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Standard Guide for Industrial Thermal Insulation Systems¹

This standard is issued under the fixed designation C1696; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reappraisal. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reappraisal.

1. Scope

1.1 This guide covers information on selection of insulation materials, systems design, application methods, protective coverings, guarantees, inspection, testing, and maintenance of thermal insulation primarily for industrial applications in a temperature range of -320 to 1200°F (-195.5 to 648.8°C).

1.2 This guide is intended to provide practical guidelines, by applying acceptable current practice while indicating the basic principles by which new materials can be assessed and adapted for use under widely differing conditions. Design engineers, the general contractors, the fabricators, and the insulation contractors will find this guide helpful.

1.3 Although some insulation system designs can serve as fire protection, this guide does not address the criteria specific to that need. API 521 Guide for Pressure-Relieving and Depressuring Systems is recommended as a reference for fire protection. This guide will however address the fire properties of insulation materials.

1.4 This guide is not intended for commercial, architectural, acoustical, marine, vehicle transport, or military use.

1.5 This guide does not address insulation system design for refractory linings or cold boxes whereby these are typically package units and of a proprietary insulation design.

1.6 The values given in inch-pound units are to be regarded as the standard. The values in parentheses are for information only. The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only. mathematical conversions to SI units that are provided for information only and are not considered standard.

1.7 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 *ASTM Standards*:²

[A167 Specification for Stainless and Heat-Resisting Chromium-Nickel Steel Plate, Sheet, and Strip](#)

[A240/A240M Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications](#)

[A653/A653M Specification for Steel Sheet, Zinc-Coated \(Galvanized\) or Zinc-Iron Alloy-Coated \(Galvannealed\) by the Hot-Dip Process](#)

[A792/A792M Specification for Steel Sheet, 55 % Aluminum-Zinc Alloy-Coated by the Hot-Dip Process](#)

[B209 Specification for Aluminum and Aluminum-Alloy Sheet and Plate](#)

[C165 Test Method for Measuring Compressive Properties of Thermal Insulations](#)

[C168 Terminology Relating to Thermal Insulation](#)

[C177 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus](#)

[C195 Specification for Mineral Fiber Thermal Insulating Cement](#)

[C203 Test Methods for Breaking Load and Flexural Properties of Block-Type Thermal Insulation](#)

[C209 Test Methods for Cellulosic Fiber Insulating Board](#)

[C240 Test Methods of Testing Cellular Glass Insulation Block](#)

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² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

- C272 Test Method for Water Absorption of Core Materials for Structural Sandwich Constructions
- C302 Test Method for Density and Dimensions of Preformed Pipe-Covering-Type Thermal Insulation
- C303 Test Method for Dimensions and Density of Preformed Block and Board-Type Thermal Insulation
- C335 Test Method for Steady-State Heat Transfer Properties of Pipe Insulation
- C354 Test Method for Compressive Strength of Thermal Insulating or Finishing Cement (Withdrawn 2002)³
- C356 Test Method for Linear Shrinkage of Preformed High-Temperature Thermal Insulation Subjected to Soaking Heat
- C411 Test Method for Hot-Surface Performance of High-Temperature Thermal Insulation
- C446 Test Method for Breaking Load and Calculated Modulus of Rupture of Preformed Insulation for Pipes (Withdrawn 2002)³
- C447 Practice for Estimating the Maximum Use Temperature of Thermal Insulations
- C449 Specification for Mineral Fiber Hydraulic-Setting Thermal Insulating and Finishing Cement
- C450 Practice for Fabrication of Thermal Insulating Fitting Covers for NPS Piping, and Vessel Lagging
- C518 Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus
- C533 Specification for Calcium Silicate Block and Pipe Thermal Insulation
- C534 Specification for Preformed Flexible Elastomeric Cellular Thermal Insulation in Sheet and Tubular Form
- C547 Specification for Mineral Fiber Pipe Insulation
- C552 Specification for Cellular Glass Thermal Insulation
- C553 Specification for Mineral Fiber Blanket Thermal Insulation for Commercial and Industrial Applications
- C578 Specification for Rigid, Cellular Polystyrene Thermal Insulation
- C591 Specification for Unfaced Preformed Rigid Cellular Polyisocyanurate Thermal Insulation
- C592 Specification for Mineral Fiber Blanket Insulation and Blanket-Type Pipe Insulation (Metal-Mesh Covered) (Industrial Type)
- C610 Specification for Molded Expanded Perlite Block and Pipe Thermal Insulation
- C612 Specification for Mineral Fiber Block and Board Thermal Insulation
- C680 Practice for Estimate of the Heat Gain or Loss and the Surface Temperatures of Insulated Flat, Cylindrical, and Spherical Systems by Use of Computer Programs
- C692 Test Method for Evaluating the Influence of Thermal Insulations on External Stress Corrosion Cracking Tendency of Austenitic Stainless Steel
- C764 Specification for Mineral Fiber Loose-Fill Thermal Insulation
- C795 Specification for Thermal Insulation for Use in Contact with Austenitic Stainless Steel
- C800 Specification for Fibrous Glass Blanket Insulation (Aircraft Type)
- C871 Test Methods for Chemical Analysis of Thermal Insulation Materials for Leachable Chloride, Fluoride, Silicate, and Sodium Ions
- C1029 Specification for Spray-Applied Rigid Cellular Polyurethane Thermal Insulation
- C1055 Guide for Heated System Surface Conditions that Produce Contact Burn Injuries
- C1057 Practice for Determination of Skin Contact Temperature from Heated Surfaces Using a Mathematical Model and Thermesthesiometer
- C1104/C1104M Test Method for Determining the Water Vapor Sorption of Unfaced Mineral Fiber Insulation
- C1126 Specification for Faced or Unfaced Rigid Cellular Phenolic Thermal Insulation
- C1139 Specification for Fibrous Glass Thermal Insulation and Sound Absorbing Blanket and Board for Military Applications
- C1289 Specification for Faced Rigid Cellular Polyisocyanurate Thermal Insulation Board
- C1393 Specification for Perpendicularly Oriented Mineral Fiber Roll and Sheet Thermal Insulation for Pipes and Tanks
- C1559 Test Method for Determining Wicking of Fibrous Glass Blanket Insulation (Aircraft Type)
- C1729 Specification for Aluminum Jacketing for Insulation
- D1621 Test Method for Compressive Properties of Rigid Cellular Plastics
- D1622 Test Method for Apparent Density of Rigid Cellular Plastics
- D2126 Test Method for Response of Rigid Cellular Plastics to Thermal and Humid Aging
- D2842 Test Method for Water Absorption of Rigid Cellular Plastics
- E84 Test Method for Surface Burning Characteristics of Building Materials
- E96/E96M Test Methods for Water Vapor Transmission of Materials
- E136 Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C
- E176 Terminology of Fire Standards
- E659 Test Method for Autoignition Temperature of Liquid Chemicals
- 2.2 *API Standard:*
- API 521 Guide for Pressure-Relieving and Depressuring Systems⁴

³ The last approved version of this historical standard is referenced on www.astm.org.

⁴ Available from the American Petroleum Institute, 1220 L St., NW, Washington, DC 20005-4070.

2.3 *NACE Standard:*

SP0198 Standard Practice—The Control of Corrosion Under Thermal Insulation and Fireproofing Materials—A System Approach⁵

2.4 *NFPA Standards:*⁶

NFPA 49 Hazardous Chemicals Data

NFPA 90A Standard for the Installation of Air Conditioning and Ventilating Systems

NFPA 259 Standard Test Method for Potential Heat of Building Materials

2.5 *Federal Standard:*

40 CFR 60 Protection of Environment—Standards of Performance for New Stationary Sources⁷

3. Terminology

3.1 *Definitions*—Terminology **C168** is recommended to provide definitions and information on symbols, units, and abbreviations of terms used in ASTM standards pertaining to thermal insulation materials and materials associated with them. Terminology **E176** is recommended to provide terms and standard definitions for fire standards. Any term used in this guide that is not defined in Terminology **C168** or **E176** will be defined in the section in which the term is used.

3.2 *Acronyms and Abbreviations:*

3.2.1 *ACM*—asbestos-containing materials

3.2.2 *ACT*—autoignition temperature

3.2.3 *ASJ*—all service jacket

3.2.4 *CPVC*—chlorinated polyvinyl chloride

3.2.5 *DFT*—dry film thickness

3.2.6 *EPA*—Environmental Protection Agency

3.2.7 *FRP*—fiberglass-reinforced plastic

3.2.8 *FS/SD*—*FSI/SDI*—flame spread/smoke density spread index/smoke developed index

3.2.9 *MSDS*—material safety data sheet

3.2.10 *NAIMA*—North American Insulation Manufacturers Association

3.2.11 *NDT*—nondestructive testing

3.2.12 *NFPA*—National Fire Protection Association

3.2.13 *OSHA*—Occupational Safety and Health Administration

3.2.14 *PVC*—polyvinyl chloride

3.2.15 *QA/QC*—quality assurance/quality control

3.2.16 *SS*—stainless steel

3.2.17 *UV*—ultraviolet

3.2.18 *WVT*—water vapor transmission

4. Significance and Use

4.1 When choosing a thermal insulation product or combination of products, physical, chemical and mechanical properties and the significance of those properties should be considered. ASTM test methods are usually performed under laboratory conditions and may not accurately represent field conditions depending on process temperature, environment, and operating conditions. Performance results obtained using ASTM test methods can be used to determine compliance of materials to specifications but do not necessarily predict installed performance. Values stated in the ASTM material standards are those that apply to the majority of materials and not to any specific product; other tested values may exist for specific material applications.

4.2 Design of thermal insulation systems requires the understanding of process requirements, temperature control, heat loss criteria, control of thermal shock, and mechanical forces on insulation generated by thermal gradients and wind environmental conditions. Sometimes, the mechanical design of piping and equipment needs to be modified to support insulation adequately and provide for insulation weatherproofing. Process requirements may dictate the control of critical temperature to prevent freezing, maintain viscosity, or minimize internal corrosion. When handling heat transfer fluids such as ethylene oxide or hot oils, the selection of insulation materials and the insulation system design becomes critical. whereby If these fluids are absorb in insulation materials, the fluid flash point could be below the fluid operating temperature. Specified heat gain or heat loss and acceptable surface temperatures could also dictate thermal design of insulation systems. Environmental corrosivity, high wind, and extreme ambient temperatures affect the selection of weatherproofing and methods of its securement. A combination of these factors plays a significant role in the selection of insulation materials and application methods to provide long-lasting trouble-free service.

⁵ Available from the National Association of Corrosion Engineers, 1440 S. Creek Dr., Houston, TX 77084-4906.

⁶ Available from the National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269-9101.

⁷ Available from the U.S. Government Printing Office, Superintendent of Documents, 732 N. Capital St., NW, Washington, DC 20402-0001.

4.3 Application methods are generally defined by the purchaser's specifications. However, some specialty insulation systems, such as prefabricated insulation panels for ductwork, precipitators, and tanks, will also have supplemental installation requirements specified by the insulation system manufacturer. defined by the specification of the manufacturer.

4.4 In any application of thermal insulation, the insulation requires protection of some type, be it protection from the elements such as rain, snow, sleet, wind, ultraviolet solar radiation, protection from external forces that can cause mechanical damage, vapor passage, fire, chemical attack, or any combination of these. This protection can be provided in by metal, plastic, coated or laminated composites or both, mastic coatings, or a combination of the above depending upon the application, service, and economic requirements. Considering the enormous overall cost of a new facility, and comparing the initial cost of the insulated portion as a small percentage of that overall cost with the substantially increased operating cost as a result of inefficient insulation protection, it is common sense to provide only the best insulation system available and the best protection for that long-term investment consistent with the appropriate design and economic requirements. Usually a new facility is very expensive and the initial cost of the insulation portion is a small percentage of that overall cost. However, increased operating costs can result from inefficient protection.

4.5 Bid invitations should contain information necessary to determine how guarantees of materials and application will be resolved.

4.6 It is recommended that the purchaser provide a quality assurance program that defines the inspection of all materials, material safety data sheets (MSDS), and specific application procedures before and during progress of the insulation work.

4.7 During contract negotiations, the contractor and purchaser should discuss and agree to the procedures to be adopted for suitable periodic inspection and maintenance of the insulation systems to ensure that the initial performance of the material will be maintained. And, where applicable, they should agree to the methods of repair and replacement to be adopted in case damage occurs during service or overhaul.

5. Significant Physical Properties of Thermal Insulation Materials

5.1 *Apparent Thermal Conductivity:*

5.1.1 The apparent thermal conductivity of an insulation material is the measure of its ability to conduct heat between the hot and cold surfaces of the insulation. In inch pound units, this property (which is also known as the "k" factor or "k" value) is expressed as the amount of heat that passes through a unit area of a unit thickness of a homogeneous substance in a specified amount of time for a unit temperature difference, Btu-in/ft²-hr-F (In SI units, this property is expressed in W/m-K). Thermal conductivity of insulation changes with mean temperature:

$$\text{Mean temperature} = (\text{inner surface temp} + \text{outer surface temp})/2 \quad (1)$$

5.1.1.1 In general, thermal conductivity of insulation increases with an increase in mean temperature. Therefore, when determining the required insulation thickness for a process temperature, thermal conductivity at the process temperature must be considered. This is best determined by a computer program such as ASTM C680. curve from that process temperature to the jacket temperature must be considered. Since this is difficult to accomplish using hand calculations, it is recommended that computer programs designed to account for this be used.

5.1.2 There are several different ASTM tests available for determining the thermal conductivity of materials depending on the temperature range and the geometry. of the sample. Some of these are Test Method C177 referred to as the guarded hot plate and Test Method C518 referred to as the heat flow meter. Both of these tests are for block or flat insulations. Test Method C335 is used for horizontal pipe insulation. The cylindrical shape of pipe insulation and the presence of a longitudinal joint in the pipe insulation can may cause the apparent thermal conductivity of the pipe insulation to be 20 % or higher than different from that for a flat, one-solid-piece configuration. Also the orientation of the insulation, vertical versus horizontal, will affect the surface coefficient of the insulation, and hence, the heat loss.

5.2 *Autoignition:*

5.2.1 Some fluids such as oxygen and some heat transfer fluids when absorbed in insulation could lower the autoignition temperature. Autoignition is the initiation of combustion of a material in air as the result of heat liberation caused by an exothermic oxidation reaction in the absence of an external ignition source such as a spark or flame. The autoignition temperature (ACT) is the lowest temperature to which a combustible mixture should be raised so that the rate of heat evolved by the exothermic oxidation reaction is greater than the rate of heat loss to the surroundings and causes ignition. Autoignition depends on specific mixtures of chemicals and the method and apparatus used for its determination. It also depends on the volume and geometry of the containing vessel, the insulation material, and the initial temperature and pressure of the mixture and the surroundings.

5.2.2 Published autoignition temperatures (NFPA 49, for example) are specific to the method of determination (Test Method E659) and may not be interpolated or extrapolated for different configurations. It is improper to state that an insulation material has the property to "suppress an autoignition temperature" of a chemical. When a chemical has access to an insulated assembly from an external or internal leak, the chemical may be between the outer covering and the insulation, in the insulation, in joints and seams between insulation segments, or between the insulation and the vessel. The autoignition temperature for such a situation is most likely to be lower than published data, but that difference may not be attributed to the composition of an insulation material.

No quantitative change can be predicted without testing the configuration. The engineer or designer should know how to design insulated systems for materials such as heat transfer oils, petroleum oils, or hazardous chemicals and consider the need to eliminate leakage sources, installation details of protective insulation coverings, and the selection of an insulating material.

5.3 *Coefficient of Thermal Expansion/Contraction:*

5.3.1 The coefficient of thermal expansion (contraction) is the material property that measures the material's dimensional change relative to a change in its temperature. When heated or cooled, materials, such as steel, will expand or contract at a constant rate. These changes (see 7.2.4.7) are reversible in some materials and will return to their original dimension when their temperature returns to where it was before being heated or cooled. This reversibility distinguishes coefficient of expansion (contraction) from the other two properties relating to dimensional changes: dimensional stability and linear shrinkage, neither of which is reversible. Not all insulation materials exhibit this reversibility property.

5.3.2 Coefficients of expansion need to be considered when designing insulation system expansion and contraction joints. The amount of movement that can be accommodated by an expansion joint, along with the differential movement between the insulation and the substrate, is needed when determining the expansion/contraction joints spacing.

5.4 *Combustion Characteristics:*

5.4.1 Not all industrial applications will require that a material be defined as noncombustible. However, when required, a material is normally considered noncombustible if, in the form in which it is used and under the conditions anticipated, it will not ignite, burn, support combustion, or release flammable vapors when subjected to fire or heat.

5.4.1.1 Test Method E136 is a test method used to determine the combustion characteristics of building materials under specified laboratory conditions. Building materials that meet the criteria of Test Method E136 are normally considered to be noncombustible. In fact, this laboratory fire test is used to determine those materials that do not support combustion or add appreciable heat to an existing fire..

5.4.1.2 In order for materials to pass Test Method E136, materials are exposed to very high temperatures (1382°F or 750°C). The materials must meet three criteria: (a) no flaming or very limited flaming (no flaming after the first 30 s), (b) no temperature rise or only a slight temperature rise (the sample temperature can not rise, at any time during the test, more than 54°F (30°C) above the furnace temperature at the beginning of the test) and (c) minimal mass loss (up to 50 % of the original mass of the material).

5.4.1.3 Test Method E136 can be used for any material or for composite systems, but in practice it is usually used to evaluate core insulation component materials only. It is rarely used to evaluate facings or adhesives individually, or as a full composite.

5.4.2 Not all industrial applications require a flame spread index or a smoke developed index.

5.4.2.1 When a building material requires a specific surface burning characteristic, Test Method E84 is specified to assess that surface burning characteristic. The test results are recorded as flame spread indices and smoke development indices. Test Method E84 is used to measure and describe the response of materials, products, or assemblies to heat and flame under controlled conditions, but does not by itself incorporate all the factors required for fire-hazard or fire risk assessment of materials, products, or assemblies under actual fire conditions.

5.4.3 A material is considered to be a limited combustible material if the material if it meets the following requirements and if it does not meet the requirement to be a noncombustible material.

5.4.3.1 The material, in the form in which it is used, exhibits a potential heat value not exceeding 3500 Btu/lb (8141 kJ/kg), where tested in accordance with NFPA 259.

5.4.3.2 The material has a structural base of a noncombustible material with a facing not exceeding a thickness of 1/8 in. (3.2 mm) where the facing exhibits a flame spread index not greater than 50 when tested in accordance with Test Method E84.

5.4.3.3 The material is composed of materials which, in the form and thickness used, neither exhibit a flame spread index greater than 25 nor evidence of continued progressive combustion when tested in accordance with Test Method E84 and are of such composition that all surfaces that would be exposed by cutting through the material on any plane would neither exhibit a flame spread index greater than 25 nor exhibit evidence of continued progressive combustion when tested in accordance with Test Method E84.

5.4.3.4 Insulation materials that typically comply with this requirement are products that have a noncombustible core but also have a facing and an adhesive.

5.4.4 The tests described in 5.4.1 through 5.4.3 can be used to assess the response of a material or a product to heat and flame under laboratory conditions, but they cannot be used to assess the fire hazard or fire risk associated with the material or product under actual fire conditions. However, the results of any of these tests may be used as elements of a fire hazard or of a fire risk assessment for a particular end use or application.

5.5 *Compressive Properties:*

5.5.1 Compressive property is the value of the compressive load required to compress or deform a material. Compressive properties are produced by forces that tend to compact the material rather than pull the material's internal structure apart. Excessive/unacceptable deformation is usually considered if permanent or, in other words, if the material does not spring back and recover from the deformation when the load is removed. Many insulation materials exhibit no elasticity or resilience, so compressive "resistance" is defined instead as the load that produces yields, such as 5 %, 10 %, or other specified deformation, per Test Method C165.

5.5.2 The most common compressive forces that insulation should endure in the field are caused by foot traffic, support forces, and differential thermal contraction or expansion between the insulation and insulated steel. Proper design and operating practices will minimize these forces. Proper selection of insulation material will minimize the resulting damage to the insulation.

5.5.2.1 *Foot Traffic*—Many times personnel must gain access to areas for maintenance. The weight of a person can be distributed over an area as small as 2 to 3 in.² (130 to 190 mm²), depending on the pipe size. For flat surfaces, the force is more evenly distributed over a larger area. If the weight of the person divided by the area of distribution exceeds the compressive strength of the material, damage will occur.

5.5.2.2 *Support Forces*—The weight of the pipe and the content should be transmitted through the insulation to the insulation support rings, bars, or bands.

(1) When insulation is required to support cold insulated piping or equipment insulation should be selected with the necessary compressive strength. An appropriate safety factor that considers static, dynamic, bending moments should be added.

5.5.2.3 *Thermal Strain*—Dimensional changes in the insulation or steel are generally a result of thermal expansion or contraction. When cold insulation is restrained between two nozzles of a steel vessel and the vessel is cooled, the contraction of the vessel and, thus the reduction of the distance between the two nozzles, will result in compression of the insulation. Excessive deformation that is inelastic will yield a material failure. When the length and diameter of a large item increases as the operating temperature increases, insulation may be compressed against the outer jacketing, decreasing the insulation thickness. Test measurements of compressive strength differ from in-service performance for many reasons. Many insulation materials behave in elastically when loaded at elevated temperatures. The load produces a deformation and the material does not "spring back" to the original configuration. The same load applied again will produce a different deformation. A permanent deformation may have previously been induced by packaging, so out-of-the-box testing could give erroneous test results.

5.5.3 The compressive strength of most materials changes with temperature, so the in-service property can be greatly different than the strength measured at room temperature and reported on the data sheet. This may be a result of thermal decomposition of the binder or another organic constituent.

5.5.4 Because of directional cell structure or fiber orientation, some materials, for example C1393 material may exhibit different compressive properties on the axis of loading. Typically, the axis of maximum strength is perpendicular to the axis of minimum strength. Test Method C165 test specimens are prepared so that the direction of loading will compress the insulation thickness. Note that contraction forces, however, may be acting perpendicular to this axis.

5.6 Corrosivity:

5.6.1 The corrosion process of metal is very complex and takes many forms depending on the nature of the metal or alloy. A number of factors, such as the presence of inclusions or surface coatings at the interface, the homogeneity of its structure, the nature of the corrosive medium (electrolyte), the incidental environmental factors such as the presence of oxygen or salt-laden air, pollution, temperature, the velocity of the electrolyte movement, and other factors such as stress, oxide scales, deposits on surfaces, galvanic effects between dissimilar metals, and the occasional presence of stray electrical currents from external sources affect the rate and type of corrosion.

5.6.2 Corrosion of piping and equipment under insulation is a serious concern and cost could cost companies millions of dollars every year in repairs, replacement, and lost production. In an effort to minimize this problem, an evaluation needs to be made as to whether the insulation and accessory materials in a particular application will significantly contribute to corrosion. Painting or coating surfaces to be insulated may be the best way to limit corrosion under insulation.

5.6.3 Chlorides or halides contained in insulation may be leached out of the insulation and can exacerbate oxidation corrosion to steel and iron pipes, ducts, and other types of insulated surfaces. In addition, they may exacerbate stress corrosion cracking on austenitic stainless steel. Sources of leachable chlorides and halides in addition to the insulation system are possibly leaking process liquid from within the piping, ambient air containing salts and wash-down water or rain. The most practical way to reduce corrosion is to protect the pipe or equipment with an appropriate coating and seal all openings in the insulation with chloride-free sealant and to use properly designed and installed jacketing and vapor retarder to minimize water entry into the insulation system.

5.6.4 If an evaluation needs to be made as to whether the insulation and accessory materials in a particular application will significantly contribute to stress corrosion cracking of austenitic stainless steel, the following ASTM test methods are currently available and may provide useful information. When applying the results from these tests, consideration must be given to other insulation system factors including the pipe operating temperature, the use of pipe coatings, and the likelihood of water entering the insulation system.

5.6.4.1 Specification C795 for Thermal Insulation for Use in Contact with Austenitic Stainless Steel—This specification covers nonmetallic thermal insulation. In addition to meeting the requirements of this specification, the materials should pass the preproduction test requirements of Test Method C692 for stress corrosion effects on austenitic stainless steel and the confirming quality control and chemical requirements when tested in accordance with the Test Methods C871. Specification C795 puts the results of Test Methods C871 in graphical form to illustrate a range of acceptable chloride plus fluoride concentrations in conjunction with sodium plus silicate concentrations.

5.6.4.2 Test Method C692 for Evaluating the Influence of Thermal Insulations on External Stress Corrosion Cracking Tendency of Austenitic Stainless Steel—This test method, often referred to as the preproduction test or 28-day test, is used in determining if a material could contribute to stress corrosion cracking. Testing can also be done with cement, coatings, adhesives, and so forth.

5.6.4.3 Test Methods **C871** for Chemical Analysis of Thermal Insulation Materials for Leachable Chloride, Fluoride, Silicate, and Sodium Ions—This analysis tells how to test for the leachable chloride, fluoride, ions that accelerate and silicate and sodium ions that inhibit the stress corrosion of stainless steel. When plotted on the graph in Specification **C795**, it gives some indication that, if the formulation of the materials has not changed and the material passed Test Method **C692**, it should not cause stress corrosion cracking. Specification **C795** requires a pH of water leached from the insulation in accordance with Test Methods **C871** to be no greater than 12.5 at 77°F (25°C).

5.6.5 *Control of Corrosion under Thermal Insulation:*

5.6.5.1 Corrosion under insulation (CUI) has been occurring for as long as hot or cold equipment has been insulated for thermal protection, conservation, or process stabilization. The destructive results and nature of the corrosion mechanism are not referenced in the literature until the 1950s. As more problems have been experienced, concern and interest has built around this subject. Many articles and symposia papers have been published since 1983 as interest and activity in CUI have increased. The increased activity was driven largely by many occurrences of severe corrosion under insulation resulting in major equipment outages, production losses, and unexpected maintenance cost in refineries, gas plants, and chemical plants.

5.6.5.2 To avoid these problems, companies have developed their own criteria and approaches to the prevention of CUI. When comparing the various approaches, it is evident that there are many similarities, some differences, some new ideas, and some old ideas that have stood the test of performance.

5.6.5.3 The following ASTM testing is available to assist in determining the effect of insulation material on metal surfaces.

(1) Standard Practice C1617 for Evaluating the Influence of Thermal Insulation on Aqueous Corrosion of Metals. This practice covers procedures for a quantitative accelerated laboratory evaluation of the influence of extraction solutions containing ions leached from thermal insulation on the aqueous corrosion of metals other than stainless steel. Prepared laboratory standard solutions are used as reference solutions and controls, to provide a means of calibration and comparison.

(2) Imbedded test method in ASTM Material Specification C665 for Mineral Fiber Blanket provides a qualitative measure of the corrosiveness of insulation material by comparison to a control.

5.6.5.4 NACE Standard Practice SP0198, The Control of Corrosion under Thermal Insulation and Fireproofing Materials—A System Approach, incorporates the experience of many companies and shows some solutions to CUI.

5.6.6 *Factors Impacting Corrosion:*

5.6.6.1 Water is the biggest enemy of thermal insulation systems. If moisture migration into the insulation system is prevented, then CUI will be kept to a minimum. In addition to being an excellent electrolyte, without which corrosion could not occur, almost all water contains chloride ions. When water is allowed to enter the insulation system and get to the hot metal surface, the water evaporates and the chloride concentrations after time can reach thousands of parts per million.

5.6.6.2 Per NACE SP0198, stress corrosion cracking of austenitic stainless steel takes place at temperatures above 120°F (50°C). Stress corrosion cracking usually occurs at temperatures just below 350°F (175°C). Processes operating at very high temperatures are subject to stress corrosion cracking during shutdowns.

5.6.6.3 The total insulation system design should take into consideration not only the primary insulation material, but also the possible corrosive contributions of fabricating adhesives, bedding compounds, bore coatings, joint sealants, caulking, facing materials, and so forth.

5.6.6.4 The presence of chloride ions (potentially from salt-laden air) is known to have a very significant effect on the rate of corrosion of steel. This is because not only do the sodium and chloride ions add to the electrical conductivity of the electrolyte, but the chloride ion specifically attacks the protective film on the metal surface. Ingress of other atmospheric species such as nitrates and sulfates are also known to add to the corrosion risk. The ingress of water from external sources containing these species, for example, rainwater, plant spillages, and water used for hosing down equipment may contain sufficient aggressive species to be potentially dangerous for corrosion.

5.6.6.5 Test Method **C871** requires that the pH of an insulation material be tested. pH is the negative logarithm of the effective hydrogen-ion concentration or hydrogen-ion activity in gram equivalents per liter in expressing both acidity and alkalinity on a scale whose values run from 0 to 14 with 7 representing neutrality, numbers less than 7 increasing acidity, and numbers greater than 7 increasing alkalinity. These values should be used to help determine the possible effect of the insulation material on corrosion of the metal surface or any coating that may have been used to protect the surface from corrosion.

5.7 *Density*—The weight of a unit volume of insulation is normally expressed as lb/ft³ (kg/m³). It is necessary to know the density to calculate loadings and the heating rate when mass is one of the functions. Density should be determined per Test Method **C302**, Test Method **C303**, or Test Method **D1622**. These tests methods may require the material to be preconditioned before testing. It is recommended for materials that contain water such as calcium silicate or perlite that the “as-manufactured density” be requested and used when material weight mass is required for design.

5.8 *Dimensional Stability:*

5.8.1 Dimensional stability is the material property that indicates an ability to retain an object’s size or shape after aging, cutting, or being subjected to temperature or moisture.

5.8.2 Dimensional changes can affect the ease of installation and may render the material unsuitable for use. Dimensional changes may also produce adverse effects in the installed system, reducing its useful service life.

5.9 Exothermic Reaction:

5.9.1 Chemical reaction that release heat are classified as exothermic. Many organic materials used in thermal insulations are exothermic during thermal decomposition when the organic material is exposed to elevated temperatures. If the heat from thermal decomposition is released faster than it can be transferred to the surroundings, the internal temperature of the insulation is elevated. In some instances, the transient internal temperature in insulation can exceed the temperature of the hot surface on which it is installed. In most cases, this transient internal temperature rise should be controlled within safe and tolerable limits. It is necessary to know the thermal stability of the system and each of its components. It is important to know how much and how fast heat is released.

5.9.2 During the design process, designers should anticipate what can occur if the maximum use temperature of the insulation material is exceeded, power is lost, there is a fire exposure, or any other unusual service condition occurs. One control measures include heat-up schedules that raise the operating temperature slowly so that the rate of heat release from any exothermic reaction can be safely dissipated. Careful control of acetylene torches and welding operations around such insulated systems should be instituted.

5.10 *Hygroscopicity*—Hygroscopicity is the tendency of a material to absorb water vapor from the air; this property is especially pertinent for materials whose physical characteristics are appreciably altered by effects of water vapor. The effect depends on the physicochemical nature of the material's surface and increases with increasing relative humidity. See also 5.12.

5.11 Liquid Water Properties:

5.11.1 It is important to prevent liquid water from entering the insulating system. The primary method of preventing water from entering the insulating system is the installation and maintenance of a protective weather barrier. A second line of defense can be constructed through the proper design and installation of the additional materials forming the insulating system. The insulation itself can be used in constructing a second line of defense. Insulations offer varying degrees of protection depending on their liquid water transmittance properties. The selection of all materials is dependent on operating conditions and the estimated equipment service life.

5.11.2 The presence of water negatively impacts the insulating system. The impact will vary depending on the operating conditions that establish the thermal gradient and the materials of construction. The following is a summary of the impact of water present within an insulating system for pipes and equipment operating over different temperature ranges.

5.11.2.1 In temperature ranges of 32°F (0°C) or less—Water will freeze if allowed to migrate to a point in the insulating system at or below 32°F (0°C). The formation of ice provides an internal destructive force on the insulating system. Ice can quickly destroy the insulating envelope through freeze-thaw cycling caused by ambient air temperature changes.

5.11.2.2 In temperature ranges of 32 to 212°F (0 to 100°C)—Water will stay in the liquid phase if allowed to migrate within the insulating system. Water can adversely impact the k-value of those insulations susceptible of retaining water as the k-value of water is well more than an order of magnitude greater than most insulation materials. The presence of water on a metal pipe surface can also lead to corrosion. Corrosion can occur if the combinations of water/metal/oxygen or water/stainless steel/chlorides are present within the insulating system. log/standards/sist/27edff66-f04a-4a54-9a3a-863a94f4bc8b/astm-c1696-13

5.11.2.3 In temperature ranges equal to or greater than 212°F (100°C)—The total thickness of the insulation material should be evaluated to determine if it is possible that some areas within the material will be at or below 212°F (100°C), thus allowing the insulation to remain wet during operation and decreasing the thermal performance of the material.

5.12 Liquid Water Absorption:

5.12.1 Liquid water absorption is the property defined as the amount of water absorbed by a material when in contact with water. Liquid water absorption test methods measure the amount of water absorbed into the insulation under a given set of conditions. Insulation water absorption data gives an indication of how the insulation might resist water given a breach in the weather barrier.

5.12.2 Liquid water absorption properties are measured by several methods that are different for the various types of insulation. All the methods are based on measuring the weight gain of a sample immersed in water following a drain or drip period. **Table 1** is a list of ASTM test methods along with the specified submersion period.

5.12.2.1 *Test Methods C209 Procedure*—Condition the specimen until the practical constant weight is obtained at a temperature of 73.4 ± 4°F (23 ± 2°C) and a relative humidity of 50 ± 5 %. Measure the thickness of the specimen with reasonable accuracy and calculate the volume from there. Then carefully weigh the specimen and submerge it horizontally under 1 in. (25 mm) of fresh tap water maintained at a temperature of 73.4 ± 4°F (23 ± 2°C). After 2 hours of submersion, place the specimen on end to drain for 10 minutes; at the end of this time, remove the excess surface water by hand with a blotting paper or paper towel and immediately weigh the specimen.

5.12.2.2 *Test Methods C240 Procedure*—Carefully measure the thickness, width, and length to the nearest 0.04 in. (1 mm) of a cellular glass block, preferably 2 by 12 by 18 in. (5 by 30.5 by 460 mm) and calculate the volume and exposed surface area. Weigh the specimen to the nearest 0.004 oz (0.1 g), and then submerge it horizontally under 1 in. (25 mm) of water maintained at 70 ± 5°F (21 ± 3°C). Inert top surface weights are required to keep it submerged. After submerging it for 2 hours, set the specimen on end on a damp cotton bath towel to drain for 10 minutes. After the 10 minutes, remove the excess surface water by hand with a damp sponge for 1 minute on the large face and 1 minute on the four sides. Wring out the sponge before and once in between for each face and pass it at least two times on each surface.

TABLE 1 ASTM Test Methods that Measure Liquid Water Absorption Properties

ASTM Test Method	Submersion Period, hours
C209 Test Methods for Cellulosic Fiber Insulating Board	2
C240 Test Methods of Testing Cellular Glass Insulation Block	2
C272 Test Method for Water Absorption of Core Materials for Structural Sandwich Constructions	24
C610 Specification for Molded Expanded Perlite Block and Pipe Thermal Insulation	48
C1511 Test Method for Determining the Water Retention (Repellency) Characteristics of Fibrous Glass Insulation (Aircraft Type)	15 min
D2842 Test Method for Water Absorption of Rigid Cellular Plastics	96

5.12.2.3 *Test Method C272 Procedure*—Completely immerse the specimens, resting on edge, in a container of distilled water maintained at a temperature of $73 \pm 5.4^{\circ}\text{F}$ ($23 \pm 3^{\circ}\text{C}$). At the end of 24 hours, remove the specimens from the water one at a time, wipe off all surface water with a dry cloth, and weigh immediately.

5.12.2.4 *Test Method D2842 Procedure*—After cutting specimens, condition them in a forced-air circulating oven for 24 hours or more at $122 + 5^{\circ}\text{F}$ ($50 \pm 3^{\circ}\text{C}$). Place the underwater weighing jig in an immersion tank. Immerse the specimens with a suitable weighted rack in an open top immersion tank filled with freshly distilled water at $73.4 \pm 3.6^{\circ}\text{F}$ ($23 \pm 2^{\circ}\text{C}$). Adjust the water level to maintain a 2-in. (50-mm) head of water over the top of the specimens with 6- by 6-in. (150 by 150 mm) faces in the horizontal position. Remove obvious air bubbles clinging to the specimen with a soft bristle brush. Cover the entire surface of the water with low-permeance plastic film. Leave specimens immersed for 96 h while maintaining a 2-in. (50 mm) head of water at $73.4 \pm 3.6^{\circ}\text{F}$ ($23 \pm 2^{\circ}\text{C}$). Attach the underwater weighing jig to balance with a wire sling such that the top horizontal surface of the jig is 2 in. (50 mm) below the surface of the water. Be sure that the submerged jig is free of trapped air bubbles. Weigh the empty submerged jig to the nearest 0.004 oz (0.1 g). Insert the test specimen into the submerged underwater weighing jig without removing the specimen from the water. Weigh to the nearest 0.004 oz (0.1 g). Do not remove any specimens from the water until all have been weighed, as removing specimens reduces the 2-in. (50 mm) head.

5.12.2.5 *Specification C610 Procedure*—This test procedure evaluates the water absorptivity of the insulation material after being exposed to an elevated temperature. Two specimens are required for this test procedure.

(1) One specimen is placed in an electric oven and the second is used as a control sample. The oven is operated at 600°F (316°C) for a minimum of 24 hours. The heat treated specimen is removed and along with the control specimen placed in a controlled environment of $73 \pm 1.8^{\circ}\text{F}$ ($23 \pm 1^{\circ}\text{C}$) and $50 \pm 5\%$ relative humidity. After the specimens have cooled for at least 12 hours in the control environment, weigh each of the specimens to the nearest 0.004 oz (0.1 g).

(2) Completely immerse each specimen so that a head of 1 in. (25 mm) of distilled water at ambient temperature is maintained for a minimum of 48 hours. Withdraw each specimen and quickly wipe off excess surface moisture with a damp cloth. Immediately weigh each specimen to the nearest 0.004 oz (0.1 g).

(3) Calculate the percent of water absorption by weight, using the weights obtained after heat soaking as the dry weight. The calculation should be as follows:

$$\text{Weight absorption} = 100 \times (W_{AI} - W_{AHS}) / W_{AHS} \quad (2)$$

where:

W_{AI} = after immersion specimen weight, and
 W_{AHS} = after heat soak specimen weight.

5.13 Maximum/Minimum Temperatures for Continuous Operation:

5.13.1 When choosing an insulation material for any given service, one major concern is system-operating temperature(s) (minimum/maximum) and the proper insulation material(s) designed for use within those operating parameters. Insulation materials' intended operating temperature ranges for insulation materials are normally specified by the insulation material manufacturers.

5.13.2 Insulation manufacturers will normally publish a recommended temperature range based on thermal properties at the rate per the recommendations of the manufacturer or with little regard to other physical properties. When selecting an insulation material, this recommended range should be the first consideration. Next, test results obtained from Test Method **C411** or Practice **C447** should be considered.

5.13.2.1 Test Method **C411** stipulates that the insulation material be applied on a test plate or pipe while at ambient temperature. The temperature is then brought up at a rate per the recommendations of the manufacturer or the rate of the intended service. After the product has been heated to the maximum temperature and held for approximately 96 h, a report is written to specify the kind

of insulation material tested, number of segments tested, temperature of test, number and extent of cracks, warpage, cracking, delamination, sagging, decrease in thickness, or any other visible changes. Also, this report should define any evidence of flaming, glowing, smoldering, smoking, and so forth.

5.13.2.2 Practice C447 requires that the pipe or plate be heated to the maximum temperature before the material is applied unless a specific heat up temperature limit is specified by the manufacturer. The product is maintained at this maximum temperature until equilibrium is reached and then held until all the major changes occur within the product, usually within 96 hours. A rapid heat up within the insulation may cause an undesirable exothermic change resulting with ultimate/irreversible damage. After exposure on the hot surface for 96 hours the product is then cooled and, in addition to visual examination and report made per Test Method C411, material properties are tested and reported, that is, compression, thermal conductivity, flexural strength, and so forth in addition to any damage resulting from excessive exotherming. Note that the properties and values obtained after testing at maximum temperature may eliminate that insulation material from consideration. Determination of material acceptability should be made by the specifier after review of the test results.

5.13.3 There is no existing ASTM standard for testing, specifying, or reporting results for minimum operating temperatures for cold-service pipe insulation materials.

5.13.4 When the temperature of the system to be insulated is cyclic in nature, operates at temperatures below ambient, and then regenerates at temperatures well above ambient or operates with combinations of maximum and minimum temperatures, it may be necessary for the specifier to look at the combinations of maximum and minimum tests results plus all associated properties to determine the need for one type of material for an inner layer and another type for the outer layer(s).

5.14 *Resilience*—Resilience is the ability of a material to recover dimensionally upon release from stress. When insulation is used to take up dimensional change, such as in an expansion (contraction) joint, a low-compressive strength may be needed. The percentage of recovery to original size upon the relief of stress is important.

5.15 *Service Life:*

5.15.1 One of the major concerns of a designer is to provide the owner with some assurances that insulated systems will perform as intended for an extended period of time. There is no accepted handbook containing recipes for establishing how to estimate the duration or “service life” periods for insulated systems in the industrial market segments. Even the definition of the term extended period of time can range from several months to as much as 20 or more years. There are too many extremes and too many variables to make specific comments applicable to every system. Service temperatures range from cryogenics up to 2300°F (1260°C), and ambient conditions range from mild indoor conditions to severe outdoor exposures of temperatures, humidity, and weather. Anecdotal information tells us that design conditions in Houston for outdoor systems are not the same for Philadelphia, Chicago, Los Alamos, or Fairbanks. Anecdotal information tells us that what should be done for cold surfaces is different from what should be done for hot surfaces. Anecdotal information tells us that what should be done for ducts, tanks, and pipes in residential buildings is simple because the major fluids in the insulated systems are usually air and water at temperatures usually below 250°F (121.1°C). The same holds true for commercial construction in which air and water are the principal fluids being contained. In the industrial sector, water is handled as a liquid, ice, saturated steam, and superheated steam. Other gasses, liquids, solids, and chemicals that may be corrosive, unstable, combustible, or toxic also should be handled in the industrial sector.

5.15.2 Long service life denotes that the designed thermal performance is maintained to some high percentage of the original design. Long service life of insulated systems requires the engineer or designer to have good knowledge of the materials in the pipes, tanks, vessels, equipment, towers, and heat exchangers. It demands the proper selection of construction materials to contain these materials safely under anticipated conditions of weather, wind, fire, shock, vibration, and seismic exposure. It needs the proper selection of the appropriate insulation materials to meet the specific thermal design requirements of the system in service and over a long period of time. It relies on the proper design details and proper installation to reduce or eliminate the deleterious effects of expansion or contraction and excessive heat flows through parallel paths. It demands the proper selection of surfacing treatments to protect the insulated system from mechanical abuse or weather-related damage in normal service. It depends on the proper selection of maintenance procedures to inspect and repair the system regularly and quickly. All of these things should be accommodated within the cost constraints superimposed by the owner.

5.15.3 Long-term service life demands that the insulated system be well designed, well built, operate as designed, and well maintained. Weaknesses in any area of design, installation, operation, or maintenance will shorten the service life of an insulated system.

5.16 *Shrinkage:*

5.16.1 Shrinkage, otherwise referred to as linear shrinkage, is the material property that indicates the dimensional or volumetric changes that occur when exposed to cryogenic or elevated temperatures. These changes are irreversible. Linear shrinkage is determined in accordance with the test method specified in the material standard. Linear shrinkage is established after the material has been subjected to a soaking heat for a period of 24 hours, usually at the maximum temperature limit of the material.

5.16.2 The linear shrinkage under soaking heat listed within various ASTM material specifications is a maximum rate. However, the rate of shrinkage is nonlinear across the material-use temperature range. That is to say, a material may experience very little or no shrinkage at low or moderate temperatures.

TABLE 2 Typical ASTM Specifications for Min/Max Values of Some Insulation Materials Used for Industrial Applications

NOTE 1—Values represent a majority of known materials. Not all materials of the same classification may have the same values. All values should be verified with the material manufacturer before use.

NOTE 2—Verify value with the material manufacturer.

NOTE 3—See Specification C610 for water absorption test and limits. Contact the manufacturer for product data.

NOTE 4—Contact the material manufacturer for Test Method C411 test results when using above 250°F (121°C). Heat rise or fall (change) should be in a linear progression not to exceed a rate of 200°F (111°C) per hour.

NOTE 5—Value varies with type and density. Contact the manufacturer.

NOTE 6—Value is at ambient temperature. Contact the manufacturer for temperatures above ambient.

NOTE 7—Consult the manufacturer for specific recommendation and properties at temperatures less than -40°F (4.4°C).

NOTE 8—Response to thermal aging per Test Method D2126.

NOTE 9—Response to thermal aging per Test Method D2126. Maximum 4 %.

NOTE 10—The water vapor permeability of mineral fiber insulation is so large that it can not be measured using standard methods. This permeability should be considered when selecting this type of material.

NOTE 11—N/A = Not applicable.

Physical Properties (Note 1) (See Definitions)	Calcium Silicate Pipe and Block	Cellular Glass Pipe and Block	Elastomeric Sheet and Tubular	Expanded Perlite Pipe and Block	Melamine Pipe and Block	Microporous
Applicable ASTM Standard	C533 Type 1	C552	C534	C610	C1410	C1676
Maximum temperature, °F (C)	1200 (649)	800 (427) (Note 4)	220 – 350 (104 to 175)	1200 (649)	350 (177)	2102 (1150)
Minimum temperature, °F (C)	80 (27)	Minus 450 (-268)	Minus 297 (-183)	80 (27)	Minus 40 (-40)	176 (80)
Density (ASTM C302 and C303) lb/ft ³ (kg/m ³)	15 (240)	6.12 to 8.62 (98 to 138)	3 to 6.5 (48 to 104)	10 to 14 (160 to 224)	0.70 ± 0.10 (11.2 ± 1.6) per ASTM D 3574 Method A	Not Stated
Block compressive strength (minimum) at 5% deformation ex- cept where noted (ASTM C165, D3574 Method B) psi (kPa)	100 (688)	60 (415) per ASTM C240 Capped	N/A	70 (483)	80 (36.3) @ 25% / 160 (72.6) @ 65% per D3574	50 – 140 (7.3 – 20.3) @ 10% deformation
Flexural strength (minimum) psi (kPa) (ASTM C446)	50 (344)	41 (283) Block per ASTM C203 Procedure A, Method I or II	Not Stated	45 (310) (Block per C203)	Not Stated	Not Stated
Dimensional change at max. temperature (%) (ASTM C356) (See Table 4)	2 %	Not Stated	7% (per ASTM C534)	Length 2% Width 2% Thick 10%	Not Stated	Length 2% Width 2% Thick 10%
Surface burning characteristics (ASTM E84) Flame Index / Smoke Developed Index	0/0 (Note 2)	5/0	Not Stated	0/0 (Note 2)	25/50 @ 1 inch (25 mm)	0 / 10
Combustion characteristics (ASTM E136)	Pass (Note 2)	Pass	Not Stated	Pass	Not Stated	Not Stated
Water Vapor permeability (ASTM E96/E96M) Perm-inch (g/Pa-s-m) (Desiccant Method)	N/A	0.005 (0.007)	0.10 (1.44 × 10 ⁻¹⁰)	N/A	Not Stated	
Water vapor sorption (by weight) Maximum (%) (ASTM C1104/C1104M)	N/A	N/A	N/A	N/A	25	10 to 5 Based on Type and Grade
Water Absorption (ASTM C209) % Self-heating (exothermic)	No	No	N/A	Note 3 No	No	No
Physical properties (Note 1) (See Definitions)	Mineral Fiber Block	Mineral Fiber Board	Mineral Fiber Board	Mineral Fiber Blanket	Mineral Fiber Blanket	Mineral Fiber Blanket
Applicable ASTM Standard	C612 Type V	C612	C612 Type IA, IB, II and III	C553	C553	C553
Maximum temperature, °F (C)	1800 (982)	Type IV A&B 1200 (649)	450 to 1000 (Note 5)	Type VII 1200 (649)	Type V and VI 1000	Type IV 850 (454)
Minimum temperature, °F (C)	0 (-18)	0 (-18)	0 (-18)	0 (-18)	0 (-18)	0 (-18)
Density (ASTM C302 and C303) lb/ft ³ (kg/m ³)	Not Stated	Not Stated	Not Stated	12 (192) Max per ASTM A167	10 (160) Max per ASTM A167	8 (128) Max per ASTM A167
Block compressive strength (minimum) at 5% deformation ex- cept where noted (ASTM C165) psi (kPa)	1000 PSF (48) 2 inch (50 mm) at 10% deformation	50 PSF (2.4) 2 inch (50 mm) at 10% deformation	25 to 12 PSF (1.2 to 0.6) 2 inch (50 mm) at 10% deformation	N/A	N/A	N/A
Flexural strength (minimum) psi (kPa) (ASTM C446)	Not Stated	Not Stated	Not Stated	Not Stated	Not Stated	Not Stated
Dimensional change at max. temperature (%) (ASTM C356) (See Table 4)	4 %	2 %	2 %	Not Stated	Not Stated	Not Stated