasion, CCS), date tested

8 Guidelines for Owners

8.1 When specifying castables and developing specifications, owners should use the most recent version of CDS and request field collected test data rather than relying on TDS properties. When selecting castables, request the most recent version of CDS and request field collected data from manufacturers to review the range of actual QC properties. The owner should clarify with the manufacturer whether the CDS data included as-installed results or not.

8.2 Prior to installation, Owners are should pre-qualify the installers and equipment setup for gunning castables using the same installation method and equipment intended for the project site, which will also verify that the material is performing as expected when gunned. This will provide the most representative test results compared to samples that were mixed, cast and tested and cast in a lab.

~~8.3 A water curve should be reviewed as part of the qualification test data. The water curve will help to identify water sensitivity and normal range of properties for that specific refractory material.~~

~~8.3 For vibration casting and pump-cast projects, mockups should be used to simulate the project site conditions. This enables the Owner to verify and qualify the castables used as well as installation methodologies. It also provides valuable test data, while also providing valuable test data.~~

~~8.4 During a mock-up it is recommended to prepare samples mixed at both minimum and maximum allowed water-/liquid ratios. This provides information about the effect of water / liquid content on properties as well as flow, response to vibration, the effects of steel fiber additions, and set times. Prepare samples that were mixed at minimum and maximum allowed water contents. This will provide information on QC properties with respect to water addition, information about how the mixed castable flows, response to vibration, the effects of adding steel fibers, and set time.~~

8.5 If material qualification results fall outside CDS limits, the manufacturer, inspector and contractor should investigate the causes and offer recommendations to the owner. ~~The owner can consider the revised refractory properties and whether they are fit for purpose and meet the design criteria, and if the properties are accepted then the deviation should be formally documented. The deviation, or non-conformance, should be shared with the manufacturer and contractor.~~

~~8.6 If field collected sample results are out of compliance, owners can require contractor and manufacturer to perform an investigation to define the reasons. A visual and hammer test of the installed lining should be performed and sampling the installed lining for additional testing could be necessary.~~

~~8.7~~ 8.6 Owners should ~~participate in sharing field collected test data with manufacturers to add to manufacturers data sets~~ ensure that test results are shared with the manufacturer to provide historical

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data for creating compliance data sheets. This extra test data will help manufacturers set realistic as-installed range and CDS limits for their products.

9 Guidelines for Refractory Contractors

9.1 The material purchaser should request the current CDS from the manufacturer prior to placing an order. This may, or may not, be the contractor. If the purchaser is not the contractor, the purchaser should issue the CDS to the contractor.

9.2 Contractors should request mixing and installation instructions, sample preparation, curing and dryout instructions from manufacturers and familiarize themselves with the products before the project starts. Each product may have unique characteristics that should be taken into consideration during installation activities and while collecting samples.

9.3 During material qualification testing, manufacturers should prepare samples at varying conditions (such as minimum and maximum mix water, minimum and maximum gunning air pressure) to allow testing a range of properties, to ensure that the maximum and minimum range is included in the contractor installation procedure.

9.4 During mockup and production, contractor should consider creating additional samples, so that retesting may be performed if a test result does not comply with the CDS.

9.5 Contractors should maintain accurate records of mixing and installation and handling of field collected samples. Maintain records of site conditions during installation and note unusual castable characteristics such as inconsistency between batches, high rebound, long set time, and flash setting. If there were unusual characteristics observed during castable installation, then it is possible that QC test results may be affected.

~~9.19.6~~ If the as-installed sample test results do not meet the ~~compliance data sheet~~CDS values, a deviation or non-conformance should be issued to the ~~owner and shared with the manufacturer~~contractor..

9.7 Any non-conforming material shall only be accepted with explicit review and approval from the owner.

~~9.29.8~~ If the as-installed sample test results do not meet the CDS values, the contractor should assist in the investigation to identify the causes and offer recommendations to the owner for path forward.

~~9.3 Contractors shall request mixing and installation instructions from manufacturers and familiarize themselves with the products before the project starts. Each product may have unique characteristics that should be taken into consideration during installation activities and while collecting samples.~~

~~9.49.9~~ Refractory contractors should send field test results to manufacturers to include in the data set for evaluating CDS limits.

~~9.51.1 Contractors should maintain accurate records of mixing and installation and handling of field collected samples. Maintain records of site conditions during installation and note unusual castable characteristics such as inconsistency between batches, high rebound, long set time, and flash setting.~~

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~~If there were unusual characteristics observed during castable installation, then it is possible that QC test results may be affected.~~

~~9.6 During mock-up or qualification test, contractors should prepare samples at varying conditions (such as minimum and maximum mix water, minimum and maximum gunning air pressure) to allow testing a range of properties.~~

~~9.71.1 The material purchaser should request the current CDS from the manufacturer prior to placing an order. This may, or may not, be the contractor. If the purchaser is not the contractor, the purchaser should issue the CDS to the contractor.~~

10 Guidelines for Refractory Testing Laboratories

10.1 Test lab shall follow the manufacturer's mixing and installation procedures to prepare samples. If the product is intended to be gunned, wet gunned (shotcreted), or pumped, the manufacturer may have special procedures for preparing small batches that may be cast into molds.

10.2 If the project requires compliance to CDS limits, the lab report should ~~only use CDS limits provided by the material purchaser. The report which~~ CDS version/revision number ~~should be specified on lab reports was used for acceptance.~~ CDS values should be included on the lab report for comparison to test results. ~~If a result is not compliant, it should be identified on the lab report.~~

10.3 If data is questionable or if there were any unusual observations during mixing, setting and preparation of samples, the lab should note this on the report. ~~inform the material purchaser.~~

10.4 Test reports should be prepared with each refractory manufacturer on a separate report page. This allows for easier sharing of test data with manufacturers, without sharing competitor data.

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Annex A (informative)

Tabulated Castable Test Data

Tables A.1, A.2, A.3, A.4, A.5, A.6, A.7, A.8 and A.9 are tabulated test results from various classifications of refractory materials, with maximum, minimum and average shown for various sets of data.

[C]	CAST: Sample was prepared by casting into a mold such as a shoebox
[G]	GUN: Sample was prepared by gunning, typically gunned into a wire mesh basket
[R]	RAM: Sample was prepared by ramming into a mold such as a bar, cube or plate
[MQ]	MATERIAL QUALIFICATION (see material qualification testing): Sample was prepared and ambient cured in a lab.
[P]	PRODUCTION SAMPLE: Sample was prepared and ambient cured during field installation activities.

Table A.1 – Lightweight Castable 1 (LWC 1)

Castable Category	Application Method CAST [C] Gun [G] Ram [R]	Material Qualification [MQ] or Production [P]	Stainless Fiber Needles %	Density (lb/ft³)			Cold Crushing Strength [CCS] (psi)		Permanent Linear Change [PLC] (%)	
				Fired Temp 1500°F			Fired Temp 1500°F		Fired Temp 1500°F	
				[MQ]	[P]	[P] (adjusted to "no-fibers")	[MQ]	[P]	[MQ] (Green to Fired)	[P] (Green to Fired)
LIGHTWEIGHT CASTABLE 1 (LWC1)										
LWC1 TDS	[C]		0%	68 to 78	68 to 78		2300 to 4000	2300 to 4000	-0.30%	-0.30%
LWC1 TDS	[G]		0%	80	80		2400	2400	-0.30%	-0.30%
LWC1 CDS	[C]		0%	70 to 78	70 to 78		1200 min	1200 min	-0.40%	-0.40%
LWC1 CDS	[G]		0%	75 to 85	75 to 85		1200 min	1200 min	-0.40%	-0.40%
			Maximum	85.6	87.1	84.9	4830.0	3351.0	-0.32	-0.34
			Average	76.3	80.6	79.4	2416.0	2407.1	-0.18	-0.21
			Minimum	71.0	74.5	72.6	1254.0	1704.0	-0.08	-0.10
LWC1-1	[C]	[MQ]	0%	71.1			1851			
LWC1-2	[G]	[MQ]	0%	77.3			2060		-0.21	
LWC1-3	[G]	[MQ]	0%	81			2902		-0.2	
LWC1-4	[G]	[MQ]	0%	79.1			3643		-0.23	
LWC1-5	[G]	[MQ]	0%	78.8			3102		-0.27	
LWC1-6	[G]	[MQ]	0%	76.7			2209		-0.19	
LWC1-7	[G]	[MQ]	0%	81.8			3396		-0.19	
LWC1-8	[G]	[MQ]	0%	77.7			1637		-0.22	
LWC1-9	[G]	[MQ]	0%	79.9			2066		-0.2	
LWC1-10	[G]	[MQ]	0%	81.2			3127		-0.17	
LWC1-11	[G]	[MQ]	0%	81.8			2849		-0.26	
LWC1-12	[C]	[MQ]	0%	74.3			3177		-0.22	
LWC1-13	[G]	[P]	3%		86.5	84.3		2648		-0.18

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LWC1-14	[G]	[P]	3%		83.8	81.7		2714		-0.13
LWC1-15	[C]	[P]	3%		76.6	74.6		2168		-0.17
LWC1-16	[C]	[P]	3%		76.4	74.4		2232		-0.2
LWC1-17	[G]	[MQ]	0%	82.1			3114		-0.16	
LWC1-18	[G]	[MQ]	0%	83.8			3944		-0.2	
LWC1-19	[G]	[MQ]	0%	82.7			3653		-0.24	
LWC1-20	[G]	[MQ]	0%	83.6			3156		-0.18	
LWC1-21	[G]	[MQ]	0%	85.6			4284		-0.15	
LWC1-22	[G]	[MQ]	0%	83.2			4478		-0.2	
LWC1-23	[G]	[MQ]	0%	84.4			3133		-0.2	
LWC1-24	[G]	[MQ]	0%	83.0			2897		-0.15	
LWC1-25	[G]	[MQ]	0%	82.3			2805		-0.08	
LWC1-26	[G]	[MQ]	0%	84.2			3046		-0.19	
LWC1-27	[G]	[MQ]	0%	78.0			3060		-0.15	
LWC1-28	[G]	[MQ]	0%	83.4			3035		-0.18	
LWC1-29	[G]	[MQ]	0%	85.4			4830		-0.16	
LWC1-30	[C]	[P]	3%		77.1	75.1		2654		-0.19
LWC1-31	[G]	[P]	0%		81.7	81.7		2458		-0.17
LWC1-32	[G]	[P]	0%		80.4	80.4		2924		-0.17
LWC1-33	[G]	[P]	0%		79.4	79.4		2851		-0.16
LWC1-34	[G]	[P]	0%		81.0	81.0		3045		-0.2
LWC1-35	[C]	[MQ]	0%	73.8			1611		-0.19	
LWC1-36	[C]	[MQ]	0%	73.8			1684		-0.21	
LWC1-37	[C]	[MQ]	0%	77.1			1796		-0.26	
LWC1-38	[C]	[MQ]	0%	78.9			2856		-0.25	
LWC1-39	[C]	[MQ]	0%	76.5			2849		-0.27	
LWC1-40	[G]	[P]	3%		79.9	77.9		2293		-0.18
LWC1-41	[G]	[P]	3%		81.8	79.7		2843		-0.26
LWC1-42	[G]	[P]	3%		82.1	80.0		2437		-0.21
LWC1-43	[G]	[P]	3%		84.7	82.6		2357		-0.21
LWC1-44	[G]	[P]	3%		78.6	76.6		2051		-0.18
LWC1-45	[G]	[P]	3%		79.2	77.2		1952		-0.22
LWC1-46	[C]	[P]	3%		80.1	78.1		2892		-0.19
LWC1-47	[C]	[P]	3%		79.2	77.2		2885		-0.34
LWC1-48	[C]	[P]	3%		86.0	83.9		3351		-0.11
LWC1-49	[C]	[P]	3%		74.5	72.6		2025		-0.29
LWC1-50	[C]	[P]	3%		75.9	74.0		2641		-0.3
LWC1-51	[G]	[P]	3%		80.8	78.8		2062		-0.22
LWC1-52	[G]	[P]	3%		87.1	84.9		2928		-0.16
LWC1-53	[C]	[P]	3%		81.5	79.4		2219		-0.17
LWC1-54	[G]	[P]	3%		84.8	82.7		2954		-0.1
LWC1-55	[C]	[MQ]	0%	74.2			1740		-0.16	
LWC1-56	[C]	[MQ]	0%	71.6			1627		-0.22	
LWC1-57	[G]	[P]	0%		81.3	81.3		2177		-0.29
LWC1-58	[G]	[P]	0%		76.9	76.9		1939		-0.32
LWC1-59	[G]	[P]	0%		82.1	82.1		2035		-0.28
LWC1-60	[G]	[P]	0%		79.6	79.6		1704		-0.33
LWC1-61	[G]	[P]	0%		79.8	79.8		1705		-0.19
LWC1-62	[G]	[P]	0%		81.9	81.9		2095		-0.29
LWC1-63	[G]	[P]	0%		83.1	83.1		2195		-0.28
LWC1-64	[G]	[P]	0%		79.9	79.9		1972		-0.18
LWC1-65	[C]	[MQ]	0%	71.0			1254		-0.15	
LWC1-66	[C]	[MQ]	0%	72.0			1405		-0.14	
LWC1-67	[C]	[MQ]	0%	73.0			1350		-0.14	
LWC1-68	[C]	[MQ]	0%	74.0			1384		-0.13	
LWC1-69	[C]	[MQ]	0%	72.5			1641		-0.12	
LWC1-70	[C]	[MQ]	0%	72.4			1730		-0.13	
LWC1-71	[C]	[MQ]	0%	74.1			1687		-0.18	
LWC1-72	[C]	[MQ]	0%	72.2			1716		-0.13	
LWC1-73	[C]	[MQ]	0%	72.4			1656		-0.13	
LWC1-74	[C]	[MQ]	0%	72.9			1683		-0.12	
LWC1-75	[C]	[MQ]	0%	76.8			2679		-0.23	
LWC1-76	[C]	[MQ]	0%	72.0			1917		-0.16	
LWC1-77	[C]	[MQ]	0%	72.1			1728		-0.15	
LWC1-78	[C]	[MQ]	0%	72.1			1660		-0.13	
LWC1-79	[C]	[MQ]	0%	78.2			3267		-0.17	
LWC1-80	[C]	[MQ]	0%	79.6			3479		-0.14	
LWC1-81	[C]	[MQ]	0%	73.8			1911		-0.1	
LWC1-82	[C]	[MQ]	0%	74.3			1793		-0.14	
LWC1-83	[C]	[MQ]	0%	75.4			2632		-0.12	

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LWC1-84	[C]	[MQ]	0%	73.5			2077		-0.14	
LWC1-85	[C]	[MQ]	0%	73.1			1949		-0.13	
LWC1-86	[C]	[MQ]	0%	73.9			1807		-0.17	
LWC1-87	[C]	[MQ]	0%	73.1			1915		-0.17	
LWC1-88	[C]	[MQ]	0%	73.1			1845		-0.13	
LWC1-89	[C]	[MQ]	0%	73.0			1994		-0.18	
LWC1-90	[C]	[MQ]	0%	74.1			1894		-0.18	
LWC1-91	[C]	[MQ]	0%	73.6			1745		-0.15	
LWC1-92	[C]	[MQ]	0%	73.7			1897		-0.12	
LWC1-93	[C]	[MQ]	0%	74.8			1673		-0.18	
LWC1-94	[C]	[MQ]	0%	73.0			1542		-0.16	
LWC1-95	[C]	[MQ]	0%	73.7			1816		-0.14	
LWC1-96	[C]	[MQ]	0%	72.4			1818		-0.17	
LWC1-97	[C]	[MQ]	0%	72.7			1543		-0.13	
LWC1-98	[C]	[MQ]	0%	72.5			1560		-0.16	
LWC1-99	[C]	[MQ]	0%	75.8			1830		-0.32	
LWC1-100	[C]	[MQ]	0%	75.8			2228		-0.3	
LWC1-101	[G]	[P]	0%		77.3	77.3		2029		-0.32
LWC1-102	[C]	[MQ]	0%	75.3			3164			-0.21
LWC1-103	[C]	[MQ]	0%	76.4			3352			-0.24
LWC1-104	[C]	[MQ]	0%	74.5			3260			-0.2
LWC1-105	[C]	[MQ]	0%	75.8			3377			-0.21
LWC1-106	[C]	[MQ]	0%	74.6			2846			-0.15
LWC1-107	[C]	[MQ]	0%	75.0			3212			-0.18
LWC1-108	[C]	[MQ]	0%	73.6			2666			-0.19

Table A.2 – Lightweight Castable 2 (LWC 2)

Castable Category	Application	Material Qualification [MQ] or Production [P]	Stainless	Density (lb/ft³)			Cold Crushing Strength [CCS] (psi)		Permanent Linear Change [PLC] (%)	
	method		Fiber	Fired Temp 1500°F			Fired Temp 1500°F		Fired Temp 1500°F	
	CAST [C] Gun [G] Ram [R]		Needles %	[MQ]	[P]	[P] (adjusted to "no-fibers")	[MQ]	[P]	[MQ] (Green to Fired)	[P] (Green to Fired)
LIGHTWEIGHT CASTABLE 2 (LWC2)										
LWC2 TDS	[G]				82		700			-0.4
LWC2 CDS	[G]			78	98		450		-0.5	+0.2 to -0.45
			Maximum	85.0	94.0	91.7	923.0	639.0	-0.40	-0.10
			Average	82.2	85.8	83.7	694.0	506.1	-0.15	0.01
			Minimum	80.0	79.0	77.0	534.0	277.0	0.00	0.20
LWC2-1	[C]	[MQ]	0%	82			592		-0.4	
LWC2-2	[C]	[MQ]	0%	81			811		-0.3	
LWC2-3	[C]	[MQ]	0%	80			534		-0.1	
LWC2-4	[C]	[MQ]	0%	81			617		-0.1	
LWC2-5	[C]	[MQ]	0%	82			664		-0.1	
LWC2-6	[C]	[MQ]	0%	83			761		-0.2	
LWC2-7	[C]	[MQ]	0%	85			923		-0.2	
LWC2-8	[C]	[MQ]	0%	83			588		-0.2	
LWC2-9	[C]	[MQ]	0%	84			764		0	
LWC2-10	[C]	[MQ]	0%	84			783		-0.1	
LWC2-11	[C]	[MQ]	0%	82			684		-0.2	
LWC2-12	[C]	[MQ]	0%	82			671		-0.2	
LWC2-13	[C]	[MQ]	0%	81			706		0	
LWC2-14	[C]	[MQ]	0%	82			717		-0.1	
LWC2-15	[C]	[MQ]	0%	82			709		-0.1	
LWC2-16	[C]	[MQ]	0%	81			580		-0.1	
LWC2-17	[G]	[P]	3%		84	81.9		538		0

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LWC2-18	[G]	[P]	3%	85	82.9	483	0.2
LWC2-19	[G]	[P]	3%	88	85.8	455	0
LWC2-20	[G]	[P]	3%	84	81.9	538	0
LWC2-21	[G]	[P]	3%	86	83.9	624	0
LWC2-22	[G]	[P]	3%	81	79.0	565	0
LWC2-23	[G]	[P]	3%	85	82.9	619	0
LWC2-24	[G]	[P]	3%	84	81.9	560	0
LWC2-25	[G]	[P]	3%	88	85.8	588	0
LWC2-26	[G]	[P]	3%	87	84.8	413	-0.1
LWC2-27	[G]	[P]	3%	85	82.9	410	0
LWC2-28	[G]	[P]	3%	81	79.0	450	0
LWC2-29	[G]	[P]	3%	94	91.7	639	0
LWC2-30	[G]	[P]	3%	79	77.0	351	0
LWC2-31	[G]	[P]	3%	87	84.8	459	0
LWC2-32	[G]	[P]	3%	91	88.8	571	0
LWC2-33	[G]	[P]	3%	89	86.8	504	0
LWC2-34	[G]	[P]	3%	81	79.0	277	0
LWC2-35	[G]	[P]	3%	91	88.8	571	0

Table A.3 – Medium Weight Castable 1 (MWC 1)

Castable Category	Application	Material Qualification [MQ]	Stainless	Density (lb/ft³)			Cold Crushing Strength [CCS] (psi)		Permanent Linear Change [PLC] (%)	
	method	or Production [P]	Fiber	Fired Temp 1500°F			Fired Temp 1500°F		Fired Temp 1500°F	
	CAST [C] Gun [G] Ram [R]		Needles %	[MQ]	[P]	[P] (adjusted to "no-fibers")	[MQ]	[P]	[MQ] (Green to Fired)	[P] (Green to Fired)
MEDIUM WEIGHT CASTABLE 1 (MWC1)										
MWC1 TDS	[C]		0%		90		600 to 2000			-0.4% max
MWC1 TDS	[G]		0%		95		800 to 2200			-0.4% max
MWC1 CDS	[C]		0%							
MWC1 CDS	[G]		0%		105 max		700 min			-0.3% max
			Maximum	104.4	114.1		3202.0	5628.0	-0.18	-0.53
			Average	103.0	108.1		3042.0	3604.5	-0.14	-0.25
			Minimum	99.7	96.2		2798.0	1613.0	-0.12	-0.17
MWC1-1	[G]	[P]	0%		96.2	96.2		1613		-0.24
MWC1-2	[G]	[P]	3%		105.5	103.0		2349		-0.24
MWC1-3	[G]	[P]	3%		111.3	108.7		4026		-0.24
MWC1-4	[G]	[P]	3%		108.6	106.0		3959		-0.24
MWC1-5	[G]	[P]	3%		104.1	101.6		2720		-0.24
MWC1-6	[G]	[P]	3%		103.3	100.8		2913		-0.24
MWC1-7	[G]	[P]	3%		102.3	99.8		2089		-0.24
MWC1-8	[G]	[P]	2%		107.7	106.0		3125		-0.24
MWC1-9	[G]	[P]	2%		104.8	103.1		1874		-0.24
MWC1-10	[G]	[MQ]	0%	104.4			2798		-0.18	
MWC1-11	[G]	[MQ]	0%	103.6			3013		-0.12	
MWC1-12	[G]	[MQ]	0%	104.3			3155		-0.13	
MWC1-13	[G]	[MQ]	0%	99.7			3202		-0.13	
MWC1-14	[G]	[P]	3%		111.8	109.2		4871		-0.21
MWC1-15	[G]	[P]	3%		111.5	108.9		4507		-0.2
MWC1-16	[G]	[P]	3%		108.0	105.4		4382		-0.3
MWC1-17	[G]	[P]	3%		110.7	108.1		4469		-0.26
MWC1-18	[G]	[P]	3%		109.8	107.2		4064		-0.3
MWC1-19	[G]	[P]	3%		108.4	105.8		3330		-0.19
MWC1-20	[G]	[P]	3%		111.1	108.5		4347		-0.31
MWC1-21	[G]	[P]	3%		114.1	111.4		5628		-0.53
MWC1-22	[G]	[P]	3%		108.5	105.9		3243		-0.2
MWC1-23	[G]	[P]	3%		109.6	107.0		3914		-0.31
MWC1-24	[G]	[P]	3%		111.9	109.3		4070		-0.17
MWC1-25	[G]	[P]	3%		110.3	107.7		3791		-0.2
MWC1-26	[G]	[P]	3%		109.6	107.0		4016		-0.24

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Table A.4 – Medium Weight Erosion-Resistant Castable 1 (MWERC 1)

Castable Category	Application	Material Qualification [MQ]	Stainless	Density (lb/ft ³)			Cold Crushing Strength [CCS] (psi)		Abrasion (cc)		Permanent Linear Change [PLC] (%)	
	method		Fiber	Fired Temp 1500°F			Fired Temp 1500°F		Fired Temp 1500°F		Fired Temp 1500°F	
	CAST [C] Gun [G] Ram [R]	or Production [P]	Needles %	[MQ]	[P]	[P] (adjusted to "no-fibers")	[MQ]	[P]	[MQ]	[P]	[MQ] (Green to Fired)	[P] (Green to Fired)
MEDIUM WEIGHT EROSION-RESISTANT CASTABLE 1 (MWERC1)												
MWERC1 TDS					139			10,500		7		-0.35%
MWERC1 CDS	[C]			125 min				3300 min		18 max		-0.35% max
MWERC1 CDS	[G]			133 min				6100 min		10 max		-0.55% max
				Maximum	144.0	142.2		10,846.0		10.3	10.5	-0.48
				Average	139.7	138.6		9164.9		8.9	8.5	-0.31
				Minimum	137.7	133.1		8160.0		7.1	6.5	-0.21
MWERC1-1	[G]	[MQ]	0%	143.9				9639		6.8		-0.47
MWERC1-2	[G]	[MQ]	0%	143.8				8895		7.1		-0.41
MWERC1-3	[G]	[MQ]	0%	142.6				8738		8.1		-0.48
MWERC1-4	[G]	[MQ]	0%	144.0				9207		7.4		-0.40
MWERC1-5	[G]	[P]	0%		142.2	142.2		12,386		7.5		-0.29
MWERC1-6	[G]	[P]	0%		139.7	139.7		10,476		7.0		-0.33
MWERC1-7	[G]	[P]	0%		137.3	137.3		10,060		9.2		-0.32
MWERC1-8	[G]	[P]	0%		138.2	138.2		10,899		7.6		-0.27
MWERC1-9	[G]	[P]	0%		138.6	138.6		10,565		6.5		-0.30
MWERC1-10	[G]	[P]	0%		137.1	137.1		8926		10.1		-0.25
MWERC1-11	[G]	[P]	0%		141.0	141.0		11,800		7.4		-0.29
MWERC1-12	[G]	[P]	0%		138.1	138.1		10,479		8.4		-0.28
MWERC1-13	[G]	[P]	0%		139.9	139.9		9289		9.2		-0.25
MWERC1-14	[G]	[P]	0%		138.4	138.4		6567		9.7		-0.32
MWERC1-15	[G]	[P]	0%		133.1	133.1		6820		10.5		-0.42
MWERC1-16	[G]	[P]	0%		140.2	140.2		11,121		8.4		-0.33
MWERC1-17	[G]	[P]	0%		137.9	137.9		7838		9.5		-0.26
MWERC1-18	[C]	[MQ]	0%	138.0				10,253		10.3		-0.32
MWERC1-19	[C]	[MQ]	0%	139.2				10,846		8.7		-0.30
MWERC1-20	[C]	[MQ]	0%	138.5				8252		9.0		-0.29
MWERC1-21	[C]	[MQ]	0%	138.4				8814		9.0		-0.21
MWERC1-22	[C]	[MQ]	0%	139.2				8775		8.3		-0.33

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MWERC1-23	[C]	[MQ]	0%	138. 4			8669		8.4		-0.32	
MWERC1-24	[C]	[MQ]	0%	138. 0			8566		10.0		-0.32	
MWERC1-25	[C]	[MQ]	0%	139. 0			9460		9.9		-0.31	
MWERC1-26	[C]	[MQ]	0%	140. 1			9689		8.3		-0.28	
MWERC1-27	[C]	[MQ]	0%	138. 6			8160		9.5		-0.27	
MWERC1-28	[C]	[MQ]	0%	139. 6			10,380		9.7		-0.21	
MWERC1-29	[C]	[MQ]	0%	137. 7			8770		9.6		-0.23	

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Table A.5 – Medium Weight Erosion-Resistant Castable 2 (MWERC 2)

Castable Category	Application	Material Qualification [MQ]	Stainless	Density (lb/ft ³)			Cold Crushing Strength [CCS] (psi)		Abrasion (cc)		Permanent Linear Change [PLC] (%)	
	method CAST [C] Gun [G] Ram [R]	or Production [P]	Fiber	Fired Temp 1500°F			Fired Temp 1500°F		Fired Temp 1500°F		Fired Temp 1500°F	
			Needles %	[MQ]	[P]	[P] (adjusted to "no- fibers")	[MQ]	[P]	[MQ]	[P]	[MQ] (Green to Fired)	[P] (Green to Fired)
MEDIUM WEIGHT EROSION-RESISTANT CASTABLE 2 (MWERC2)												
MWERC-2 TDS	[C]				130			8000 to 11,000		10 max		-0.4% max
MWERC-2 CDS	[C]			136 max				8000 min		10 max		-0.4% max
			Maximum	132.6	135.0	132.0	14,076.0	12,721.0	8.3	11.4	-0.30	-0.29
			Average	130.5	131.7	128.7	11,951.6	9919.6	6.3	9.7	-0.20	-0.23
			Minimum	129.0	130.2	127.3	10,484.0	9209.0	4.3	8.8	-0.15	-0.13
MWERC2-1	[C]	[MQ]	0%	132.6			13,764		5.4		-0.20	
MWERC2-2	[C]	[MQ]	0%	130.0			12,894		5.0		-0.20	
MWERC2-3	[C]	[MQ]	0%	130.0			14,076		4.3		-0.20	
MWERC2-4	[C]	[MQ]	0%	129.0			11,769		6.8		-0.20	
MWERC2-5	[C]	[MQ]	0%	131.0			13,146		4.8		-0.20	
MWERC2-6	[C]	[MQ]	0%	129.0			10,971		6.3		-0.20	
MWERC2-7	[C]	[MQ]	0%	131.0			12,952		5.4		-0.20	
MWERC2-8	[C]	[MQ]	0%	130.0			11,709		5.8		-0.20	
MWERC2-9	[C]	[MQ]	0%	131.0			12,032		5.0		-0.20	
MWERC2-10	[C]	[MQ]	0%	129.0			10,986		5.4		-0.20	
MWERC2-11	[C]	[MQ]	0%	131.0			11,445		4.5		-0.30	
MWERC2-12	[C]	[MQ]	0%	131.0			11,369		6.5		-0.20	
MWERC2-13	[C]	[P]	3%		133.1	130.1		10,756		8.8		-0.22
MWERC2-14	[C]	[P]	3%		131.5	128.6		12,721		9.0		-0.16
MWERC2-15	[C]	[P]	3%		134.6	131.6		11,248		9.0		-0.14
MWERC2-16	[C]	[P]	3%		135.0	132.0		11,082		9.6		-0.13
MWERC2-17	[C]	[P]	3%		133.1	130.1		10,778		11.4		-0.18
MWERC2-18	[C]	[P]	3%		133.9	130.9		10,860		11.3		-0.22
MWERC2-19	[C]	[MQ]	0%	131.2			10,484		8.2		-0.29	
MWERC2-20	[C]	[MQ]	0%	131.9			11,024		7.6		-0.21	
MWERC2-21	[C]	[MQ]	0%	130.9			11,515		7.8		-0.21	
MWERC2-22	[C]	[MQ]	0%	130.4			11,945		8.0		-0.20	
MWERC2-23	[C]	[MQ]	0%	129.6			11,751		7.9		-0.15	
MWERC2-24	[C]	[MQ]	0%	130.7			11,605		8.3		-0.17	
MWERC2-25	[C]	[MQ]	0%	130.5			11,643		7.5		-0.16	
MWERC2-26	[C]	[P]	3%		130.5	127.6		9234		9.7		-0.26
MWERC2-27	[C]	[P]	3%		130.7	127.8		9241		9.6		-0.25
MWERC2-28	[C]	[P]	3%		131.6	128.7		9365		9.4		-0.23
MWERC2-29	[C]	[P]	3%		130.4	127.5		9227		9.8		-0.27
MWERC2-30	[C]	[P]	3%		130.6	127.7		9238		9.6		-0.26
MWERC2-31	[C]	[P]	3%		131.3	128.4		9314		9.5		-0.23
MWERC2-32	[C]	[P]	3%		130.2	127.3		9234		9.5		-0.28
MWERC2-33	[C]	[P]	3%		130.6	127.7		9221		9.7		-0.26
MWERC2-34	[C]	[P]	3%		131.4	128.5		9365		9.4		-0.23
MWERC2-35	[C]	[P]	3%		130.5	127.6		9209		9.9		-0.29
MWERC2-36	[C]	[P]	3%		130.7	127.8		9219		9.8		-0.24
MWERC2-37	[C]	[P]	3%		130.3	127.4		9241		9.7		-0.26

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Table A.6 – Medium Weight Erosion-Resistant Castable 3 (MWERC 3)

Castable Category	Application	Material Qualification [MQ] or Production [P]	Stainless	Density (lb/ft³)			Cold Crushing Strength [CCS] (psi)		Abrasion (cc)		Permanent Linear Change [PLC] (%) Fired Temp 1500°F	
	method		Fiber	Fired Temp 1500°F			Fired Temp 1500°F		Fired Temp 1500°F		Fired Temp 1500°F	
	CAST [C] Gun [G] Ram [R]		Needles %	[MQ]	[P]	[P] (adjusted to "no-fibers")	[MQ]	[P]	[MQ]	[P]	[MQ] (Green to Fired)	[P] (Green to Fired)
MEDIUM WEIGHT EROSION-RESISTANT CASTABLE 3 (MWERC3)												
MWERC3 TDS	[G]		0%		106 to 114			6500 to 10,500		7 to 14		-0.5% max
MWERC3 CDS	[G]		0%		105 to 117			6000 min		14 max		-0.5% max
			Maximum	118.0	114.6	111.0	14,884.0	11,322.0	13.7	20.0	-0.40	-0.39
			Average	113.4	110.9	107.6	12,286.4	8496.0	8.9	12.9	-0.19	-0.28
			Minimum	105.9	106.7	105.0	6675.0	6371.0	6.7	8.8	-0.07	-0.18
MWERC3-1	[G]	[P]	4%		108.6	105.2		6537		20.0		
MWERC3-2	[G]	[P]	4%		111.5	108.0		9147		13.0		
MWERC3-3	[G]	[P]	4%		111.7	108.2		9880		14.0		
MWERC3-4	[G]	[P]	4%		109.8	106.3		6371		15.9		
MWERC3-5	[G]	[P]	4%		112.5	109.0		9002		9.8		
MWERC3-6	[G]	[P]	4%		108.6	105.2		6537		20.0		
MWERC3-7	[G]	[P]	4%		111.5	108.0		9147		13.0		
MWERC3-8	[G]	[P]	4%		111.7	108.2		9880		14.0		
MWERC3-9	[G]	[P]	4%		109.8	106.3		6371		15.9		
MWERC3-10	[G]	[P]	4%		112.5	109.0		9002		9.8		
MWERC3-11	[C]	[MQ]	0%	110.0			11,843		11.2		-0.09	
MWERC3-12	[C]	[MQ]	0%	110.9			14,554		10.0		-0.07	
MWERC3-13	[C]	[MQ]	0%	112.0			14,884		9.7		-0.09	
MWERC3-14	[C]	[MQ]	0%	110.2			13,728		10.4		-0.07	
MWERC3-15	[C]	[MQ]	0%	110.9			14,249		9.9		-0.08	
MWERC3-16	[C]	[MQ]	0%	112.3			14,611		9.5		-0.10	
MWERC3-17	[G]	[P]	4%		109.7	106.2		9100		8.8		-0.32
MWERC3-18	[G]	[P]	4%		111.9	108.4		10,879		8.8		-0.26
MWERC3-19	[G]	[P]	4%		112.9	109.4		7808		11.4		-0.23
MWERC3-20	[G]	[P]	4%		111.8	108.3		9098		11.1		-0.24
MWERC3-21	[G]	[P]	4%		114.6	111.0		9179		10.7		-0.39
MWERC3-22	[G]	[P]	4%		109.6	106.1		8465		13.9		-0.22
MWERC3-23	[G]	[P]	4%		109.9	106.4		7281		16.9		-0.23
MWERC3-24	[G]	[P]	4%		113.8	110.3		10,337		13.4		-0.21
MWERC3-25	[G]	[P]	4%		113.1	109.6		8023		12.4		-0.26
MWERC3-26	[G]	[P]	4%		110.9	107.4		6867		14.3		-0.35
MWERC3-27	[G]	[P]	3%		108.9	106.3		6932		11.9		-0.37
MWERC3-28	[G]	[P]	3%		109.2	106.6		7193		11.7		-0.38
MWERC3-29	[C]	[MQ]	0%	118.0			11,116		9.4		-0.18	

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MWERC3-30	[C]	[MQ]	0%	116.7			13,073		10.2		-0.16	
MWERC3-31	[C]	[MQ]	0%	116.0			12,995		6.7		-0.21	
MWERC3-32	[C]	[MQ]	0%	114.9			12,436		7.8		-0.20	
MWERC3-33	[C]	[MQ]	0%	115.0			12,512		8.5		-0.21	
MWERC3-34	[C]	[MQ]	0%	114.7			11,688		7.0		-0.22	
MWERC3-35	[C]	[MQ]	0%	114.4			12,195		7.2		-0.16	
MWERC3-36	[C]	[MQ]	0%	115.0			10,867		7.3		-0.18	
MWERC3-37	[C]	[MQ]	0%	115.3			10,758		7.2		-0.25	
MWERC3-38	[C]	[MQ]	0%	113.8			11,398		9.3		-0.33	
MWERC3-39	[C]	[MQ]	0%	114.0			10,537		9.9		-0.40	
MWERC3-40	[C]	[MQ]	0%	113.6			11,304		7.4		-0.32	
MWERC3-41	[C]	[MQ]	0%	114.3			11,383		7.9		-0.26	
MWERC3-42	[G]	[P]	2%		106.7	105.0		9545		10.5		-0.18
MWERC3-43	[G]	[P]	2%		110.4	108.7		11,322		8.9		-0.24
MWERC3-44	[G]	[MQ]	0%	105.9			6675		13.7		-0.26	
MWERC3-45	[G]	[MQ]	0%	106.1			6798		12.4		-0.10	
MWERC3-46	[C]	[MQ]	0%	115.3			13,986		7.7		-0.17	
MWERC3-47	[C]	[MQ]	0%	114.9			12,984		8.0		-0.17	
MWERC3-48	[C]	[MQ]	0%	114.9			14,664		8.3		-0.20	
MWERC3-49	[C]	[MQ]	0%	113.7			13,367		7.1		-0.21	
MWERC3-50	[C]	[MQ]	0%	114.7			13,060		8.6		-0.17	
MWERC3-51	[C]	[MQ]	0%	114.5			13,110		8.8		-0.15	
MWERC3-52	[C]	[MQ]	0%	113.5			13,338		8.3		-0.23	
MWERC3-53	[C]	[MQ]	0%	113.4			12,076		8.4		-0.19	
MWERC3-54	[C]	[MQ]	0%	113.7			12,404		8.7		-0.14	

Table A.7 – Medium Weight Erosion-Resistant Castable 4 (MWERC 4)

Castable Category	Application	Material Qualification [MQ]	Stainless	Density (lb/ft ³)			Cold Crushing Strength [CCS] (psi)		Abrasion (cc)		Permanent Linear Change [PLC] (%)	
	method		Fiber	Fired Temp 1500°F			Fired Temp 1500°F		Fired Temp 1500°F		Fired Temp 1500°F	
	CAST [C] Gun [G] Ram [R]	or Production [P]	Needles %	[MQ]	[P]	[P] (adjusted to "no-fibers")	[MQ]	[P]	[MQ]	[P]	[MQ] (Green to Fired)	[P] (Green to Fired)
MEDIUM WEIGHT EROSION-RESISTANT CASTABLE 4 (MWERC4)												
MWERC4 TDS	[C]		0%	110 typical	110 typical		6000 to 11,000	6000 to 11,000	12	12	-0.4%	-0.4%
MWERC4 CDS	[C]		0%	114 max	114 max		6000 min	6000 min	12 max	12 max	-0.4% max	-0.4% max
			Maximum	124.1	118.1	115.4	11,706.0	8128.0	11.5	14.7	-0.33	-0.20
			Average	113.1	110.4	107.4	10,030.4	7955.0	9.4	10.6	-0.20	-0.17

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			Minimum	107.2	107.1	104.1	8603.0	7782.0	7.3	8.5	-0.12	-0.14
MWERC4-1	[C]	[MQ]	0.0%	124.1			10340		7.43		-0.17	
MWERC4-2	[C]	[MQ]	0.0%	123.9			11441		7.34		-0.18	
MWERC4-3	[C]	[MQ]	0.0%	123.0			9236		7.53		-0.21	
MWERC4-4	[C]	[MQ]	0.0%	118.1			9575		7.37		-0.25	
MWERC4-5	[C]	[MQ]	0.0%	116.2			9159		8.49		-0.22	
MWERC4-6	[C]	[MQ]	0.0%	118.8			9877		8.94		-0.20	
MWERC4-7	[C]	[MQ]	0.0%	118.5			8791		8.61		-0.18	
MWERC4-8	[C]	[MQ]	0.0%	118.2			8974		9.38		-0.18	
MWERC4-9	[C]	[MQ]	0.0%	118.8			9421		8.56		-0.18	
MWERC4-10	[C]	[MQ]	0.0%	117.6			9621		8.84		-0.21	
MWERC4-11	[C]	[MQ]	3.0%	119.7			8603		9.14		-0.33	
MWERC4-12	[C]	[MQ]	3.0%	119.0			9492		8.94		-0.20	
MWERC4-13	[C]	[MQ]	3.0%	120.3			8671		10.47		-0.21	
MWERC4-14	[C]	[P]	3.0%		118.1	115.4		7782		10.48		-0.15
MWERC4-15	[C]	[P]	3.0%		116.8	114.1		8128		10.46		-0.19
MWERC4-16	[C]	[P]	3.5%		109.6	106.6				9.08		-0.19
MWERC4-17	[C]	[P]	3.5%		107.1	104.1				10.20		-0.14
MWERC4-18	[C]	[P]	3.5%		109.5	106.5				8.57		-0.17
MWERC4-19	[C]	[P]	3.5%		110.3	107.3				11.86		-0.17
MWERC4-20	[C]	[P]	3.5%		107.8	104.8				8.51		-0.18
MWERC4-21	[C]	[P]	3.5%		111.6	108.5				11.05		-0.17
MWERC4-22	[C]	[P]	3.5%		107.2	104.2				9.20		-0.19
MWERC4-23	[C]	[P]	3.5%		107.2	104.2				12.43		-0.19
MWERC4-24	[C]	[P]	3.5%		111.4	108.3				10.81		-0.2
MWERC4-25	[C]	[P]	3.5%		110.7	107.7				10.37		-0.14
MWERC4-26	[C]	[P]	3.5%		107.7	104.7				14.71		-0.15
MWERC4-27	[C]	[MQ]	0.0%	110.2			10,686		9.55		-0.18	
MWERC4-28	[C]	[MQ]	0.0%	110.0			10,652		9.27		-0.27	
MWERC4-29	[C]	[MQ]	0.0%	108.8			9894		8.66		-0.22	
MWERC4-30	[C]	[MQ]	0.0%	110.7			11,366		9.99		-0.16	
MWERC4-31	[C]	[MQ]	0.0%	109.6			10,410		8.34		-0.15	
MWERC4-32	[C]	[MQ]	0.0%	109.9			10,883		9.84		-0.15	
MWERC4-33	[C]	[MQ]	0.0%	107.9			11,073		9.49		-0.12	
MWERC4-34	[C]	[MQ]	0.0%	109.7			11,204		9.19		-0.16	
MWERC4-35	[C]	[MQ]	0.0%	109.3			10,984		9.94		-0.15	
MWERC4-36	[C]	[MQ]	0.0%	109.8			11,706		9.53		-0.12	
MWERC4-37	[C]	[MQ]	0.0%	108.2			10,414		9.94		-0.13	
MWERC4-38	[C]	[MQ]	0.0%	108.3			8935		11.08		-0.14	
MWERC4-39	[C]	[MQ]	0.0%	109.0			9555		9.51		-0.20	
MWERC4-40	[C]	[MQ]	0.0%	108.2			9734		10.24		-0.18	

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MWERC4-41	[C]	[MQ]	0.0%	107.6			9947		11.47		-0.20	
MWERC4-42	[C]	[MQ]	0.0%	107.9			10,709		10.38		-0.24	
MWERC4-43	[C]	[MQ]	0.0%	107.4			9477		10.91		-0.22	
MWERC4-44	[C]	[MQ]	0.0%	108.1			9989		10.12		-0.23	
MWERC4-45	[C]	[MQ]	0.0%	107.2			10,204		11.50		-0.24	
MWERC4-46	[C]	[MQ]	0.0%	108.5			9980		10.54		-0.26	

Table A.8 – Dense Castable 1 (DC 1)

Castable Category	Application method CAST [C] Gun [G] Ram [R]	Material Qualification [MQ] or Production [P]	Stainless Fiber Needles %	Density (lb/ft ³) Fired Temp 1500°F			Cold Crushing Strength [CCS] (psi) Fired Temp 1500°F		Permanent Linear Change [PLC] (%) Fired Temp 1500°F	
				[MQ]	[P]	[P] (adjusted to "no-fibers")	[MQ]	[P]	[MQ] (Green to Fired)	[P] (Green to Fired)
				DENSE CASTABLE 1 (DC1)						
DC1 TDS	[G]		0%	156 to 167	156 to 167		7000 to 13,000	7000 to 13,000	-0.5% max	-0.5% max
DC1 CDS	[G]		0%	140 to 180	140 to 180		6000 min	6000 min	-0.4% max	-0.4% max
			Maximum	165.6	165.0	161.6	15,641.0	14,087.0	-0.24	-0.20
			Average	162.9	155.5	156.1	12,244.3	8905.1	-0.12	-0.13
			Minimum	160.0	147.3	151.0	6506.0	5036.0	-0.05	-0.04
DC1-1	[G]	[P]	0%		165.0			11393		-0.08
DC1-2	[C]	[MQ]	0%	163.6			10,627		-0.05	
DC1-3	[C]	[MQ]	0%	164.1			12,032		-0.08	
DC1-4	[C]	[MQ]	0%	164.0			12,303		-0.10	
DC1-5	[C]	[MQ]	0%	161.8			12,392		-0.09	
DC1-6	[C]	[MQ]	0%	160.4			13,174		-0.11	
DC1-7	[C]	[MQ]	0%	162.0			13,396		-0.12	
DC1-8	[C]	[MQ]	0%	164.5			13,410		-0.09	
DC1-9	[C]	[MQ]	0%	162.0			14,178		-0.09	
DC1-10	[C]	[MQ]	0%	162.3			14,209		-0.11	
DC1-11	[C]	[MQ]	0%	164.2			14,318		-0.11	
DC1-12	[C]	[MQ]	0%	162.6			15,154		-0.10	
DC1-13	[C]	[MQ]	0%	162.1			15,419		-0.09	
DC1-14	[G]	[P]	0%		159.4	159.4		7771		-0.12
DC1-15	[C]	[P]	0%		161.6	161.6		10,195		-0.04
DC1-16	[C]	[MQ]	0%	162.1			12,523		-0.17	
DC1-17	[C]	[MQ]	0%	162.2			12,744		-0.16	
DC1-18	[C]	[MQ]	0%	160.9			12,194		-0.17	
DC1-19	[C]	[MQ]	0%	165.6			13,527		-0.13	
DC1-20	[C]	[MQ]	0%	161.3			12,555		-0.14	
DC1-21	[C]	[MQ]	0%	162.6			12,313		-0.11	
DC1-22	[C]	[MQ]	0%	162.9			12,690		-0.15	
DC1-23	[C]	[MQ]	0%	163.1			13,984		-0.12	
DC1-24	[C]	[MQ]	0%	162.5			13,662		-0.10	
DC1-25	[C]	[MQ]	0%	161.2			13,789		-0.12	
DC1-26	[G]	[P]	0%		151.0	151.0		5104		-0.20
DC1-27	[G]	[P]	0%		151.3	151.3		5373		-0.18
DC1-28	[G]	[P]	0%		156.8	156.8		6336		-0.15
DC1-29	[G]	[P]	0%		156.4	156.4		6950		-0.12
DC1-30	[C]	[MQ]	0%	160.0			6506		-0.10	
DC1-31	[C]	[MQ]	0%	162.7			8017		-0.11	
DC1-32	[C]	[MQ]	0%	163.3			8160		-0.11	
DC1-33	[C]	[MQ]	0%	164.2			8375		-0.10	
DC1-34	[C]	[MQ]	0%	165.0			8733		-0.24	
DC1-35	[C]	[MQ]	0%	163.2			8803		-0.12	
DC1-36	[C]	[MQ]	0%	163.3			8858		-0.08	

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DC1-37	[C]	[MQ]	0%	162.2			9010		-0.13	
DC1-38	[C]	[MQ]	0%	162.8			9072		-0.12	
DC1-39	[C]	[MQ]	0%	162.2			9937		-0.10	
DC1-40	[C]	[MQ]	0%	164.2			10,217		-0.11	
DC1-41	[C]	[MQ]	0%	164.9			10,623		-0.13	
DC1-42	[C]	[P]	0%		158.6			6889		-0.20
DC1-43	[G]	[P]	0%		160.2			10,748		-0.06
DC1-44	[C]	[MQ]	0%	164.4			11,120		-0.13	
DC1-45	[C]	[MQ]	0%	162.9			9712		-0.13	
DC1-46	[C]	[MQ]	0%	163.3			10,616		-0.15	
DC1-47	[C]	[MQ]	0%	163.9			12,156		-0.17	
DC1-48	[C]	[MQ]	0%	162.7			11,664		-0.20	
DC1-49	[C]	[MQ]	0%	162.2			12,509		-0.11	
DC1-50	[C]	[MQ]	0%	162.3			11,028		-0.11	
DC1-51	[C]	[MQ]	0%	162.0			13,212		-0.16	
DC1-52	[C]	[MQ]	0%	162.1			11,726		-0.16	
DC1-53	[C]	[MQ]	0%	162.5			11,597		-0.10	
DC1-54	[C]	[MQ]	0%	162.3			13,374		-0.16	
DC1-55	[C]	[MQ]	0%	164.2			13,268		-0.20	
DC1-56	[C]	[MQ]	0%	164.0			15,077		-0.13	
DC1-57	[C]	[MQ]	0%	162.4			15,019		-0.09	
DC1-58	[C]	[MQ]	0%	163.0			15,641		-0.11	
DC1-59	[C]	[MQ]	0%	164.5			15,510		-0.11	
DC1-60	[C]	[MQ]	0%	164.0			15,543		-0.11	
DC1-61	[C]	[MQ]	0%	162.7			14,790		-0.10	
DC1-62	[C]	[MQ]	0%	162.2			15,092		-0.11	
DC1-63	[C]	[MQ]	0%	163.8			15,632		-0.12	
DC1-64	[G]	[P]	0%		160.0			13,909		-0.12
DC1-65	[G]	[P]	0%		156.0			14,087		-0.17
DC1-66	[G]	[P]	0%		154.0			12,588		-0.20
DC1-67	[G]	[P]	0%		153.0			9148		-0.18
DC1-68	[G]	[P]	0%		155.0			9941		-0.18
DC1-69	[G]	[P]	0%		153.0			9351		-0.18
DC1-70	[C]	[P]	0%		150.9			9072		-0.05
DC1-71	[C]	[P]	0%		149.2			6402		-0.11
DC1-72	[G]	[P]	0%		147.3			5036		-0.04

Table A.9 – Erosion Resistant Castable 1 (ERC 1)

Castable Category	Application	Material Qualification [MQ]	Stainless	Density (lb/ft³)			Cold Crushing Strength [CCS] (psi)		Abrasion (cc)		Permanent Linear Change [PLC] (%)	
	method		Fiber	Fired Temp 1500°F			Fired Temp 1500°F		Fired Temp 1500°F		Fired Temp 1500°F	
	CAST [C] Gun [G] Ram [R]	or Production [P]	Needles %	[MQ]	[P]	[P] (adjusted to "no-fibers")	[MQ]	[P]	[MQ]	[P]	[MQ] (Green to Fired)	[P] (Green to Fired)
EROSION RESISTANT CASTABLE 1 (ERC1)												
ERC1 TDS	[R]		0%	178	186		15,000	15,000	3.0	3.0	-0.40%	-0.40%
ERC1 CDS	[R]		0%	178	186		15,000	15,000	3.0	3.0	-0.40%	-0.40%
			Maximum	182.1	184.4	184.4	25,000.0	29,621.0	2.5	4.2	-0.43	-0.50
			Average	181.0	180.7	180.8	24,113.4	22,737.3	2.3	2.6	-0.36	-0.38
			Minimum	180.4	171.5	171.5	21,576.0	14,767.0	2.0	2.0	-0.30	-0.29
ERC1-1	[R]	[P]	0%		179.5	179.5		25,000		2.50		
ERC1-2	[R]	[P]	0%		179.6	179.6		25,000		2.46		
ERC1-3	[R]	[P]	0%		179.7	179.7		25,000		2.38		
ERC1-4	[R]	[P]	0%		179.4	179.4		25,000		2.38		
ERC1-5	[R]	[P]	0%		181.5	181.5		25,000		2.39		
ERC1-6	[R]	[P]	0%		179.6	179.6		24,603		2.29		
ERC1-7	[R]	[P]	0%		178.7	178.7		24,501		2.06		
ERC1-8	[R]	[P]	0%		180.1	180.1		25,000		2.36		
ERC1-9	[R]	[P]	0%		180.9	180.9		25,000		2.23		
ERC1-10	[R]	[P]	0%		180.2	180.2		25,000		2.35		
ERC1-11	[R]	[P]	0%		180.4	180.4		24,304		2.16		
ERC1-12	[R]	[P]	0%		180.3	180.3		25,000		2.18		

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ERC1-13	[R]	[P]	0%		180.2	180.2		25,000		2.35		
ERC1-14	[R]	[P]	0%		181.3	181.3		24,456		2.25		
ERC1-15	[R]	[P]	0%		180.6	180.6		25,000		2.39		
ERC1-16	[R]	[P]	0%		182.3	182.3		25,000		2.52		
ERC1-17	[R]	[P]	0%		180.4	180.4		25,000		2.37		
ERC1-18	[R]	[P]	0%		180.3	180.3		25,000		2.34		
ERC1-19	[R]	[P]	0%		180.4	180.4		24,416		2.64		
ERC1-20	[R]	[P]	0%		180.5	180.5		25,000		2.48		
ERC1-21	[R]	[P]	0%		178.0	178.0		18,111		2.20		-0.5
ERC1-22	[R]	[P]	0%		182.0	182.0		23,937		2.30		-0.5
ERC1-23	[R]	[P]	0%		179.0	179.0		19,733		2.30		-0.4
ERC1-24	[R]	[P]	0%		181.0	181.0		22,210		2.00		-0.4
ERC1-25	[R]	[P]	0%		181.0	181.0		25,972		2.10		-0.5
ERC1-26	[R]	[MQ]	0%	181.2			25,000		2.45		-0.33	
ERC1-27	[R]	[MQ]	0%	180.4			24,480		2.37		-0.37	
ERC1-28	[R]	[MQ]	0%	180.4			25,000		2.32		-0.37	
ERC1-29	[R]	[MQ]	0%	181.3			25,000		2.32		-0.34	
ERC1-30	[R]	[MQ]	0%	180.5			23,616		2.33		-0.35	
ERC1-31	[R]	[MQ]	0%	181.2			24,122		2.40		-0.3	
ERC1-32	[R]	[P]	0%		179.3	179.3		21,189		3.10		
ERC1-33	[R]	[P]	0%		172.0	172.0		17,373		3.10		
ERC1-34	[R]	[P]	0%		172.3	172.3		15,708		3.90		
ERC1-35	[R]	[P]	0%		180.2	180.2		18,858		3.00		
ERC1-36	[R]	[P]	0%		180.8	180.8		21,811		3.60		
ERC1-37	[R]	[P]	0%		176.0	176.0		16,181		3.00		
ERC1-38	[R]	[P]	0%		178.5	178.5		16,683		2.80		
ERC1-39	[R]	[P]	0%		179.1	179.1		17,773		3.10		
ERC1-40	[R]	[P]	0%		178.8	178.8		16,911		3.10		
ERC1-41	[R]	[P]	0%		180.3	180.3		17,311		3.10		
ERC1-42	[R]	[P]	0%		177.9	177.9		18,015		3.60		
ERC1-43	[R]	[P]	0%		180.8	180.8		18,601		3.30		
ERC1-44	[R]	[P]	0%		180.3	180.3		21,463		3.70		
ERC1-45	[R]	[P]	0%		171.5	171.5		14,767		4.20		
ERC1-46	[R]	[P]	0%		178.0	178.0		16,990		3.60		
ERC1-47	[R]	[P]	0%		176.4	176.4		16,807		3.20		
ERC1-48	[R]	[P]	0%		183.0	183.0		25,000		2.72		
ERC1-49	[R]	[P]	0%		183.1	183.1		25,000		2.96		
ERC1-50	[R]	[P]	0%		183.0	183.0		24,139		2.76		
ERC1-51	[R]	[P]	0%		183.4	183.4		25,000		2.37		
ERC1-52	[R]	[P]	0%		182.5	182.5		25,000		2.72		
ERC1-53	[R]	[P]	0%		181.4	181.4		23,868		2.88		
ERC1-54	[R]	[P]	0%		181.0	181.0		24,114		2.47		
ERC1-55	[R]	[P]	0%		183.3	183.3		25,000		2.62		
ERC1-56	[R]	[P]	0%		182.3	182.3		25,000		2.62		
ERC1-57	[R]	[P]	0%		180.4	180.4		24,149		2.75		
ERC1-58	[R]	[P]	0%		180.4	180.4		25,000		2.70		
ERC1-59	[R]	[P]	0%		183.0	183.0		25,000		2.63		
ERC1-60	[R]	[P]	0%		183.1	183.1		24,235		2.69		
ERC1-61	[R]	[P]	0%		182.5	182.5		25,000		2.83		
ERC1-62	[R]	[P]	0%		183.3	183.3		25,000		2.56		
ERC1-63	[R]	[P]	0%		183.5	183.5		25,000		2.90		
ERC1-64	[R]	[P]	0%		176.1	176.1		29,621		3.20		-0.46
ERC1-65	[R]	[P]	0%		173.8	173.8		21,795		3.50		-0.48
ERC1-66	[R]	[P]	0%		181.5	181.5		25,000		2.34		
ERC1-67	[R]	[P]	0%		181.5	181.5		25,000		2.44		
ERC1-68	[R]	[P]	0%		181.5	181.5		25,000		2.37		
ERC1-69	[R]	[P]	0%		182.5	182.5		25,000		2.31		
ERC1-70	[R]	[P]	0%		180.8	180.8		25,000		2.47		
ERC1-71	[R]	[P]	0%		181.7	181.7		25,000		2.28		
ERC1-72	[R]	[P]	0%		182.3	182.3		25,000		2.69		
ERC1-73	[R]	[P]	0%		182.2	182.2		25,000		2.41		
ERC1-74	[R]	[P]	0%		183.5	183.5		25,000		2.35		
ERC1-75	[R]	[P]	0%		183.4	183.4		25,000		2.49		
ERC1-76	[R]	[P]	0%		181.7	181.7		25,000		2.23		
ERC1-77	[R]	[P]	0%		181.4	181.4		25,000		2.46		
ERC1-78	[R]	[P]	0%		181.7	181.7		25,000		2.37		
ERC1-79	[R]	[P]	0%		182.7	182.7		25,000		2.31		
ERC1-80	[R]	[P]	0%		182.3	182.3		25,000		2.43		
ERC1-81	[R]	[P]	0%		183.4	183.4		25,000		2.32		

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ERC1-82	[R]	[P]	0%		182.9	182.9		25,000		2.46		
ERC1-83	[R]	[P]	0%		184.4	184.4		25,000		2.27		
ERC1-84	[R]	[P]	0%		180.2	180.2		25,000		2.65		
ERC1-85	[R]	[P]	0%		183.2	183.2		25,000		2.44		
ERC1-86	[R]	[P]	0%		182.8	182.8		25,000		2.27		
ERC1-87	[R]	[P]	0%		183.6	183.6		25,000		2.31		
ERC1-88	[R]	[MQ]	0%	182.1			21,576		2.00		-0.43	
ERC1-89	[R]	[P]	0%		181.0	181.0		20,779		2.60		-0.36
ERC1-90	[R]	[P]	0%		183.5	183.5		19,476		2.50		-0.29
ERC1-91	[R]	[P]	0%		181.7	181.7		18,659		2.80		-0.31
ERC1-92	[R]	[P]	0%		183.2	183.2		18,094		2.00		-0.35
ERC1-93	[R]	[P]	0%		183.1	183.1		19,906		2.70		-0.33
ERC1-94	[R]	[P]	0%		183.9	183.9		18,668		2.80		-0.31
ERC1-95	[R]	[P]	0%		184.3	184.3		18,492		2.70		-0.34
ERC1-96	[R]	[P]	0%		180.6	180.6		17,443		2.70		-0.29
ERC1-97	[R]	[P]	0%		182.4	182.4		19,005		2.80		-0.39
ERC1-98	[R]	[P]	0%		182.4	182.4		19,090		2.30		-0.37
ERC1-99	[R]	[P]	0%		181.3	181.3		18,892		2.50		-0.3
ERC1-100	[R]	[P]	0%		176.2	176.2		17,774		2.90		-0.35
ERC1-101	[R]	[P]	0%		177.5	177.5		20,421		2.40		-0.4

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Annex B **(normative)**

Refractory Compliance Datasheet²

B.1 ScopeGeneral

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

Definition

Compliance datasheet—lists physical 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.2 Application

Compliance datasheets are applicable to material qualification, certification, and qualification testing of refractory materials. They may also be used as a part of laboratory and technician qualification procedures. For as-installed testing, the compliance datasheet values may be modified in accordance with 8.4.4.1 and Table 3.

B.3 Requirements

B.3.1 Compliance datasheets shall be developed for any refractory material commonly used in or marketed to the refining and petrochemical Industry. They may be developed for any refractory material. Each compliance datasheet shall include a statement of identification as a compliance datasheet.

B.3.2 The refractory manufacturer shall provide compliance datasheets to the purchaser upon request. Standard compliance datasheets containing the data listed in B.3.3 shall be prepared in advance and retained on file for immediate transmission to the purchaser. Additional compliance data, as listed in B.3.3, shall be delivered to the purchaser within three weeks of the request.

B.3.3 Standard compliance datasheets shall include values for bulk density (dried and fired), CCS, PLC, and for materials intended for erosive services, abrasion resistance. For plastic refractories, the workability index shall also be included.

The purchaser may request compliance data on the following additional properties: chemical analysis, modulus of rupture, apparent porosity, and thermal conductivity. A note indicating that this information may

² Users of datasheets should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

Where applicable, authorities having jurisdiction should be consulted.

Work sites and equipment operations may differ. Users are solely responsible for assessing their specific equipment and premises in determining the appropriateness of applying the instructions. At all times users should employ sound business, scientific, engineering, and judgment safety when using this Standard.

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be requested shall be included on each standard compliance datasheet, along with the test methods to be used.

B.3.4 Values on the compliance datasheet shall be based upon the test method listed in Table B.1 for the applicable property. Values shall be given for each temperature or range described in Table B.1. The compliance datasheet shall include a listing of the test method, edition (date), and the edition of this standard (API 936) used for each value listed. Samples shall not contain metal reinforcing fibers.

B.3.5 Compliance datasheets shall include a statement similar to the following, “Dry gunned samples of <<Insert product name>> will meet the following values for the listed properties when tested in accordance with the specified method(s). All tests and listed properties conform to the requirements of API Standard 936, Annex B, and are based upon samples without metal reinforcing fibers unless otherwise noted. The property values are valid whenever the total water content is within the listed range.”

Table B.1—Compliance Datasheet Property Listings

<u>Property</u>	<u>Test Method</u> ^a	<u>Temperature</u>	<u>Range</u>
<u>Bulk density</u>	<u>See 8.1.4</u>	<u>After drying at 105 °C (220 °F) and after firing to 815 °C (1500 °F)</u>	<u>Provide an upper and/or lower limit</u>
<u>Cold crushing strength</u>	<u>ASTM C133 as modified by 8.1.2^b</u>	<u>After firing to 815 °C (1500 °F)</u>	<u>Provide a minimum value</u>
<u>Abrasion resistance</u> ^c	<u>ASTM C704 as modified by 8.1.3</u>	<u>After firing to 815 °C (1500 °F)</u>	<u>Provide a maximum value</u>
<u>Permanent linear change</u>	<u>ASTM C113 as modified by 8.1.5</u>	<u>After drying at 105 °C (220 °F) and after firing to 815 °C (1500 °F)</u>	<u>Provide an upper and lower limit of green-to-dried and dried-to-fired values</u>
<u>Chemical analysis</u>	<u>ASTM E1172, ASTM E1184, or ASTM E1479^{d,e}</u>		<u>Provide an upper and/or lower limit</u>
<u>Apparent porosity</u>	<u>ASTM C20^f</u>	<u>After drying at 105 °C (220 °F)^g and after firing to 815 °C (1500 °F)</u>	<u>Provide an upper and lower limit</u>
<u>Thermal conductivity</u>	<u>ASTM C201 and ASTM C417^h</u>	<u>At 425 °C (800 °F) (mean) and at 540 °C (1000 °F) (mean)</u>	<u>Provide a maximum value</u>
<u>Cold modulus of rupture</u>	<u>ASTM C133ⁱ</u>	<u>After firing to 815 °C (1500 °F)</u>	<u>Provide a minimum value</u>
<u>Workability index</u>	<u>ASTM C181</u>	<u>18 °C to 24 °C (65 °F to 75 °F)</u>	<u>Provide a minimum value</u>

a Tests shall be conducted at a laboratory that has been mutually agreed upon by the owner, refractory contractor, and manufacturer.

b Specimens shall be 2 in. × 2 in. × 2 in. (50 mm × 50 mm × 50 mm).

c Applicable only to materials intended for abrasive service.

d The test method is selected by the refractory manufacturer and noted on the compliance datasheet.

e Perform analysis on blended and cast as formed samples of the finished product (not on the raw materials).

f Specimens shall be one-half of the specimen used for permanent linear change testing, i.e. 2 in. × 2 in. × 4.5 in. (50 mm × 50 mm × 112 mm).

g Determination of the apparent porosity at 220 °F (105 °C) does not apply to phosbonded or plastic materials

h Specimens to be dried but not fired. Data to be from the ascending curve.

i Specimens shall be 2 in. × 2 in. × 9 in. (50 mm × 50 mm × 225 mm). Ensure that opposing surfaces are parallel. In the tested position, a nonformed, noncut face shall be on the bottom. For gunned properties, specimens shall be cut from the center (i.e. not the perimeter) of a gunned panel. One 2 in. × 9 in. (50 mm × 225 mm) face shall be the surface of the gunned panel.

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B.3.6 For applications involving water addition, compliance datasheets shall include a water range (variation in the amount of mixing water used) within which the property values listed for density, CCS, PLC, and abrasion resistance (when applicable) are valid. For dry gunning installations, this applies to predamping water only. The same water range shall be used when an optional property is requested. The refractory manufacturer shall determine the water range. A range of $\pm 10\%$ of the optimum water content is suggested.

B.3.7 The compliance datasheet shall include the installation method for which the data is valid (e.g. casting, dry gunning, wet gunning, etc.). The compliance data shall be based upon specimens prepared by the listed method.

B.3.8 If a test is not applicable to the specific material (e.g. abrasion resistance for a lightweight insulating material), the words “not applicable” shall be entered into the appropriate place on the compliance datasheet.

B.3.9 The compliance datasheet shall include a manufacturer defined shelf life for the refractory.

B.4 Sample Compliance Datasheet

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

IMPERVIUM 519

Compliance Datasheet—Dry Gunned Installation

Impervium RP519 was developed to address all refining and petrochemical applications with a single product. It has excellent abrasion resistance and thermal insulating properties. It is also inert to all atmospheres found in refining and petrochemical processes. It may be installed by casting, vibracasting, or gunning.

Dry gunned samples of Impervium 519 will meet the following values for the listed properties when tested in accordance with the specified method(s). All tests and listed properties conform to the requirements of API Standard 936, Annex B, and are based upon samples without metal reinforcing fibers unless otherwise noted. The property values are valid whenever the total water content is within the listed range.

<u>Water Content</u>	<u>(**) to (**) weight percent</u>
<u>Bulk Density</u>	<u>Dried density (**) to (**) pcf</u>
<u>(API Standard 936, Third Edition)</u>	<u>Density after firing (**) to (**) pcf</u>
<u>Cold Crushing Strength</u>	<u>(**) psi (minimum)</u>
<u>(ASTM C133-97—as modified by API Standard 936, Third Edition)</u>	
<u>Permanent Linear Change</u>	<u>(**) to (**) percent (green to dried)</u>
<u>(ASTM C113-02—as modified by API Standard 936, Third Edition)</u>	<u>(**) to (**) percent (dried to fired)</u>
<u>Abrasion Resistance</u>	<u>(**) cc (maximum)</u>

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<u>(ASTM C704-01—as modified by API Standard 936, Third Edition)</u>				
<u>Workability Index</u>			<u>(**) (minimum)</u>	
<u>(ASTM C181-03—as modified by API Standard 936, Third Edition)</u>			<u>(**) months</u>	
<u>Shelf Life</u>				
<u>Chemical Analysis</u>				
<u>[ASTM E1172-87(2003) X-Ray Florescence Spectroscopy]</u>				
<u>Al₂O₃</u>	<u>SiO₂</u>	<u>Fe₂O₃</u>	<u>Imp₂O₃</u>	<u>Misc</u>
<u>(**) to (**)</u>	<u>(**) to (**)</u>	<u>(**) to (**)</u>	<u>(**) to (**)</u>	<u>(**) to (**)</u>
<u>Additional Properties</u>				
<u>Compliance values for the following properties are available upon request: modulus of rupture (in accordance with ASTM C133-97), apparent porosity (in accordance with ASTM C20-00), and thermal conductivity (in accordance with ASTM C201-93 and ASTM C417-05).</u>				

Figure B.1—Sample Compliance Datasheet

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³ American Concrete Institute

~~⁴ American Concrete Institute~~

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