Designation: D6515 – 00 (Reapproved 2016)

Standard Test Method for Rubber Shaft Seals Determination of Recovery From Bending[1]

This standard is issued under the fixed designation D6515; 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 a procedure to determine the recovery response of rubber after particular bending deformation, subsequent to aging in selected media at a specified temperature, and for a specified time period, thus providing a measure of the relative performance potential of compounds used in the manufacture of shaft seals.

1.2 The values stated in SI units are to be regarded as the standard. The values given 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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D412 Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension

D471 Test Method for Rubber Property—Effect of Liquids

D1349 Practice for Rubber—Standard Conditions for Testing

D3183 Practice for Rubber—Preparation of Pieces for Test Purposes from Products

D4483 Practice for Evaluating Precision for Test Method Standards in the Rubber and Carbon Black Manufacturing Industries

3. Summary of Test Method

3.1 The ends of rectangular specimens of candidate shaft seal compounds are clipped together and the specimens exposed under specified conditions of time and temperature in a fluid environment that best simulates anticipated operating conditions. Upon completion of the exposure, the clamps are removed and the specimen are allowed to recover from bending. After a specified period of time, the distance between ends of the specimens is measured and the amount of recovery calculated.

4. Significance and Use

4.1 Among the factors affecting shaft seal life are the ability to retain elasticity and compensate for shaft eccentricity, ability to recover from bending, and resistance to wear and the swelling effects of contact fluids. In-service testing of candidate materials is time consuming and therefore costly. Measurement of recovery from bending after exposure in fluids at elevated temperatures provides a means of quickly assessing the material's potential and acceptability for use. Comparative recovery data may then be screened and optimum performing compounds selected for further improvement or seal fabrication. It has been found that good to excellent correlation exists between a material's ability to recover from bending and sealing effectiveness.

4.2 This method is designed to measure the recovery of different rubber compounds after aging in any liquid medium, including hydraulic oils and water. This method can also be used to test rubber compounds after aging in air. Test liquids should be chosen based on the intended end use.

5. Apparatus

5.1 *Glass Test Tubes,* 300 by 38 mm (12 by 1½ in.)

5.2 *Specimen Hangers.*

5.3 *Binder Clips.*

5.4 *Aluminum Block Heater.*

5.5 *Aluminum Plate,* 300 by 400 by 2.3 mm (12 by 16 by 0.09 in.) with surface roughness, Ra = 0.4–0.5 µm (16 to 20 µin).

5.6 *Tweezers.*

5.7 *Oven.*

5.8 *Ruler,* graduated in 0.5 mm (0.02 in.).

[1] This test method is under the jurisdiction of ASTM Committee D11 on Rubber and is the direct responsibility of Subcommittee D11.37 on Coated Fabrics, Rubber Threads and Seals.

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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. Test Temperatures

6.1 Unless otherwise specified, the standard temperature for testing shall be 23 ± 2°C (73.4 ± 3.6°F). Specimens shall be conditioned for at least 3 h when the test temperature is 23°C (73.4°F). If the material is affected by moisture, maintain the relative humidity at 50 ± 5 % and condition the specimens for at least 24 h prior to testing. When testing at any other temperature is required, use one of the temperatures listed in Practice D1349.

7. Test Specimen

7.1 Test specimens shall be cut from test sheets with a thickness of 2.0 ± 0.2 mm (0.080 ± 0.05 in.) of each compound to be evaluated, prepared according to the procedure detailed in Practice D3183. Test sheets shall be vulcanized according to the same conditions of time and temperature as would be used for molding the sheets for testing physical properties in tension (see Test Method D412).

7.2 After the test sheets have been conditioned for at least 16 h at 23°C (73.4°F), prepare three 100 ± 0.5 by 10 ± 0.05 by 2.0 ± 0.2 mm (3.937 ± 0.02 by 0.393 ± 0.002 by 0.080 ± 0.008 in.) specimens for each material to be evaluated. Specimens shall be cut parallel to the mill grain direction.

8. Procedure

8.1 Mark each of three specimens of one compound type 5 ± 0.5 mm (0.2 ± 0.02 in.) from each end. Bring the ends of a specimen together and place a piece of aluminum foil 10 by 15 mm (0.395 by 0.590 in.) between them to prevent sticking. Insert the specimen in a binder clip to a depth of 5 mm (0.2 in.) in the lowest position so that the edge of it is even with the end of the clip. This will avoid deforming the specimen when cutting. (see Figs. 1-3).

8.2 Place each group of three specimens on the hanger shown in Fig. 4 and insert the assembly in a 300 × 38-mm test tube, as in Fig. 5. Do not allow specimens to make contact.

8.3 Add 225 ± 5 cm of test fluid to each test tube, insert a cork stopper, and attach an identifying label.

8.4 Place the test tubes in an oven block set at the desired test temperature, and age for the specified time as detailed in Test Method D471, for suggested durations of 168, 336, and 504 h. Verify the oil temperature periodically during exposure.

8.5 When the specified aging period is completed:

8.5.1 Remove the specimens, leaving them still in the clamps for 15 ± 1 s to allow dripping of excess oil.

8.5.2 Place the specimens on their edge, as shown in Fig. 1, on the aluminum plate, with edge surfaces parallel to the surface of the plate. DO NOT touch the rubber surface. No more than nine specimens (three compounds) shall be placed on an aluminum plate, as shown in Fig. 6.

8.5.3 In sequence, cut each group of three specimens from the clamps with a razor blade, preferably at a distance of about 1.0 to 1.5 mm (0.04 to 0.06 in.) from clamp edges and allow them to relax for 15 ± 1 min. If the aluminum foil sticks to the specimen, do not attempt to remove it, thus preventing specimen distortion.

8.5.4 After the 15 ± 1-min relaxation period at room temperature is complete, place the aluminum plate containing the specimens in a preheated oven at 100 ± 1°C (212 ± 2°F) for 30 ± 1 min to allow further relaxation.

8.5.5 Upon completion of the 30 ± 1-min relaxation period in the oven, remove the aluminum plate and allow the specimens and plate to cool to ambient temperature.

8.5.6 Leaving each specimen on its side, measure the distance between inside edges A and B, as shown in Figs. 6 and

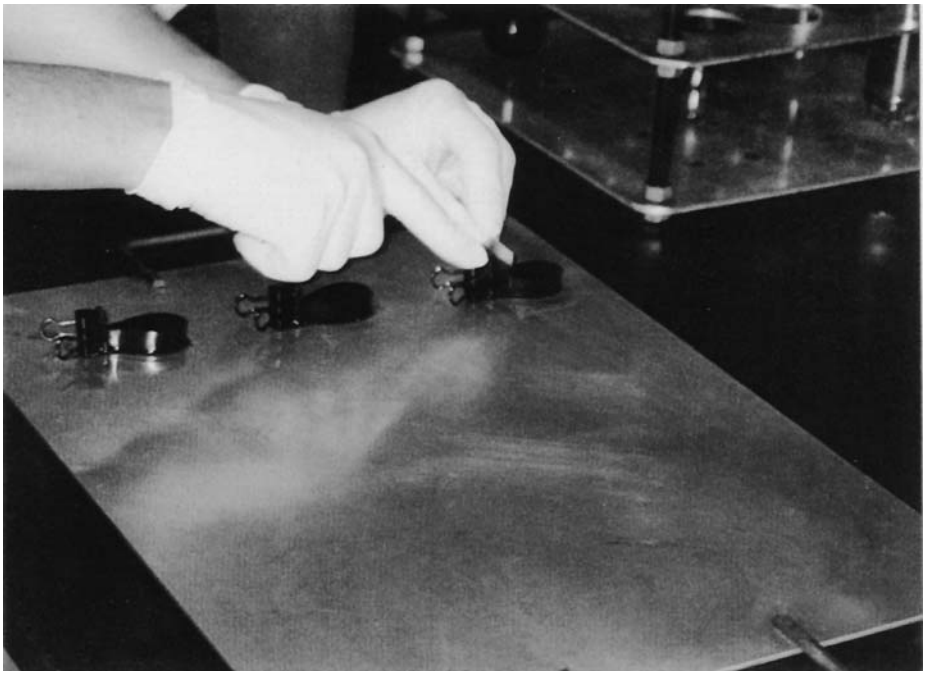


FIG. 1 Placement Binder Clips with Rubber Specimen on the Aluminum Plate

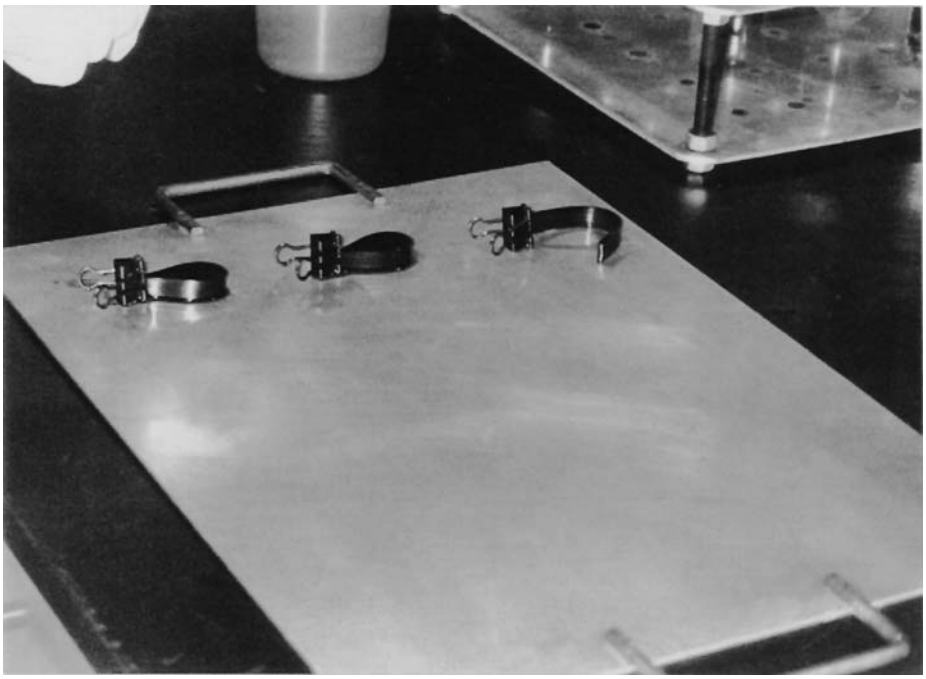
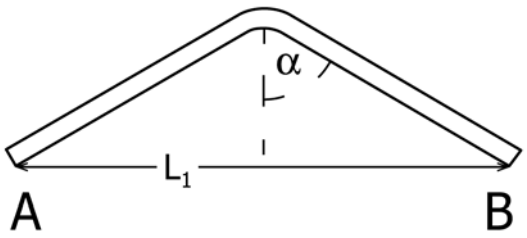


FIG. 2 After Cutting the Specimen



L_1 - length between A and B
L_2 - length of the flat sample

FIG. 3 Measurement of the Angle of Recovery

7, using a ruler graduated in 0.5 mm (0.02 in.). Do not touch or move specimens during measurement. To maximize measurement accuracy, take all readings using the central portion of the ruler, rather than the en or zero point. Both hands can then be used to stabilize the ruler.

8.5.7 Record the values taken as L_1 (see Fig. 8).

8.5.8 When all measurements have been completed, remove the specimens from the aluminum plate with the tweezers, holding them at the maximum point of bending. Place the specimens on a cleaned dry surface, flatten them, and measure their length with the ruler, as is shown in Fig. 9.

8.5.9 Record the values taken as L_2.

9. Calculation

9.1 Calculate the recovery from bending for each specimen as follows:

$$RFB = L_1/L_2 = \sin \alpha \quad (1)$$

$$AOR = 2\ \alpha \quad (2)$$

$$P = L_1/L_2\ x\ 100 \quad (3)$$

where:

RFB = recovery from bending,
AOR = angle of recovery,
L_1 = distance between specimen ends after relaxation for 30 min at 100°C (212°F),
L_2 = length of the flattened specimen, and
P (%) = percent recovery from bending.

9.2 Report results as the mean of the three specimens tested for each material being evaluated.

10. Report

10.1 Report the following information:

10.1.1 Results calculated in accordance with Section 9,

10.1.2 Type or description of the specimen,

10.1.3 Date of test,

10.1.4 Temperature and humidity of test room, if not as specified,

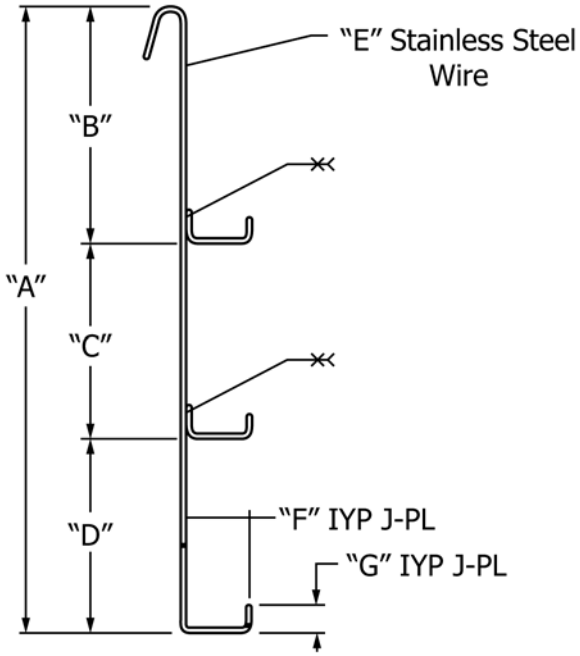
10.1.5 Temperature of conditioning oven, aluminum plate, and test, if other than specified, and

10.1.6 Date of vulcanization and preparation of the specimens, if known.

11. Precision and Bias

11.1 Precision and bias has been determined in accordance with Practice D4483. Refer to this practice for terminology and other statistical calculation details. Results are contained in the appendix.

11.2 A Type I interlaboratory test program was conducted using three different vulcanized rubber compounds (materials). Test slabs were prepared in one laboratory and distributed to



Drawing labels	Units	Dimensions	Tolerance, ±
A	mm	240	3.0
	in.	9.45	0.12
B	mm	90	1.0
	in.	3.54	0.04
C	mm	75	1.0
	in.	2.95	0.04
D	mm	75	1.0
	in.	2.95	0.04
E	mm	1.6	0.1
	in.	0.062	0.004
F	mm	25	1.0
	in.	0.98	0.04
G	mm	10	1.0
	in.	0.39	0.04

FIG. 4 Hanger for Specimens

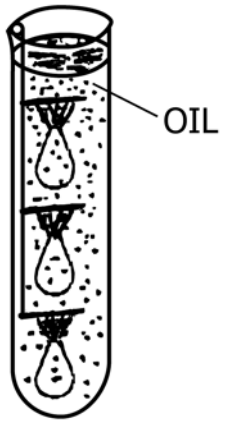


FIG. 5 Immersion of Specimens

the six participating laboratories. All test liquids were purchased from approved sources. Refer to Appendix X1 for additional details and precision and bias results.

12. Keywords

12.1 recovery from bending; rubber; shaft seals

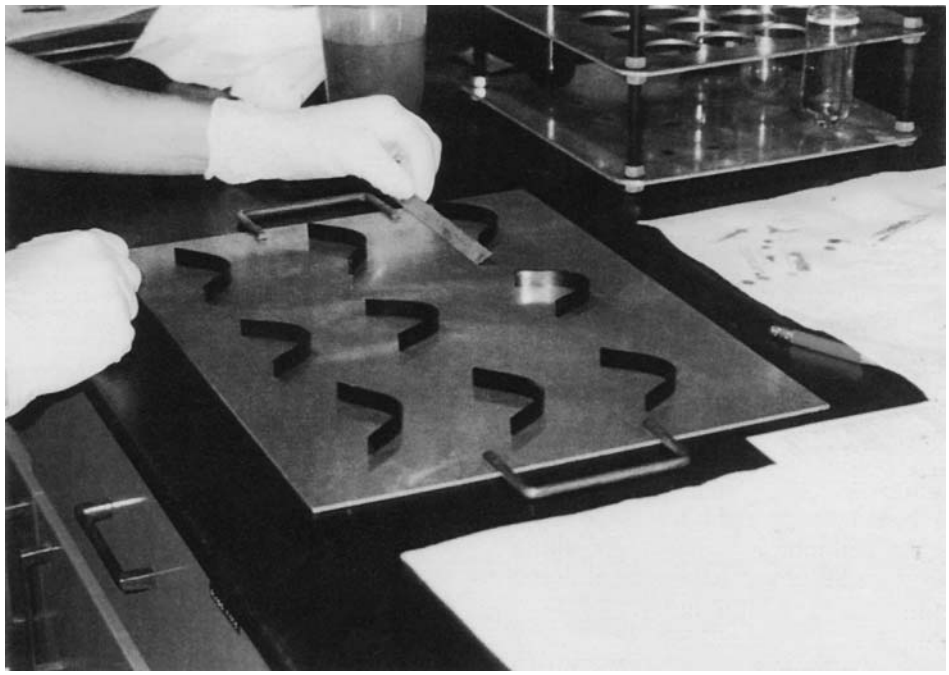


FIG. 6 Measurement of the Distance Between the Inside Edges After Aluminum Plate was Taken from the Oven and Cooled for 30 min

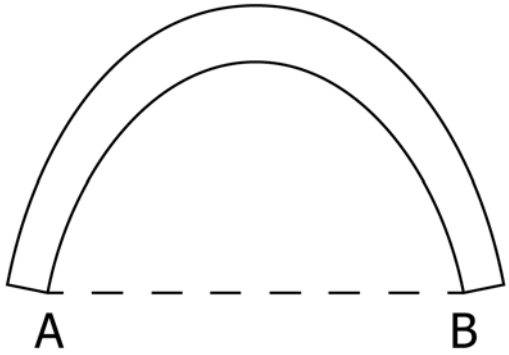


FIG. 7 Measurement of the Recovery after Relaxation

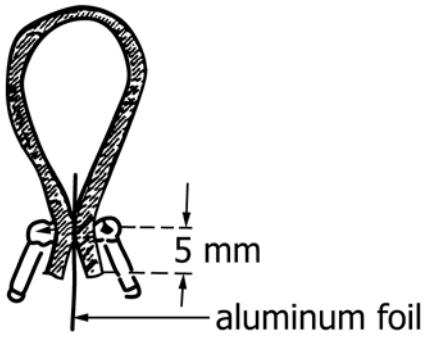


FIG. 8 Clamping of Specimens

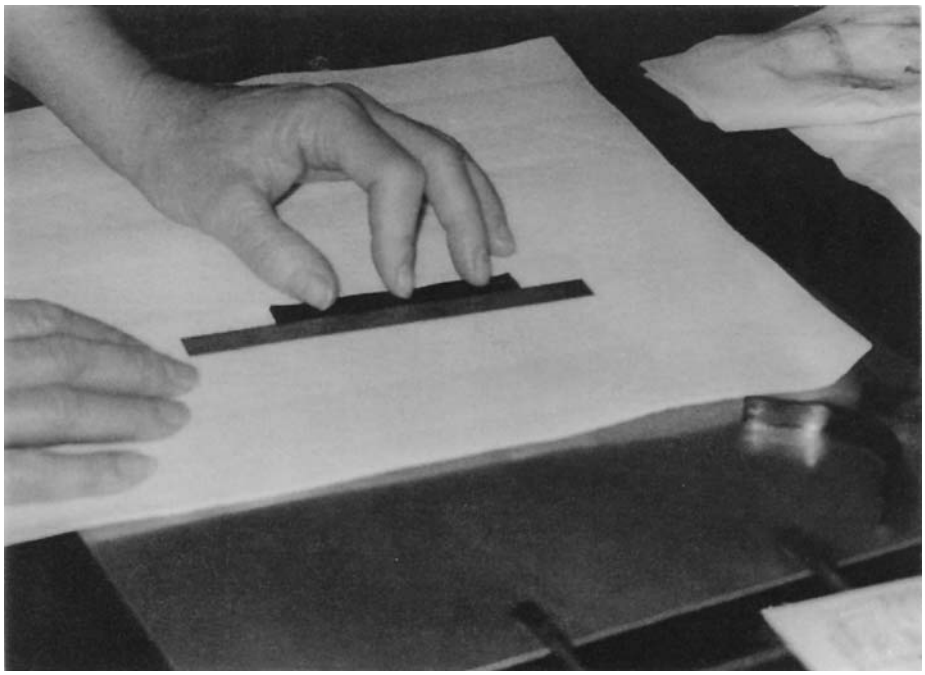


FIG. 9 Measurement of Flattened Samples

APPENDIX

X1. RECOMMENDED PRECISION SECTION FOR RECOVERY FROM BENDING

X1.1 Precision and Bias[3]

X1.1.1 This precision and bias section has been prepared in accordance with Practice D4483. Please refer to this practice for terminology and other statistical calculation details.

X1.1.2 The precision results in this precision and bias section give an estimate of the precision of this test method with the materials (rubbers, etc.) used in the particular interlaboratory test program (ITP) as described below. The precision parameters should not be used for acceptance or rejection testing of any group of materials without documentation that the parameters are applicable to the particular group of materials and the specific testing protocols of the test method.

X1.1.3 *Precision Program 1*—Two interlaboratory test programs (ITP) were conducted in the development of this test. Program 1 was conducted in 1998 on three materials or compounds, using three rubbers; VMQ, FKM, and HNBR. Seven laboratories participated in the ITP conducting tests for three period of oil immersion; 168, 336, and 504 h (7, 14, 21 days). Cured sheets from a common supply were sent and three test specimens prepared and tested in each laboratory for each rubber (compound) and each immersion period.

X1.1.3.1 The D11 precision standard, Practice D4483, calls for precision (repeatability) evaluation to be conducted on the basis of replicate test results on two (or more) separate days. However Program 1 was not conducted on a Day 1 versus Day 2 basis, and the repeatability as given in precision Table X1.1 was evaluated from the variation among the three test specimens for each immersion period. Thus the repeatability is designated as a limited or special repeatability (it does not include a day-to-day variation) and a test result is a single measurement of recovery from bending rather than the mean of three as specified in the test method. Outlier analysis of the database disclosed that there was one outlier laboratory for

TABLE X1.1 Special Type 1 Precision for: Recovery from Bending (Repeatability Calculated from Variation Among Three Test Specimens)[A, B]

Aging Period, h	Material	Mean	Within Labs			Between Labs		
			Sr	*r*	(*r*)	*SR*	*R*	(*R*)
168	VMQ	0.920	0.006	0.017	1.85	0.013	0.036	3.88
	FKM	0.872	0.007	0.020	2.30	0.019	0.052	6.01
	HNBR	0.804	0.037	0.103	12.8	0.067	0.187	23.3
336	VMQ	0.888	0.009	0.024	2.74	0.028	0.079	8.88
	FKM	0.823	0.024	0.067	8.20	0.034	0.094	11.4
	HNBR	0.706	0.033	0.092	13.0	0.082	0.228	32.3
504	VMQ	0.867	0.012	0.035	3.99	0.048	0.135	15.5
	FKM	0.772	0.039	0.108	14.1	0.040	0.112	14.6
	HNBR	0.683	0.046	0.130	19.0	0.099	0.278	40.7

[A] Within-lab results do not contain a day-to-day component of variation, See Precision section for explanation.

[B] *Sr* = Special within-lab standard deviation, measurement units.
r = Special repeatability = 2.83 x *Sr* ; measurement units.
(*r*) = Special relative repeatability; percent of mean value.
SR = Between-Lab standard deviation, measurement units.
R = Reproducibility = 2.83 x *SR*; measurement units.
(*R*) = Relative reproducibility; percent of mean value.

[3] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR: D11-1092.

each rubber and thus the final precision for all three rubbers is based on six laboratories.

X1.1.3.2 *Repeatability*—The special Program 1 repeatability, *r*, of this test method has been established as the value tabulated in Table X1.1 for each material and immersion time. Two single specimen test values, obtained under normal test method procedures, that differ by more than this tabulated *r* (for any given level) must be considered as derived from different or non-identical sample populations.

X1.1.3.3 *Reproducibility*—The Program 1 reproducibility, *R*, of this test method has been established as the value tabulated in Table X1.1 for each material and immersion time. Two single test results (the mean of three specimens) obtained in two different laboratories, under normal test method procedures, that differ by more than the tabulated *R* must be considered to have come from different or non-identical sample populations.

X1.1.3.4 The relative special repeatability and reproducibility, (*r*) and (*R*), are also given in Table X1.1; these precision parameters have the same applicability statements as those given in X1.1.3.2 and X1.1.3.3.

X1.1.4 *Precision Program 2*—The second ITP was conducted in 1999 using one material (or compound) based on FKM. Six laboratories participated in the ITP conducting tests for an immersion period of 168 h at 150 °C. Cured sheets from a common supply were sent to each participating laboratory and two sets of three test specimens each were prepared. Each set of three was tested in each laboratory on two separate days within the a time period of one week. For this program a test result is the mean of three test specimens.

X1.1.4.1 Outlier analysis of the Program 2 database disclosed that there was one outlier laboratory and thus the final precision for FKM is based on five laboratories.

X1.1.4.2 *Repeatability*—The Program 2 repeatability, *r*, of this test method has been established as the value tabulated in Table X1.2. Two test results (mean of three specimens), obtained under normal test method procedures, that differ by more than this tabulated *r* (for any given level) must be considered as derived from different or non-identical sample populations.

X1.1.4.3 *Reproducibility*—The Program 2 reproducibility, *R*, of this test method has been established as the value tabulated in Table X1.2. Two test result values (the mean of three specimens) obtained in two different laboratories, under normal test method procedures, that differ by more than the tabulated *R* must be considered to have come from different or non-identical sample populations.

TABLE X1.2 Precision for Type 1 Program on FKM: Recovery from Bending[A]

		Within Labs			Between Labs		
Material	Mean	*Sr*	*r*	(*r*)	*SR*	*R*	(*R*)
FKM[B]	0.885	0.0043	0.012	1.37	0.0096	0.0268	3.03

[A] *Sr* = Within-Lab standard deviation, measurement units,
r = repeatability = 2.83 x *Sr*, measurement units,
(*r*) = relative repeatability; percent of mean value,
SR = Between-Lab standard deviation, measurement units,
R = reproducibility = 2.83 x *SR*, measurement units,
(*R*) = relative reproducibility; percent of mean value.
[B] Aged 168 h at 150°C.

X1.1.4.4 The relative special repeatability and reproducibility, (*r*) and (*R*), are also given in Table X1.2; these precision parameters have the same applicability statements as those given in X1.1.4.2 and X1.1.4.3.

X1.1.5 A review of Table X1.1 will show that precision (both repeatability and reproducibility) depends on the rubber as well as the period of aging or immersion. The precision decreases (*r* and *R* grow larger) as the recovery decreases or in the order: VMQ, FKM, HNBR. Precision also decreases as the immersion period is increased. Graphical analysis (not included in this section) indicates that the increase in *r* and *R* is essentially linear with immersion time for the periods included in Program 1.

X1.1.5.1 Comparing the precision results for FKM at 168 h in Tables X1.1 and X1.2 (Programs 1 and 2) shows that the precision of Table X1.2 is better than Table X1.1. This increase in precision is partly explained by the use of means of three specimens for Program 2 and partly due to a gain in testing skill after the completion of Program 1.

X1.1.6 *Bias*—In test method terminology, bias is the difference between an average test result or value and the reference (or true) test property value. Reference values do not exist for this test method since the value (of the test property) is exclusively defined by the test method. Bias cannot therefore be determined.