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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 and health practices and determine the applicability of regulatory limitations prior to use.*

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:

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

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

[1] This practice 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.

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

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 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.