Designation: ~~E517 – 19~~ E517 – 24

Standard Test Method for Plastic Strain Ratio *r* for Sheet Metal[1]

This standard is issued under the fixed designation E517; 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 special tension testing for the measurement of the plastic strain ratio, *r*, of sheet metal intended for deep-drawing applications.

1.2 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.3 *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.*

1.4 *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]

E6 Terminology Relating to Methods of Mechanical Testing
E8/E8M Test Methods for Tension Testing of Metallic Materials
E83 Practice for Verification and Classification of Extensometer Systems
E92 Test Methods for Vickers Hardness and Knoop Hardness of Metallic Materials
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 *Definitions of Terms Common to Mechanical Testing:*

3.1.1 The definitions relating to tension testing appearing in Terminology E6 shall apply to this test method. Some of those important terms include discontinuous yielding, gauge length, axial strain, true strain, reduced section, yield-point elongation, and upper yield strength.

3.2 *Definitions of Terms Specific to This Standard:*

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[1] This test method is under the jurisdiction of ASTM Committee E28 on Mechanical Testing and is the direct responsibility of Subcommittee E28.02 on Ductility and Formability.

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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**

3.2.1 *axial gauge length,* l_i*, n*—a gauge length aligned with the long axis of the specimen.

3.2.1.1 *Discussion*—
The specific measurement to be used for the axial gauge length is based on which procedure (*Manual*,*Automatic*, or *Combined*) and specimen type are used.

3.2.1.2 *Discussion*—
Since "gauge length" is by definition the original length, the final length associated with the axial gauge length would be the final axial length, l_f.

3.2.1.3 *Discussion*—
In uniaxial testing, dimensions aligned with the longitudinal or long axis of the specimen are frequently referred to as "axial" dimensions, for example, axial gauge length. The word "longitudinal" describes the long-axis direction of the specimen and has no assumed relationship to the rolling direction of the sheet metal being tested.

3.2.2 *earing tendency, delta r or* Δ*r, n*—measure of the tendency of sheet to draw in nonuniformly and to form ears in the flange of deep-drawn cylindrical parts in the directions of higher values of *r* (see 10.4).

3.2.2.1 *Discussion*—
In cold-reduced and annealed low-carbon steel sheet, r_0 and r_{90} are usually greater than r_{45}, while in hot-rolled steels r_{45} can be greater. Other earing tendencies occur; thus, for some materials the earing tendency can be better represented by $r_{max} - r_{min}$.

3.2.3 *plastic strain ratio, r, n*—in sheet metal that has been strained by uniaxial tension sufficiently to induce plastic flow, the ratio of the true strain that has occurred in a widthtransverse direction (ε_w w) perpendicular to the direction of applied stress and in the plane of the sheet, to the concomitant true strain in the thickness direction (ε_t t.).

3.2.3.1 *Discussion*—
The plastic strain ratio, *r*, is numerically equal to

$$r = \varepsilon_w / \varepsilon_t \tag{1}$$

where:

ε_w = width strain, and
ε_t = thickness strain.

ε_w = true transverse strain, and
ε_t = true thickness strain.

3.2.3.2 *Discussion*—
Due to difficulty in measuring thickness changes with sufficient precision, in practice an equivalent relationship is commonly used, based on length and widthaxial and transverse strain measurements (see 9.1.2).

3.2.3.3 *Discussion*—
The term "transverse" describes the width direction of the specimen and has no assumed relationship to the rolling direction of the sheet metal being tested.

3.2.4 *reduced parallel section, n*—the central portion of the specimen that has a nominally uniform cross section, that is smaller than that of the ends that are gripped, not including the fillets.

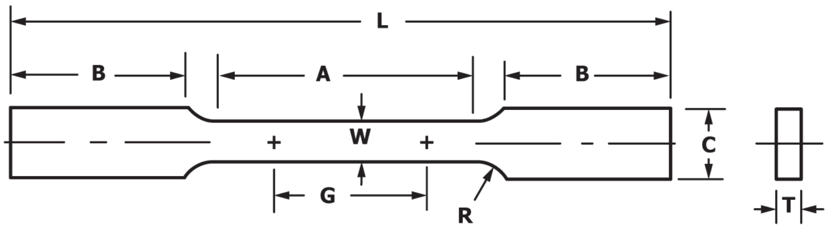
3.2.4.1 *Discussion*—
This term is often called the "parallel length" in other standards.

3.2.4.2 *Discussion*—
This term is very similar to the Terminology E6 term "reduced parallel section", except in this standard the tolerance on the reduced parallel section parallelism is much tighter, as shown in Fig. 1.

3.2.5 *transverse gauge length,* w_i*, n—in sheet products*, a gauge length aligned across the width of the specimen and perpendicular to the axial gauge length.

3.2.5.1 *Discussion*—
The specific measurement to be used for the transverse gauge length is based on which procedure (*Manual*,*Automatic*, or *Combined*) and specimen type are used.

3.2.5.2 *Discussion*—
Since "gauge length" is by definition the original length, the final length associated with the transverse gauge length would be the final transverse length, w_f.



+ gauge mark or extensometer

Dimensions

		Specimen A			
		Standard		Alternative	
		in.	mm	in.	mm
~~G~~	~~Gauge length~~	~~2.00 ± 0.01~~	~~50± 0.25~~	~~1.00 ± 0.005~~	~~25 ± 0.13~~
G	Axial gauge mark spacing	2.00 ± 0.01	50 ± 0.25	1.00 ± 0.005	25 ± 0.13
W	Width (Note 1 and Note 2)	0.500 ± 0.01	12.5 ± 0.25	0.500 ± 0.01	12.5 ± 0.25
T	Thickness thickness of material		thickness of material		
R	Radius of fillet, min	½	13	½	13
L	Overall length, min	8	200	7¼	180
A	Length of reduced parallel section, min	3	75	2¼	60
B	Length of grip section, min	2	50	2	50
C	Width of grip section, approximate	¾	20	¾	20

NOTE 1—The edges of the reduced parallel section shall be machined parallel over ~~the~~length, ~~*gauge*~~*G*, ~~length~~ within a tolerance of 0.0005 in. ~~(0.012~~(0.01 mm).

NOTE 2—The ends of the reduced parallel section shall not differ in width by more than 0.005 in. or ~~0.013 mm.~~(0.1 mm). However, the width within the ~~gauge~~ length *G* shall conform to 8.3.

FIG. 1 Rectangular Tension Test Specimens with Reduced Parallel ~~Section~~Section, Specimen A

3.2.5.3 *Discussion—*
Since the thickness of the specimen is also referred to in this test method, the symbol *w* is used for the transverse length rather than *t* to prevent confusion with the measurements in the thickness direction.

3.2.5.4 *Discussion—*
The term "transverse" describes the width direction of the specimen and has no assumed relationship to the rolling direction of the sheet metal being tested.

3.2.6 *transverse strain, n—in sheet products*, linear strain in the plane of the specimen perpendicular to the longitudinal axis of the specimen.

3.2.6.1 *Discussion—*
This definition of transverse strain, in sheet products, is a more specific version of the term "transverse strain" as defined in Terminology E6, but transverse strain in sheet products is limited to the width direction of the specimen.

3.2.6.2 *Discussion—*
The true transverse strain is denoted as ε_w in this standard.

3.2.6.3 *Discussion—*
The terms "transverse" and "longitudinal" describe the in-plane directions of the specimen and have no assumed relationship to the rolling direction of the sheet metal being tested.

3.2.7 *thickness strain, n—in sheet products*, linear strain through the thickness of the specimen perpendicular to the longitudinal axis of the specimen.

3.2.7.1 *Discussion—*
This definition of thickness strain, in sheet products, is a more specific version of the term "transverse strain" as defined in Terminology E6, but thickness strain in sheet products is limited to the thickness direction of the specimen.

3.2.7.2 *Discussion—*
The true thickness strain is denoted as ε_t in this standard.

3.2.7.3 *Discussion—*
The terms "transverse" and "longitudinal" describe the in-plane directions of the specimen and have no assumed relationship to the rolling direction of the sheet metal being tested.

3.2.8 *weighted-average plastic strain ratio,* r_m, *n*—the weighted average of values of *r* obtained in three in-plane directions: 0° (parallel), 45° (diagonal), and 90° (transverse) to the rolling direction.

3.2.8.1 *Discussion—*
Some materials exhibit significantly different values of plastic strain ratio, *r*, for other test directions, in which case the weighted-average plastic strain ratio may include these values when special note is made and another subscript is used to avoid confusion with r_m as defined in ~~3.2.3~~3.2.8.

3.2.8.2 *Discussion—*
Symbols that are often used interchangeably with r_m are $\bar{r}$ and *r*-Bar.

4. Significance and Use

4.1 The plastic strain ratio *r* is a parameter that indicates the ability of a sheet metal to resist thinning or thickening when subjected to either tensile or compressive forces in the plane of the sheet. It is a measure of plastic anisotropy and is related to the preferred crystallographic orientations within a polycrystalline metal. This resistance to thinning or thickening contributes to the forming of shapes, such as cylindrical flat-bottom cups, by the deep-drawing process. The value of *r*, therefore, is considered a measure of sheet-metal drawability. It is particularly useful for evaluating materials intended for parts where a substantial portion of the blank is drawn from beneath the blank holder into the die opening.

4.2 For many materials the plastic strain ratio remains essentially constant over a range of plastic strains up to maximum applied force in a tension test. For materials that give different values of *r* at various strain levels, a superscript is used to designate the percent strain at which the value of *r* was measured. For example, if a 20 % elongation is used, the report would show r^{20}.

4.3 Materials usually have different values of *r* when tested in different orientations relative to the rolling direction. The angle of sampling of the individual test specimen is noted by a subscript. Thus, for a test specimen whose length is aligned parallel to the rolling direction, plastic strain ratio, *r*, is reported as r_0. If, in addition, the measurement was made at 20 % elongation and it was deemed necessary to note the percent strain at which the value was measured, the value would be reported as r_0^{20}.

4.4 A material that has an upper yield strength (yield point) ~~point~~ followed by discontinuous yielding stretches unevenly while this yielding is taking place. In steels, this is associated with the propagation of ~~Lüders'~~Lüders' bands on the surface. The accuracy and reproducibility of the determination of plastic strain ratio, *r*, will be reduced unless the test is continued beyond this yield-point elongation. Similarly, the discontinuous yielding associated with large grain size in a material decreases the accuracy and reproducibility of determinations of plastic strain ratio, *r*, made at low strains.

5. Interferences

5.1 Many factors affect the measurements taken for determining the value of *r*. In particular, errors in the measurement of the change in width can cause the reported ~~the~~ value of *r* to be invalid. The following phenomena are known to cause severe errors in the measurement of the change in width and affect the value of *r* reported.

5.1.1 *Canoeing*—Canoeing is a phenomenon that occurs in some materials when they are stretched. In these materials, the test specimen bows about its longitudinal axis and takes on a shape resembling the bottom of a canoe. In this case, unless the transverse measurements of the change in width are compensated for, there will be significant errors in the calculated value of *r*.

5.1.2 *Sharp Knife Edges*—Knife edges, used to measure the transverse change in width automatically, while the specimen is ~~stretched,~~ stretched longitudinally, can cause localized deformation of the specimen under the knife edges. This problem is intensified if the knife edges are sharp and attached to the specimen with high forces. This combination produces a compressive stress 90° to the tensile stress being applied to stretch the specimen, which causes localized deformation. As a result, excessively high values of *r* are calculated.

6. Apparatus

6.1 *Dimension-Measuring Devices*—Instruments for measuring length and width shall be checked for accuracy and be graduated to permit measurements to be made to ±0.001 in. (± 0.02 mm) or better.

6.2 ~~*Measuring Devices:*~~ *Extensometer Systems—*

~~6.1.1 Instruments for measuring length and width shall be checked for accuracy and be graduated to permit measurements to be made to ±0.001 in. (± 0.02 mm) or better.~~If the axial strain or the transverse strain, or both, are to be obtained using an extensometer system (mechanical, optical, or otherwise), then the extensometer system shall conform to Practice E83 as Class C or better, including verification over the range of strains used in the determination of plastic strain ratio, *r*.

~~6.1.2 If the longitudinal strain or the transverse strain, or both, are to be obtained using an extensometer, the extensometer system shall conform to Practice E83 as Class C or better. The extensometer system shall be verified over a range appropriate for the strains used to determine the plastic strain ratio, *r*.~~

6.3 *Testing Machine*—The testing machine used to strain the specimen shall be capable of uniaxially straining the specimen in accordance with the requirements in 9.2.5 or 9.3.4.

7. Test Specimen

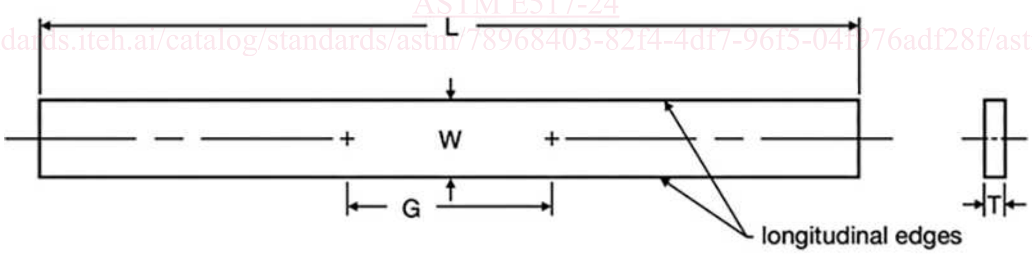
7.1 *Type*—Any of three types of specimen may be used. Other types including subsize specimens may be used provided they give comparable values of equivalent accuracy.

7.1.1 *Specimen A, with reduced parallel section, as shown in* Fig. 1—While this is similar to the Sheet-Type Specimen of Test Methods E8/E8M, the reduced parallel section shall be parallel-sided rather than tapered.

7.1.2 *Specimen B, with a uniform width of 0.75 in. (20 mm),* machined edges, and no reduced section, as shown in Fig. 2.

7.1.3 *Specimen C with a uniform width of 1.125 in. (28.58 mm),* precision-sheared or with machined edges and no reduced section, as shown in Fig. 3.

7.2 *Size*—The length and width of the specimen are not critical, provided care is used to stretch the gauge section in a uniform manner, avoiding grip effects and anomalous changes along the gauge lengths.



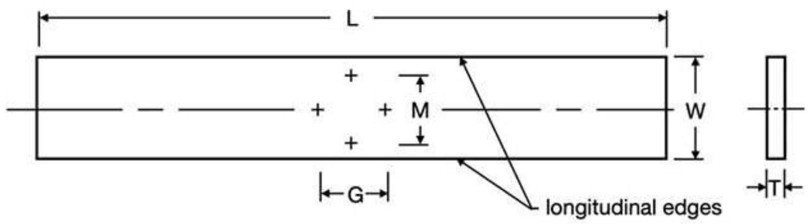
+ gauge mark or extensometer

Dimensions

		Specimen B				
		Standard		Alternative		
		in.	mm	in.	mm	
	~~G~~	~~Gauge length~~	~~2.00 ± 0.01~~	~~50 ± 0.25~~	~~1.00 ± 0.005~~	~~25 ± 0.13~~
	~~W~~	~~Gauge width~~	~~0.75 ± 0.005~~	~~20 ± 0.13~~	~~0.75 ± 0.005~~	~~20 ± 0.13~~
	G	Axial gauge mark spacing	2.00 ± 0.01	50 ± 0.25	1.00 ± 0.005	25 ± 0.1
W	Width (Note 1)	0.75 ± 0.005	20 ± 0.13	0.75 ± 0.005	20 ± 0.13	
	T	Thickness thickness of material				
	L	Overall length, min	8	200	7	175
	~~G~~	~~Width of specimen (Note)~~	~~0.75 ± 0.005~~	~~20 ± 0.13~~	~~0.75 ± 0.005~~	~~20 ± 0.13~~

NOTE 1—~~Edges~~ Longitudinal edges of Specimen B shall be machined parallel over the full length within a tolerance of 0.0008 in. (0.020 mm).

FIG. 2 Machined Rectangular Tension Test Specimens, Parallel ~~Strip~~Strip, Specimen B



+ gauge mark or extensometer

Dimensions

		Specimen C	
		in.	mm
~~G~~	~~Gauge length~~	~~0.75 ± 0.005~~	~~20 ± 0.13~~
G	Axial gauge mark spacing	0.75 ± 0.005	19.0 ± 0.1
M	Transverse gauge mark spacing	0.75 ± 0.005	19.0 ± 0.1
~~W~~	~~Gauge width~~	~~0.75 ± 0.005~~	~~20 ± 0.13~~
W	Width	1.125 ± 0.125	28.58±3.18
T	Thickness	thickness of material	
L	Overall length, min	7	175
~~C~~	~~Width of specimen~~	~~1.125 ± 0.125~~	~~28.58 ± 3.17~~

FIG. 3 Sheared Rectangular Tension Test Specimen, Parallel ~~Strip~~Strip, Specimen C

7.2.1 The specimen shall include the full sheet thickness unless otherwise specified.

7.2.2 The thickness of the gauge section of the specimen shall be uniform within 0.0005 in. ~~(0.013 mm) in the gauge section.~~ (0.01 mm). If the as-received surface is nonuniform, the surface shall be prepared by machining or by grinding to this tolerance.

7.2.3 The distance between a ~~gauge mark and a grip~~ grip and either a gauge mark, mechanical extensometer attachment point, or the pattern/feature to be measured by an optical extensometer system shall be at least twice the ~~width of~~specimen width, ~~*the*~~*W*, ~~reduced section~~ (or ~~gauge width~~ transverse gauge mark spacing, *M,* for parallel ~~strips) of the specimen.~~strips).

NOTE 1—To permit proper gripping of the specimen while meeting the 7.2.3 requirement, the overall length dimension, *L*, is listed as a minimum, thus allowing for longer specimens to allow more grip section length.

~~7.1.4 Duplicate specimens should be tested and the average value of *r* of these reported for each test direction. If necessary, a third determination may be made, rejecting the extreme.~~

7.3 ~~*Type*—Any~~ Duplicate specimens should be tested and the average value of ~~*three*~~*r* ~~types of specimen may be used. Other types including subsize specimens may be used provided they give comparable values of equivalent accuracy.~~of these reported for each test direction. If necessary, a third determination may be made, rejecting the extreme.

~~7.2.1 *Specimen A, with reduced section, as shown in* Fig. 1—While this is similar to Fig. 6 of Test Methods E8/E8M, the reduced section shall be parallel-sided rather than tapered.~~

~~7.2.2 *Specimen B, with a uniform width of 0.75 in. (20 mm),* machined edges, and no reduced section, as shown in Fig. 2.~~

~~7.2.3 *Specimen C,* precision-sheared a uniform width of 1.125 in. (28.58 mm), or with machined edges and no reduced section, as shown in Fig. 3.~~

~~7.2.3.1 Gauge lengths for Specimen C shall be marked on the sheet surface perpendicular to and parallel to the specimen edges. The gauge marks shall be made with Vickers diamond indenters described in Test Method E92, or similar precise marks.~~

8. Specimen Preparation

8.1 Specimen blanks shall be sheared or sawed individually and, with the exception of Specimen ~~C,~~C which may be used as sheared, shall be machined individually or in packs to remove cold-worked edges.