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An American National Standard

Standard Specification for Transportation Tunnel Structural Components and Passive Fire Protection Systems[1]

This standard is issued under the fixed designation E3134; 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 reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

Fire poses a serious threat to the structural stability of tunnels as shown by real fires in tunnels over the last decade. The damage is a serious threat to life safety and results in costly repairs and lost service time. The damage is mitigated with heat-resistant concrete and passive fire-resistive materials and systems. The result is limited spalling of concrete, limited structural damage of the concrete via cracks to the cold zone, and limited temperature increases of the reinforcing steel. Further, the fire-resistive methods employed are also optionally evaluated against common environmental exposures, which could adversely affect the performance or fire-resistance rating.

1. Scope

1.1 This specification is applicable to the fire resistance of concrete tunnel linings, fire-resistive materials, and structural tunnel members.

1.2 Concrete mix design, tunnel linings, and passive fire protection methods are specific to each tunnel project. Therefore results of the spalling test are only valid for the specific materials and systems employed during each test, notwithstanding maximum and minimum limitations.

1.3 Tunnels are potentially exposed to ground water, even those passing through elevated terrain, such as mountains, road salt, and maintenance surface washing. Consideration shall be given to potential adverse effects that result, such as material degradation due to these exposures.

1.4 Movement joints shall be considered and their impact on the overall fire resistance shall be assessed by testing. Tests shall be conducted as a system.

1.5 This specification does not address mechanical attachment methods for equipment due to the vast variety of possible methods and loads. However, consideration shall be given to methods that appreciably affect the concrete temperature during the heating conditions. Consideration shall be given to a second test conducted with the attachment to evaluate the effect. The attachment test shall include the largest diameter anchor, the deepest installed anchor, and the largest load applied to the anchor. This requirement results in a single anchor being tested or multiple anchors being tested. If multiple anchors are required to be tested, then each shall be tested under its maximum load.

1.6 This specification requires testing of both horizontal and vertical orientations. For fire-resistive materials, it is generally accepted that the horizontal orientation represents the worst case test scenario.

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

1.8 *This standard 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 factors required for fire hazard or fire risk assessment of the materials, products, or assemblies under actual fire conditions.*

1.9 *Fire testing is inherently hazardous. Adequate safeguards for personnel and property shall be employed in conducting these tests.*

1.10 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.11 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the*

[1] This specification is under the jurisdiction of ASTM Committee E05 on Fire Standards and is the direct responsibility of Subcommittee E05.11 on Fire Resistance.

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Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C109 Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)

E84 Test Method for Surface Burning Characteristics of Building Materials

E119 Test Methods for Fire Tests of Building Construction and Materials

E176 Terminology of Fire Standards

E1966 Test Method for Fire-Resistive Joint Systems

G85 Practice for Modified Salt Spray (Fog) Testing

2.2 *Other Standard:*[3]

2008-Efectis-R0695 Fire testing procedure for concrete tunnel linings

3. Terminology

3.1 *Definitions*—For definitions of terms found in this specification, refer to Terminology E176.

4. Summary of Test Method

4.1 Different fire protection approaches are chosen in the design and construction of tunnels. The approaches addressed in this specification are limited to concrete mix design and fire-resistive materials, and the potential impact of environmental exposures (optional). A minimum of one fire test is required for each assembly, configuration, and orientation. For cases where the concrete mix design is intended to address the fire load independent of fire-resistive materials, the Spalling Test in accordance with 9.1 is applicable. For cases where standard or general concrete design mix is intended and protected by fire-resistive materials, the Fire-Resistive Material Test is applicable. For cases where both the concrete design mix and fire-resistive materials are combined to address the fire load, both test criteria are applicable but can be accomplished with one fire test for each assembly, configuration, and orientation.

4.1.1 *Surface Burning Test:*

4.1.1.1 Flame Spread Index (FSI) and Smoke Developed Index (SDI) in accordance with Test Method E84 are provided for fire-resistive materials.

4.1.2 *Environmental Tests (Optional):*

4.1.2.1 Ground Water Test is a means to assess the effect of water and moisture on concrete tunnel lining and fire-resistive materials.

4.1.2.2 Road Salt Test assesses the effect of salt on concrete tunnel lining and fire-resistive materials.

4.1.2.3 Tunnel Interior Surface Washing assesses the effects of repeated washing on concrete tunnel lining and fire-resistive materials.

4.1.2.4 *Spalling Test*—The Spalling Test is intended to assess the spalling behavior of concrete mix designs specific to tunnel project specification. The test assesses the reinforcing steel by means of temperature and temperature of other critical locations, such as post tension sleeves.

4.1.2.5 *Fire-Resistive Material Test*—The Fire-Resistive Material Test is intended for materials whose purpose is to protect the concrete by limiting the temperature at the interface with the concrete and limiting reinforcing steel temperatures within the concrete.

4.1.3 *Fire-Resistive Joint Test*—When movement joints are used as part of the tunnel construction, they shall be assessed for fire resistance and the ability to undergo movement without reducing the fire rating.

5. Significance and Use

5.1 The test methods described in this specification are used to determine the performance of tunnel construction elements with respect to exposure to a standard time-temperature fire test. The performance of the elements is dependent upon the specific assembly of materials tested.

5.2 The test exposes a specimen to the selected fire exposure, as described in this specification, controlled to achieve specified temperatures throughout a specified time period.

5.3 The test standard provides for the following:

5.3.1 *Flame Spread*—Comparative measurements of flame spread and smoke developed in accordance with Test Method E84.

5.3.2 *Environmental Considerations*—Potential effects on the fire resistance from environmental conditions expected within a transportation tunnel.

5.3.3 *Spalling*—Susceptibility of concrete design mixes to spalling when exposed to the fire exposure, as described in this specification.

5.3.4 *Transmission of Heat*—The ability to limit temperatures at critical locations such as reinforcing steel and interface of fire-resistive materials and concrete.

5.3.5 *Fire-Resistive Joints*—The ability to maintain fire resistance continuity when the assembly requires a joint to mitigate the effects of movement.

5.4 The test standard does not provide the following:

5.4.1 Evaluation of active fire protection methods or systems or other techniques not appropriate for evaluation by this specification.

5.4.2 Information as to performance of specimens constructed with components or lengths other than those tested.

5.4.3 Evaluation of the degree by which the specimen contributes to the fire hazard by generation of smoke, toxic gases, or other products of combustion.

5.4.4 Measurement of the degree of control or limitation of the passage of smoke or products of combustion through the specimen.

[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.

[3] Available from efectis nederland, P.O. Box 554, 2665 ZN Bleiswijk, Brandpuntlaan Zuid 16, 2665 NZ Bleiswijk, The Netherlands, http://efectis.com/wp-content/uploads/2016/07/RWSProcedureFireProtectionforTunnels.pdf.

6. Flame Spread

6.1 Fire-resistive materials shall be tested in accordance with Test Method E84. The FSI shall be ≤25 and SDI ≤50.

7. Environmental Tests

7.1 Environmental tests shall be conducted when the test sponsor, design professional, or authority having jurisdiction has a concern about the impact on fire resistance from the presence of water, road salt, or repeated surface washing, or combinations thereof. The environmental tests are performed in advance of the fire testing to evaluate environmental impact. Included are ground water test, road salt test, and tunnel interior surface washing. For more details on the environmental tests, see Appendix X1.

8. Control of Fire Tests for Fire Resistive Materials

8.1 *Time-Temperature Curve:*

8.1.1 The fire exposure shall be controlled to conform to the modified Rijkswaterstaat (RWS) curve, taken from 2008-Efectis-R0695, presented in Tables 1 and 2, and as shown in Fig. 1.

8.1.2 As an option, an alternate time-temperature curve is presented in Annex A1. The alternative time-temperature curve presented incorporates the highest temperatures of the various furnace fire exposures known at the time this document was written. The intent is to provide a worst case test to allow for multiple approvals from one test.

8.1.3 The samples shall undergo a cool down period by decreasing the furnace temperature by 10 °C (18 °F) per minute for 100 min, see Table 2.

8.2 *Furnace Temperature:*

8.2.1 The temperature fixed by the curve shall be the average temperature obtained from the readings of thermocouples symmetrically distributed within the test furnace to show the temperature near all parts of the assembly. Use a minimum of three thermocouples, with no fewer than five thermocouples per 9.3 m^2 (100 ft^2) of exposed floor surface, and no fewer than nine thermocouples per 9.3 m^2 (100 ft^2) of exposed wall surface.

8.2.2 The furnace thermocouples shall be Type B, platinum-rhodium, 0.81 mm (0.032-in.) wire, exposed junction thermocouples. One conductor contains 30 % rhodium and the other conductor contains 6 % rhodium.

TABLE 1 Tunnel Fire Test Time-Temperature Curve for Control of Fire Tests

Time (min)	Temperature [°C (°F)]
0	20 (68)
3	891 (1635)
5	1141 (2085)
10	1199 (2190)
30	1299 (2370)
60	1349 (2460)
90	1299 (2370)
≥120	1199 (2190)

TABLE 2 Tunnel Fire Test Cool Down, Time Interval Versus Temperature Decrease

Added Time (min) from Time of Desired Rating Period	Furnace Temperature [°C (°F)] Decrease from Time of Desired Rating Period
+10	–100 (–180)
+20	–200 (–360)
+30	–300 (–540)
+40	–400 (–720)
+50	–500 (–900)
+60	–600 (–1080)
+70	–700 (–1260)
+80	–800 (–1440)
+90	–900 (–1620)
+100	–1000 (–1800)

8.2.3 For samples in the horizontal orientation, place the junction of the thermocouple 305 mm (12.0 in.) away from the exposed face of the sample.

8.2.4 For samples in the vertical orientation, place the junction of the thermocouple 152 mm (6.0 in.) away from the exposed face of the sample.

8.2.5 Read and record the temperature at intervals not exceeding 1 min.

8.2.6 The accuracy of the furnace control shall be such that the area under the temperature-time curve, obtained by averaging the results from the furnace thermocouple readings, is within 15 % of the corresponding area under the standard temperature-time curve presented in Tables 1 and 2, and as shown in Fig. 1, for the time period between 5 and 10 min, 10 % for the time period between 10 and 30 min and 5 % from 30 min to the end of the test.

NOTE 1—The spalling of concrete will expose new, cold concrete surfaces that will increase the need for energy input in order to maintain furnace control within tolerance.

8.3 *Furnace Pressure:*

8.3.1 Measure the differential pressure between the exposed and unexposed surfaces of the test assembly. The pressure shall be measured using a tee-shaped probe, or a tube probe, as shown in Fig. 2, manufactured from stainless steel, or other suitable material.

8.3.2 Measure the pressure by means of a manometer or equivalent transducer. The manometer or transducer shall be capable of reading 2.5-Pa (0.01-in. H_2O) increments with a measurement precision of 1.25 Pa (0.005 in. H_2O).

8.3.3 *Horizontal Specimen*—The required differential pressure plane shall be located within the furnace 305 mm (12 in.) below the specimen.

8.3.4 *Vertical Specimen*—The required differential pressure plane shall be located within the furnace at the mid-height of the specimen.

8.3.5 Following the first 5 min of the test, the pressure shall be controlled at below 50 Pa (0.2 in. H_2O), then following the first 10 min, the pressure shall be controlled at 20 ± 4 Pa (0.08 ± 0.016 in. H_2O).

NOTE 2—It is recognized that the dynamic nature of the furnace limits the ability of pressure control within the furnace, so there is a greater tolerance for the first 10 min of startup. However, the goal is to achieve a stable pressure of 20 Pa as quickly as possible.

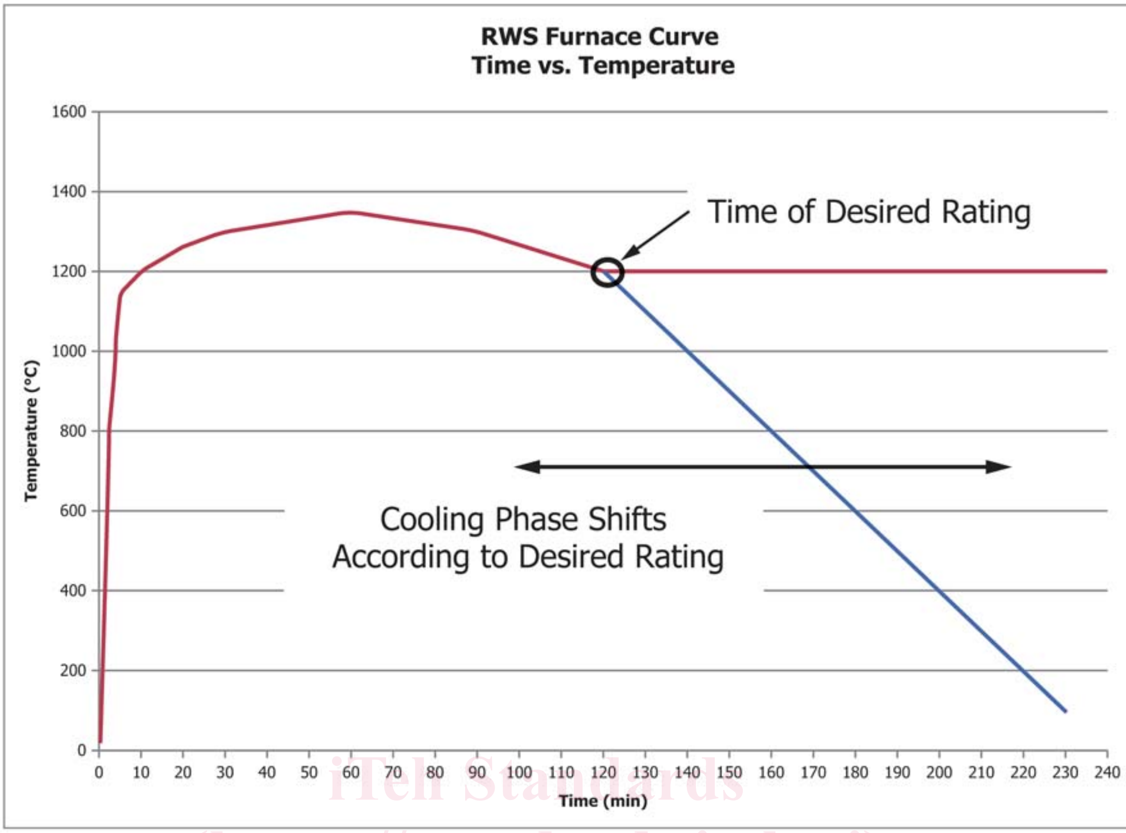

FIG. 1 Tunnel Fire Test Time-Temperature

9. Test Specimen for Fire Resistive Materials

9.1 *Spalling Test:*

9.1.1 The orientation of the specimen for the test is based on the element it represents. Walls shall be tested vertically and ceilings tested horizontally. If the specimen represents both vertical and horizontal application, it shall be tested in both orientations.

9.1.2 The concrete mix design, casting, and finishing shall be to the sponsor's specifications or subject to certification listing. This includes aggregate type and size, additives, added fibers, other fillers, cement type and quantity, water cement ratio, etc., and application and bonding, fastening, attachment, etc., of external fire-resistive materials.

9.1.3 Reinforcement type, size, spacing, location, minimum concrete cover, etc., shall be to the sponsor's specifications or subject to certification listing.

9.1.4 The sample shall be large enough to avoid edge effects. At a minimum, the horizontal sample size shall expose 16.75 m^2 (180 ft^2) with no area dimension less than 3050 mm (10 ft). Vertical sample size shall expose 9.3 m^2 (100 ft^2) with no area dimension less than 2750 mm (9 ft). Sample thickness shall be the actual thickness in the intended applications but limited to 610 mm (24 in.).

9.1.5 *Preparation:*

9.1.5.1 Concrete casting shall be the intended end-use condition including type of formwork and orientation. Specimens for ceiling locations shall be cast in a horizontal orientation such that the bottom, formwork side, is exposed to the furnace conditions. Wall specimens shall be cast vertically.

9.1.5.2 Thermocouples for internal measurement of steel and the concrete temperature gradient shall be placed in the specimen prior to casting of concrete. Care must be taken to assure that the locations are not altered during casting.

9.1.5.3 There shall be a minimum of nine thermocouples positioned within the slab, evenly distributed on the reinforcing steel closest to the heating conditions. If the slab is protected with fire-resistive material on the exposed face, a minimum of nine additional thermocouples shall be positioned and evenly distributed at the fire-resistive material and concrete interface, to record the concrete surface temperature. Care must be taken with the application of the thermocouples so casting of the concrete or installation of the fire-resistive material does not lead to inadequate contact of the thermocouple junction with the concrete surface. If the system has joints, an additional five thermocouples shall be located behind the joints. If post-tensioning is used for compressive loading, one thermocouple shall be located at the center of each post-tensioning sleeve included with the concrete casting, positioned closest to the heating condition. The thermocouples shall be type-K, chromel-alumel and shall be firmly affixed so as to not move during the casting. The thermocouples shall be capable of being cast into the concrete without disturbing their operation. Route the thermocouple leads parallel to the isothermal planes

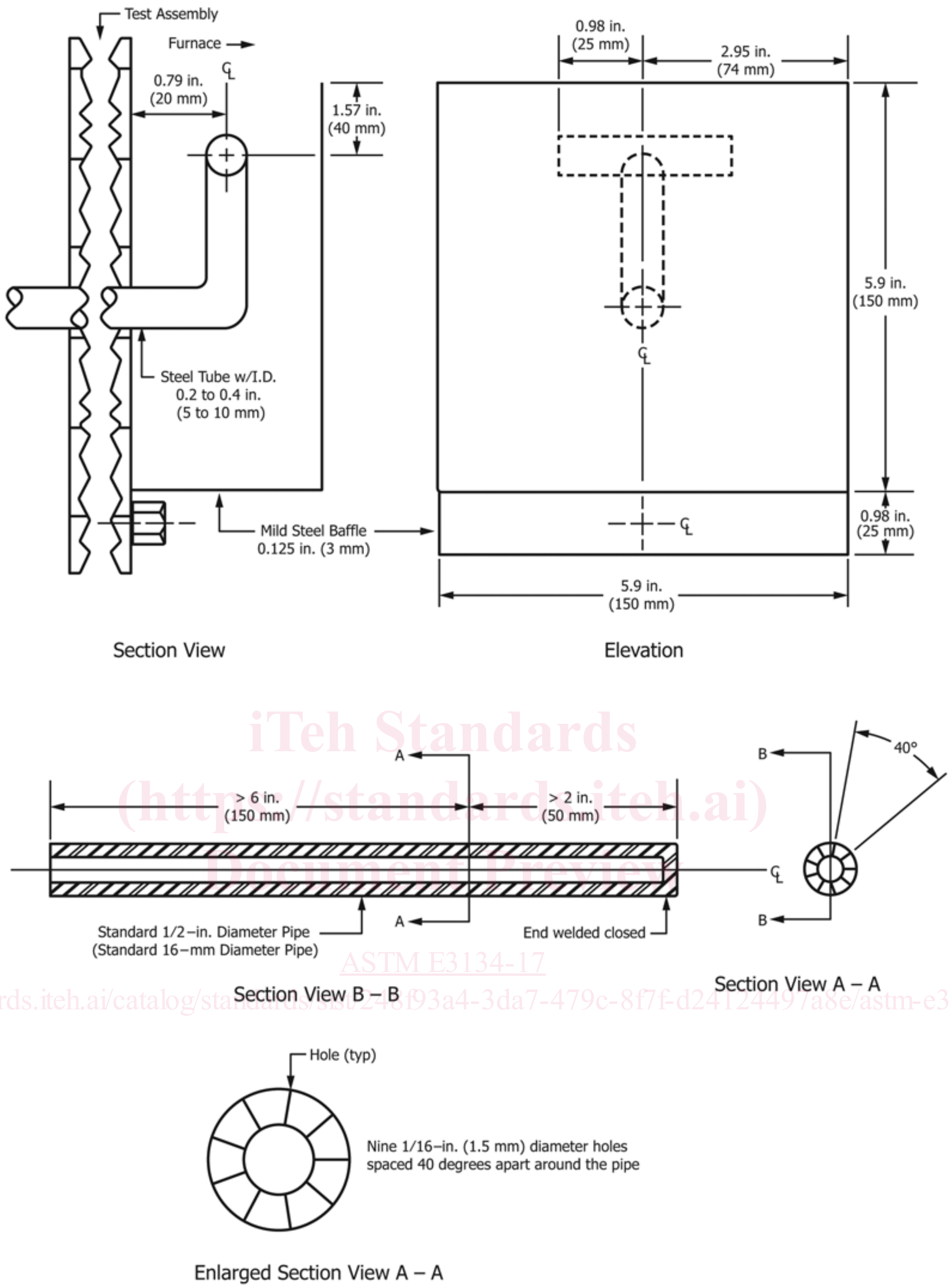

FIG. 2 Pressure Sensing Probe

for a distance of 150 mm (6 in.) from the measuring junction to minimize error associated with cooling from the leads.

9.1.5.4 Compressive loading shall be accomplished with post-tensioning or hydraulic jacks bearing against a reaction frame. If post-tensioning is used, sleeves shall be installed prior to casting the concrete. Exact positioning of the sleeves is important and consideration shall be given to potential loss of load due to thermal expansion of the steel. The compressive load and eccentricity shall be equal to the design value as provided by the tunnel lining design engineer.

9.1.6 Any externally applied fire-resistive material shall be applied in the same manner as it is in the intended end-use application. This includes surface preparation, attachments, application orientation, thickness, and joints.

9.2 *Fire-Resistive Material Test:*

9.2.1 Fire-resistive material is not specific to a single system; therefore, qualification for application over different systems is necessary. A standardized concrete slab is used for fire-resistive material qualification.

9.2.2 The standardized concrete slab shall be cast with normal weight, 27.6-N/mm^2 (4000-psi) strength concrete. At a minimum, the horizontal sample size shall expose 16.75 m^2 (180 ft^2) with no area dimension less than 3050 mm (10 ft). Vertical sample size shall expose 9.3 m^2 (100 ft^2) with no area dimension less than 2750 mm (9 ft), with a thickness of 6 in. (150 mm).

9.2.3 The standardized concrete slab shall be reinforced with 10M, nominal diameter 11.3 mm, (No. 4, nominal diameter ½ in.) reinforcing steel, spaced 305 mm (12 in.) on center in perpendicular directions. The center of the reinforcing steel shall be located at the mid-depth between the exposed and unexposed surfaces of the slab.

9.2.4 There shall be a minimum of nine thermocouples positioned within the horizontal, or vertical, standardized concrete slab, evenly distributed on the reinforcing steel closest to the heating conditions and a minimum of nine evenly distributed at the interface between the concrete and the fire-resistive material. If the system has joints, an additional five thermocouples shall be located behind the joints. The thermocouples shall be type-K, chromel-alumel and shall be firmly affixed so as to not move during the casting. The thermocouples shall be capable of being cast into the concrete without disturbing their operation. Route the thermocouple leads parallel to the isothermal planes for a distance of 150 mm (6 in.) from the measuring junction to minimize error associated with cooling from the leads.

9.2.5 The fire-resistive materials shall be attached or adhered to the slab in the same manner as is in intended applications.

9.2.6 Any surface preparation shall be as in intended applications.

9.2.7 Representative joints shall be included if the fire-resistive material system includes joints.

9.2.8 When spray applied materials are used, the horizontal or vertical structural assembly shall be positioned for application in the same orientation as it would be in the tunnel. For example, if the spray applied material is to be applied to the ceiling, the test slab shall be suspended and the material spray applied from underneath.

9.2.9 Fire-resistive materials shall not be tested until nominal moisture content equilibrium has been achieved. Samples prepared in accordance with 9.2.10 shall be used for determining nominal moisture content equilibrium described in 9.2.11.

9.2.10 In addition to the fire test specimen, prepare three 305 × 305 mm (12 × 12 in.) samples of the material. For materials other than boards, blankets, etc., that are cut to size, use a 305 × 305 mm (12 × 12 in.) pan that prevents moisture from leaving the sample from all but one face. The thickness shall be the same thickness as applied to the slab.

9.2.11 The three prepared samples for determining moisture equilibrium shall be kept with the fire test specimen so they are exposed to the same environmental conditions. The material shall be weighed at the time of preparation, and periodically thereafter. The weights shall be recorded and percent weight change calculated. Nominal moisture content equilibrium is obtained when the weight of each of the three samples does not change ±5 % over a 5-day period.

9.2.12 Thickness and density of the fire-resistive materials shall be measured and reported. Density shall be determined at the nominal moisture content equilibrium condition.

9.3 *Protection and Conditioning of the Test Specimen*—The test specimen shall be protected and conditioned in accordance with requirements of Test Methods E119.

10. Conduct of Test

10.1 The furnace exposure shall be conducted for a length of time designated by the sponsor. The samples shall undergo a cool down period. During the cool down period, any applied load shall be maintained and sample temperatures shall continue to be recorded. Ratings shall be assigned as per Test Methods E119 based on the amount of furnace exposure, not including the cool down period, even though the cool down period is considered part of the test.

10.2 The orientation shall be as intended in applications. Ceilings shall be tested in the horizontal position with the fire conditions from the underneath. Walls shall be tested in the vertical position.

10.3 The testing laboratory shall terminate the test whenever the laboratory determines conditions to be unsafe due to severe spalling of concrete, heating of the post tensioning steel, or near collapse.

10.4 The Spalling Test and the Fire-Resistive Material Test are separate tests.

10.5 *Loading:*

10.5.1 The compressive level for the test shall be equal to the compressive level of the exposed face on the intended applications.

10.5.2 Eccentric loading is permitted so long as the eccentricity is not greater than in intended applications and the compressive level on the exposed face is at least as great as that in intended applications.

10.5.3 The Fire-Resistive Material Test is conducted without any applied load.

10.6 *Conditions of Acceptance:*

10.6.1 For both the Spalling Test and the Fire-Resistive Material Test, the temperatures on the reinforcing steel, or at 25 mm (1 in.) from the heated surface of the concrete shall be limited to 250 °C (482 °F) for any single measurement. This is applicable for both the furnace exposure period and the cool down period.

10.6.2 For the Fire-Resistive Material Test, the temperatures on the concrete/fire-resistive material interface shall be limited to 380 °C (716 °F) for any single measurement. This is applicable for both the furnace exposure period and the cool down period. Sacrificial concrete systems shall be designed such that this criterion is met at the designed concrete cover depth into the concrete.

NOTE 3—The temperature criteria related to the concrete and steel are explained in the referenced literature, which suggest that concrete heated above 300 to 400 °C will sustain permanent damage, both for strength properties as well as durability, and with a view to limit the risk of irreversible deformations (with exorbitant high repair costs) temperatures in reinforcing steel should be limited to 250 °C. In the Netherlands, design limits have been set therefore, 380 °C as the maximum concrete surface