This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Designation: A1100 – 16 (Reapproved 2022)

Standard Guide for Qualification and Control of Induction Heat Treating[1]

This standard is issued under the fixed designation A1100; 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 guide covers the process control and product properties verification of continuous heat treating of material using a quench and temper induction process (surface hardening, surface heat treating, and batch heat-treated products using induction are not considered in this guide). Examples of products covered by this guide may include products covered by API Specifications 20E, 5L, and 5CT.

1.2 This guide indicates some features of induction heat treating compared to furnace heat treating. Induction heat treating processes typically operate at higher temperatures compared to furnace processes.

1.3 This guide addresses the features and requirements necessary for induction heating and ancillary equipment. However, induction equipment may be used in combination with convection heating equipment (for example, gas or electric furnaces).

1.4 *Units*—The values stated in SI units are to be regarded as the standard. No other units of measurement are included in this standard.

1.5 *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.*

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

A255 Test Methods for Determining Hardenability of Steel

A751 Test Methods and Practices for Chemical Analysis of Steel Products

A941 Terminology Relating to Steel, Stainless Steel, Related Alloys, and Ferroalloys

A1058 Test Methods for Mechanical Testing of Steel Products—Metric

E7 Terminology Relating to Metallography

E10 Test Method for Brinell Hardness of Metallic Materials

E18 Test Methods for Rockwell Hardness of Metallic Materials

E112 Test Methods for Determining Average Grain Size

E384 Test Method for Microindentation Hardness of Materials

2.2 *ASM Standards:*[3]

ASM Handbook Volume 4C Induction Heating and Heat Treatment

2.3 *API Specifications*[4]

20E Alloy and Carbon Steel Bolting for Use in the Petroleum and Natural Gas Industries

5CT Specification for Casing and Tubing

5L Specification for Line Pipe

2.4 *ANSI Standard:*[5]

ANSI/NCSL Z540.3 Requirements for the Calibration of Measuring and Test Equipment

3. Terminology

3.1 For definitions of terms used in this guide, refer to Terminologies A941 and E7.

[1] This guide 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 American Society for Metals (ASM International), 9639 Kinsman Rd., Materials Park, OH 44073-0002, http://www.asminternational.org.

[4] Available from American Petroleum Institute (API), 1220 L. St., NW, Washington, DC 20005-4070, http://www.api.org.

[5] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

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3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *induction heat treating, v*—process by which an electromagnetic field is used to induce a voltage in an electrically conductive material thereby causing current flow and heat is generated in the electrically conductive material through the Joule heating effect. (See ASM Handbook 4C, p. 18.)

3.2.2 *major rebuild, n*—any rebuild or repair that could alter the temperature uniformity characteristics of an induction heat treat line.

3.2.3 *product, n*—set of similar materials to be heated by passing through induction coils under the same conditions as defined in 6.3 process variables. (Including as examples bar, rod, tube, pipe.)

3.2.4 *quench media, n*—coolant used to quench out the work piece.

3.2.4.1 *Discussion*—Typically, it contains water or water and a polymer-based quench media.

3.2.5 *refractometer, n*—device used to measure the concentration of quench media that is mixed with water.

3.2.5.1 *Discussion*—Typical units are in degrees Brix and are approximately equivalent to half the volume concentration.

3.2.6 *sensors, n*—need to identify the type of sensors as they are already in some standards.

3.2.7 *skin depth, n*—also called depth of current penetration; the depth to which an alternating current will flow in a conductor. (See Appendix X3.)

4. Significance and Use

4.1 This guide helps purchasers assess induction processes including the critical parameters that can affect product quality. It guides the evaluation of heat-treating vendor performance and capabilities to ensure higher and more consistent product quality.

4.2 Refer to Appendix X1 for a flow chart for the use of this guide.

5. Equipment

5.1 *Equipment Capabilities*—Equipment used to produce the desired heat-treated product shall be capable of achieving target heat-treat parameters. Parameters shall be documented as per Section 6, and Section 7 shall be used to verify that the manufacturing procedure has been well developed, proper parameter tolerances have been selected, and equipment is capable of achieving all parameter settings. Documented procedures for the verification of equipment capabilities, calibration, and maintenance shall be maintained. These documented procedures shall address all critical equipment for the induction heat treatment line including, at minimum, the following:

5.1.1 All power supply units including relevant components,

5.1.2 All induction coils,

5.1.3 Quench system and components,

5.1.4 Pyrometers and other temperature-sensing devices,

5.1.5 Material handling as it pertains to line speed control, and

5.1.6 Controls.

5.2 The documented procedures shall address verification, calibration, and maintenance of the equipment as described in the following.

5.3 *Verification and Calibration of Equipment*—Equipment for the heat-treating line shall be verified and calibrated at a level necessary to achieve the tolerances determined in Section 6. It is recommended that calibration of test equipment follow the guidelines in ANSI/NCSL Z540.3. Equipment capabilities are related to the product chemistry, product dimensions, and production rate. It is possible that different products may require different tolerance ranges for parameter settings. These tolerance ranges shall be documented as part of the manufacturing procedures (Section 6). Classification and characterization of a heat-treat line based on equipment accuracy ranges and equipment capabilities may be conducted using the method described in Appendix X4. It is recommended that verification of equipment performance be conducted with heated product. Cold tests (for example, testing material handling, sensors, and controls) are useful, but equipment on an induction heat treating line may behave differently with heated product.

5.3.1 *Power Supply Units:*

5.3.1.1 The power supply units shall be capable of achieving the rated power and nominal frequency designated for the equipment by the manufacturer. Heating capabilities to achieve target temperatures should be verified at the point of installation of new power equipment, including ancillary equipment and devices such as connecting power cables and induction coils, and records of these capabilities should be kept (see 9.1).

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NOTE 1—The output power is a function of the voltage and current of the electrical system. If voltage or current is limited (because of high inductance, for example), the maximum power will be limited. For this reason, it is important to ensure that the power supply is evaluated with the induction coil and desired product so that accurate power capabilities are determined.

5.3.1.2 The power level for any given manufactured product may be selected at the heat treater's discretion to achieve the necessary target manufacturing procedure parameters. The output power stability should be monitored at regular intervals to ensure sufficient power stability to achieve the tolerance levels documented in Section 6. Incoming power to the plant can affect output power stability; therefore, incoming power may be monitored to ensure consistent output power capabilities. Various power quality measuring devices are available for monitoring incoming plant power and output power during operation.

5.3.1.3 The frequency at each induction coil should be verified and documented within each manufacturing procedure to ensure heating consistency. Periodic checks of the frequency at the induction coils should be conducted.

NOTE 2—The frequency is affected by the power level and the inductance of the system. Changes to the coil design, size of product, cooling media through the coil, current/voltage ratio, coil cable connections, and other factors can affect the frequency at the output coil. Changes in the output frequency can affect the depth of the induced current in the work piece (skin depth) and, therefore, the thermal gradient within the work piece (see Appendix X3). Frequency can be measured using most standard multi-meters.

5.3.1.4 It is not expected that power supply units will require calibration unless otherwise stipulated by the manufacturer of the equipment. Calibration and verification shall follow the manufacturer's recommended schedule or the schedule outlined in Table 1, whichever is more frequent.

5.3.2 *Induction Coils*—Induction coils are an important part of the power supply units. The verified power output and voltage/current match depend on the interconnection of coils and power supply units. For example, connecting coils in series or parallel to a power supply may significantly affect efficiency, inductance, and overall ability to heat the product. Verification of equipment should include consideration of coil connections and interconnect wiring functionality. Reverification of output power capabilities should occur after any changes to the coil designs or the interconnections. In the instance of multiple induction coil designs on the same line, all coils will be properly identified, and design/model number will be specified in the manufacturing procedure.

5.3.3 *Quench System:*

5.3.3.1 Quench media composition shall be documented for every manufacturing procedure. Composition may include documentation of polymer chemistry, supplier, age, brine concentration, water chemistry, and so forth as applicable. Verification of quench media composition, if applicable, shall be conducted at the interval specified in Table 1. Use of a refractometer is recommended, when applicable, to determine the concentration at the start and during the operation. Note that quench media compositions are also affected by waste material in the quench (that is, scale, rust, and so forth). It may be necessary to periodically discard and replace quench media as it becomes contaminated with minerals, oil, scale, rust, and other undesirable materials. The frequency of this refreshing of the quenchant depends on results from periodic monitoring of quenchant chemistry.

5.3.3.2 Quench flow rate shall be verified periodically according to the schedule in Table 1 using a method suggested by the equipment manufacturer or selected by the producer and described in a documented procedure maintained by the heat treater.

5.3.4 *Pyrometers:*

5.3.4.1 Pyrometers shall be placed at positions along the heat treat line to establish heating rates and soak times accurately, as appropriate for the application. Pyrometer position shall be consistent and recorded (see 9.1).

5.3.4.2 Pyrometer calibration by the pyrometer manufacturer typically entails calibration using a blackbody furnace under highly controlled conditions. The tolerance and accuracy of a pyrometer on a heat-treat mill can be significantly reduced compared to measurement of a blackbody furnace in laboratory conditions. The tolerance and accuracy for each pyrometer shall be provided by the pyrometer manufacturer based on the target material composition and temperature for the pyrometer application. In addition, it is recommended that pyrometer accuracy be verified during production with the use of a "master" pyrometer. The master pyrometer may be a hand-held or other unit in which the accuracy of the device has been verified off-line using a target material with similar surface finish, composition, temperature, and ambient conditions compared to the heated product. Temperature accuracy of the master pyrometer is typically verified through the use of

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TABLE 1 Verification and Calibration Frequency

	Parameters/Features to Verify	Event	Reverification Frequency[A]
Power Supply	• Power Stability • Nominal frequency range	After installation/commissioning of new power supply unit	Once per year
		Creation of a new MP[B]	At time of new MP verification
		After major rebuild[C] of equipment	Once per year
Induction Coils	• Visual inspection of interconnect wiring and coil connections	After installation/commissioning of new coils	Once per year
		After major rebuild of equipment	Once per year
Quench	• Composition	Installation/commissioning of new quench system or component; after flushing quench system	Monthly
		Mill startup	After system remains dormant for more than 14 days
		Creation of new MP	At time of new MP verification
	• Flow	Installation/commissioning of new quench system or component	Once every 3 months for first year, annually thereafter
		Creation of new MP	At time of new MP verification
Pyrometers	• Temperature accuracy	Installation of new pyrometer	Once every 3 months for first year, annually thereafter[D]
		Pyrometer is sent out for repair	Once every 3 months for first year, annually thereafter[D]
		Pyrometer is exposed to conditions not recommended by the manufacturer	After each event
Line Speed	• Speed	Installation of new drive equipment or measurement device[E]	Once every 6 months for first year, annually thereafter
		Major rebuild or repair of drive equipment or measurement device	Once every 6 months for first year, annually thereafter

[A] Verify parameter at time of "event" and after initial verification follow this frequency.
[B] MP = Manufacturing procedure.
[C] See Note 5.
[D] The use of a master pyrometer for verification is recommended.
[E] Line speed measurement device may include tachometer, laser velocimeter, or other suitable means to determine line speed of product.

thermocouples attached to the off-line target material. Comparison to the master pyrometer should not be considered a replacement for regular calibration of the on-line pyrometers, which should be performed according to the manufacturer's specification. Records of pyrometer calibration and verification shall be maintained (see 9.1). Calibration and verification should follow the manufacturer's recommended schedule or the schedule outline in Table 1.

NOTE 3—Proper selection of an appropriate pyrometer technology is essential to ensuring the accuracy. Single-wavelength pyrometers are most common, but also least accurate. Higher accuracy can typically be achieved with shorter wavelength pyrometers, but pyrometer accuracy is also highly influenced by the emissivity setting. Additional information on pyrometer technologies is provided in X4.1.

5.3.5 *Verifying Line Speed*—Line speed and product rotation are critical parameters that affect the heating and cooling rates as well as the soak time. Line speed shall be documented in the manufacturing procedure as described in 6.3.4. Verification and calibration of material-handling capabilities should include a means for verifying line-speed measuring devices as well as synchronization of rolls and drives (that is, gap control). Synchronization of driven rolls becomes critical for control of uniform rotation of product and control of gaps between products to minimize end effects during heating (see Appendix X3 for additional information on end effects). Methods for verification and calibration of material-handling equipment shall follow the equipment manufacturer's instructions and may include the use of a calibrated off-line measurement device such as a laser velocimeter or other suitable device. Verification of line speed should be conducted at multiple locations along the heat treat line (for example, entry, austenitizing section, tempering section, and so forth) taking into account thermal expansion of the product, as applicable. Calibration and verification records shall be maintained (see 9.1) and shall follow the manufacturer's recommended schedule or the schedule outline in Table 1, whichever is more frequent.

5.3.6 *Controls:*

5.3.6.1 Functionality and calibration of controls should be verified during installation and after any major rebuild (see Note 5) to the heat-treat line and performed according to the equipment manufacturer's recommendation.

5.3.6.2 The heat-treat producer shall have a documented procedure that addresses the verification and maintenance of the controls for each qualified line according to the guidelines of Table 1 or the equipment manufacturers' recommendation, whichever is more stringent.

5.3.7 *Maintenance*—The heat-treat producer shall have a documented and fully implemented preventive maintenance procedure that addresses the following equipment and follows the manufacturer's recommendations:

5.3.7.1 Material handling,

5.3.7.2 Induction coils,

5.3.7.3 Power supply units,

5.3.7.4 Quench systems including regular inspection and cleaning of spray nozzles and maintenance of pumps, and

5.3.7.5 Pyrometers.

6. Procedure

6.1 *Manufacturing Procedure*—A manufacturing procedure shall be established and maintained as a record (see 9.1) by the heat treater for each product. The manufacturing procedure shall include details of the process variables outlined in 6.3.

NOTE 4—Although API 20E also outlines a "manufacturing procedure" with similar elements, the procedure described here is separate and distinct with no intention to exactly match the format of API Specification 20E.

6.2 *Manufacturing Procedure Qualification*—The manufacturing procedure shall be qualified through product testing as described in Section 7. Product testing as described in Section 7 may also be used to establish the tolerance ranges for the process variables in the manufacturing procedure. Requalification of the manufacturing procedure is required for any major rebuild of the equipment.

NOTE 5—Examples of items that constitute a major rebuild that could change the temperature uniformity characteristics include, but are not limited to: (*1*) Changes in induction coil design or placement; transformer design changes; inverter component changes; or changes to connecting power cables to, between, and from power supply units and coils; (*2*) Changes in the location, type, or manufacturer of temperature-measuring devices; (*3*) New designs for components used to convey parts through the process; and (*4*) Changes to the quench media, design, or position or changes to the quench plumbing that may impact the exit flow and pressure of quenchant.

6.3 *Product and Process Variables*—The manufacturing procedure may be structured in a format determined by the heat treater provided that it contains details on the process variables as stipulated in 6.3.1 – 6.3.9. Tolerances for each process variable are determined by the heat treater based on each individual product physical property requirements.

6.3.1 *Product Composition*—Nominal composition, steel grade, or range of chemistries for any given product shall be included in the manufacturing procedure.

6.3.2 *Product Dimensions*—Nominal dimensions or range of dimensions shall be listed for the manufacturing procedure. Dimensions shall include length, outside diameter and, in the case of tube and pipe, wall thickness and inside diameter.

NOTE 6—Wall thickness variations may require power and line speed adjustment to maintain target temperature.

6.3.3 *Product Prior Microstructure*—Prior microstructure or thermal processing method may be included in manufacturing procedure at the heat treater's choice.

6.3.4 *Line Speed*—Line speed for each stage of the heat-treat process and methods for its verification shall be included in manufacturing procedure. The method for measuring and verifying the line speed shall be described in the manufacturing procedure. The device(s) used to measure the line speed shall be calibrated and maintained as described in 5.3.5.

6.3.5 *Austenitizing*—Target temperature and respective tolerances for austenitizing shall be included in the manufacturing procedure. It is the temperature at which the product is held before quenching. The method for verifying the target temperature shall be described in the manufacturing procedure. The time that product is held at the target austenitizing temperature shall be included in the manufacturing procedure. This may be recorded as a combination of distance (length of coils, number

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of coils, and space between coils) and line speed or total time at target temperature. Verification of adequate austenitizing soak time may involve the use of in-line or handheld temperature measurement devices (for example, a master pyrometer), modeling and simulation, metallurgical evaluation, or other means at the heat treater's choice.

6.3.6 *Quench Media*—The quench media type (for example, water, oil, emulsions, mill coolant compositions) and the quench media temperature shall be included in the manufacturing procedure. The quench media temperature may be measured at a location convenient to the manufacturer; however, this location shall be consistent to ensure reliable process monitoring.

6.3.7 *Quench Flow and Pressure*—The flow rate and pressure of the quenchant shall be included in the manufacturing procedure, or as an alternative, the as-quenched hardness of the product shall be measured to demonstrate that the flow and pressure are adequate to achieve the desired martensitic transformation.

6.3.8 *As-Quenched Product Temperature*—The target temperature or temperature range at the exit of the quench section shall be included in the manufacturing procedure. The method for verifying the target temperature or temperature range shall be described in the manufacturing procedure. As an alternative, the as-quenched hardness of the product may be measured.

6.3.9 *Tempering*—Target temperature and respective tolerances for tempering shall be included in manufacturing procedure. It is the temperature at which the product is held before exit from the tempering section. The method for verifying the target temperature shall be described in the manufacturing procedure. Time that product is held at the target-tempering temperature shall be included in the manufacturing procedure. This may be reported as a combination of distance (length of coils, number of coils, space between coils) and line speed or total time at target temperature. Verification of adequate tempering soak time may involve the use of in-line or handheld temperature measurement devices (for example, a master pyrometer), modeling and simulation, metallurgical evaluation, or other means, or combinations thereof, at the heat treater's choice.

7. Manufacturing Procedure Validation Testing Requirements

7.1 Upon creation of a new manufacturing procedure, testing should be performed and records maintained (see 9.1) to establish the adequacy of a manufacturing procedure and determine acceptable tolerance ranges for the manufacturing procedure process variables. This testing should be repeated only if the manufacturing procedure is modified or after a major rebuild as outlined in Note 5.

7.2 *Chemical Analysis*—Chemistry of the product should be known. Chemical analysis should be performed in accordance with Test Methods, Practices, and Terminology A751 or a corresponding national standard with all intentionally added and residual elements reported. These analyses are not necessarily performed by the heat treater, and chemistry specifications or heat analyses provided by product supplier are sufficient.

NOTE 7—Ideal diameter (DI) values (measured or calculated based on chemical analysis per Test Method A255 methods) are very useful for each heat-lot material hardenability evaluation. Capability of each lot of material to achieve the required final properties for each size/grade/class of final product should be carefully considered based on reported chemistry, DI, and prior conditions. Test Method A255-calculated DI values are based on average grain size—7 typical for as many as-rolled, fully killed steels with grain refiners such as Al, Nb/Cb, and others. Larger grains tend to increase DI, while smaller result in somewhat lower hardenability.

7.3 *Mechanical Properties:*

7.3.1 Hardness, tensile, and Charpy impact testing of finished product should be used as applicable to validate each product manufacturing procedure and establish acceptable tolerance ranges for process variables. Test Methods A1058 or other suitable standard should provide guidance on these test methods.

7.3.2 Cross-sectional hardness checks on larger diameter bars and thick-walled tube with DI values indicating material limitations for through-hardening can provide valuable data on depth of martensitic transformation and through thickness uniformity of mechanical properties. Test Method A255 may be used for checking hardenability during the creation of a new manufacturing procedure or as a verification step during production.

7.3.3 When performed, bulk hardness measurements may be conducted in accordance with internationally recognized Test Methods such as E10 or E18, as appropriate. Microhardness measurements may be conducted in accordance with Test Method E384. Hardness measurements should be taken in opposite quadrants of a sample cross section and along a sample length as indicated in Fig. 1 to verify process consistency and proper selection of process variables for the established manufacturing procedure. Once a manufacturing procedure is verified, hardness testing should be conducted as required for product specification or purchase agreement as appropriate. For certain materials and products it may be necessary to perform full circumference, through thickness hardness testing. Refer to the standards and requirements for the individual product testing requirements.

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7.4 *Metallurgical Evaluation*—Depending on the heat-treating requirements, microstructural evaluation may be used for verification of prior austenite grain size, final grain size (Test Methods E112), martensite transformation depth and completion (on an "as-quenched" sample), or the effects of tempering. (**Warning—**Depending on carbon content, very high stresses (1379 MPa and above) could be present in "as-quenched" samples. Special cutting and grinding equipment and handling care may be necessary to safeguard against unexpected release of internal stress in the material during sample preparation.)

7.5 *Dimensional and Visual Inspection*—As with all heat-treated products, dimensions of finished bar and pipe change depending on prior stress state, cold work, and final microstructure. Induction heated bar and tube ends may exhibit higher hardness and circular ("toe nail") end cracking. For that reason, approximately 1.3 to 5 cm may be removed from each end. Respective dimensional allowances for raw material bars should be considered before heat treating.

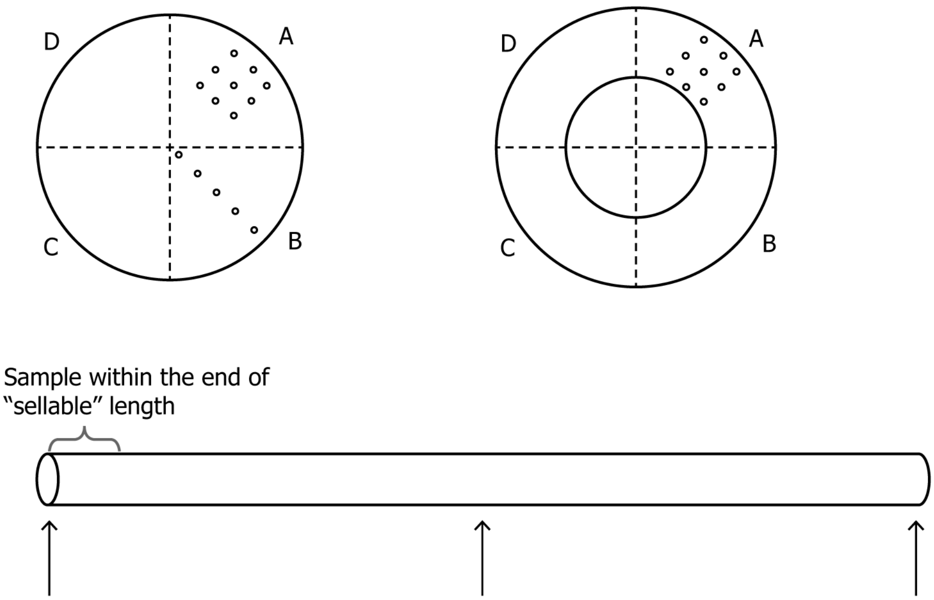

FIG. 1 Hardness Testing May be Conducted in the Pattern Shown in Region A or B as Appropriate, and Testing Should be Conducted in Opposite Quadrants of the Cross Section to Verify Uniformity; Samples from Ends and Middle of a Rod/Bar/Tube/Pipe as Indicated with the Arrows will Provide the Best Verification of Property Consistency along the Length of the Product

8. Report

8.1 The contents of the production report should be decided by purchase agreement.

9. Record Retention

9.1 Records shall be maintained in accordance with the heat-treater's quality system requirements and, at a minimum, for one year from production. Records recommended by this guide include power capabilities (5.3.1), pyrometer calibration (5.3.4), line speed measurement device calibration (5.3.5), manufacturing procedure, product as-quenched hardness (6.3.8 and 6.3.9) as an option, and manufacturing procedure testing (Section 7).

10. Keywords

10.1 austenitize quench and temper; bar; full body heat treat; induction heating; pipe; steel; tube

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APPENDIXES

(Nonmandatory Information)

X1. FLOW CHART FOR THIS GUIDE

X1.1 The flow chart in Fig. X1.1 provides a visual guide to the interpretation and use of this guide.

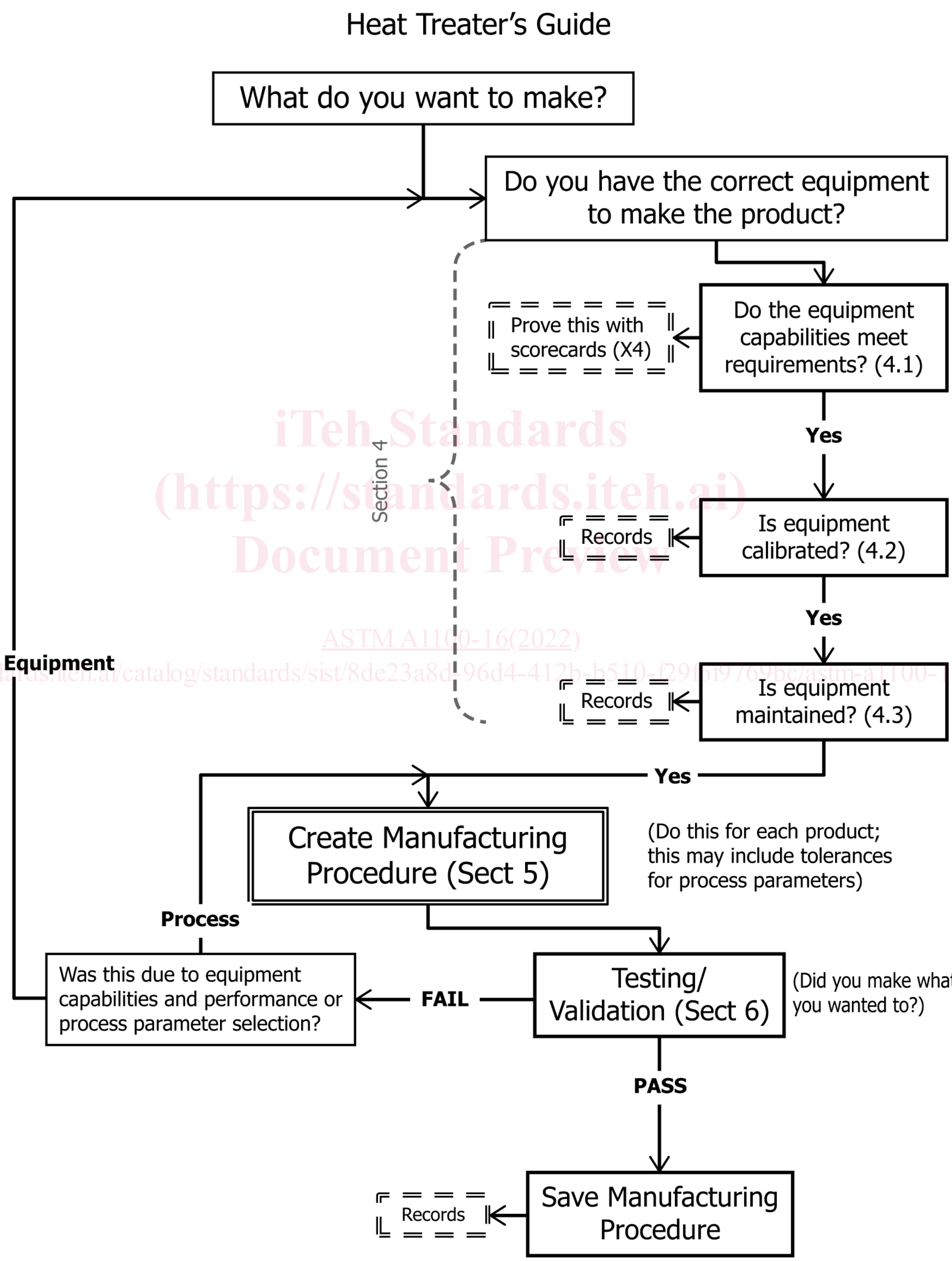

FIG. X1.1 Flow Chart

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