

Designation: E1877 - 00 (Reapproved 2010)

Standard Practice for Calculating Thermal Endurance of Materials from Thermogravimetric Decomposition Data¹

This standard is issued under the fixed designation E1877; 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 additional treatment of the Arrhenius activation energy data determined by Test Method E1641 to develop a thermal endurance curve and derive a relative thermal index for materials.
- 1.2 This practice is generally applicable to materials with a well-defined decomposition profile, namely a smooth, continuous mass change with a single maximum rate.
- 1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard
 - 1.4 There is no ISO standard equivalent to this practice.
- 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 and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 ASTM Standards:²

E1641 Test Method for Decomposition Kinetics by Thermogravimetry

3. Terminology

- 3.1 Definitions of Terms Specific to This Standard:
- 3.1.1 *failure*, *n*—change in some chemical, physical, mechanical, electrical or other property of sufficient magnitude to make it unsuitable for a particular use.
- 3.1.2 *failure temperature* ($T_{\rm f}$), n—the temperature at which a material fails after a selected time.
- 3.1.3 *relative thermal index (RTI)*, *n*—a measure of the thermal endurance of a material when compared with that of a control with proven thermal endurance characteristics.

¹ This practice is under the jurisdiction of Committee E37 on Thermal Measurements and is the direct responsibility of Subcommittee E37.10 on Fundamental, Statistical and Mechanical Properties.

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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.

3.1.3.1 *Discussion*—The RTI is also considered to be the maximum temperature below which the material resists changes in its properties over a defined period of time. In the absence of comparison data for a control material, a time-to-failure of 60 000 h has been arbitrarily selected for measuring RTI. The RTI is therefore, the failure temperature, T_f , obtained from the thermal endurance curve.

4. Summary of Practice

4.1 The Arrhenius activation energy obtained from Test Method E1641 is used to construct the thermal endurance curve of a material from which an estimate of lifetime at certain temperatures may be obtained.

5. Significance and Use

- 5.1 Thermogravimetry provides a rapid method for the determination of the temperature-decomposition profile of a material.
- 5.2 This practice is useful for quality control, specification acceptance, and research.
- 5.3 This practice shall not be used for product lifetime predications unless a correlation between test results and actual lifetime has been demonstrated. In many cases, multiple mechanisms occur during the decomposition of a material, with one mechanism dominating over one temperature range, and a different mechanism dominating in a different temperature range. Users of this practice are cautioned to demonstrate for their system that any temperature extrapolations are technically sound.

6. Calculation

- 6.1 The following values obtained by Test Method E1641 are used to calculate thermal endurance, estimated thermal life and failure temperature.
 - 6.1.1 The following definitions apply to 6.1 and 6.3:
 - 6.1.1.1 E = Arrhenius activation energy (J/mol),
 - 6.1.1.2 R = Universal gas constant (= 8.314510 J/(mol K)),
 - 6.1.1.3 β = Heating rate (K/min),
- 6.1.1.4 β' = Heating rate nearest the mid-point of the experimental heating rates (K/min),
 - 6.1.1.5 a = Approximation integral taken from Table 1,
 - 6.1.1.6 α = Constant conversion value,

TABLE 1 Numerical Integration Constants

8	E/RT	TABLE 1 Numerical integration constants
9		a
10 6.4157 11 6.9276 12 7.4327 13 7.9323 14 8.4273 15 8.9182 16 9.4056 17 9.8900 18 10.3716 19 10.8507 20 11.3277 21 11.8026 22 12.2757 23 12.7471 24 13.2170 25 13.6855 26 14.1527 27 14.6187 28 15.0836 29 15.5474 30 16.0103 31 16.4722 32 16.9333 33 17.3936 34 17.8532 35 18.3120 36 18.7701 37 19.2276 38 19.6845 39 20.1408 40 20.5966 41 21.5066 41 21.5066 41 22.5066 41 22.4148 45 22.8682 46 47 23.37738 48 24.2260 49 24.4779 50 25.1294 46 21.9609 47 23.7738 48 24.2260 49 24.6779 50 25.1294 51 25.5806 52 27.3823 56 27.3823 56 27.3823		
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26		13.2170
27	25	13.6855
28	26	14.1527
29	27	14.6187
30	28	15.0836
31	29	15.5474
32	30	16.0103
33	31	16.4722
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60 29.6281		

- 6.1.1.7 t_f = Estimated thermal life for a given value of α (min),
- 6.1.1.8 T_c = Temperature for the point of constant conversion for β (K), and
 - 6.1.1.9 T_f = Failure Temperature for a give value of α (K).

Note 1—The precision of the calculation in this practice are exponentially dependent on the uncertainty of activation energy value used. Care should be taken to use only the most precise values of E.

6.2 Use Eq 1 or Eq 2^3 and trial values of T_f to plot the logarithm of estimated thermal life (t_f) versus reciprocal of T_f as, by example, shown in Fig. 1.

$$\log t_f = E / (2.303 R T_f) + \log [E / (R \beta)] - a$$
 (1)

$$T_f = E / (2.303 R [\log t_f - \log \{E / (R \beta) + a])$$
 (2)

6.2.1 To calculate t_f , select the value for the temperature at the constant conversion point (T_c) for a heating rate (β) nearest the mid-point of the experimental heating rates. Use this value, along with the Arrhenius activation energy (E) to calculate the quantity $E/(R T_c)$ to select the value in Table 1.^{4, 5, 6} Arbitrarily select a number of temperatures in the region of the chosen percent mass loss, indicative of failure, in the mass change curve at the midpoint heating rate. Calculate the logarithm of the thermal life from Eq 1. Plot the thermal endurance curve, as shown in Fig. 1, with thermal life on the ordinate and reciprocal of absolute temperature on the abscissa.

Note 2—The values for E and β may be obtained by the procedure described in Test Method E1641.

6.3 The thermal endurance of two or more materials may be compared by calculating the RTI for each material. To compute RTI for each material; select some common thermal life for comparison, a typical value may be 60 000 h (6.8 years), insert that value (in minutes) and the appropriate activation energy for each material into Eq 2 to obtain T_f . This value of temperature is called the "relative thermal index (RTI) at the specified time". Materials with greater resistance to thermal decomposition will have a larger RTI.

7. Report

- 7.1 Report the following information:
 - 7.1.1 If data other than that generated by Test Method E1641 is used in these calculations, then include a description of the data source in the report,
 - 7.1.2 Designation of the material under test, including the name of the manufacturer, the lot number, and supposed chemical composition when known, and
 - 7.1.3 The calculated thermal life (t_f) and RTI values.
 - 7.1.4 The specific dated version of this practice that is used.

8. Precision and Bias ⁷

8.1 The precision and bias of these calculations depend on the precision and bias of the kinetic data used in them. To provide an example of the precision expected, thermal life was calculated by the procedure in this practice using data for poly(tetrafluoroethylene) from the interlaboratory study conducted to develop the precision and bias statement for Test Method E1641. Extreme values of thermal life were calculated using an arbitrarily chosen value for temperature of 600 K and the extreme values of *E* corresponding to the 95 % confidence level from that interlaboratory study. The resulting calculated extreme values were 9 years and 3700 years for this material.

³ Krizanovsky, L., and Mentlik, V., Journal of Thermal Analysis, Vol 13, 1978.

⁴ Flynn, J.H., and Wall, L.A., *Polymer Letters*, Vol 4, 1966 pp. 323–328.

⁵ Flynn, J.H., *Journal of Thermal Analysis*, Vol 27, 1983, pp. 95–102.

⁶ Toop, D.J., *IEEE Transactions on Electrical Insulation*, Vol EI-6, 1971, pp. 2–12.

⁷ Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:E37-1024.