Fire Resistance Proficiency Testing of Gypsum/Steel-Stud Wall Assemblies

by

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ABSTRACT

This paper summarizes the results of a proficiency test program conducted in 2006 by the North American Fire Testing Laboratories (NAFTL) consortium. Gypsum/steel-stud wall assemblies, nominally rated at 1-h, were tested by six different organizations employing nine different furnace facilities following the guidance provided in ASTM E119-00. The program was completed successfully and forms the basis for future proficiency programs aimed at testing additional structural materials, elements, and systems subjected to fire test standards referenced in building codes.

KEYWORDS: structural fire resistance, fire tests, gypsum walls, proficiency programs

1.0 INTRODUCTION

In the aftermath of the World Trade Center collapse, a possible building code requirement that highrise structures withstand a complete burnout is being discussed in the U.S. Compartmentation and the integrity of bearing and non-bearing walls play a role in the severity and rate of spread of the fire, and thus the fate of the structure in a burnout scenario.

The ability of a structural element or system to withstand a fire is rated by subjecting the element, or a representative section of the system, to the heat of a furnace. Wall systems approximately 3 m by 3 m (10 ft by 10 ft) in area are evaluated by mounting them in a fixture and exposing them to a flame in a furnace with a prescribed temperature rise. (A photograph of a typical wall furnace is shown in Fig. 1.)

ASTM E 119-00: *Standard Test Methods for Fire Tests of Building Construction Materials* is often cited in the U.S. model building codes; NFPA 251 and UL 263 are equivalent test methods. ISO 834-1 is the similar international standard, although it is never used in U.S. construction. Details on these and other test methods used to characterize the fire resistance of walls and other building elements are reviewed elsewhere (e.g., Grosshandler, 2002; Grosshandler, 2006). While there are some differences among the test protocols, the general procedures and many of the measurements prescribed in all four test methods are similar.

The fire resistance of the wall assembly in an actual building fire is assumed to be related to the length of time necessary for the test specimen to meet any one of several failure criteria:

- the maximum temperature increase on the unexposed side of the wall exceeds 181 °C (325 °F);
- the average temperature increase on the unexposed side of the wall exceeds 139 °C (250 °F);
- a breach occurs in the wall that allows hot gases from the furnace to penetrate and ignite a cotton target on the unexposed side of the wall; or
- the wall is unable to maintain its design load.

The fire resistance rating of the wall system is defined as the time (to the next lowest half-hour increment for times up to two

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hours, and to the next lowest hour for longer times) when any of the criteria indicated are exceeded. It is expected that a 2-h rated wall would resist failure in a real fire for a longer period of time than a similarly functioning 1-h rated wall, and this is invariably the case. What can not be expected, however, is that a 2-h rated wall would necessarily withstand an actual fire in a building for two hours, or that the wall would necessarily fail after two hours. The inability of the fire resistance rating to act as an absolute predictor of performance in an actual fire was recognized from the beginning when the forerunner of ASTM E119 was published in 1918. Over the years, however, the reference to fire resistance ratings in common time units has become erroneously interpreted to relate closely (or at least conservatively) to the actual time that a wall would be expected to resist a fire.

The shortcomings of the current methods for rating the fire resistance of wall systems are numerous; some are obvious and have been recognized for years:

- The maximum size of the wall system is limited by the size of the furnace.
- The load conditions for the test article may not adequately mimic field use.
- The thermal environment of the furnace does not mimic a real fire.
- The tests reveal no fundamental information about the performance of the specimen and provide little guidance on how to improve performance.
- The furnaces themselves are not standardized; hence, the same specimen could receive different ratings if tested in two different facilities.
- Ratings are based upon a single test, with no way to quantify the uncertainty or safety factor.

In spite of severe shortcomings, these test methods continue to be used throughout the world because (i) a massive data base has been established and is in continual use, (ii) history suggests that the test methods are conservative, and (iii) alternative methods have not been developed yet that are acceptable to the major parties involved.

2.0 NAFTL PROFICIENCY TEST PROGRAM

Designing structures to withstand the hazard posed by an unconfined building fire requires that the standard fire resistance tests be reliable and consistent, independent of the laboratory performing the test. Ascertaining the consistency of testing in North America is the focus of this paper.

2.1 North American Fire Testing Laboratories Consortium[2]

The North American Fire Testing Laboratories (NAFTL) consortium was formed in 2004 to provide a forum for the exchange of technical information, to conduct studies, and to develop industry consensus positions relating to the full range of fire tests; e.g., reaction to fire, fire suppression, fire resistance and fire detection. The organization is open to any North American-based independent commercial laboratory engaged in fire testing or research. Current members include Southwest Research Institute (SwRI), Underwriters Laboratories (UL); FM Approvals, Intertek, NGC Testing, and Western Fire Center. NIST, the National Research Council of Canada (NRC-C), and the Fire Testing Laboratory of the Bureau of Alcohol, Tobacco, and Firearms (ATF) are non-voting associate members of NAFTL.

The operations of the member laboratories of NAFTL are certified according to ISO 17025. As part of the certification process, organizations must demonstrate to a certifying body that they are proficient in conducting fire testing services offered to their customers, a task which is difficult for a test like ASTM E119. For this reason, and to gain a better understanding of the test itself as a means to overcome the shortcomings previously enumerated,

[2] http://www.naftl.org/

NAFTL organized a proficiency test program for ASTM E119-00 using a common structural element: a gypsum/steel-stud wall assembly.

2.2 Participants and Objectives

A total of nine different laboratories representing six different organizations participated in the proficiency test program. They included Intertek (three locations), UL (two locations), SwRI, NGC, Western Fire Center, and NRC-C. All of these laboratories routinely operate large-scale furnaces that rate the fire resistance of structural elements such as building partitions and non-load-bearing walls.

The guidance provided in ASTM E119-00 is imprecise with regard to the details on the design of the testing furnace, and the guidance allows some leeway in how the sample is to be prepared and instrumented, as well as the way the test is to be conducted. Thus, it is not surprising that different laboratories develop different standard operation procedures that are still within the constraints of the prescribed test method. In addition, the dimensions and materials used in constructing the test article often differ, and may not be within the control of the fire testing laboratory. When differences in ratings occur of ostensibly the same test article, it is not possible to attribute the cause of the difference to the test article itself, to the differences in furnace design and instrumentation, or to the differences in operational procedures. In order to assess these differences and how they might lead to uncertainty in the fire resistance rating of a product, proficiency testing is necessary using a standardized product, with the results of the testing accumulated and analyzed by a qualified independent party.

The objective of the current proficiency test program is to compare the behavior of different vertical furnaces and identify operational parameters that influence the performance of a generic non-load-bearing wall assembly undergoing an ASTM E119-00 resistance to fire test. The testing was conducted in accordance with the standard operating protocol of each participant.

The data from each test were collected in a common format and sent to the American Council of Independent Laboratories (ACIL), who acts as the secretariat for NAFTL. ACIL removed all identifying information from the data and delivered it to NIST, who was the qualified independent party responsible for analyzing and reporting the data.

The outcome from this proficiency test program is being used by the participating organizations to assess the relative performance of their furnaces. The data collected are also being used by NIST to help develop the needed relationship between furnace behavior and actual fires.

3.0 TEST PROCEDURES

3.1 Wall Assembly Description

The wall assembly was designed to be non-load bearing, nominally 1-h fire resistance rated, and consisting of a 15.9 mm (5/8 in) thick type X gypsum board (ASTM C36/1396), 3 m by 3 m (10 ft by 10 ft) with taped, staggered vertical seams, on each side of steel studs located on 0.41 m (16 in.) centers. The gypsum board was purchased by the individual laboratories in a single lot from the manufacturer since it was desired to have as little variation as possible in the gypsum board. All laboratories used the same steel studs (25 gauge) and fasteners (32 mm (1 ¼ in) long Type S drywall screws). The walls were constructed using each laboratories' established practice. The tests were documented and, in several cases, witnessed by NIST research staff.

3.2 Instrumentation

The furnace and wall assembly were instrumented according to the provisions in ASTM E119-00. Additional thermocouples (type K) were located as indicated in Fig. 2

to measure the temperature within the wall cavity. A thermal imaging camera was used in several of the tests to view the unexposed side of the wall assembly. The actual instrumentation employed and its placement on the specimen was documented by each laboratory.

3.3 Conduct of Test

The instrumented specimen was mounted on the vertical wall furnace and prepared for testing using the standard procedure of the respective laboratory. The furnace was controlled to follow the standard time-temperature curve specified in ASTM E119-00. Temperatures of the specimen and furnace were collected at least once a minute. A video record of the entire test was made, along with photos of observed damage to the specimen when it occurred.

The test was designed to continue until all of the following conditions were met:

- at least one thermocouple used in standard practice by the laboratory on the unexposed side of the specimen reached a temperature 181 ^{o}C (325 ^{o}F) above its initial temperature;
- the average temperature of thermocouples used in standard practice by the laboratory on the unexposed side of the specimen reaches 139 ^{o}C (250 ^{o}F) above its initial average temperature; and
- a crack opens up in the specimen large enough and hot enough to ignite cotton waste.

The hose stream test (which is specified in ASTM E119-00) was not applied to the specimen.

3.4 Data Treatment

Each laboratory prepared a standard ASTM E119-00 data sheet for the tests conducted. In addition, the following data were compiled:

- temperature vs. time for all specimen thermocouples
- temperature vs. time for the standard specimen thermocouples
- temperature vs. time for the furnace control thermocouples

These data were collected by ACIL and sent to NIST for analysis, without identifying which data set belonged to which laboratory. Proficiency is based upon how much an individual lab differed from the following composite results of the group:

- time for the first thermocouple to reach 181 ^{o}C (325 ^{o}F) above its initial temperature
- time for the average temperature to reach 139 ^{o}C (250 ^{o}F) above its initial average
- time for a crack to open up sufficient to ignite a cotton swab
- T vs. t for the peak temperature
- T vs. t for the average temperature

4.0 TEST RESULTS

4.1 Average Furnace Temperatures

The temperature of the furnace is determined from the average of multiple shielded, slow time-response thermocouples located within the furnace cavity. Most furnaces are controlled manually, with an experienced operator increasing or decreasing the fuel flow to different burners to maintain uniformity at the temperature specified in ASTM E119-00. The standard time-temperature curve is shown in Fig. 3 as the dotted red line. At five minutes, the furnace temperature is required to be 538 ^{o}C (1000 ^{o}F); at fifteen minutes it must be 759 ^{o}C (1399 ^{o}F); the target temperature at one hour is 927 ^{o}C (1700 ^{o}F); and at 2 hours the temperature is 1010 ^{o}C (1850 ^{o}F).

The temperatures of the nine laboratory furnaces, designated A1 through A9, are also plotted in Fig. 3. The vertical bars represent one standard deviation around the mean of the nine tests. During the start-up period, several of the furnaces tend to either lag or over-correct, but by fifteen minutes into the test, eight of the nine furnaces fall close to a single curve. Furnace A3 lags the group until about 40 minutes into the test.

The Standard requires that the integral of the temperature over time be within 7.5 % of the specified curve for tests lasting more than one hour. For the nine furnaces in the proficiency test program, the areas under the temperature curves were all within 2 % of the area specified in ASTM E119-00.

4.2 Peak Wall Temperatures

Because each furnace has a unique design and method of temperature control, it is not possible to predict which of the thermocouples positioned on the side of the wall that is unexposed to the flames will be the hottest. For most of the current testing, the temperature increase indicated by TC6 was within one minute of being the hottest, and for ease of comparison, this temperature increase is plotted in Fig. 4 for the nine furnace tests. Note that the ambient temperature (which varied between 17 ^{o}C and 33 ^{o}C (62 ^{o}F to 92 ^{o}F)) has been subtracted from the temperature of TC6. The dotted line in Fig. 4 represents the failure criteria (181 ^{o}C (325 ^{o}F)) specified in ASTM E119-00. The first laboratory to reach the limit is A7, at 62 minutes; laboratory A9 is the last, with TC6 reaching the limit more than 10 minutes later.

The highest temperature increases measured on the unexposed surface of the wall assembly at any given time (regardless of thermocouple location) are plotted on the vertical axis in Fig. 5 against the average of the nine tests on the horizontal scale. If all of the tests were identical, the data would fall on the solid line. Up to about 93 ^{o}C (200 ^{o}F), the tests are well correlated; however, at higher values the maximum temperature increases at any given time diverge greatly, ranging from more than 55 ^{o}C (100 ^{o}F) higher to 55 ^{o}C (100 ^{o}F) lower for mean high temperature increases equal to the limiting temperature in ASTM E119-00 (the vertical dotted line at 181 ^{o}C (325 ^{o}F) indicates the limit).

4.3 Average Wall Temperatures

The average of the thermocouples measuring the temperatures on the unexposed side of the wall specimen is shown in Fig. 6 for the nine furnace tests; Fig. 7 is a plot of the standard deviation of these temperatures around the mean. The average temperatures are well grouped for the first 55 minutes of the test, with standard deviations less than 6 ^{o}C (10 ^{o}F), except for a short period of time during start-up. At 70 minutes, the individual average unexposed face temperature increases deviate from the overall mean by as much as 139 ^{o}C (250 ^{o}F).

4.4 Fire Resistance Ratings

The key output of ASTM E119-00 is the fire resistance rating. In all nine furnace tests, this wall design received a rating of 1-h. For five of the laboratories, the failure time was based upon the average temperature increase on the unexposed face exceeding 139 ^{o}C (250 ^{o}F). The maximum allowed individual temperature on the backside of the wall (181 ^{o}C (325 ^{o}F)) was the failure limit for the remaining four laboratories. In no case was the wall breached in less than 70 minutes. The wall was not designed to be loaded; hence, the failure to maintain a load was not examined.

The chart in Fig. 8 indicates the time that the specimen failed for each of the furnace tests. The overall average time was 65 minutes, with a standard deviation of 3 minutes. Laboratory A6 exceeded the average by more than one standard deviation, and laboratory was less that the average by more than one standard deviation.

Table 1 displays these times, as well as the failure criteria. The far right column indicates additional temperature failure criteria that occurred within one minute of the first failure. Note that the fire resistance rating, shown in the second column, is the same for all nine laboratories: 1-h.

5.0 CONCLUSIONS

Round-robin testing programs have been attempted in the past to identify uncertainties in the results and deficiencies in the ASTM E119-00 test method. A proficiency test program, in contrast, focuses upon the laboratory rather than the test method. The results of the proficiency program can be used by the participating laboratories to satisfy the requirements for ISO 17025 certification. The proficiency test program undertaken by the NAFTL consortium and described here is the first ever to target a fire resistance test of this magnitude.

The following conclusions can be drawn from the results of this effort:

- The participating laboratories, using their individual standard operating procedures, were able to arrive at an identical 1-h rating for the gypsum wall specimen.
- The variability among laboratories in measured time-to-failure for a 1-h rated gypsum wall, based upon ASTM E119-00, should not be expected to be better than plus/minus 5 minutes.
- The variability in individual peak temperature increase measurements at similar locations on different 1-h rated gypsum wall assemblies is likely to be at least plus/minus 22 ^{o}C (40 ^{o}F) for times greater than one hour.
- Individual temperature increases measured on the unexposed side of a 1-h rated gypsum wall diverge quickly among laboratories as the specimens approach failure, differing by as much as 166 ^{o}C (300 ^{o}F) at the average time of failure.
- The proficiency test program conducted by the NAFTL consortium will assist the participating laboratories in maintaining ISO 17025 certification, and will act as a model for future proficiency programs for additional fire test methods.

6.0 ACKNOWLEDGEMENT

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Figure 1: Photograph of the interior of a typical wall furnace showing multiple gas burners (courtesy of Underwriters Laboratories).

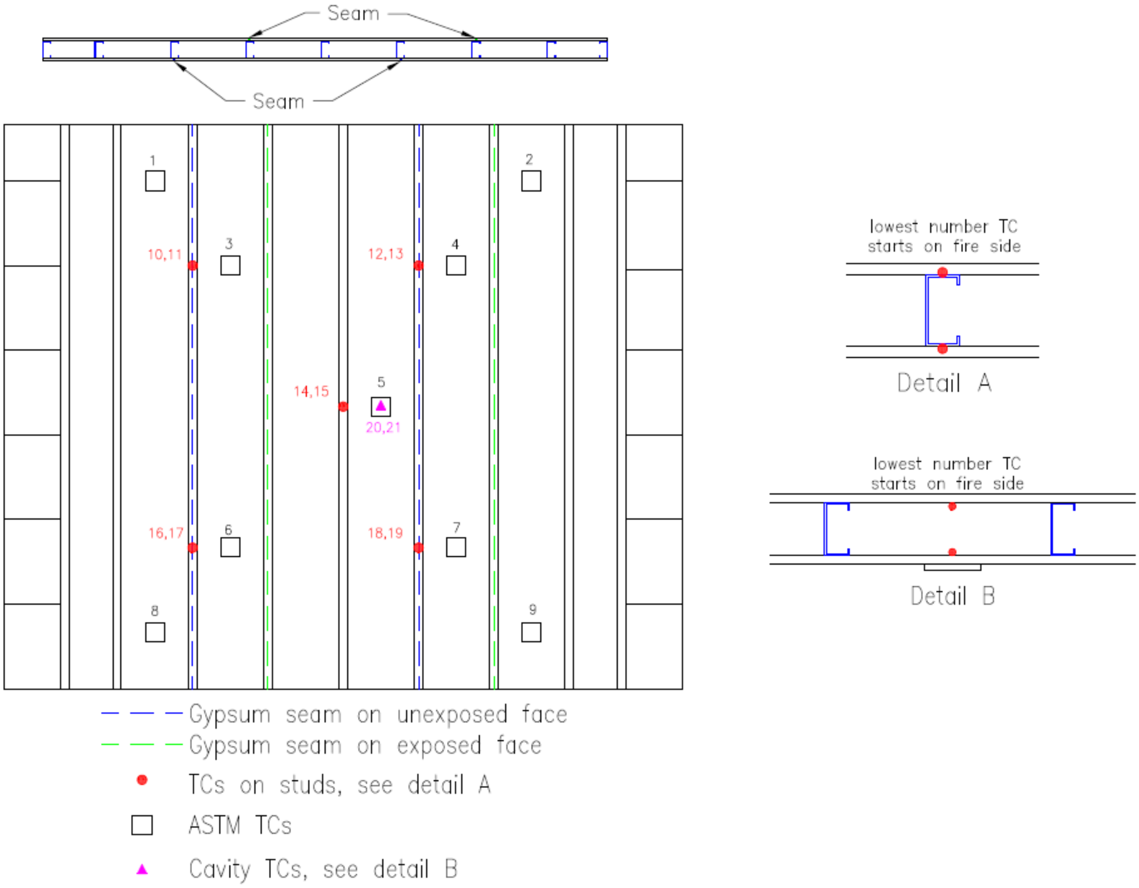

Figure 2: Gypsum/steel-stud wall assembly and location of thermocouples

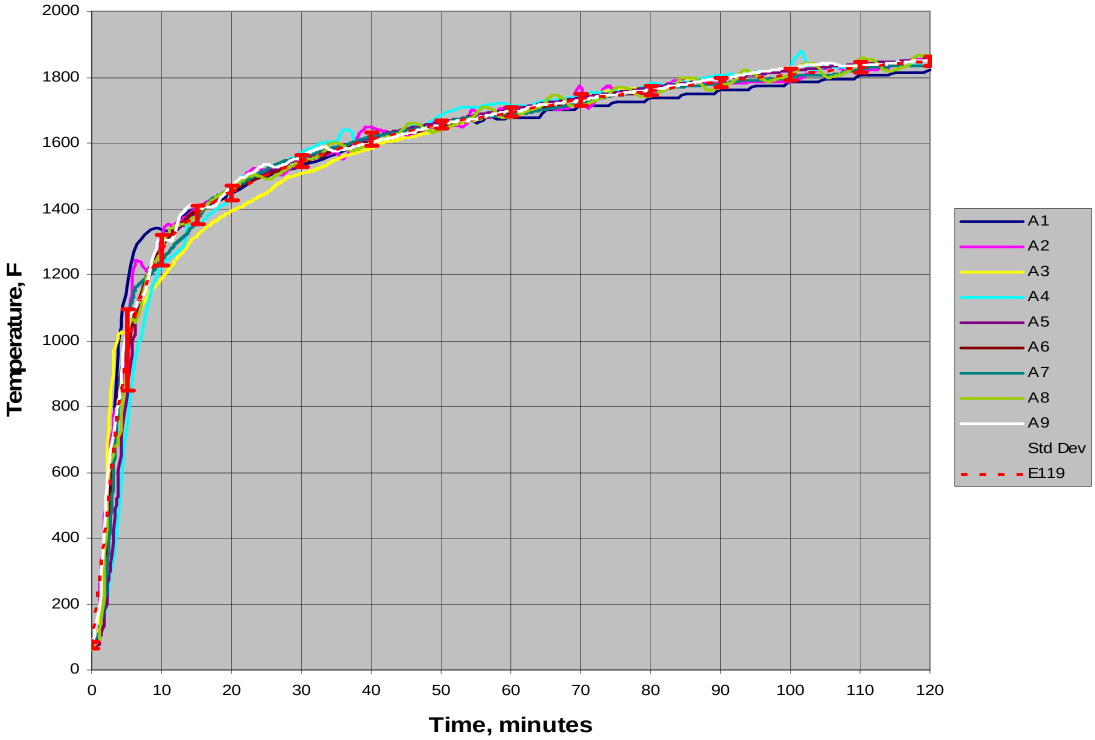

Figure 3: Average furnace temperatures

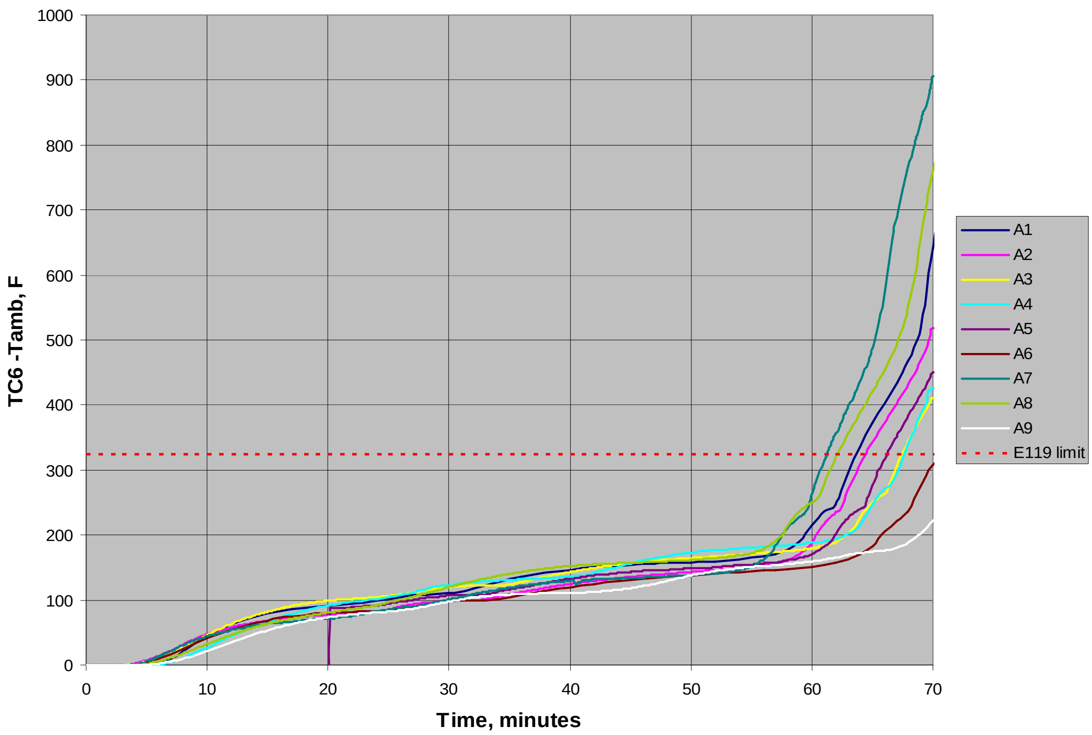

Figure 4: Peak temperature increase on unexposed side of wall (TC 6)

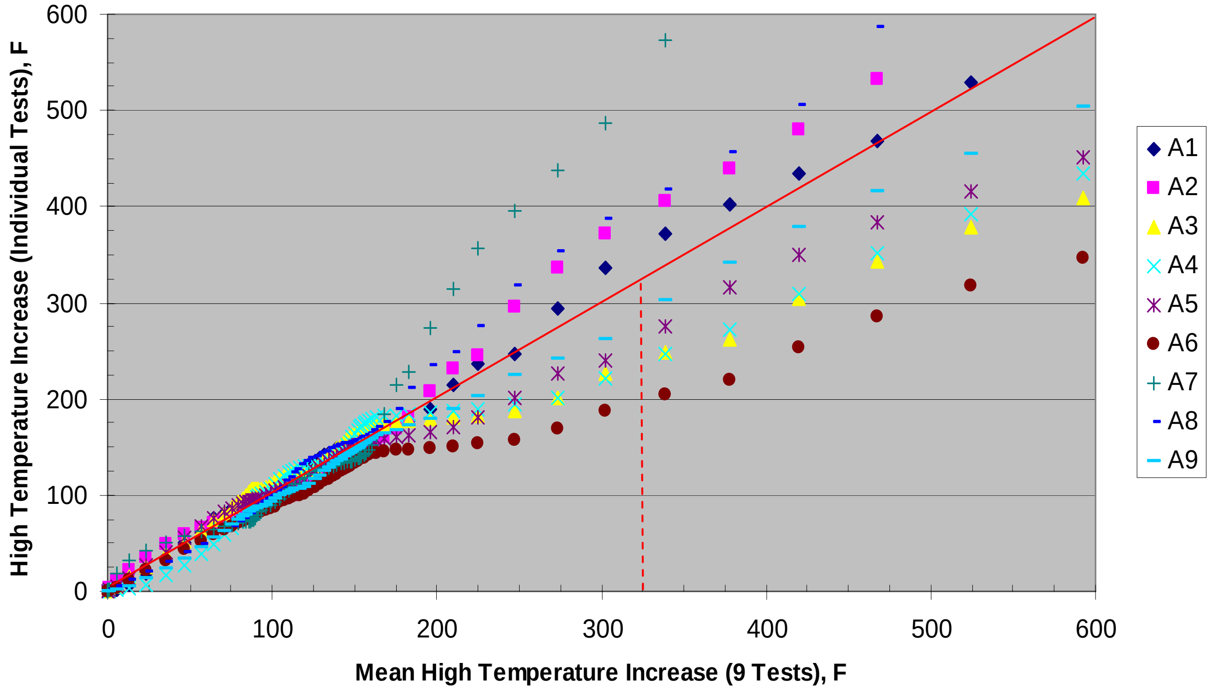

Figure 5: Highest temperature increases on unexposed side of wall, plotted vs. the nine-test average

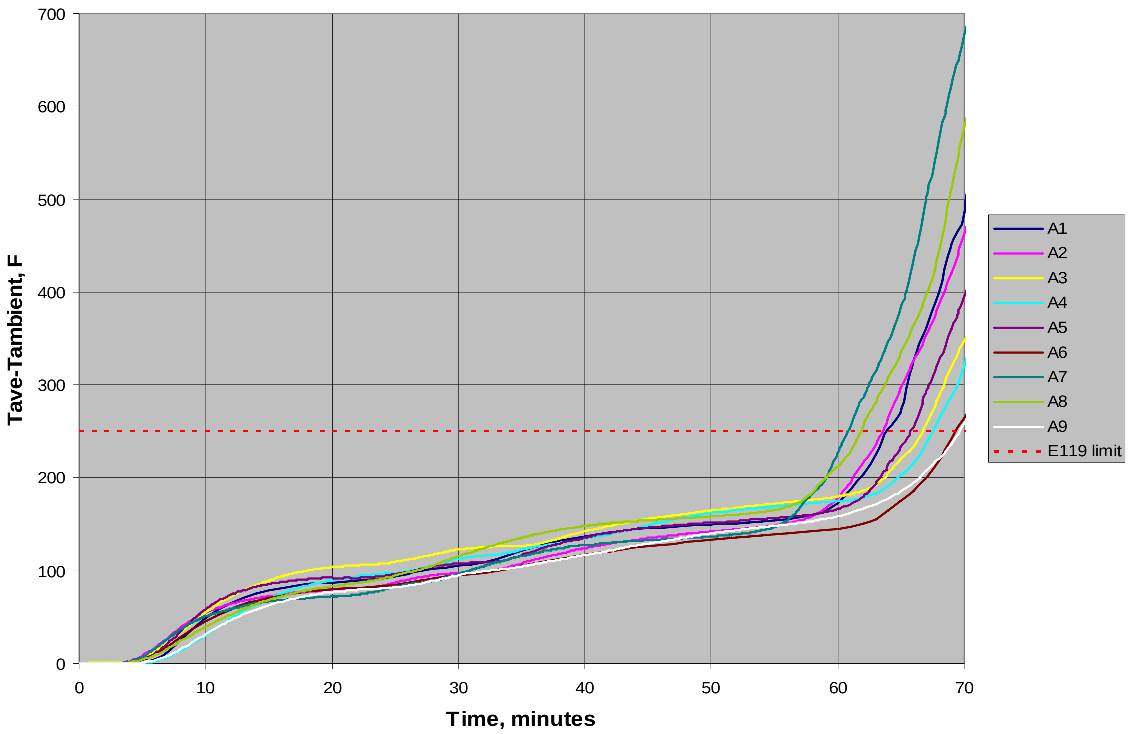

Figure 6: Average thermocouple temperature increase on unexposed side of wall

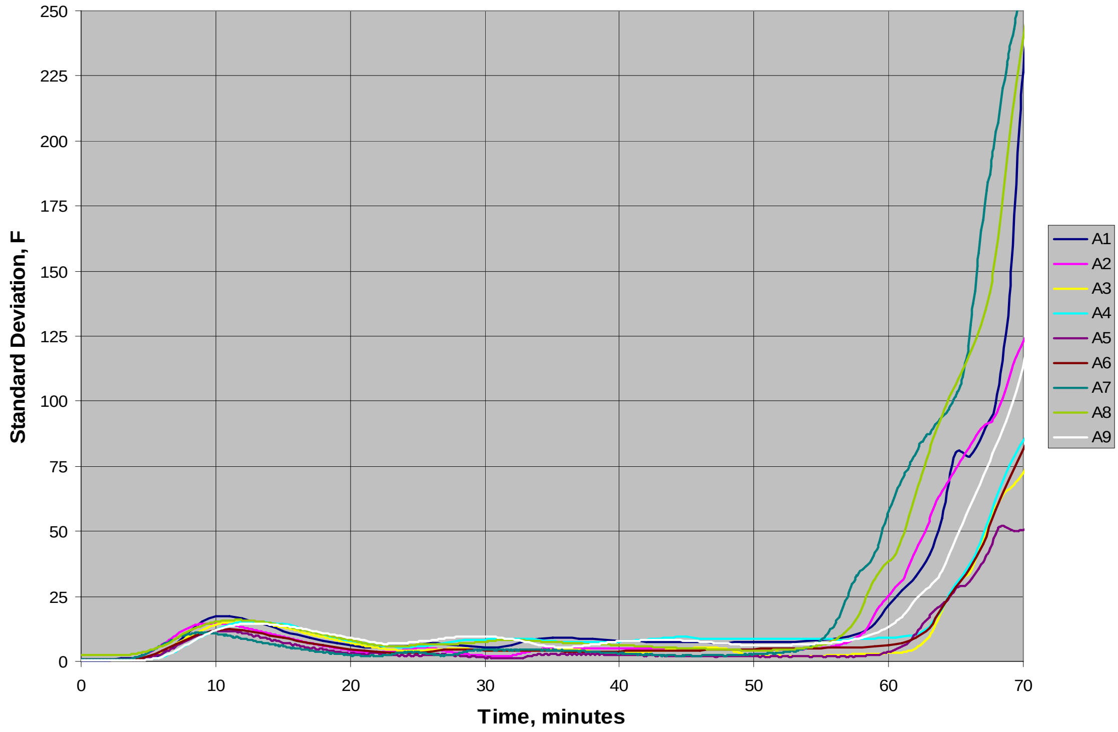

Figure 7: Standard deviation of average temperatures on unexposed side of wall

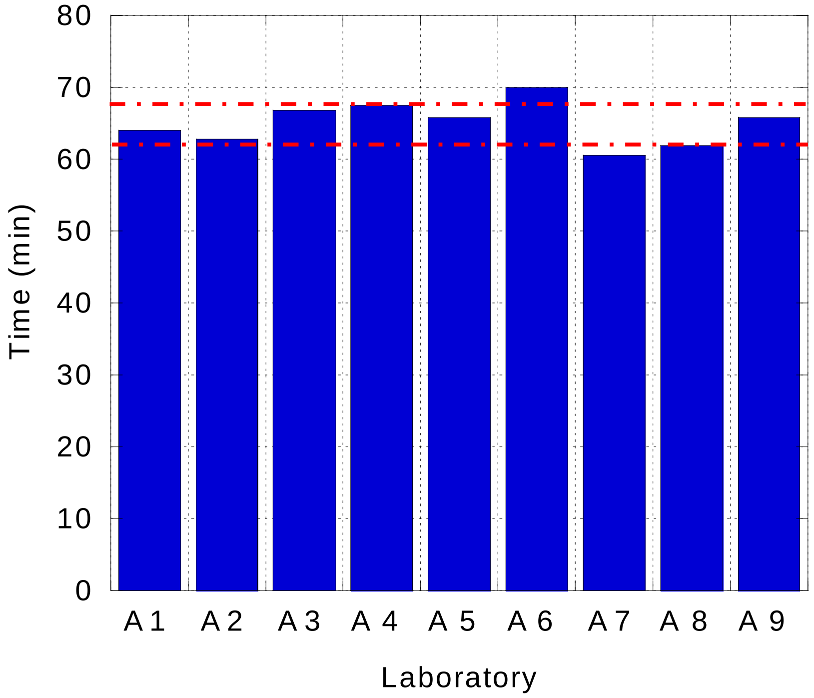

Figure 8: Time to First Failure Criteria in Each of Nine Furnace Tests; $t_{average}$ = 65.0 min. Dotted lines represent standard deviation of +/- 3.0 min.

Table 1: Summary of Failure Criteria

Laboratory	Fire Resistance Rating	Time to First Failure, minutes	Failed Thermocouple Reading	Other TC's Failing Within 1 Minute
A1	1 hour	64	average	TC3, 5, 7
A2	1 hour	62.8	TC3	average
A3	1 hour	66.8	average	TC4, 6, 8
A4	1 hour	67.5	average	TC3, 6, 8
A5	1 hour	65.8	average	TC6
A6	1 hour	70	TC3	TC4, 5, 6, 7, average
A7	1 hour	60.6	TC7	TC3, 5, 6, average
A8	1 hour	61.9	average	TC3, 4, 6
A9	1 hour	65.8	TC5	none