<img>ASTM INTERNATIONAL</img>

Designation: A1033 – 18

Standard Practice for
Quantitative Measurement and Reporting of Hypoeutectoid Carbon and Low-Alloy Steel Phase Transformations[1]

This standard is issued under the fixed designation A1033; 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 practice covers the determination of hypoeutectoid steel phase transformation behavior by using high-speed dilatometry techniques for measuring linear dimensional change as a function of time and temperature, and reporting the results as linear strain in either a numerical or graphical format.

1.2 The practice is applicable to high-speed dilatometry equipment capable of programmable thermal profiles and with digital data storage and output capability.

1.3 This practice is applicable to the determination of steel phase transformation behavior under both isothermal and continuous cooling conditions.

1.4 This practice includes requirements for obtaining metallographic information to be used as a supplement to the dilatometry measurements.

1.5 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.6 *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.*

1.7 *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]

E3 Guide for Preparation of Metallographic Specimens
E112 Test Methods for Determining Average Grain Size
E407 Practice for Microetching Metals and Alloys

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *diametrical linear engineering strain*—the strain, either thermal or resulting from phase transformation, that is determined from a change in diameter as a result of a change in temperature, or over a period of time, and which is expressed as follows:

$$e_D = \Delta d/d_0 = (d_1 - d_0)/d_0$$

3.1.2 *hypoeutectoid steel*—a term used to describe a group of carbon steels with a carbon content less than the eutectoid composition (0.8 % by weight).

3.1.3 *longitudinal linear engineering strain*—the strain, either thermal or resulting from phase transformation, that is determined from a change in length as a result of a change in temperature, or over a period of time, and which is expressed as follows:

$$e_L = \Delta l/L_0 = (l_1 - l_0)/l_0$$

3.1.4 *steel phase transformation*—during heating, the crystallographic transformation from ferrite, pearlite, bainite, martensite or combinations of these constituents to austenite. During cooling, the crystallographic transformation from austenite to ferrite, pearlite, bainite, or martensite or a combination thereof.

3.1.5 *volumetric engineering strain*—the strain, either thermal or resulting from phase transformation, that is determined from a change in volume as a result of a change in temperature, or over a period of time, and which is expressed as follows:

*A Summary of Changes section appears at the end of this standard

$$e_V = \Delta v/v_0 = (v_1 - v_0)/v_0$$
$$e_V \approx 3e_L \approx 3e_D$$

3.2 *Symbols:* e_L = longitudinal linear engineering strain

e_D = diametrical linear engineering strain

e_V = volumetric engineering strain

Δl = change in test specimen length

l_1 = test specimen length at specific temperature or time, or both

l_0 = initial test specimen length

Δd = change in test specimen diameter

d_1 = test specimen diameter at specific temperature or time, or both

d_0 = initial test specimen diameter

Δv = change in test specimen volume

v_1 = test specimen volume at a specific temperature or time, or both

v_0 = initial test specimen volume

Ac_1 = the temperature at which austenite begins to form on heating

Ac_3 = the temperature at which the transformation of ferrite to austenite is complete on heating

M_s = the temperature at which the transformation of austenite to martensite starts during cooling

4. Summary of Practice

4.1 This practice is based upon the principle that, during heating and cooling of steels, dimensional changes occur as a result of both thermal expansion associated with temperature change and phase transformation. In this practice, sensitive high-speed dilatometer equipment is used to detect and measure the changes in dimension that occur as functions of both time and temperature during defined thermal cycles. The resulting data are converted to discrete values of strain for specific values of time and temperature during the thermal cycle. Strain as a function of time or temperature, or both, can then be used to determine the beginning and completion of one or more phase transformations.

5. Significance and Use

5.1 This practice is used to provide steel phase transformation data required for use in numerical models for the prediction of microstructures, properties, and distortion during steel manufacturing, forging, casting, heat treatment, and welding. Alternatively, the practice provides end users of steel and fabricated steel products the phase transformation data required for selecting steel grades for a given application by determining the microstructure resulting from a prescribed thermal cycle.

5.1.1 There are available several computer models designed to predict the microstructures, mechanical properties, and distortion of steels as a function of thermal processing cycle. Their use is predicated on the availability of accurate and consistent thermal and transformation strain data. Strain, both thermal and transformation, developed during thermal cycling is the parameter used in predicting both microstructure and properties, and for estimating distortion. It should be noted that these models are undergoing continued development. This process is aimed, among other things, at establishing a direct link between discrete values of strain and specific microstructure constituents in steels. This practice describes a standardized method for measuring strain during a defined thermal cycle.

5.1.2 This practice is suitable for providing data for computer models used in the control of steel manufacturing, forging, casting, heat-treating, and welding processes. It is also useful in providing data for the prediction of microstructures and properties to assist in steel alloy selection for end-use applications.

5.1.3 This practice is suitable for providing the data needed for the construction of transformation diagrams that depict the microstructures developed during the thermal processing of steels as functions of time and temperature. Such diagrams provide a qualitative assessment of the effects of changes in thermal cycle on steel microstructure. Appendix X2 describes construction of these diagrams.

5.2 It should be recognized that thermal and transformation strains, which develop in steels during thermal cycling, are sensitive to chemical composition. Thus, anisotropy in chemical composition can result in variability in strain, and can affect the results of strain determinations, especially determination of volumetric strain. Strains determined during cooling are sensitive to the grain size of austenite, which is determined by the heating cycle. The most consistent results are obtained when austenite grain size is maintained between ASTM grain sizes of 5 to 8. Finally, the eutectoid carbon content is defined as 0.8 % for carbon steels. Additions of alloying elements can change this value, along with Ac_1 and Ac_3 temperatures. Heating cycles need to be employed, as described below, to ensure complete formation of austenite preceding strain measurements during cooling.

6. Ordering Information

6.1 When this practice is to be applied to an inquiry, contract, or order, the purchaser shall so state and should furnish the following information:

6.1.1 The steel grades to be evaluated,

6.1.2 The test apparatus to be used,

6.1.3 The specimen configuration and dimensions to be used,

6.1.4 The thermal cycles to be used, and

6.1.5 The supplementary requirements desired.

7. Apparatus

7.1 This practice is applicable to several types of commercially available high-speed dilatometer apparatus, which have certain common features. These include the capabilities for: heating and cooling a steel specimen in vacuum or other controlled atmosphere; programmable thermal cycles; inert gas or liquid injection for rapid cooling; continuous measurement of specimen dimension and temperature; and digital data storage and output. The apparatus differ in terms of method of specimen heating and test specimen design.

7.1.1 *Dilatometer Apparatus Using Induction Heating*—The test specimen is heated by suspending it inside an induction-heating coil between two platens as shown schematically in Fig. 1. Cooling is accomplished by a combination of controlled

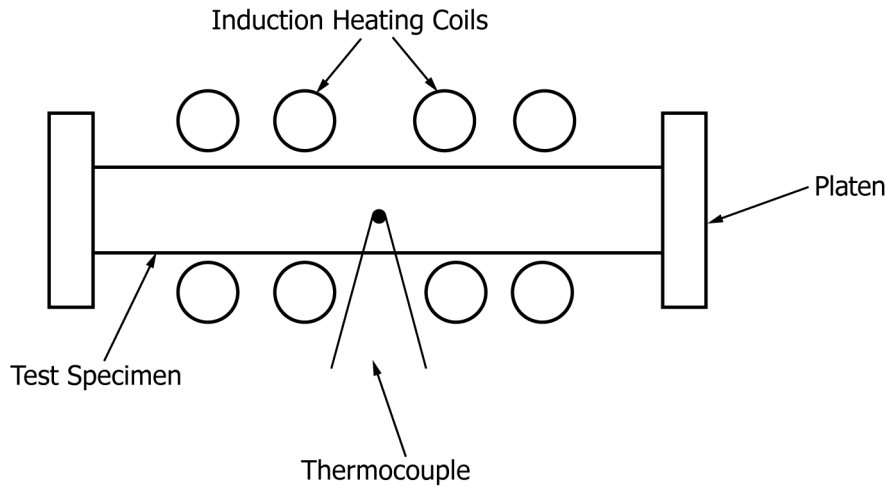Induction Heating Coils

Platen

Test Specimen

Thermocouple

FIG. 1 Schematic of Transformation Testing Using Induction Heating

reduction in heating current along with injection of inert gas onto the test specimen. Dimensional change is measured by a mechanical apparatus along the longitudinal axis of the test specimen, and temperature is measured by a thermocouple welded to the surface of the specimen at the center of the specimen length. For this apparatus, only Type R or S thermocouples should be used.

7.1.2 *Dilatometer Apparatus Using Resistance Heating*[3]— The test specimen is supported between two grips as shown schematically in Fig. 2, and heated by direct resistance heating. Cooling is accomplished by a combination of controlled reduction in heating current along with injection of inert gas onto the test specimen or internal liquid quenching. Dimensional change is measured along a diameter at the center of the test specimen length, and temperature is measured by a thermocouple welded to the surface of the specimen at the center of the specimen length. Dimensional change can be measured by either mechanical or non-contact (laser) dimen-

sion measuring apparatus. Temperature measurement can be made using Type K, Type R, or Type S thermocouples.

8. Test Specimens and Sampling of Test Specimens

8.1 *Test Specimens*—The test specimens to be used with each type of test equipment shall be selected from those shown in Figs. 3-5.

8.1.1 *Dilatometers Apparatus Using Induction Heating*— The specimens to be used with this type of apparatus are shown in Fig. 3. The solid specimen may be used for all thermal cycling conditions. The hollow specimens may also be used for all thermal cycling conditions. The hollow specimens will achieve the highest cooling rates when gas quenching is employed.

8.1.2 *Dilatometer Apparatus Using Resistance Heating*[3]— The specimens for use with this type of apparatus are shown in Figs. 4 and 5. The specimen with the reduced center section (Fig. 4) allows for internal cooling of the specimen ends by either liquid or gas. The solid specimen shown in Fig. 5 may be used for all thermal cycling conditions. The hollow specimen shown in Fig. 5 may also be used for all thermal cycling conditions. The hollow specimens will achieve the highest cooling rates when quenching is employed.
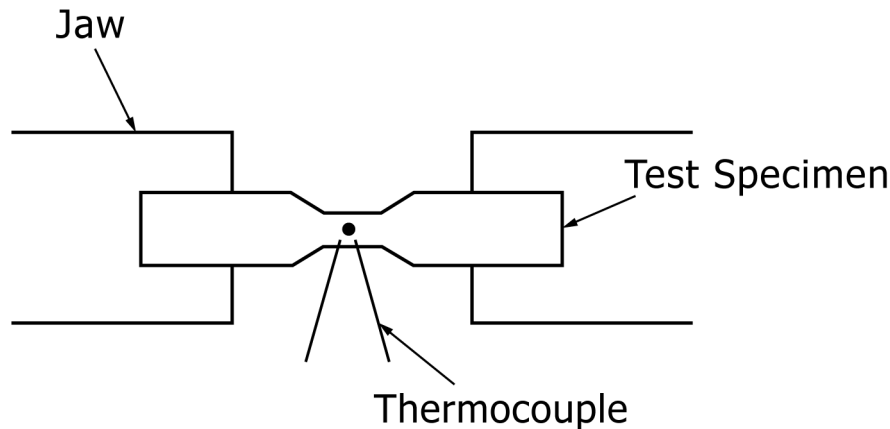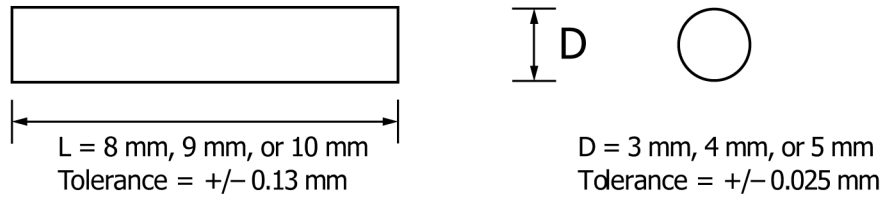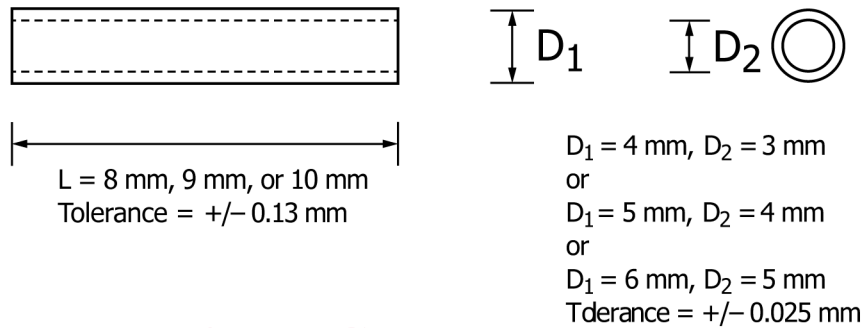
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[3] The sole source of supply of the apparatus known to the committee at this time is Dynamic Systems Incorporated, Postenkill, NY. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee[1], which you may attend.

Jaw

Test Specimen

Thermocouple

FIG. 2 Schematic of Transformation Testing Using Resistance Heating

Solid Test Specimens

L = 8 mm, 9 mm, or 10 mm
Tolerance = +/– 0.13 mm

D

D = 3 mm, 4 mm, or 5 mm
Tolerance = +/– 0.025 mm

Hollow Test Specimens

L = 8 mm, 9 mm, or 10 mm
Tolerance = +/– 0.13 mm

D_1 D_2

D_1 = 4 mm, D_2 = 3 mm
or
D_1 = 5 mm, D_2 = 4 mm
or
D_1 = 6 mm, D_2 = 5 mm
Tolerance = +/– 0.025 mm

NOTE 1—All machining surface finishes being 0.8 μm RMS

FIG. 3 Test Specimens for Induction Heating Apparatus

L3
45°
2 PLS
0.50 mm RAD.
2 PLS
½ L3
D1
D2
D3
L4
L2
L1

NOTE 1—All machining surface finishes being 0.8 μm RMS

Test Specimen Dimension Guide Table

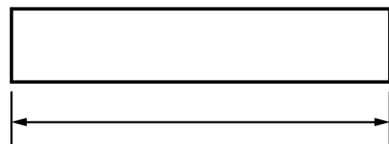| Specimen Length, L1 ± 0.10 (mm)	Specimen Half Length, L2 ± 0.05 (mm)	Reduced Section Length, L3 ± 0.025 (mm)	Reduced Section Diameter, D3 ± 0.025 (mm)	OD at Grip End, D1 ± 0.025 (mm)	ID at Grip End, D2 ± 0.025 (mm)	Grip End Drill Depth, L4 ± 0.05 (mm)
90	45	6	6	10	6.3	40
84	42	6	6	10	6.3	37
84	42	5	5	10	6.3	37

FIG. 4 Test Specimens with Reduced Center Section for Resistance Heating Apparatus

8.2 *Sampling*—Test specimens may be obtained from any steel product form, including steel bar, plate, and sheet and strip products. Care should be exercised to avoid the effects of metallurgical variables, such as chemical segregation, in determining where test specimens are obtained from a product form. Procedures have been designed that offer the advantage of equivalency of strain determination using specimens from both types of apparatus described in 7.1.1 and 7.1.2. For equivalency of strain, the orientation of the longitudinal axis of test specimens for induction heating apparatus should be at 90 degrees to the longitudinal axis of specimens for resistance heating.

8.2.1 *Example Sampling for Steel Bar Product Forms*— Where material thickness permits, a selected test specimen
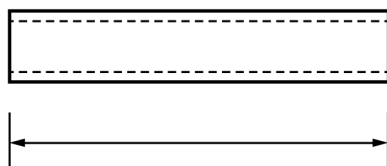
Solid Test Specimens
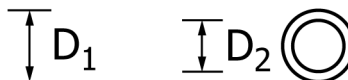
L = 71 or 86 mm
Tolerance = +/− 0.8 mm

D = 6 mm or 10 mm
Tolerance = +/− 0.025 mm

Hollow Test Specimens

L = 71 or 86 mm
Tolerance = +/− 0.8 mm

D$_1$ = 6 mm, D$_2$ = 4 mm
or
D$_1$ = 10 mm, D$_2$ = 8 mm
Tolerance = +/− 0.025 mm

NOTE 1—All machining surface finishes being 0.8 μm RMS.

Test Specimen Dimension Guide Table

Specimen Length, L1 ± 0.10 (mm)	Specimen Half Length, L2 ± 0.05 (mm)	Reduced Section Length, L3 ± 0.025 (mm)	Reduced Section Diameter, D3 ± 0.025 (mm)	OD at Grip End, D1 ± 0.025 (mm)	ID at Grip End, D2 ± 0.025 (mm)	Grip End Drill Depth, L4 ± 0.05 (mm)
90	45	6	6	10	6.3	40
84	42	6	6	10	6.3	37
84	42	5	5	10	6.3	37

FIG. 5 Test Specimens for Resistance Heating Apparatus

should be machined from the mid-radius position. Where material thickness is insufficient to permit machining a selected test specimen from the mid-radius position but sufficient to permit machining the test specimen from the mid-diameter position, the test specimen may be obtained from the mid-diameter position. In all cases, material thickness must be sufficient to permit machining a fully dimensioned test specimen.

8.2.1.1 *Dilatometer Apparatus Using Induction Heating*—The test specimens are to be machined with the longitudinal axis of the test specimen perpendicular to the rolling direction of the bar. Fig. 6 shows example orientations.

8.2.1.2 *Dilatometer Apparatus Using Resistance Heating*—The test specimens are to be machined with the longitudinal axis of the test specimen parallel to the rolling direction of the bar. Fig. 6 shows example orientations.

9. Calibration

9.1 *Apparatus and Components*—Individually calibrate the temperature, time (sampling rate), and length change signals according to appropriate manufacturer's recommendations.

9.2 *Use of Standard Reference Material*—To ensure accurate test results, a calibration procedure must be followed which involves using the apparatus to measure strain as a function of temperature for a standard reference material. A test

specimen should be prepared from a standard reference material for which thermal expansion data has been documented. The test specimen should be heated to 1000 ± 5°C, at a nominal rate of 1°C/s, held at temperature for 60 s and then cooled at a nominal rate of 1°C/s to room temperature. This is to be followed by a second thermal cycle whereby the test specimen is heated to 1000 ± 5°C, at a nominal rate of 10°C/s and then cooled at a nominal rate of 10°C/s to room temperature. The appropriate specimen dimension is to be continuously measured during each thermal cycle.

9.3 *Standard Reference Material*—The standard reference material recommended for calibration is high purity nickel (99.995 %).

9.4 *Calibration Curves*—Curves of strain versus temperature are to be prepared from the dimension measurements for both thermal cycles. Such curves must compare favorably with an accepted strain-temperature curve for the selected reference material. A recommended strain-temperature curve for high purity nickel is shown in Fig. 7. The band describes an error band of ±3 % strain calculated at 800°C. The curves determined by the user of this practice must fall within this band.

10. Procedure

10.1 *Test Environment*—All thermal cycles employed shall be carried out under a vacuum of 1.33×10^{-3} PA maximum.
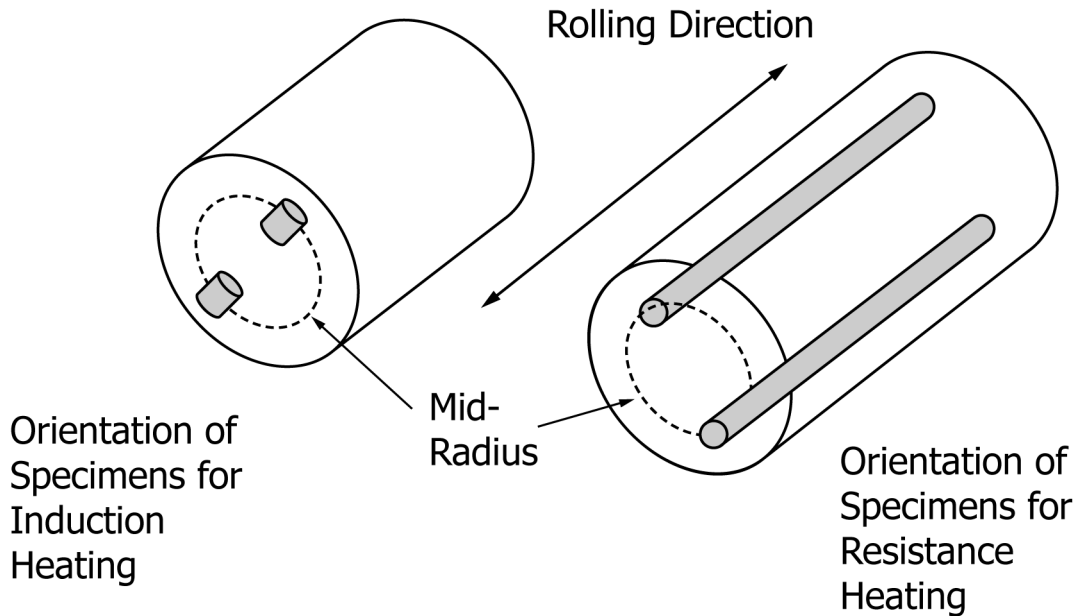
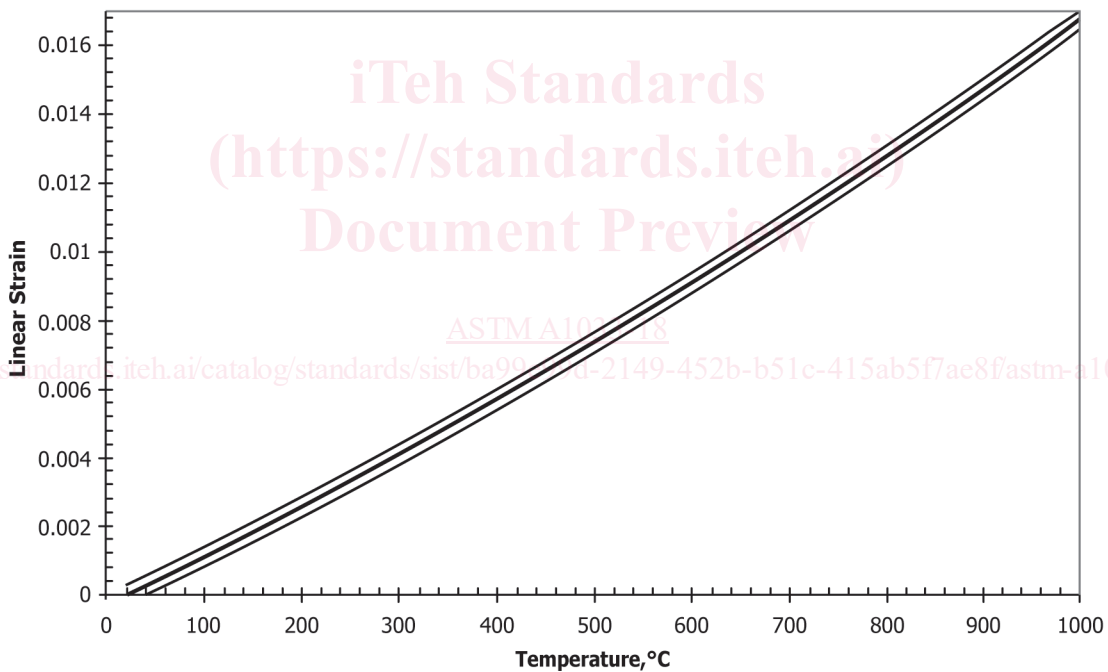FIG. 6 Machining Orientations for Bar Steel Product Forms

FIG. 7 Strain versus Temperature for High Purity Nickel

10.2 *Test Specimen Preparation*—Test specimens are to be machined from steel product stock to the dimensions and tolerances shown in Figs. 3-5. Test specimens must be properly prepared and thermocouples must be properly attached to the specimens to ensure reliable and repeatable results. Care must also be taken to properly install specimens in the dilatometer apparatus. Procedures for specimen preparation and installation are described below.

10.2.1 *Dilatometer Apparatus Using Induction Heating*—The test specimen must be degreased using a solvent such as acetone or methyl alcohol. To achieve a proper connection of the thermocouple to the test specimen, the surface of the test specimen, at the point of thermocouple attachment, must be lightly sanded using a 600 grit paper to remove any surface oxide. Significant removal of metal must be avoided. The length and diameter of the test specimen must then be