Designation: E 1928 – 99

Standard Practice for Estimating the Approximate Residual Circumferential Stress in Straight Thin-walled Tubing[1]

This standard is issued under the fixed designation E 1928; 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 A qualitative estimate of the residual circumferential stress in thin-walled tubing may be calculated from the change in outside diameter that occurs upon splitting a length of the tubing. The Hatfield and Thirkell formula, as later modified by Sachs and Espey,[2] provides a simple method for calculating the approximate circumferential stress from the change in diameter of straight, thin-walled, metal tubing.

1.2 *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:*

E 6 Terminology Relating to Methods of Mechanical Testing[3]

3. Terminology

3.1 The definitions in this practice are in accordance with Terminology E 6.

4. Significance and Use

4.1 Residual stresses in tubing may be detrimental to the future performance of the tubing. Such stresses may, for example, influence the susceptibility of a tube to stress corrosion cracking when the tube is exposed to certain environments.

4.2 Residual stresses in new thin-walled tubing are very sensitive to the parameters of the fabrication process, and small variations in these parameters can produce significant changes in the residual stresses. See, for example, Table 1, which shows the residual stresses measured by this practice in samples from successive heats of a ferritic Cr-Mo-Ni stainless steel tube and a titanium condenser tube. This practice provides a means for estimating the residual stresses in samples from each and every heat.

TABLE 1 Residual Stresses in Successive Heats of Tubing

Heat No.	Ferritic Cr-Mo-Ni Stainless Steel		Titanium	
	kPa	psi	kPa	psi
1	234000	34000	37000	5400
2	272000	39400	52000	7600
3	217000	31500	30000	4300
4	183000	26500	52000	7500
5	241000	34900	59000	8600
6			30000	4300
7			59000	8600
8			30000	4300
9			52000	7500
10			37000	5400

4.2.1 This practice may also be used to estimate the residual stresses that remain in tubes after removal from service in different environments and operating conditions.

4.3 This practice assumes a linear stress distribution through the wall thickness. This assumption is usually reasonable for thin-walled tubes, that is, for tubes in which the wall thickness does not exceed one tenth of the outside diameter. Even in cases where the assumption is not strictly justified, experience has shown that the approximate stresses estimated by this practice frequently serve as useful indicators of the susceptibility to stress corrosion cracking of the tubing of certain metal alloys when exposed to specific environments.

4.3.1 Because of this questionable assumption regarding the stress distribution in the tubing, the user is cautioned against using the results of this practice for design, manufacturing control, or other purposes without supplementary information that supports the application.

4.4 This practice has primarily been used to estimate residual fabrication stresses in new thin-walled tubing between 19-mm (0.75-in.) and 25-mm (1-in.) outside diameter and 1.3-mm (0.05-in.) or less wall thickness. While measurement difficulties may be encountered with smaller or larger tubes, there does not appear to be any theoretical size limitation on the applicability of this practice.

5. Procedure

5.1 On new material, the stress determination shall be made on at least one representative sample obtained from each lot or

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[1] This practice is under the jurisdiction of ASTM Committee E-28 on Mechanical Testing and is the direct responsibility of Subcommittee E28.13 on Residual Stress Measurement.

Current edition approved October 10, 1999. Published December 1999. Originally published as E 1928 - 98. Last previous edition E 1928 - 98.

[2] Sachs, G. and Espey, G., “A New Method for Determination of Stress Distribution in Thin-walled Tubing,” *Transactions of the AIME*, Vol 147, 1942.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

heat of material in the final size and heat treatment. The results of tests on brass and steel tubes, reported by Sachs and Espey,[2] indicate that the length of the sample piece of tube should be at least three times the outside diameter in order to avoid significant end effects.

5.2 At the midlength of the tube sample, measure the outside diameter at four locations (every 45°) around the tube circumference in order to verify that the cross section is reasonably circular.

5.3 Select and mark a straight line lengthwise on the sample, indicating where the split will be made. If the tube thickness is not uniform around the periphery, some practitioners prefer the split to be made at the thinnest location.

5.4 Determine the average outside diameter, D_o, of the sample by measuring the diameter at 90° to the line where the split will be made, and at four equally spaced locations along the length, and averaging. Any measuring system may be used provided that the measurement uncertainty does not exceed 0.013 mm (0.0005 in.) or 0.07 %, whichever is larger. See 5.6 and Note 2.

5.5 Split the sample longitudinally on one side over its full length along the preselected line. Care must be taken to avoid the development of additional residual stresses in the splitting operation. Monitoring the specimen temperatures during the splitting operation may help to ensure that new stresses are confined to the vicinity of the split.

NOTE 1—The tube may be split by electric discharge machining, by sawing on a milling machine, or by any other gentle cutting method which does not severely distort the stresses. On a milling machine the specimen shall be held by clamps which apply only longitudinal compressive stresses to the tube ends.

5.6 After splitting, determine the average final outside diameter, D_f, of the sample by measuring the diameter at 90° to the split and at four equally spaced locations along the length, and averaging. Use the same measuring system as that used in 5.4.

NOTE 2—It is important not to deform the sample while measuring the diameter. After splitting, the diametral stiffness of the sample is very low. For this reason, a non-contact measurement method is preferred. If a contact measuring instrument, such as a micrometer or calipers, is used, special care or an electrical contact sensor must be used to minimize the contact pressure applied.

5.7 After splitting, determine the effective thickness, *t*, of the tube wall by measuring the thickness to the nearest 0.013 mm (0.0005 in.) at 180° to the split and at four equally spaced locations along the length of the sample, and averaging. Ball points or pointed ends should be used with micrometers, calipers, or similar instruments in order to obtain correct wall thicknesses.

NOTE 3—The instrument used for the thickness measurements should be calibrated against a standard test block prior to use.

6. Calculation

6.1 The circumferential stress is estimated from the change in outside diameter occurring on splitting a length of tubing.

6.2 The bending moment *M*, per unit length of tubing, that is released by such a flexure is given as follows:

$$M = \frac{EI}{1-\mu^2}\left[\frac{1}{R_o} - \frac{1}{R_1}\right] = \frac{EI}{1-\mu^2} \times \frac{R_1 - R_o}{R_o R_1} \tag{1}$$

where:
E = modulus of elasticity,
μ = Poisson's ratio,
R_o = mean outside radius before splitting,
R_1 = mean outside radius after splitting, and
I = cross-sectional moment of inertia of unit length of tube wall.

6.2.1 Standard reference book values of the modulus of elasticity and Poisson's ratio may be used for this purpose.

6.3 The release of this bending moment corresponds to a release of the bending stresses in the section. If the stress distribution is such that the stresses vary linearly from one surface to the other, then the minimum and maximum stresses occur at the surfaces and are given as follows:

$$S = \frac{Mt}{2I} = \pm \frac{E}{1-\mu^2} \times \frac{t}{2} \times \frac{R_1 - R_o}{R_o R_1} \tag{2}$$

where:
t = average thickness of tube wall.

6.4 Rewriting the equation in terms of tube diameter

$$S = \pm \frac{Et}{1-\mu^2} \times \frac{D_f - D_o}{D_f D_o} \tag{3}$$

where:
D_o = mean outside diameter of tube before splitting,
D_f = mean outside diameter of tube after splitting.

NOTE 4—If $D_f > D_o$, the maximum tensile residual stresses are on the outer surface of the tube. If $D_f < D_o$, the maximum tensile residual stresses are on the inner surface of the tube.

6.5 Calculate and record the maximum residual circumferential stress.

7. Report

7.1 If a report is required, it should contain, as a minimum, the following information for each sample tested:

7.1.1 Identification of the material, lot, heat, and so forth, of the sample,

7.1.2 Length of the sample,

7.1.3 Average outside diameter, D_o, before splitting,

7.1.4 Average outside diameter, D_f, after splitting,

7.1.5 Effective wall thickness, *t*, and

7.1.6 Minimum and maximum residual circumferential stress, *S*.

8. Precision and Bias

8.1 *Precision*—Since this is a destructive practice, it is impossible to conduct replicate tests on the same specimen to evaluate the precision of this practice.

8.1.1 Users are encouraged to conduct tests on a series of nominally identical specimens cut from adjacent sections of a single tube in order to estimate the approximate repeatability achieved with alternate splitting techniques as applied to the tube materials of interest.

8.2 *Bias*—The bias of this practice depends upon the actual stress distribution through the thickness of the tube and its departure from the linear stress distribution that this practice assumes. The actual stress distribution depends, in turn, upon the fabrication processes, the service history, and the tube material.

8.2.1 While the bias of this practice in any specific instance could be evaluated by mounting strain gages on the specimen prior to splitting, this may not be especially useful since the merit of this practice lies not in the actual value of the estimated residual circumferential stress but in the relationship between the estimated stress determined by this simple practice and the subsequent performance of the tube. In this sense, users are encouraged to develop and maintain comprehensive historical records to assess, for specific tube materials, fabrication processes, and environments, the relationships between the estimated stresses and subsequent performance.

8.3 Some residual stress measurement results obtained with 6 % Mo austentic stainless steel tubing of two sizes are summarized in Table 2. For each tubing size the samples were taken adjacent to each other from a single tube. These results show good agreement between measurements made on adjacent samples. The results also show good agreement between measurements made by this standard practice and measurements made using resistance strain gages with the grids oriented parallel to the residual circumferential stresses.

TABLE 2 Residual Stress Measurements on Austenitic Stainless Steel Tubing

$D_o \times t$, mm (in.)	Measurement Method	Stress, kPa (psi)
22 × 0.71 (7⁄8 × 0.028)	This standard practice	154000 (22300)
	This standard practice	160000 (23200)
	Circumferential strain gages	165000 (24000)
25 × 0.71 (1 × 0.028)	This standard practice	160000 (23200)
	Circumferential strain gages	174000 (25300)

9. Keywords

9.1 residual stress measurement; tubing