NBSIR 75-673

Development of a Fire Test Method for Flexible Connectors in Air Distribution Systems

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NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

SI Conversion Units

In view of present accepted practice in this technological area, U. S. customary units of measurement have been used throughout this report. It should be noted that the U. S. is a signatory to the General Conference on Weights and Measures which gave official status to the metric SI system of SI units in 1960. Readers interested in making use of the coherent system of SI units will find conversion factors in ASTM Standard Metric Practice Guide, ASTM Designation E 380-72 (available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103). Coversion factors for units used in this paper are:

Length

1 in = 0.0254* metre

1 ft = 0.3048* metre

Area

1 in^2 = 6.4516* x 10^{-4} $metre^2$

1 ft^2 = 9.2903 x 10^{-2} $metre^2$

Force

1 lb (lbf) = 4.448 newton

1 kip = 4448 newton

Pressure, Stress

1 psi = 6895 pascal

1 psf = 47.88 pascal

Energy

1 ft-lbf = 1.3558 joule

Moment

1 lbf-ft = 1.3558 newton-metre

Temperature

°C = 5/9 (Temperature °F - 32)

CONTENTS

DEVELOPMENT OF A FIRE TEST METHOD FOR FLEXIBLE CONNECTORS IN AIR DISTRIBUTION SYSTEMS

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The report describes fire tests on four flexible connectors of the type used in air conditioning systems. Four flexible connectors (aluminum, felted glass fiber, steel, and woven glass fiber) were exposed to a standard ASTM E-119 fire test. The results were in agreement with previous results in which a different sized branch duct was used in the assemblies. The results indicated a need to control furnace pressures. The test results were used to develop a proposed test method for fire testing flexible connectors. This proposed test method is described in the report.

Key words: Aluminum; ducts; fire tests; flexible connectors; furnace pressures; glass fiber; heat ventilating and air conditioning systems; high-rise buildings; steel; terminal units.

1. INTRODUCTION

At present there is very little information on the effects of fire on ducts, dampers, connectors and other components of heating ventilating and air conditioning (HVAC) systems, and on the influence of fire and smoke spread within HVAC systems.

In the current construction of high-rise buildings, the ducts and connectors are usually not protected by fire rated ceilings; that is, they are behind an ornamental, non-rated, drop ceiling. Such a ceiling will fail quickly exposing the flexible connectors to direct fire exposure. The flexible connector which connects a branch duct to a terminal unit can fail by separation from the branch duct, by failure of the blocking around the connector where it penetrates a fire barrier, or by melting or pyrolysis of the connector material. Any failure of the flexible connector could allow smoke, flame, hot and noxious gases to enter the HVAC system and the connected modules.

The need for a test method for flexible connectors became apparent after the One New York Plaza fire in August 1970 in which failure of flexible connectors was considered partly responsible for the spread of fire and smoke [1][1]. A task group of the National Fire Protection Association (NFPA) dealing with revisions to their specifications governing

[1]Numbers in brackets correspond with the literature references listed in Appendix B.

air conditioning and ventilating systems [2] requested the aid of the National Bureau of Standards in developing a test method for evaluating the fire resistance of flexible connectors. These tests and the proposed test method which is described in the appendix of this paper are in response to this request.

The NFPA Task Group agreed that a major measure of satisfactory fire performance for a flexible connector assembly would be the ability to prevent a fire breaking into the HVAC system and the adjoining occupancy module for one hour under standard fire endurance conditions. Such a performance requirement would probably eliminate from use the more hazardous materials that might be used for flexible connectors. Other requirements could include a limitation on smoke and toxic gas generation by the flexible connector assembly.

The proposed flexible connector test method, which is given in the appendix, is a step in the direction of testing and evaluating the fire resistance of a portion of a HVAC system consisting of a duct, connector and terminal unit assembly. This test differed from previous tests in the following manner: 1) a smaller size branch duct was used, 2) an improved furnace closure and deck was used, and 3) an attempt was made to take smoke density measurements. This report supplements the previously reported tests [3].

2. CONSTRUCTION AND INSTRUMENTATION

2.1. General

In the test setup four independent flexible connector assemblies were set in the National Bureau of Standards floor furnace. The assemblies consisted of a branch duct inside the furnace, a terminal unit with an architectural enclosure outside of the furnace, and a flexible connector between the branch duct and the terminal unit which were separated by the furnace closure.

2.2. Furnace Closure

As in the previous tests, a raised closure was used to provide clearance above the furnace burners for the branch ducts and flexible connectors [3]. In this test an improved floor/ceiling construction was used to close in the top of the furnace.

The closure consisted of 10-inch open-web steel joist framing, with two layers of 5/8-inch type X gypsum board, screw attached to the bottom chords, and on top of which rested gypsum planks. The steel joists rested on a 24-inch high stud wall protected with gypsum board and sprayed vermiculite plaster over expanded metal lath. One side of each joist was covered with 5/8-inch type X gypsum board. This was to prevent flames which might break through, at a flexible connector penetration, from affecting an adjacent assembly. The space between the joists was left open to observe the behavior of that portion of the flexible connectors that was immediately outside of the furnace, and to allow the opening in the furnace closure to be closed-off if a flexible connector melted or pyrolized. The details of the closure are shown in figure 1.

2.3. Branch Ducts

In these tests a smaller branch duct (18" x 18" x 6') was used as compared with previous tests (24" x 24" x 10' and 18" diameter x 10'). This was done in order to see if a smaller branch duct would provide similar information, as this would be easier to set up, and could be set up in a smaller furnace than the 14' x 18' (nominal) National Bureau of Standards facility. The branch ducts had closed ends and as in previous tests there was no air circulation through them because it is assumed that the ventilation fans in an HVAC system will be shut down when a fire occurs.

2.4. Flexible Connectors

Four types of flexible connectors were tested simultaneously: aluminum, steel, felted glass fiber, and woven glass fiber. The felted glass fiber connector was 5 inches in diameter[2] and the others were all 6 inches in diameter.

The layout of the four independent duct/connector/terminal unit assemblies within the furnace is shown in figure 2. Construction details are shown in figures 3 and 4. Each end of the flexible connector was open.

The connectors were attached to the duct with a flange plate and friction band, in accordance with the manufacturer's instructions for the type of connector used. Previous tests [3] indicated that the attachment was sturdy and able to withstand the fire exposure for the desired period. This attachment was used here because the test was intended to provide information for the proposed test method and it was desirable to have an attachment that would last for at least one hour.

The flexible connectors were left bare in this test, unlike earlier tests [3] in which the connectors were wrapped with glass fiber insulation.

The penetration through the furnace closure was faced with a steel flange plate and the annular space between the flexible connector and the furnace closure was blocked with mineral wool packing (see fig. 5). The plate was attached to the gypsum board with screws.

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[2]At the time of the test is was not possible to get a felted glass fiber connector 6 inches in diameter because of an industry strike.

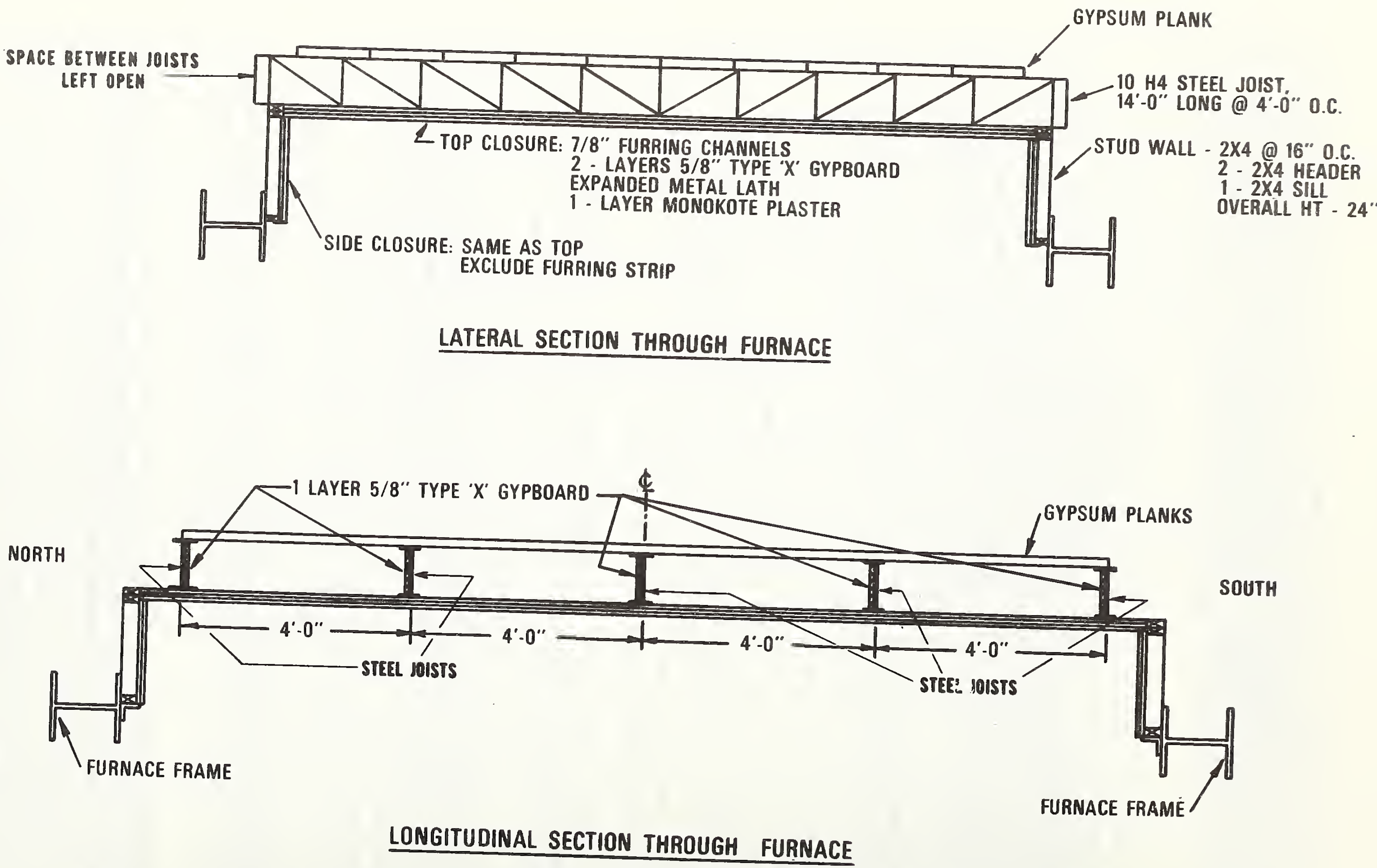


FIGURE 1 TEST 532 FURNACE CLOSURE DETAILS

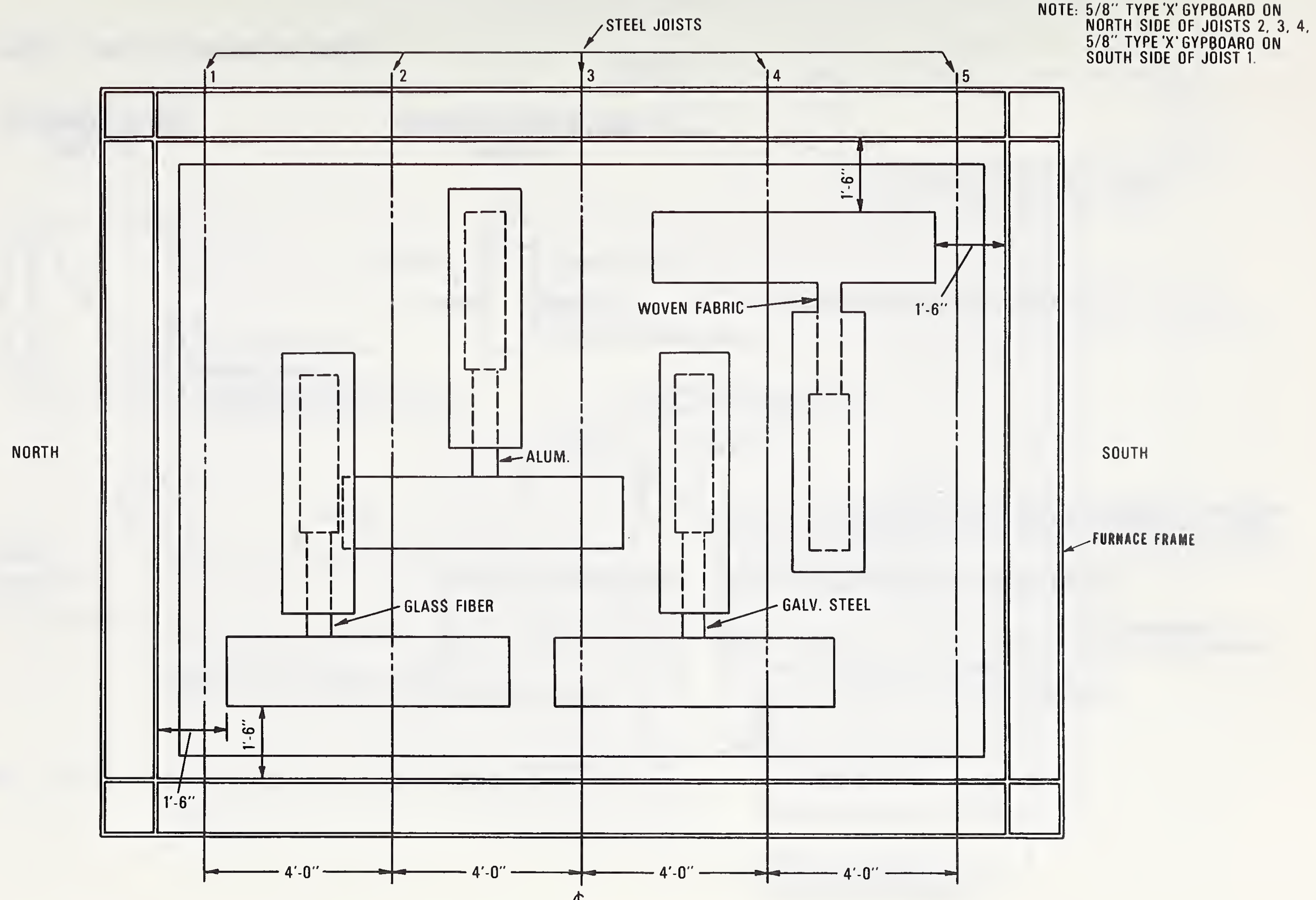


FIGURE 2 TEST 532 SCHEMATIC LAYOUT OF ASSEMBLIES IN PLAN

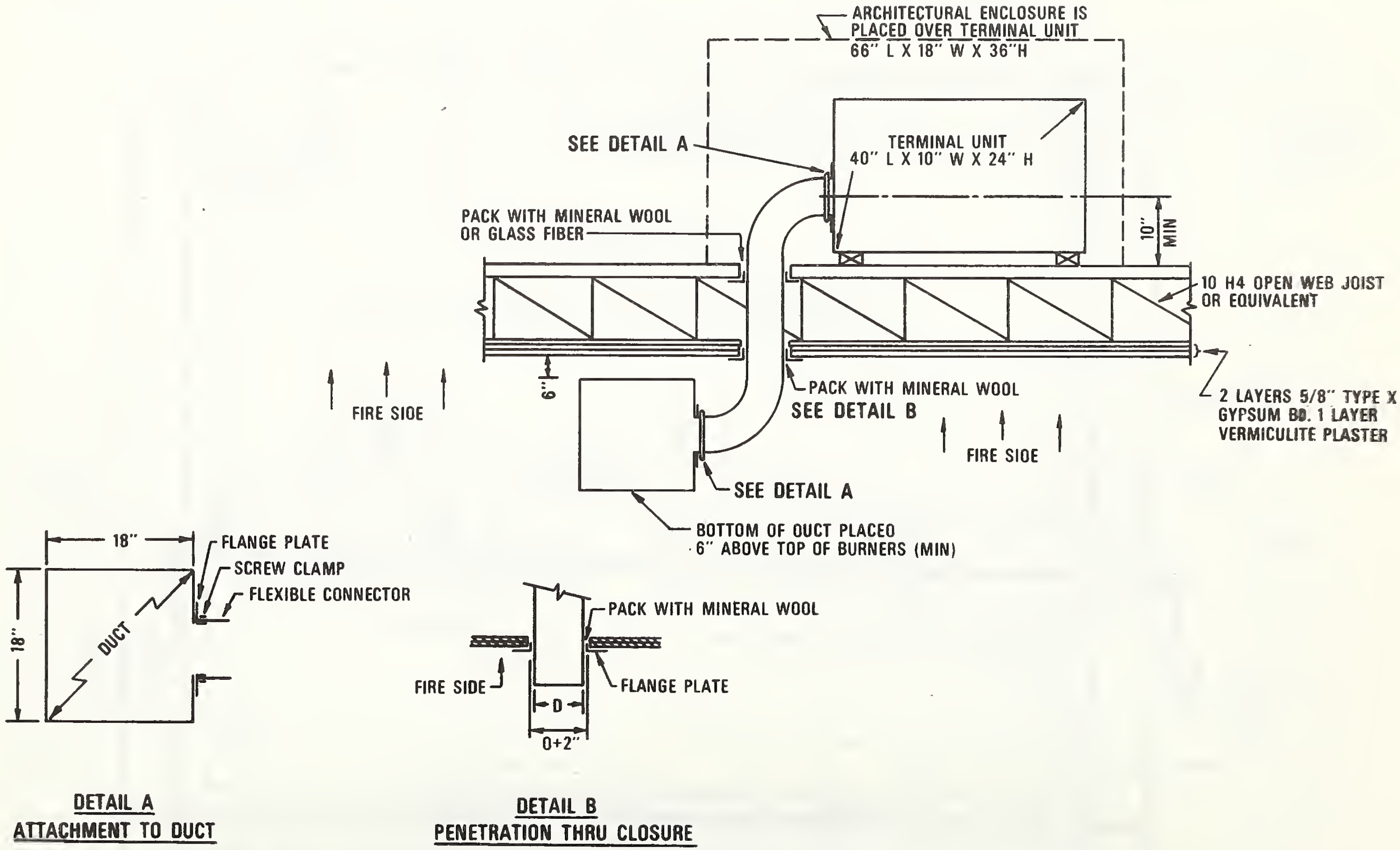


FIGURE 3 TEST 532 CONSTRUCTION DETAILS

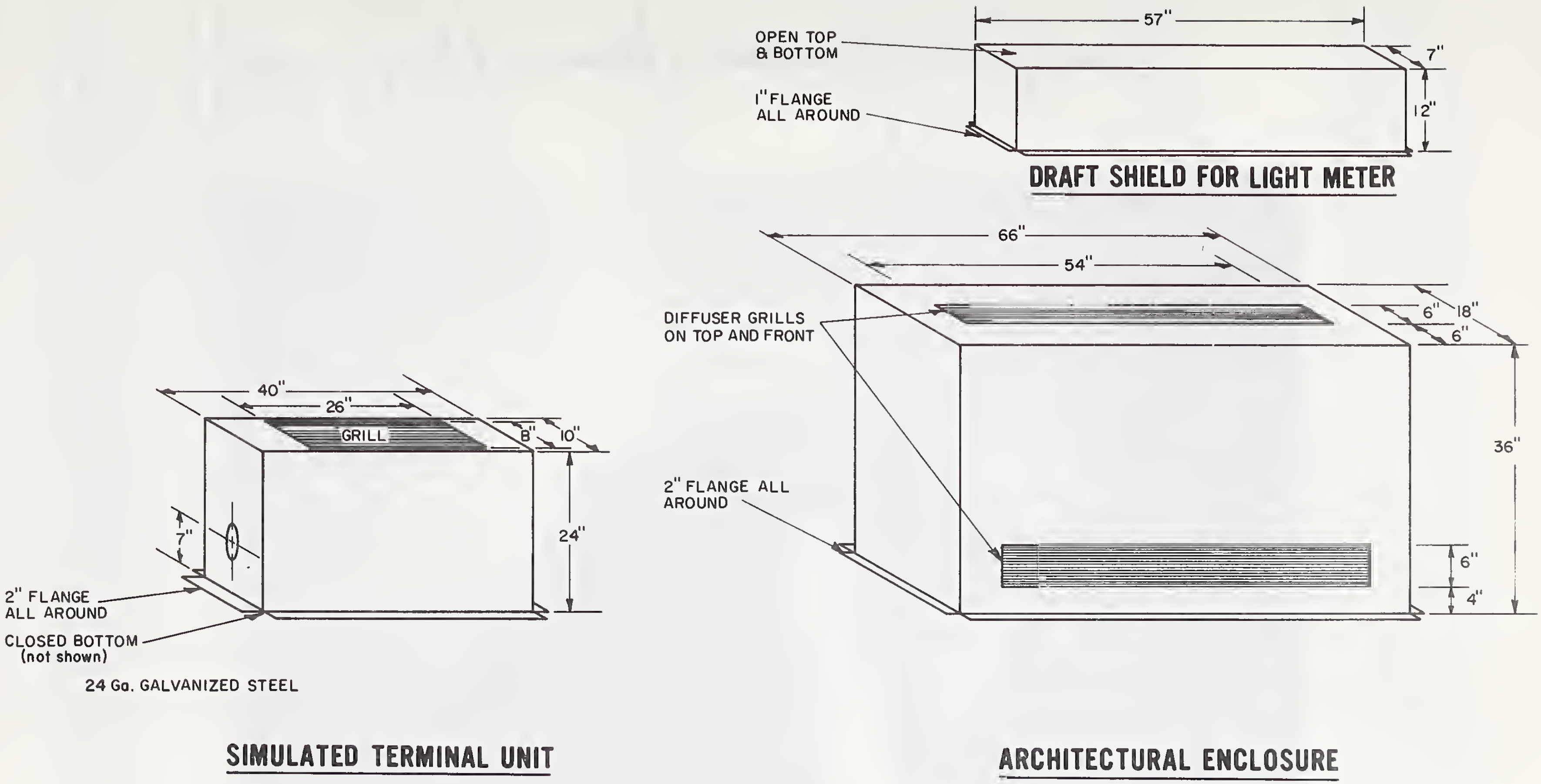


FIGURE 4 DETAILS OF TERMINAL UNIT AND ARCHITECTURAL ENCLOSURE

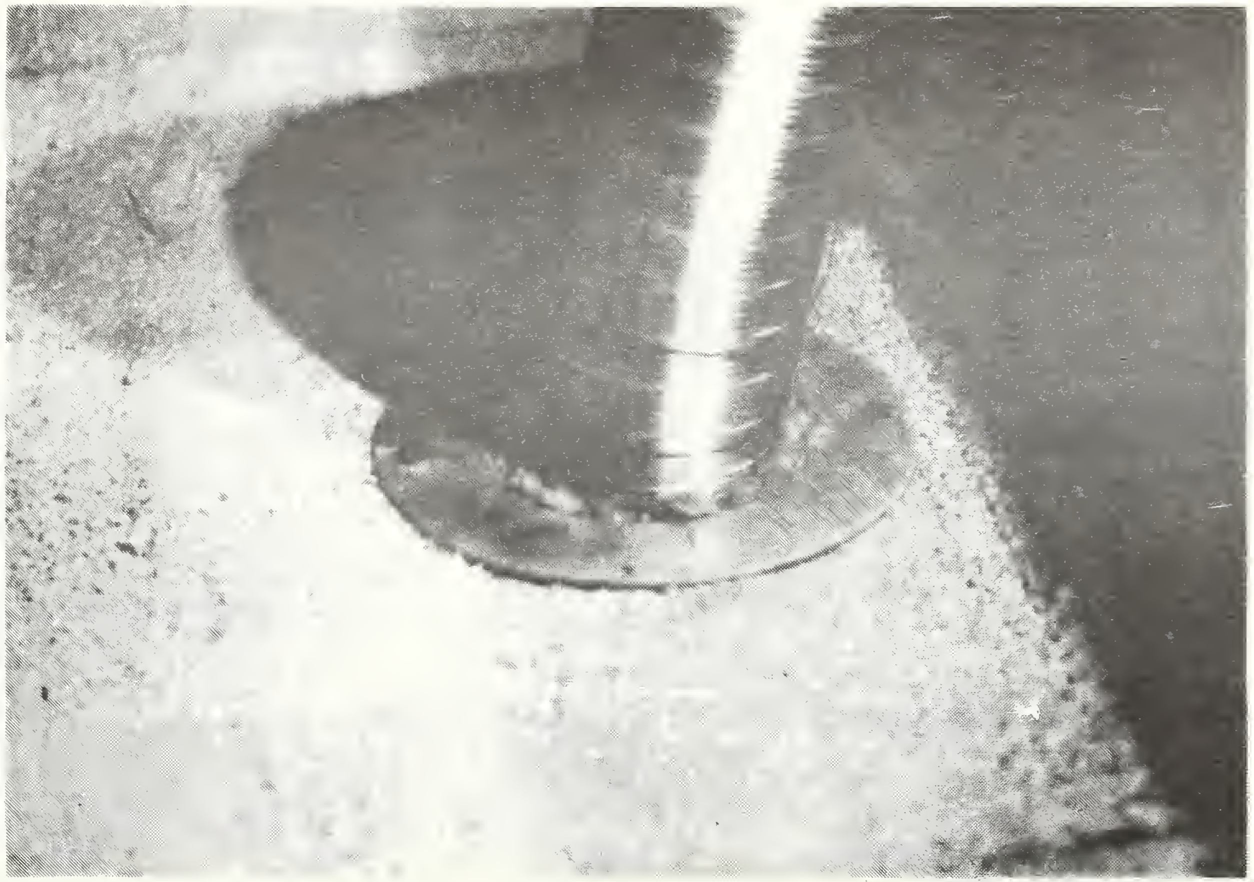


Figure 5. Blocking and packing at penetration of furnace closure.

Simulated terminal units and architectural enclosures, similar to those used in previous tests were placed on the deck. The dimensions of these items are shown in figure 4. The terminal unit did not contain any heating/cooling unit as it was felt that a finned pipe insert would only marginally affect any air movements.

2.5. Instrumentation

Each assembly was instrumented with an optical density device and thermocouples. The optical density device was located at the outlet grill of the architectural enclosure. The thermocouples were located at points where it was desirable to monitor the temperatures of the assembly.

Each assembly was instrumented with 15 thermocouples distributed as follows: two in the branch duct, six on the flexible connector between the branch duct and the simulated terminal unit, one at the middle of the inlet on the terminal unit, two at the outlet of the terminal unit, two on the inlet of the architectural enclosure, and two on the outlet of the architectural enclosure. The thermocouples were all fabricated from 24 gage diameter type K chromel-alumel wire. The locations of the thermocouples are shown in figure 6.

3. TEST RESULTS

3.1. Furnace Temperatures

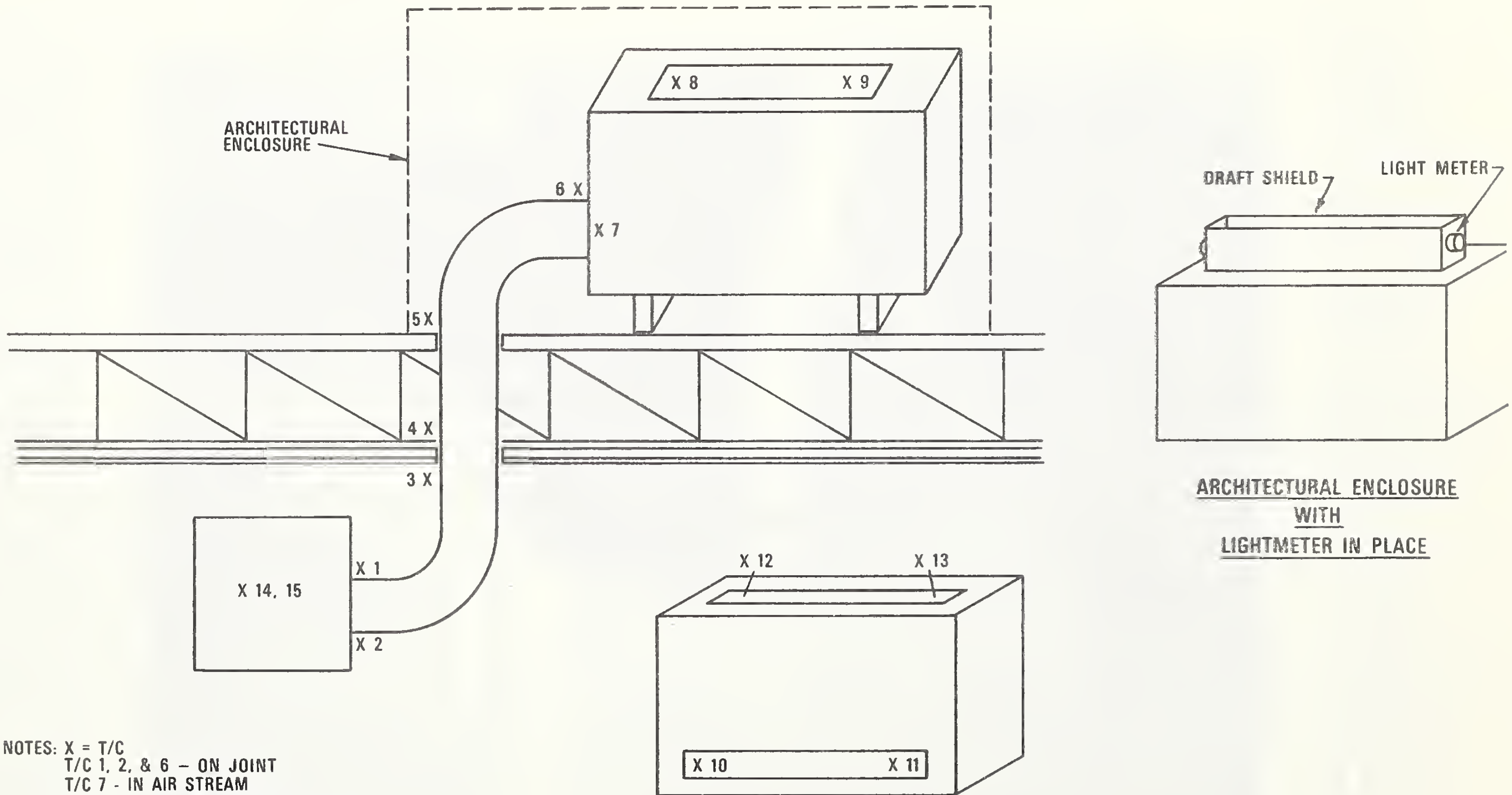
During the test the furnace temperatures closely followed the values prescribed in the standard [4] (see fig. 7).

3.2. Assembly Temperatures and Performance

The temperatures within each assembly are summarized on two figures. The first figure of each set shows the temperatures from the duct to the terminal unit, the second shows the temperature in the terminal unit and architectural enclosure. This data is shown on consecutive pairs of figures for each flexible connector assembly in figures 8 to 15. A comparison of the outlet temperatures on the architectural enclosures is shown in figure 16.

The aluminum connector melted at about 7 minutes and the opening at the closure was sealed with a noncombustible board to permit the continuation of the one-hour test. This is shown in figures 8 and 9 where the thermocouples that were located above the closure showed a rapid decrease in temperature after 8 minutes.

The performance of the felted glass fiber and of the woven glass fiber connectors were closely similar in this test: both fell into the furnace at 20 minutes. The difference in behavior compared to test 516 [3] was that the woven glass fiber connector was bare in this test and



NOTES: X = T/C
T/C 1, 2, & 6 – ON JOINT
T/C 7 - IN AIR STREAM
T/C 3, 4, &5 - ON CONNECTOR
T/C 8 TO 13 - IN AIR STREAM
T/C 14 & 15 - IN AIR STREAM IN DUCT PUT AT MID HT. ON STRAP

T/C ON ARCHITECTURAL ENCLOSURE

ARCHITECTURAL ENCLOSURE WITH LIGHTMETER IN PLACE

TYPICAL INSTRUMENTATION LAYOUT FOR FLEXIBLE CONNECTOR TESTS

FIGURE 6 TEST 532 THERMOCOUPLE LOCATIONS

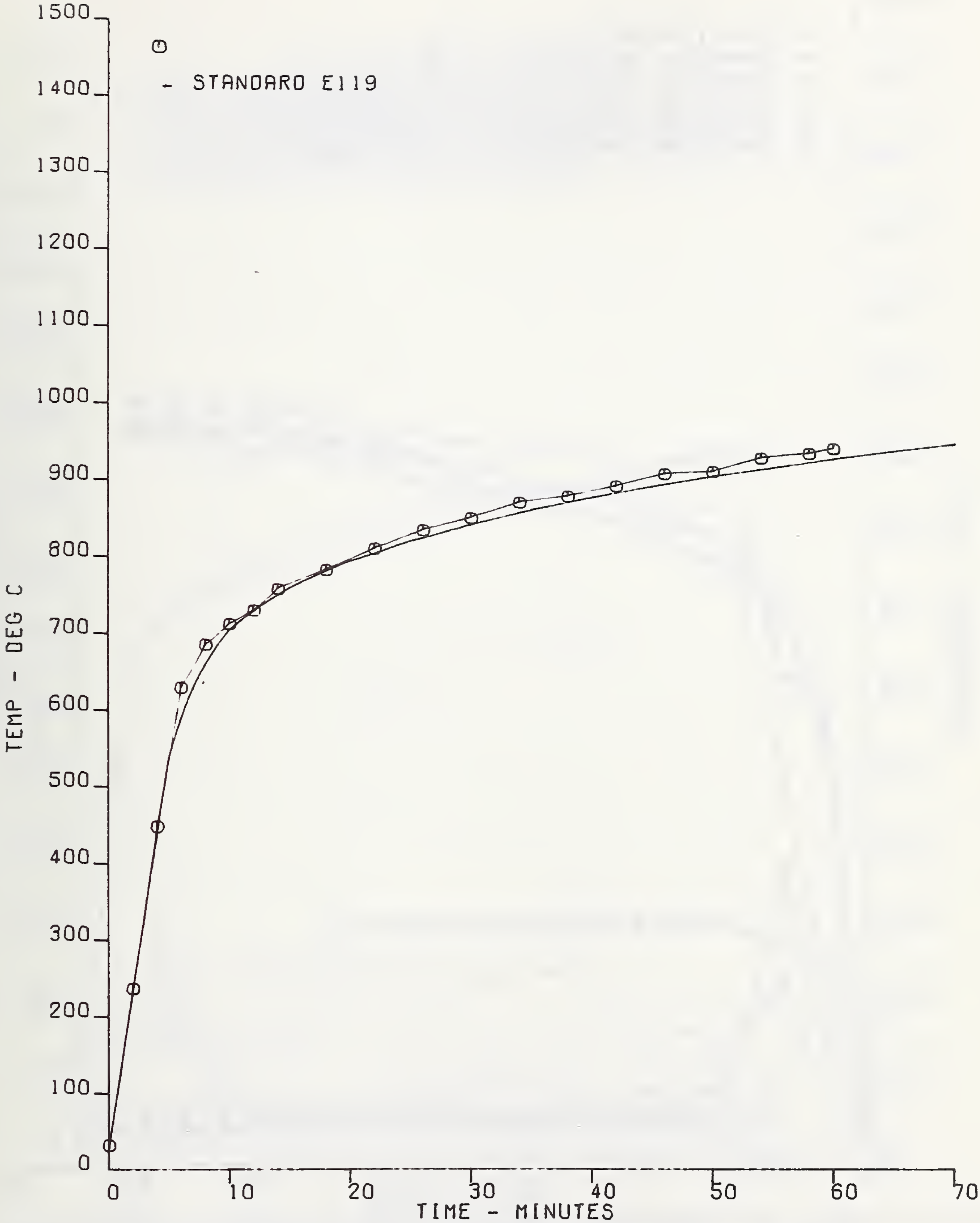


FIGURE 7 TEST 532 FURNACE TEMPERATURE

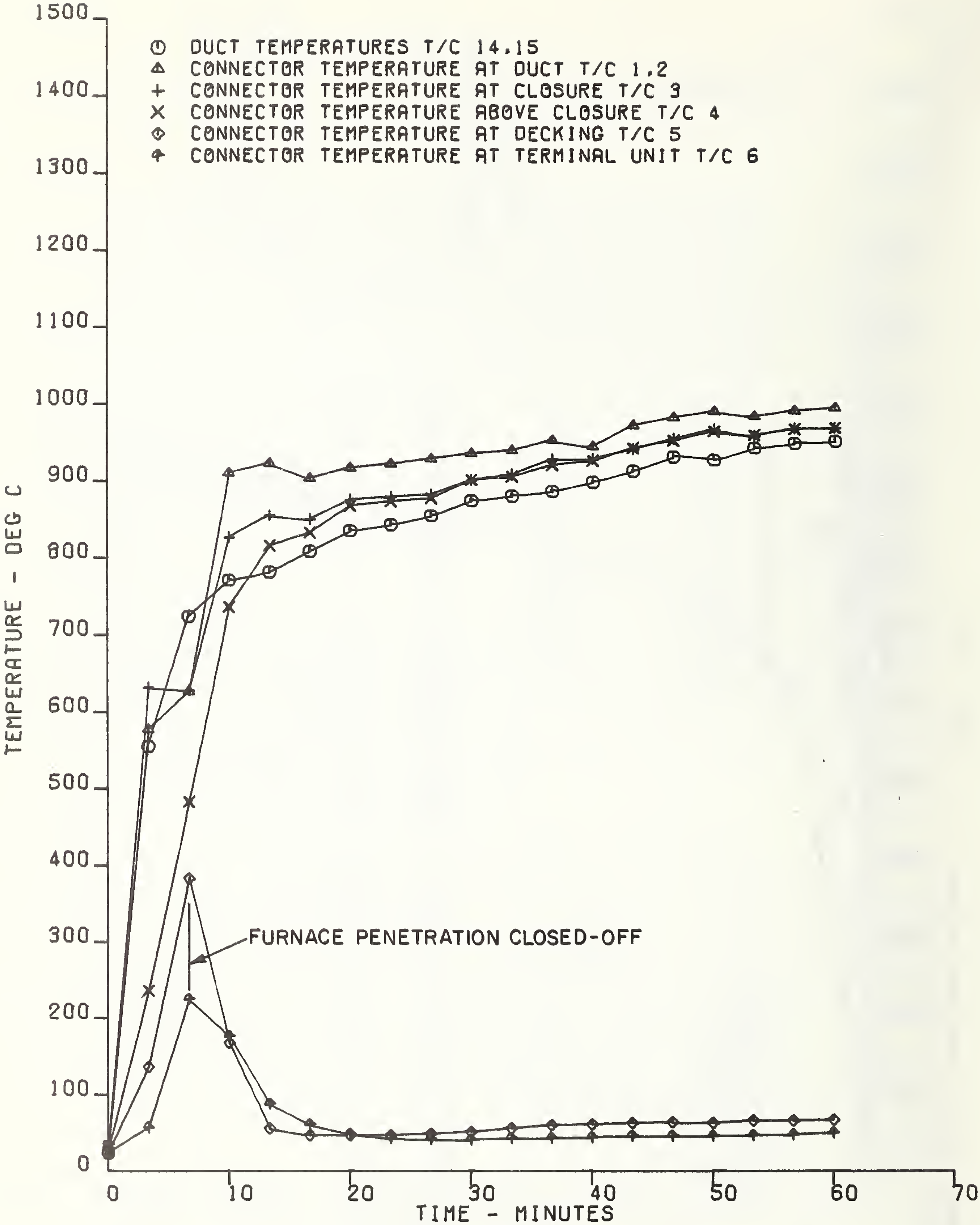


FIGURE 8 TEST 532 TEMPERATURES ALONG ALUMINUM CONNECTOR BETWEEN DUCT AND TERMINAL UNIT

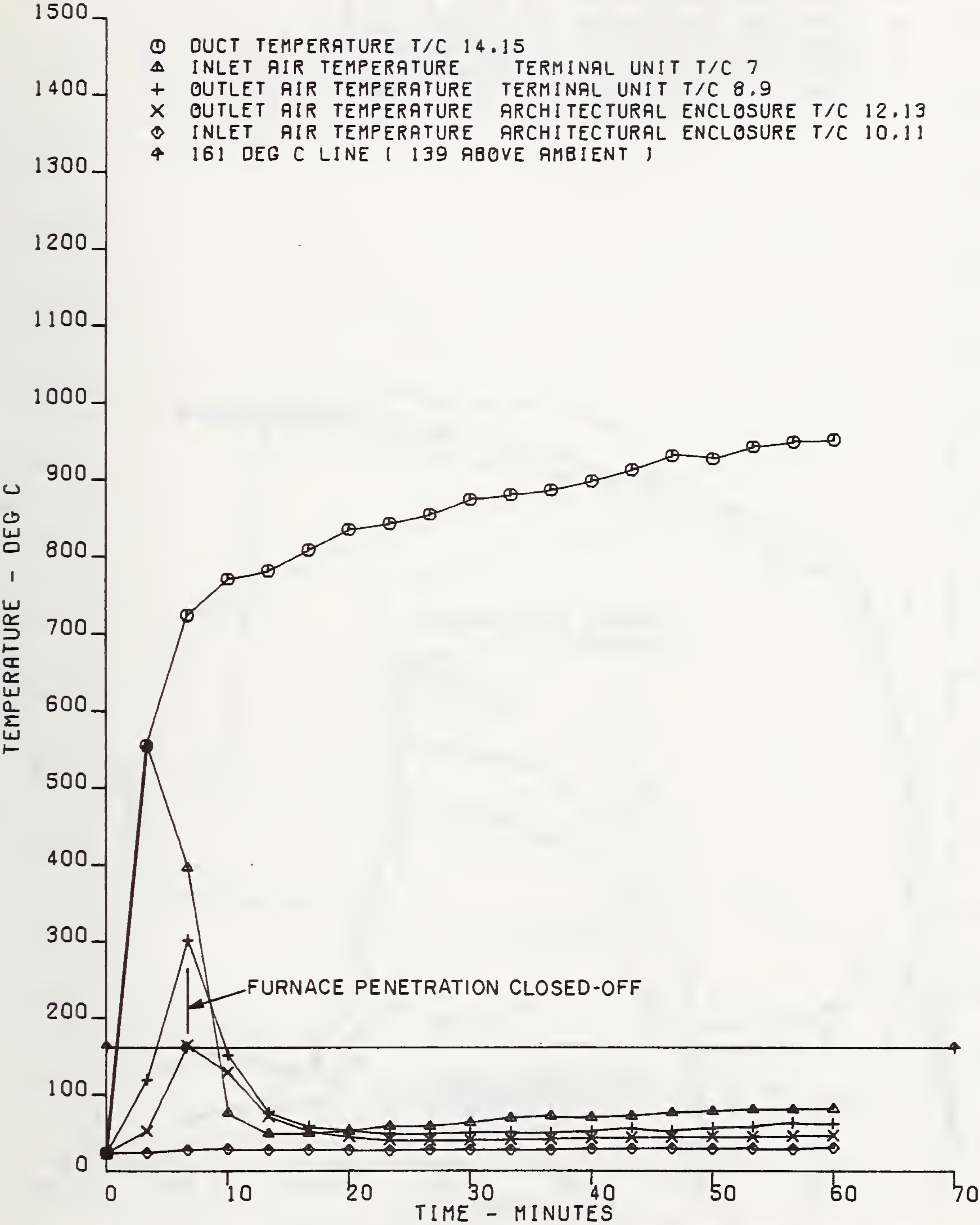


FIGURE 9. TEST 532 ALUMINUM ASSEMBLY TEMPERATURES ALONG TERMINAL UNIT AND ARCHITECTURAL ENCLOSURE

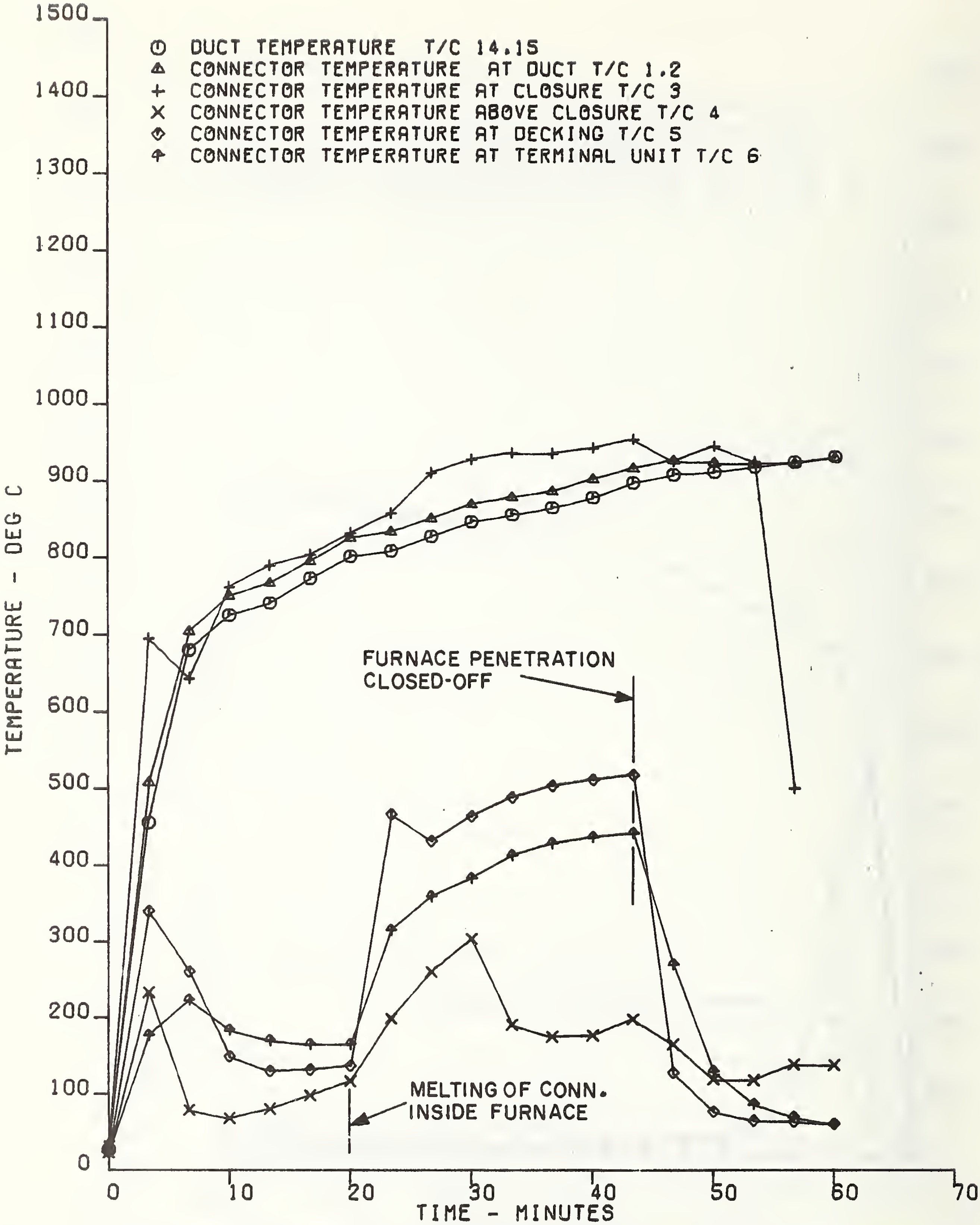


FIGURE 10 TEST 532 TEMPERATURES ALONG FELTED GLASS FIBER CONNECTOR BETWEEN DUCT AND TERMINAL UNIT

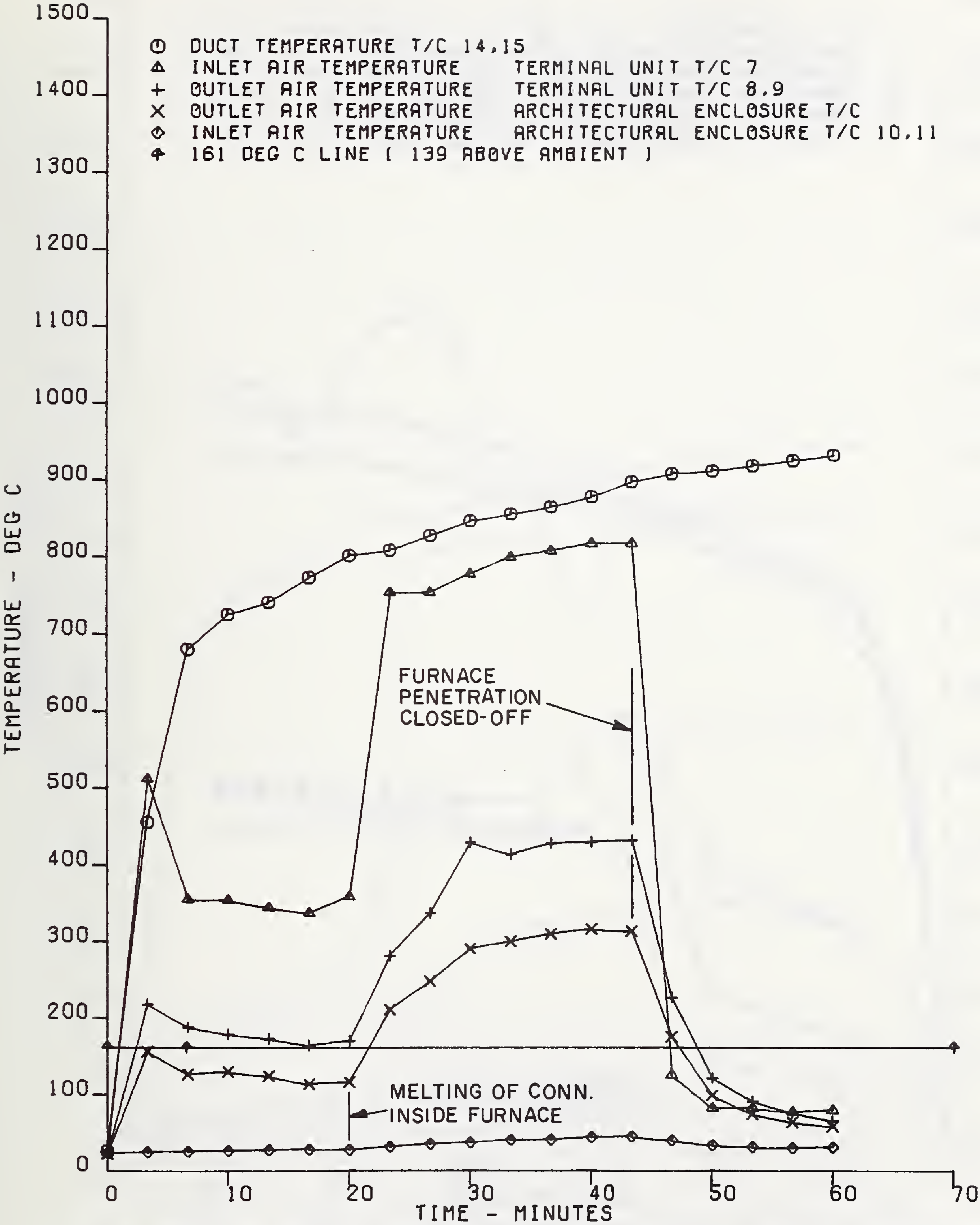


FIGURE 11 TEST 532 FELTED GLASS FIBER ASSEMBLY TEMPERATURES ALONG TERMINAL UNIT AND ARCHITECTURAL ENCLOSURE

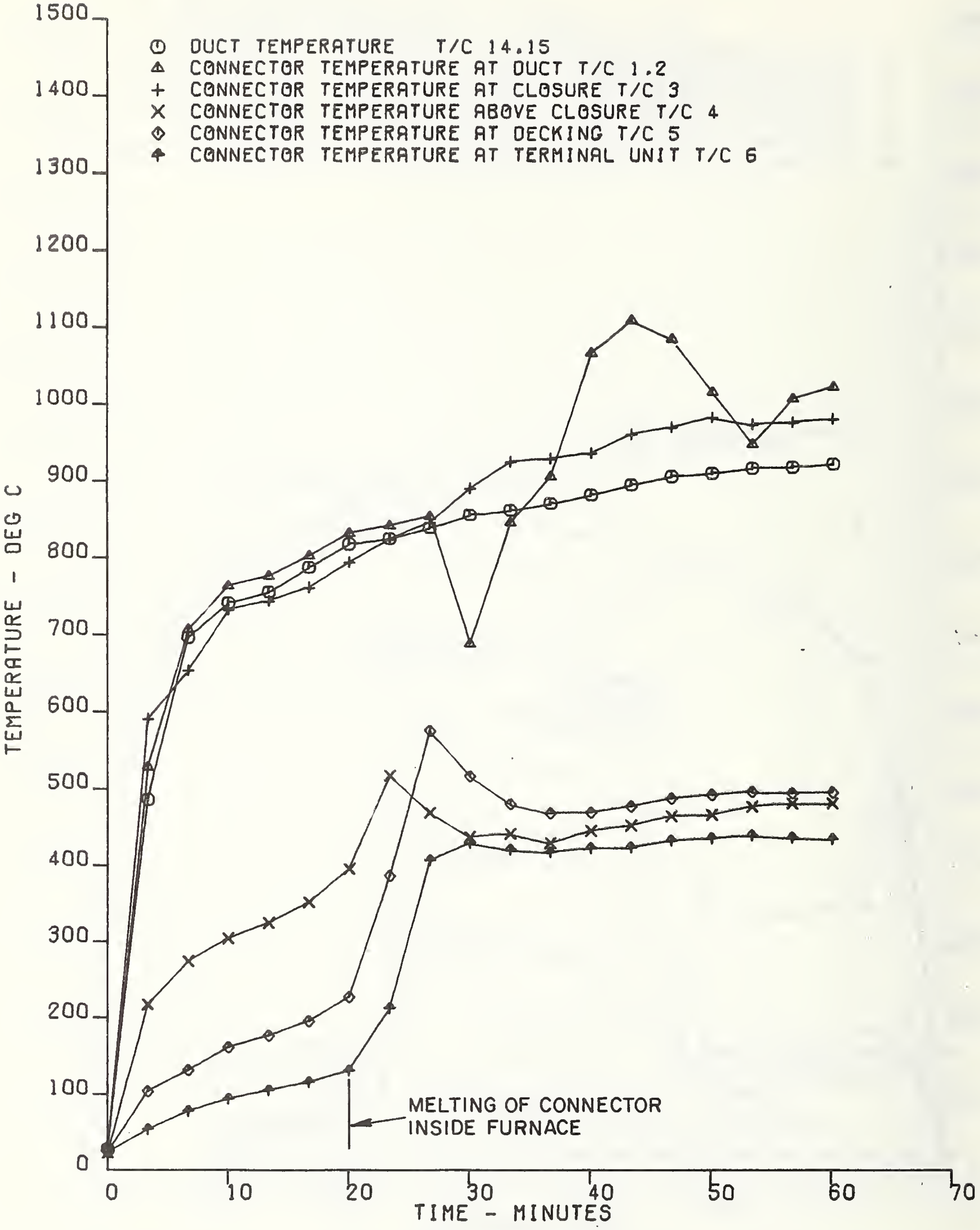


FIGURE 12 TEST 532 TEMPERATURES ALONG WOVEN GLASS FIBER CONNECTOR BETWEEN DUCT AND TERMINAL UNIT

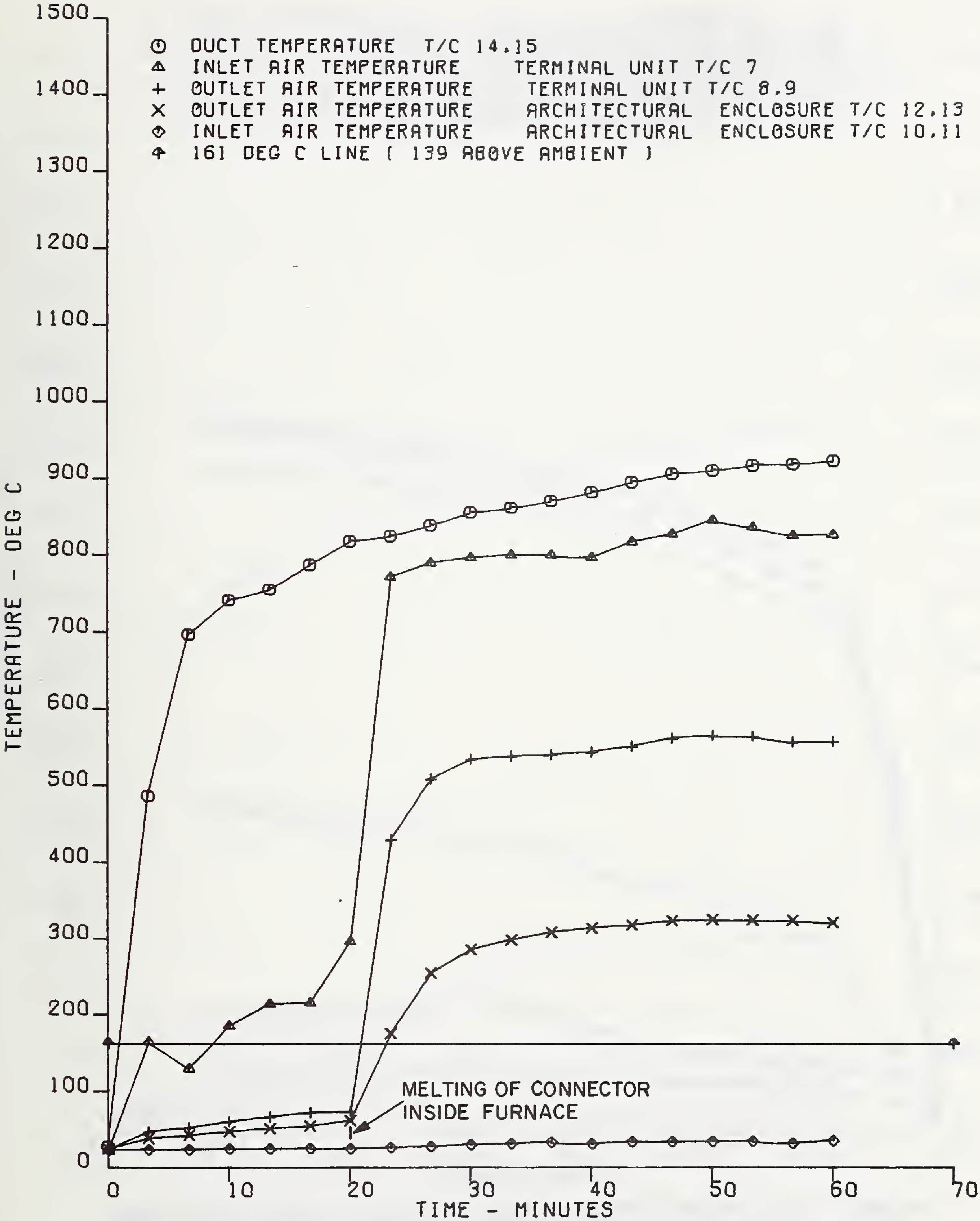


FIGURE 13 TEST 532 WOVEN GLASS FIBER ASSEMBLY TEMPERATURES ALONG TERMINAL UNIT AND ARCHITECTURAL ENCLOSURE

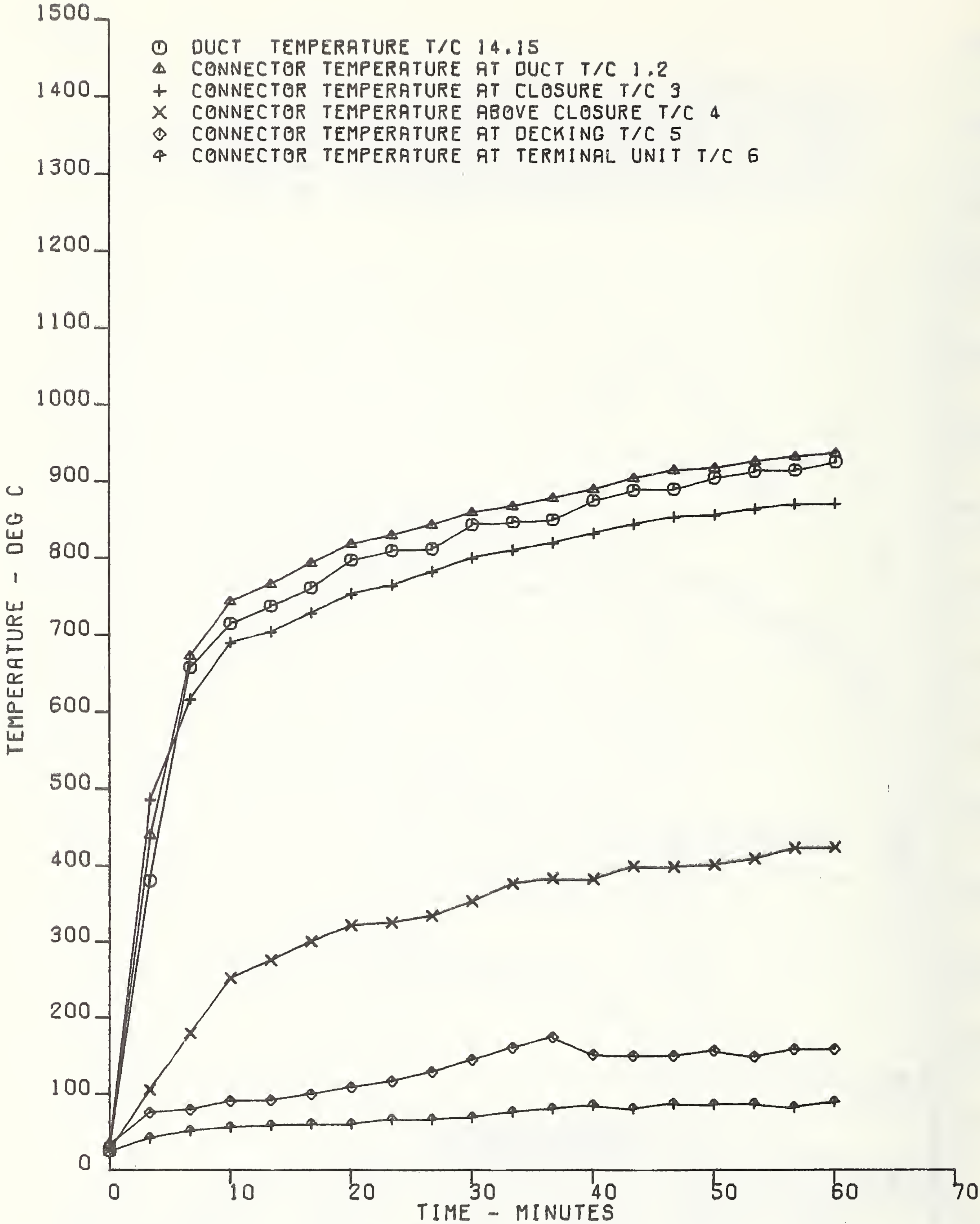


FIGURE 14 TEST 532 TEMPERATURES ALONG STEEL CONNECTOR BETWEEN DUCT AND TERMINAL UNIT

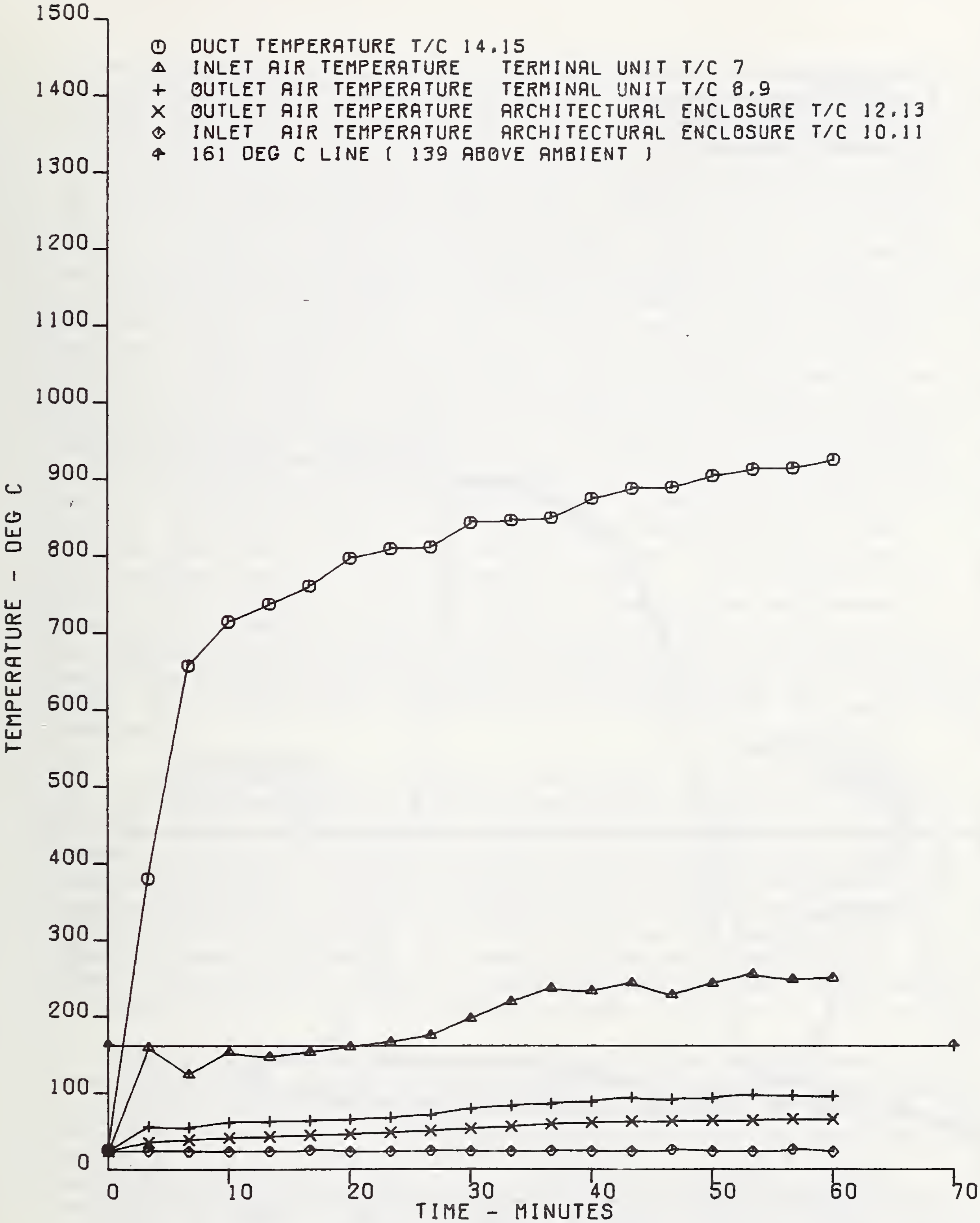


FIGURE 15 TEST 532 STEEL ASSEMBLY TEMPERATURES ALONG TERMINAL UNIT AND ARCHITECTURAL ENCLOSURE

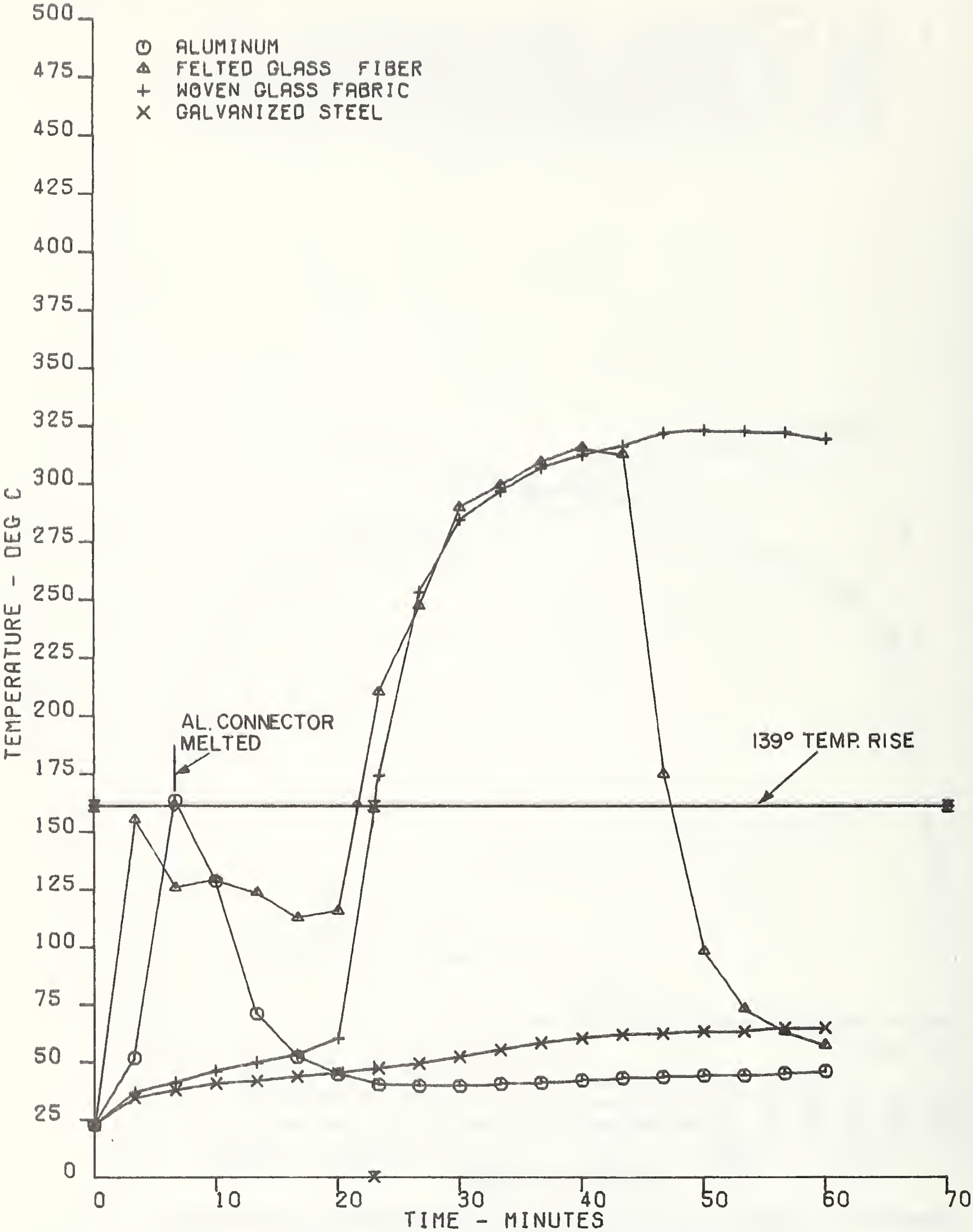


FIGURE 16 COMPARISON OF OUTLET AIR TEMPERATURES ON ARCHITECTURAL ENCLOSURES

it was covered with 1-inch glass fiber insulation in the earlier test. In this test the penetration at the felted glass fiber connector was manually closed off at 47 minutes as the connector was glowing red above the furnace closure. The woven glass fiber was not closed off as this connector maintained some structural integrity outside the furnace after the portion inside the furnace had melted. During the test the temperature of both glass fiber assemblies varied from what would be expected from the changes in the furnace temperatures. Referring to figures 10 and 11 for the felted glass fiber connector assembly: the connector and air temperatures rose rapidly for the first 4 minutes or so of test, then fell until 20 minutes of test, then rose again rapidly reaching a maximum at 30 minutes of test, and then (with the exception of the connector temperature above the closure) rose gradually or remained more or less constant until the penetration through the closure was closed at 47 minutes. Referring to figures 12 and 13 for the woven glass fiber connector assembly: the connector and air temperatures rose gradually until 20 minutes of test, the temperature then rose rapidly during the next 3 to 8 minutes all reaching more or less a maximum by about 20 minutes, after this time the air temperatures remained more or less constant while the connector temperatures dropped a little and then also remained constant until the end of the test. The explanation for this is that during the test the flow of hot gases from the furnace through the assemblies varied in quantity and direction. When the flow was from the furnace outwards, the air temperatures at the terminal unit rose; when it was zero or from the room into the furnace, the temperatures fell. Thus, unless furnace pressures are controlled, the test may not be repeatable.

In a real world fire situation, the pressure of the hot gases from the fire would be positive, that is, greater than the ambient pressures. Thus, in order to have performance that reflects the expected levels of pressure in a fire situation, the furnace should be run under slight positive pressure. The data also suggest that the flow conditions between the flexible connector assembly and the furnace are marginally stable, that is, changes in local conditions, such as failure of a flexible connector assembly, can result in changes in the direction of flow. This may also be true for actual installations where there may be an induced air flow in a HVAC system even when the blower is not operating.

Though the level of pressure to be run in a test is difficult to establish, certain qualitative and quantitative parameters can be used to establish limits on the range of pressure. With the currently available test furnace, if too high a pressure is used, the test room will be filled with smoke and gases from the test. Another factor is the range of pressures that a fire can produce: analysis and test results [5,6] indicate that the positive pressure to be expected from a fire can range from a maximum of about 0.1 inches water with many values being less than about .05 inches water and ranging down to zero.

Though in a real fire situation the positive pressures that can be developed vary over a range of values, a rating test probably needs to consider only a more limited range of pressures. A justification for this viewpoint can be drawn from the operation of ASTM E-119 where test and analytic data indicate that many actual fires differ in intensity and duration from that applied by ASTM E-119 [7]. For these reasons it is proposed at this time that the furnace be run at a positive pressure of .01 $\pm$ .003 inches of water.

The steel connector maintained its integrity for the 60 minutes of test. That is, at the end of the test the attachment to the branch duct was intact and the blocking at the penetration of the furnace closure was intact.

3.2.1. Enclosure Outlet Air Temperatures

In figure 16 the outlet temperatures of the four architectural enclosures are compared. The outlet temperature of the galvanized steel assembly is below the allowable temperature rise of 139°C (250°F) which is usually taken to represent the temperature rise limit.

3.3. Smoke Measurements

An attempt was made to take optical density measurements of smoke at the outlet of the flexible connector. The experimental arrangement used did not work properly because of a defect in the setup and no usable smoke data were obtained.

3.4. Closure

In this test an elaborate furnace closure was used. This closure made it easier to set up the test, to make observations on the top of the deck in the space between the closure and the deck. This closure had no significant affect on the test results as compared with previous tests [3].

4. SUMMARY

A test to develop information from a proposed method for testing flexible connectors was run at NBS on March 5, 1974. The test was arranged to test a range of connectors (aluminum, steel, felted glass fiber and woven glass fiber) simultaneously.

The results indicated that the fire performance of a connector, the method of attaching a connector to its branch duct and the integrity of the penetration through the fire barrier can be evaluated.

The criterion of specifying a limit on the outlet air temperatures at the architectural enclosure is similar to the maximum unexposed surface temperature criterion for the fire resistance of floors [4]. Since the outlet air temperature appears to be dependent on the furnace pressure, a requirement for furnace pressures is included in the proposed test method.

Although no furnace pressure measurements were made, in order to simulate fire conditions and to improve uniformity in testing, the furnace should be run under a positive pressure.

Further tests should be run to improve the method for taking smoke measurements.

As in other areas of fire endurance evaluations, consideration should be given to using supplementary laboratory tests such as smoke generation, potential heat, flame spread, and ease of ignition to evaluate other fire performance properties of the assembly and its components.

APPENDIX A

A PROPOSED METHOD OF TEST FOR FIRE RESISTANCE OF FLEXIBLE CONNECTORS FOR HEATING VENTILATING AND AIR CONDITIONING SYSTEMS

A1. Scope

This method evaluates the fire performance of a flexible connector system in terms of: a) resistance of the flexible connectors to failure by direct fire penetration, b) adequacy of attachment method of the flexible connector to the duct, c) effectiveness of the blocking (fire-stopping) of the penetration through a fire-rated floor and ceiling, and d) visual observations of smoke density at the outlet of an architechural enclosure. This test is applicable to flexible connectors made in whole or in part of metal, plastic, ceramic or other material. The test provides a measure of the performance of a flexible connector system in a prescribed arrangement during the fire exposure period only, and does not imply suitability for use after test. The results are applicable to other constructions only when similar methods of attaching the flexible connector to its branch duct and when similar blocking or firestopping are used.

The terminal unit is not included for evaluation in this proposed test procedure. Instead, a standard simulated terminal unit and architectural enclosure are used so that the performance of a flexible connector is evaluated independent of a specific type of terminal unit.

Note: The test arrangement is based on experiments that were made at the National Bureau of Standards in 1972, and which are described in reference [3] and in the accompanying paper. The test arrangement is the same as that shown in figures 1, 3, 4 and 6 of the preceding report. These tests, which were based on the fire performance of an assembly under exposure conditions of the standard fire resistance test [4], indicated that the proposed test arrangement will provide a measure of the pertinent factors. Correlation of the performance of flexible connectors and systems in other configurations is not intended or implied.

A test result is expressed in terms of the time period to failure as indicated by one or more of the following events: a) melting or pyrolysis of the flexible connector, b) partial or complete separation of the flexible connector from its duct, c) passage of hot gases, flame, or smoke through the blocking at the penetration through the furnace closure[1] and, or d) the temperature at the discharge opening of the top of the architechural enclosure rising 250°F (139°C) above the initial temperature at the beginning of the test.

[1]By visual observation and the temperatures of thermocouple 4 (see figure 6).

A2. Significance

Pipes, shafts, ducts and flexible connectors often pierce major fire barriers in buildings and the integrity of these items may be critical in terms of the spread or containment of the fire. This test provides a means of comparing and evaluating the fire performance of a flexible connector system when exposed to the direct effects of a prescribed severe fire. A single test is used to evaluate the flexible connector, the attachment of the flexible connector to its duct, and the method of firestopping (backpacking) the penetration through a fire barrier of a flexible connector.

A3. Test Procedure

A3.1. Fire Exposure

The fire exposure is the same as that described in ASTM E-119 [2]. The furnace pressure at the connector level should be maintained at .01 $\pm$ .003 inches of water.

A3.2. Locations of Thermocouples on the Specimen

A minimum of 15 thermocouples are placed in or on components of the assembly. The thermocouples are placed at the following locations: two on the outside of the flexible connector at its junctions with the duct, one on the flexible connector on the fire-side of the furnace closure, one on the flexible connector on the room side of the furnace closure, one at the junction of the flexible connector and the terminal unit, one in the air inlet stream of the terminal unit at the junction with the flexible connector, two in the outlet air stream of the terminal unit, two in the inlet air stream of the architectural enclosure, and two in the outlet air stream of the architectural enclosure.

The passage of flames directly through the flexible connector or through an opening at the junction of the connector and duct will be shown by a rapid rise in air temperature at the outlet to the architectural enclosure.

A4. Construction Details

The test specimen consists of a length of flexible connector one end of which is connected to a simulated duct inside the furnace, and the other end which is connected to a simulated terminal unit outside the furnace. The length of the shortest side, or the diameter of the simulated duct, should be at least 18 inches. The length of the simulated duct should be at least 6 feet, and the ends are to be closed. There is no specified length for the flexible connector, but the length inside the furnace should be at least six diameters and not less than 2 feet 6 inches. Any bends should either conform to the recommendations of the manufacturer of the flexible connector or to specifications of the approval authority for whom the test is being run. Only one flexible connector may be attached to any one simulated duct and terminal unit assembly, but more than one assembly may be tested at the same time by utilizing separate installations in the furnace. The ends of the flexible connector are to be open to permit flow between the branch duct and the architectural enclosure.

A4.1. Method of Attachment

The method of attaching the flexible connector to the simulated duct must be clearly described and shown on the drawings and in the report for the test. The method of attaching the flexible connector should be either as specified by the manufacturer or should be representative of local field methods depending on the requirements of the local code authority.

A4.2. Firestop at Penetrations

The method of blocking and firestopping the penetrations of the flexible connector through the furnace closure must be clearly described and shown on the drawings and in the report for the test.

A4.3. Furnace Closure

The furnace closure may be framed by precast concrete joists or steel joists. The joists shall be protected by a furnace closure that remains intact and dimensionally stable for at least 1-1/2 hours. (A type of closure that meets this requirement consists of two layers of 5/8-inch type X gypsum board protected by one layer of vermiculite or perlite plaster on expanded metal lath attached with bugle head type screws spaced at not over 12 inches on center at right angles to tuning channels at not over 24 inches on center). The joists may be covered with a concrete plank, or gypsum plank, or gypsum board cover. The spaces between the top and bottom of the joists should be left open so that the condition of that portion of the flexible connectors, that is outside of the furnace, can be observed during the test.

A5. Report of Results

The report should include the following information: a) assembly drawings showing pertinent dimensions, b) details of method of attaching flexible connector to simulated duct, c) details of method of blocking penetration through furnace closure, d) locations of thermocouples and details of method or attaching assembly, e) temperatures measured during test at least every 5 minutes, f) visual observations of the smoke emitted by the assembly, (The time when there are significant changes in the quantity and density of the emitted smoke should be noted. Observations should be made at least every 10 minutes), g) observations of the condition of the assembly and of significant events during the test including the time that the flexible connector separates from the simulated branch duct, the time that fire breaks into the flexible connector, and visual changes in the amount and character of any smoke emitted at the discharge of the architectural enclosure, and h) any other pertinent information including photographs that will assist in evaluating the fire resistance of the flexible connector.

A6. Criteria for Evaluation

The criteria for evaluation are:

1. For the rating period all parts of the assembly wall shall remain fastened, without gaps or openings developing. If any part of the assembly (attachment, blocking, joints, materials) fails before the end of the rating period, it shall be cause for rejection.

2. The outlet air temperature at the architectural enclosure shall not rise more than 139°C (212°F) during the rating period.

APPENDIX B. REFERENCES

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USCOMM-NBS-DC

NBS-114A (REV. 7-73)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 75-673	2. Gov't Accession No.	3. Recipient's Accession No.
4. TITLE AND SUBTITLE Development of a Fire Test Method for Flexible Connectors in Air Distribution Systems			5. Publication Date April 1975 6. Performing Organization Code
7. AUTHOR(S) Lionel A. Issen			8. Performing Organ. Report No.
9. PERFORMING ORGANIZATION NAME AND ADDRESS NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234			10. Project/Task/Work Unit No. 4926676 11. Contract/Grant No.
12. Sponsoring Organization Name and Complete Address (Street, City, State, ZIP) same as No. 9			13. Type of Report & Period Covered Final 14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

16. ABSTRACT (*A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.*)

The report describes fire tests on four flexible connectors of the type used in air conditioning systems. Four flexible connectors (aluminum, felted glass fiber, steel, and woven glass fiber) were exposed to a standard ASTM E-119 fire test. The results were in agreement with previous results in which a different sized branch duct was used in the assemblies. The results indicated a need to control furnace pressures. The test results were used to develop a proposed test method for fire testing flexible connectors. This proposed test method is described in the report.

17. KEY WORDS (*six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons*) Aluminum; ducts; fire tests; flexible connectors; furnace pressures; glass fiber; heat ventilating and air conditioning systems; high-rise buildings; optical density; steel; terminal units.

18. AVAILABILITY	19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
XX Unlimited ☐ For Official Distribution. Do Not Release to NTIS	UNCLASSIFIED	32
☐ Order From Sup. of Doc., U.S. Government Printing Office Washington, D.C. 20402, SD Cat. No. C13 XX Order From National Technical Information Service (NTIS) Springfield, Virginia 22151	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. Price $3.75

USCOMM-DC 29042-P74