Designation: A 991/A 991M – 98 (Reapproved 2004)

Standard Test Method for Conducting Temperature Uniformity Surveys of Furnaces Used to Heat Treat Steel Products[1]

This standard is issued under the fixed designation A 991/A 991M; 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.

1. Scope

1.1 This test method covers the procedures used to conduct a temperature uniformity survey on a furnace used to heat treat steel products. This method is used to determine the capability of the furnace to meet the permissible temperature variation specified in the applicable product specification, or as agreed to by the purchaser and supplier of heat treat services. Survey documentation requirements, and the procedure used to subsequently establish the furnace working zone, are defined in this test method.

1.2 This test method covers heat treat furnaces in any of the following categories:

1.2.1 Continuous or semi-continuous conveyance furnaces,

1.2.2 Batch furnaces, and

1.2.3 Salt or liquid baths and fluidized beds.

1.3 This test method only applies when specified in the product specification or the purchase order.

1.4 Controlling a heat treatment of steel products using thermocouples attached to the extremities of each load is an alternative to performing a furnace survey.

1.5 By mutual agreement between the purchaser and the supplier of heat treat services, more stringent and/or additional requirements may be specified. The acceptance of any such additional requirements shall be dependent on negotiations with the supplier and must be included in the order as agreed upon by the purchaser and supplier.

1.6 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system is to be used independently of the other, without combining values in any way.

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]

E 207 Test Method for Thermal EMF Test of Single Thermoelement Materials by Comparison with a Reference Thermoelement of Similar EMF-Temperature Properties

E 220 Test Method for Calibration of Thermocouples By Comparison Techniques

E 230 Specification and Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples

E 608/E 608M Specification for Mineral-Insulated, Metal-Sheathed Base Metal Thermocouples

2.2 *SAE Standard:*

AMS 2750 Pyrometry[3]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *batch furnace*, *n*—heating device in which material may be stationary or oscillating during the processing cycle.

3.1.2 *continuous conveyance furnace*, *n*—heating device through which material is moved intentionally at a constant rate during the processing cycle.

3.1.3 *extremities*, *n*—as referring to furnace working zone; outer boundaries in all three dimensions (length, width, and height) of the material being processed.

3.1.4 *operating range*, *n*—expected range of temperature over which a furnace will be controlled to heat treat steel products.

3.1.5 *primary survey*, *n*—initial evaluation of the furnace, or an evaluation triggered by the initiation of a major furnace modification.

3.1.6 *secondary survey*, *n*—evaluation of the furnace triggered by the expiration of a time requirement.

3.1.7 *semi-continuous conveyance furnace*, *n*—heating device through which material is moved intentionally with a predetermined start-stop-start pattern during the processing cycle.

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[1] This test method is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.13 on Mechanical and Chemical Testing and Processing Methods of Steel Products and Processes.

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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.

[3] Available from Society of Automotive Engineers (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001.

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3.1.8 *working zone*, *n*—maximum volume and location in the furnace that meet the permissible temperature variation.

4. Significance and Use

4.1 Furnaces for heat treatment of steel products are used in many industries, in many ways. Regardless of heat treat furnace type, or processing cycle, it may be necessary for users to know the temperature uniformity in the furnace and whether the material is processed in a zone within the furnace that is capable of meeting the applicable permissible temperature variation requirements.

4.2 The procedures in this test method may be used by those using, manufacturing, and providing calibration service for, heat treat furnaces used to process steel products.

5. Furnace Survey Equipment

5.1 *Thermocouples*:

5.1.1 Metal sheathed thermocouples shall be in accordance with Specification E 608/E 608M.

5.1.2 The use of extension wires is permitted when compensated connectors, plugs, jacks, and terminal strips are used.

5.1.3 Thermocouples made from spool wire shall meet the requirements of AMS 2750.

5.1.4 The use of spliced extension wire is prohibited.

5.1.5 Thermocouples may be reused if the requirements of AMS 2750 (except Paragraph 3.1.1.7.2 of Rev. C) are met.

5.2 *Calibration*:

5.2.1 All reference, primary, secondary, test and working equipment, instrumentation and sensors used in conjunction with this test method shall meet the requirements of calibration defined by Test Methods E 207 and E 220.

5.2.2 Temperature measuring devices shall be calibrated within three months prior to use.

5.2.3 Calibration shall be traceable to the National Institute of Standards Technology standards, or equivalent national standards. Calibration to such national standards shall be done at least once every two years.

5.2.4 Calibration shall be within the temperature range to be used in the survey and at intervals not greater than 200°F [100°C] for primary and secondary standards.

5.2.5 Correction factors, limits of error, and deviations shall be in accordance with Specification E 230.

6. Requirements

6.1 *Uniformity Survey Test Conditions*:

6.1.1 The furnace to be surveyed shall be capable of being tested at set point temperature(s) typical for the normal operating range.

6.1.1.1 If the operating range does not exceed a spread of 300°F [150°C], the midpoint temperature shall be selected for the survey.

6.1.1.2 If the operating range exceeds a spread of 300°F [150°C], survey at the minimum and maximum set point temperature for the normal operating range, except that the maximum temperature need not be higher than 2000°F [1100°C].

6.1.2 Typical production size and weight furnace loads shall be utilized during the survey. Use of representative material to simulate product during survey is permitted.

6.1.3 The furnace atmosphere and operating conditions shall be representative of those used in production.

6.2 *Frequency of Uniformity Surveys*:

6.2.1 Primary Surveys:

6.2.1.1 A primary survey shall have been performed within twelve months prior to, or run concurrently with, the first production heat treatment to which this test method applies.

6.2.1.2 A primary survey shall have been conducted when a major furnace modification is completed. A major furnace modification includes, but is not limited to, the installation of the following: a different burner type, a new heating element design, a different type of insulation system, and, a different type of temperature controlling device.

6.2.1.3 Replacement of worn parts with similar parts or patching of insulation that does not change the furnace characteristics does not constitute a major furnace modification.

6.2.1.4 The survey shall be conducted within twelve months prior to, or run concurrently with, the first production heat treatment performed after the modification.

6.2.2 *Secondary Surveys*:

6.2.2.1 To maintain conformance with this test method, a secondary survey shall be conducted within twelve months after the primary survey.

6.2.2.2 Secondary surveys shall be conducted at a typical furnace set point temperature within the normal operating range. All other conditions described in 6.1 shall apply.

7. Procedure

7.1 Survey measuring equipment shall meet the requirements of Section 5.

7.2 Test conditions and test frequency shall be as defined in 6.1 and 6.2, respectively.

7.3 Place thermocouples to monitor time and temperature profiles in the furnace to evaluate the uniformity of the intended working zone. Place them at the outer extremities, the center of the proposed working zone, and in areas of suspected variability in the proposed working zone. Attach survey test sensors to, or set them in the load.

7.4 For proposed working zones less than 12 in. [300 mm] in height, it is acceptable to monitor the center height location, it is not necessary to monitor both the top and bottom of the heating chamber. For proposed working zones greater than, or equal to, 12 in. [300 mm] in height, both top and bottom extremities must be monitored.

7.5 *Continuous Conveyance and Semi-Continuous Conveyance Furnaces*:

7.5.1 Convey test sensors through the furnace. The rate of conveyance shall be representative of normal operating conditions.

7.5.2 The frequency of temperature recordings shall be capable of detecting variations from the test temperature range during the entire conveyance through the furnace.

7.5.3 Several conveyances with the test sensors attached to the steel product, under the same conditions, may be made to ensure that any recurrent temperature profiles are determined at all test locations throughout the furnace.

7.5.4 Alternative surveying techniques are described in 7.7.

7.6 *Batch and Batch Liquid Media Furnaces*:

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7.6.1 Take readings starting when the control instrument rises to within 200°F [100°C] of the set point temperature and continue throughout the hold cycle at the set point temperature.

7.6.2 Take readings at a minimum frequency of 1/10 the normal hold time.

7.6.3 Take the readings frequently enough to detect variations from the test temperature range and to determine the extremes of the recurrent temperature profile, if any.

7.6.4 Alternative surveying techniques are described in 7.7.

7.7 *Alternative Surveying Techniques*—When agreed to by the purchaser and the supplier of heat treat services, alternative surveying techniques may be used to characterize the temperature uniformity of the furnace and subsequently define the size and location of the working zone. Examples of these surveying techniques are listed below.

7.7.1 *Statistical Sampling*:

7.7.1.1 When it is impossible or impractical to perform the tests outlined in 7.5 and 7.6, it is permissible to substitute an analysis of the resultant mechanical properties of the steel products heat treated in the subject furnace to validate temperature uniformity. Details of this procedure shall be as agreed to between purchaser and supplier.

7.7.2 *Sequential Load Sensors*:

7.7.2.1 This procedure may be used as an alternative to those described in 7.5 and 7.6. It provides validation of temperature uniformity by a series of tests rather than a single test. In each test, determine the temperature variation pattern at one or more of the test locations.

7.7.2.2 The frequency of test shall be six months.

7.7.2.3 The temperature shall be within the normal operating range, with the narrowest permissible variation for the material applied to the survey.

7.7.2.4 Run the furnace with a load similar to that used in a normal production cycle.

7.7.2.5 Load or test sensors shall be arranged in, or in contact with, the test load.

7.7.2.6 Control setting(s) shall be identical to those used in normal production.

7.7.2.7 Take readings starting when the control instruments rises to within 200°F [100°C] of the set point temperature and continued throughout the hold cycle at the set point temperature.

7.7.2.8 Record the temperature of all load test and working sensors frequently enough to detect when the specified operating range is exceeded, and at least five cycles of any recurrent pattern have been observed.

7.7.2.9 If no recurrent temperature profile is detected, take readings at intervals of five minutes or less, for at least 30 min after thermal equilibrium is reached.

8. Documentation of Survey Results

8.1 Organizations performing surveys in accordance with this test method shall keep pertinent documentation of the conditions and procedures used in the completion of the survey on file for a minimum of five years.

8.2 Pertinent documentation shall include, but not be limited to, the following:

8.2.1 Specific identification of furnace surveyed,

8.2.2 Date of the uniformity survey,

8.2.3 Identification of the heat treat procedure,

8.2.3.1 Set point temperatures,

8.2.3.2 Type of atmosphere,

8.2.3.3 Conveyance speed (when applicable),

8.2.4 Size and weight of steel product loaded in furnace at time of survey,

8.2.5 Item identification numbers (lot, heat serial, etc.),

8.2.6 Time and temperature data, including original temperature charts or original manually recorded data,

8.2.7 Dimensions and location of the working zone(s),

8.2.8 Number and location of the survey thermocouples,

8.2.9 Largest observed temperature variation from the set points during the hold cycle,

8.2.10 The time interval of the test, including the total elapsed time. Starting time and chart speed shall be marked on the original temperature charts,

8.2.11 All pertinent equipment calibration information,

8.2.12 Deviations from the test method including, but not limited to, thermocouple failure, malfunction, or disconnection.

8.2.13 Name of personnel conducting the survey, and

8.3 All data may be electronically recorded.

9. Interpretation of Results and Establishment of the Working Zone

9.1 The results of the primary survey describe the temperature uniformity of a furnace under a specific set of operating conditions. Results of the application of this test method shall be expressed as a variation from a temperature set point.

9.2 Establishment of the furnace working zone is made by comparing the temperature variation required by the product specification, or agreed to by purchaser and supplier of heat treat services, with the variation from the temperature set point as determined by this uniformity survey.

9.3 The working zone may either be the entire heating volume, or it may only be some portion of the heating volume of the furnace. The working zone may be comprised of one or more heating zones in the furnace.

10. Heat Treatment in the Working Zone

10.1 When invoked by the product specification, or agreed to by purchaser and supplier of heat treat services, steel products shall be heat treated, as specified, only in the working zone.

11. Keywords

11.1 furnace survey; temperature; uniformity; working zone

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