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# Standard Practice for Determining the Extent of Cracking in a Sealant using the Difference between the Compressive and Tensile Modulus[1]

This standard is issued under the fixed designation C1851; 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 a procedure for quantitatively determining the extent of cracking in a sealant sample by evaluating the difference between the measured compressive and tensile modulus of a sealant relative to an unexposed or uncracked version of the same sealant. The cracks will reduce the area of the sealant in the tensile modulus, but in the compressive modulus measurement they will not change the area over which the modulus is determined.

1.2 The values in SI units are to be regarded as standard. The values in parentheses are for information only.

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]

C717 Terminology of Building Seals and Sealants
C719 Test Method for Adhesion and Cohesion of Elastomeric Joint Sealants Under Cyclic Movement (Hockman Cycle)
C1735 Test Method for Measuring the Time Dependent Modulus of Sealants Using Stress Relaxation
E631 Terminology of Building Constructions

## 3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this practice, refer to Terminologies E631 and C717.

## 4. Summary of Practice

4.1 This practice consists of measuring the modulus of the sealant using Test Method C1735 in both tension and compression. Once these values have been determined the formula presented in this practice will be used to determine the degree of cracking in the sealant relative to an unexposed or uncracked sample of the same sealant.

4.2 The motivation for this practice is to quantitatively determine the extent of cracking in the sealant. This measurement is currently determined with a qualitative measure of cracking determined by visual inspection. The degree of cracking has been used as a measure of performance for sealant.

4.3 This practice will enable determination of the percent of cracking of a sealant relative to an unexpected or uncracked vesion of the same sealant.

## 5. Significance and Use

5.1 The intent of this practice is to quantitatively determine the amount of cracking of a sealant relative to an unexposed or uncracked sample. Some samples of sealant have been observed to exhibit some degree of cracking some period after installation. The degree of cracking is assessed visually in a qualitative manner that takes into account the area of the cracks at the exposed surface of the sealant, but does not take into account the depth or profile of the cracks. The degree of cracking in the sealant has been used as an indication of performance change.

## 6. Procedure

6.1 The modulus of the sealant is determined in compression and separately in tension using Test Method C1735. These values are determined from a new sample (the unexposed reference without any cracking), and the sample of interest.

6.2 From the four modulus measurements obtained from Test Method C1735, determine the value of the modulus at 100 s for each of these four conditions:



[1] This practice is under the jurisdiction of ASTM Committee C24 on Building Seals and Sealants and is the direct responsibility of Subcommittee C24.20 on General Test Methods.

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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.

6.2.1 New Sample (the unexposed reference without any cracking), compression ($E_{100,bo,C}$),

6.2.2 New Sample (the unexposed reference without any cracking), Tension ($E_{100,bo,T}$),

6.2.3 Test Sample, Compression, ($E_{100,C}$),

6.2.4 Test sample, Tension ($E_{100,T}$).

6.3 Insert the four values determined in 6.2 into the following two empirically derived relationships:[3]

$$E_{100,T} = d \cdot E_{100,bo,T}\{1 - a_2 f - (1 - a_2) f^2\} \quad (1)$$

$$E_{100,C} = d \cdot E_{100,bo,C}(1 - a_1 f) \quad (2)$$

6.4 In these expressions, the experimentally determined values should be used, $a_1$= 0.118 and $a_2$= 0.562. With these expressions and the values determined in 6.3, there are two equations and two unknowns.

6.5 Solve for the two remaining undermined values *f* and *d*. The unknown *f* represents the fraction of cracks and has a value between 0 and 1. Since Eq 1 is quadratic, *f* will have two values. Only the positive value should be used. The *d* parameter measures the change in modulus that is not due to crack formation. The details of the derivation of these two expressions (Eq 1 and Eq 2) are detailed in Appendix X1. Additionally, a worked example is presented in Appendix X2.

[3] The derivation of these relationships are shown in Appendix X1 and Appendix X2 of this practice.

## 7. Report

7.1 Report the following information:

7.1.1 Identification of the sealant measured, including type, source, manufacturer code number, curing conditions employed,

7.1.2 Identification of the substrates,

7.1.3 Name and description of primers that were used, if any,

7.1.4 Number of specimens tested,

7.1.5 Description of the sealant appearance.

7.1.6 The value calculated for *f*. This can be reported as the calculated 0-1 value or if multiplied by 100 as % cracked.

7.1.7 The value calculated for modulus change not attributed to cracking, *d*.

## 8. Keywords

8.1 compression; cracks; modulus; sealant; tension



## APPENDIXES

### X1. ANALYSIS OF A CRACKED SEALANT

X1.1 A Test Method C719 sealant sample is characterized using Test Method C1735. This standard yields a modulus versus time curve for the sealant. This performed in both tension and compression. See Fig. X1.1.

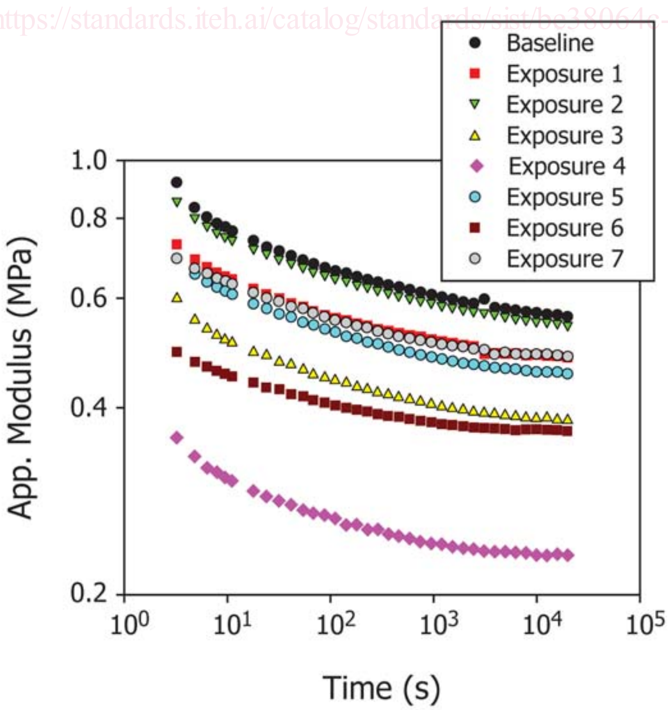


FIG. X1.1 Modulus versus Time Curve

X1.2 The black circles in this plot are the pre-exposure results from the Test Method C1735 tensions tests. The compression baseline results would look very similar.

X1.3 The sample experiences some type of exposure. The sample is removed from the exposure and once again Test Method C1735 is performed in two tests, compression modulus and tensile modulus. In Fig. X1.1, a series of Test Method C1735 tensile modulus results after different exposures are plotted. At this point it is important to note that the curve shape is the same but the exposure has caused the modulus to be lower.

X1.4 Instead of keeping the entire time dependence, the changes to the entire curve can be represented by a single time point. An arbitrary choice of 100 s after the stress relaxation component of the Test Method C1735 test is chosen to be far enough away from the complications associated with imposed strain and not too long to start to see extensive relaxation of the sealant affecting the sealant. The modulus value recorded at 100 s is represented by: $E_{100}$. So now we have four values for the 100 s modulus determined by the four Test Method C1735 tests:

X1.4.1 The initial (baseline modulus) in tension: $E_{100}$, *T*, *bo*.

X1.4.2 The value in tension after some exposure *b*: $E_{100}$, *T*.

X1.4.3 The initial (baseline modulus) in compression: $E_{100}$, *C*, *bo*.

X1.4.4 The value in compression after some exposure *b*: $E_{100}$, *C*.

X1.5 Now we can use the following expressions:

$$E_{100,T} = d \cdot E_{100,bo,T}\{1 - a_2 f - (1 - a_2)f^2\} \quad \text{(X1.1)}$$

$$E_{100,C} = d \cdot E_{100,bo,C}(1 - a_1 f) \quad \text{(X1.2)}$$

X1.6 There are several factors needed to define in these expressions: $a_1$, $a_2$, $f$, and $d$. The factors $a_1$ and $a_2$ are factors that depend only on the geometry of the samples. These are discussed later in this paragraph. The symbol $d$ in the above expression is the fractional of the original modulus that would be retained if there were no flaws or debonding and only molecular level changes (range from 1 to 0). So the fraction of modulus loss produced by molecular level changes is (1-$d$). The parameter $f$ is the fraction of the cross-section that is not flawed or debonded (range 1 to 0). The fraction cross-section that is flowed or debonded cross-section is (1-$f$). The fit constraints are $a_1$ and $a_2$. The values for $a_1$ and $a_2$ were determined from a series of three different sealant chemistry samples with a variety of induced known cracks and no degradation. It as found that the sealant chemistry of the nature of the cracks (symmetric or asymmetric, front or back, top or bottom) did not affect the determined values of $a_1$ and $a_2$ as expected as these are purely geometric dependent values. $a_1$ and $a_2$ were determined by experimental fit to the data in Fig. X1.2 to be $a_1$ = 0.118, and $a_2$ = 0.52 (note that this assumes $f$ is not in percent but in the range from 1 to 0.

X1.7 Table X1.1 shows the types of cracks induced in the three different sample chemistries and the resulting modulus ratio versus effective debonded area is plotted in Fig. X1.2. In the figure, the model predictions are from Eq X1.1 and Eq X1.2. The interfaces refer to the position of the induced crack, in the center of the sealant or near the interface with the substrate. The side refers to the location of the crack relative to the front or back of the sealant or from the side. The symmetric or asymmetric refers to whether the crack is just on one side (asymmetric) or balanced on both sides (symmetric).

X1.8 From Eq X1.1 and Eq X1.2 the values of $a_1$ and $a_2$ are known. Additionally, we have measured the four modulus values: $E_{100}$,$T$,$bo$; $E_{100}$,$T$; $E_{100,C,bo}$; $E_{100,C}$. At this point it is useful to define the ratios $R_C$, $R_T$ and $R$ as follows:

Let:.

$R_C$ = $E_{100,C}/E_{100,bo,C}$,
$R_T$ = $E_{100,T}/E_{100,bo,T}$, and
$R$ = $R_T/R_C$= $(E_{100,T}\ E_{100,bo,C})/(E_{100,bo,T}\ E_{100,C})$

X1.9 With these defined relationships, the next task is to find the $f$ and $d$. By substituting in the values of $RC$, $RT$, $R$ into Eq X1.1 and Eq X1.2, the following expression is produced:

$$R = \frac{1 - a_2 f - (1 - a_2)f^2}{1 - a_1 f} \quad \text{(X1.3)}$$

so:

$$1 - a_2 f - (1 - a_2)f^2 = R - Ra_1 f$$

and:

$$(1 - a_2)f^2 + (a_2 - Ra_1)f + (R - 1) = 0 \quad \text{(X1.4)}$$

The fraction of cross section without debonds or flaws is:

$$f = \frac{(Ra_1 - a_2) \pm \sqrt{(a_2 - Ra_1)^2 - 4(1 - a_2)(R - 1)}}{2(1 - a_2)} \quad \text{(X1.5)}$$

The values of $E_{100}$ if only molecular level changes were present are:



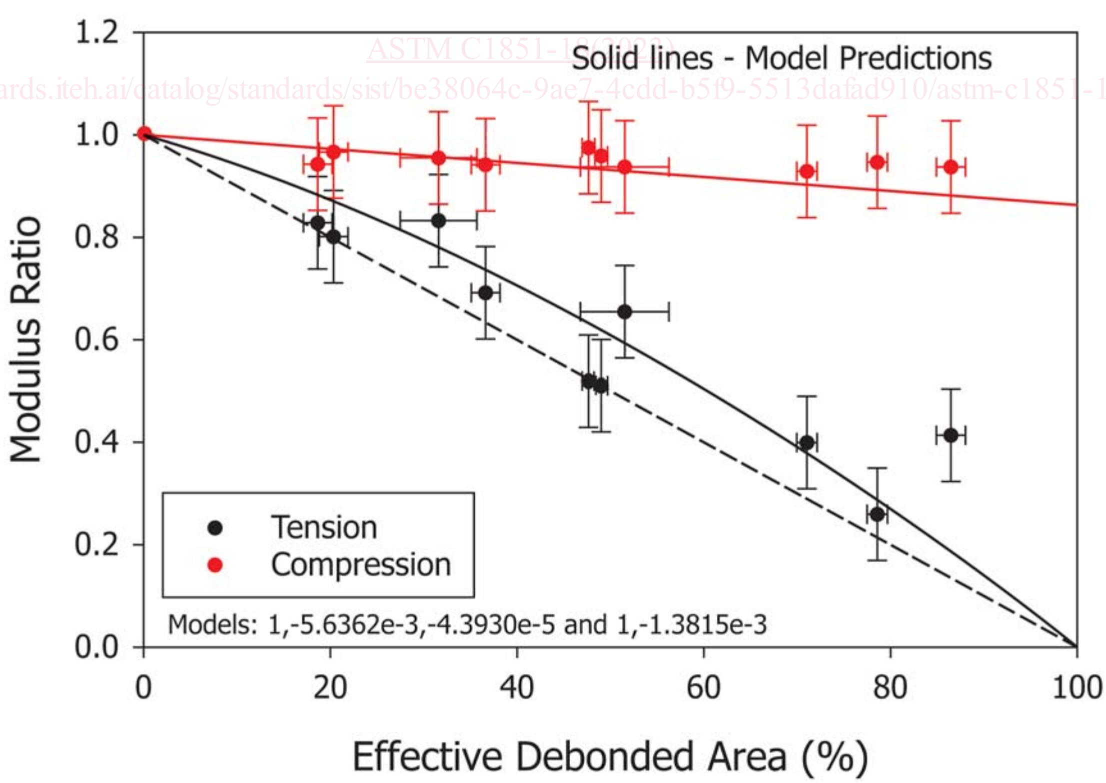


FIG. X1.2 Effective Debonded Area (%)

TABLE X1.1 Crack Characteristics

| Sample | Interface<br>Center | Side<br>Front/Back | Symmetric<br>Asymmetric |
|---|---|---|---|
| 1C1 | Interface | Side | Asymmetric |
| 1C2 | Interface | Side | Symmetric |
| 2C1 | Center | Side | Asymmetric |
| 3C1 | Interface | Back | Asymmetric |
| 4C1 | Center | Front/Back | Symmetric |
| 5C1 | Interface | Side | Asymmetric |
| 2C2 | Center | Side | Asymmetric |
| 5C2 | Interface | Both Sides | Asymmetric |
| 3C2 | Interface | Back plus both sides | Asymmetric |
| 4C2 | Center | F/B plus both sides | Symmetric |

$$d\,E_{100,bo,T} = E_{100,T}/\{1 - a_2 f - (1 - a_2)f^2\} \quad (X1.6)$$

$$d\,E_{100,bo,C} = E_{100,C}/(1 - a_1 f)$$

and the degradation factor is:

$$d = R_T/\{1 - a_2 f - (1 - a_2)f^2\} = R_C/(1 - a_1 f) \quad (X1.7)$$

X1.10 Eq X1.6 is quadratic so there are two values for $f$ possible. An examination of the graphs suggests that one will be positive and the other negative. Since $f$ must be in the range from 0 to 1, the positive value is required. Generally, this means the plus sign on the radical. For the values of $a_1$ and $a_2$ given above, the solutions for different values of $R$ are given in Table X1.2. Note that as the value of $R$ goes from 1 to 0, the corresponding $f$ results go from 0 to 1 as must be the case.

X1.11 From this procedure, the values of $f$ and $d$ can be determined.

X1.11.1 The validity of this procedure was examined by doing the following experiment. A set of aged white samples that had developed cracks were measured using the procedure outlined in this appendix. Values for $f$ and d were determined. The same samples were then coated with black ink. The black ink dried. The samples were pulled to failure. This resulted in a sample where the cracked areas of the failure surface were coated black and the sealant was white. Image analysis was used to determine the fraction of cracked sample $f$. The results are shown in Table X1.3.

X1.11.2 Within the relative standard error of the measurements, the image analysis and the procedure outlined in this standard were statistically equivalent.