



Designation: D1414 – 22

Standard Test Methods for Rubber O-Rings¹

This standard is issued under the fixed designation D1414; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 These test methods describe the procedures for determining the physical properties of O-rings and changes in these properties due to aging.

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, 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

[D297 Test Methods for Rubber Products—Chemical Analysis](#)

[D395 Test Methods for Rubber Property—Compression Set](#)

[D412 Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension](#)

[D471 Test Method for Rubber Property—Effect of Liquids](#)

[D573 Test Method for Rubber—Deterioration in an Air Oven](#)

[D865 Test Method for Rubber—Deterioration by Heating in Air \(Test Tube Enclosure\)](#)

[D1329 Test Method for Evaluating Rubber Property—](#)

[Retraction at Lower Temperatures \(TR Test\)](#)

[D1415 Test Method for Rubber Property—International Hardness](#)

[D2240 Test Method for Rubber Property—Durometer Hardness](#)

[D3767 Practice for Rubber—Measurement of Dimensions](#)

[D4483 Practice for Evaluating Precision for Test Method Standards in the Rubber and Carbon Black Manufacturing Industries](#)

2.2 *Aerospace Standard:*

[AS568A O-ring Sizes](#)³

3. Terminology

3.1 *Definitions:*

3.1.1 *O-ring*—a rubber seal of homogeneous composition molded in one piece to the configuration of a torus with circular cross section. The O-ring is used as a dynamic or static seal usually installed in a machined groove.

4. Significance and Use

4.1 These test methods provide acceptable procedures for quality control purposes and for the determination of engineering characteristics.

5. General Methods

5.1 Except as otherwise specified in these test methods for rubber O-rings, the following ASTM test methods applicable in general to vulcanized rubber, shall be complied with as required and are hereby made a part of these test methods:

5.1.1 *Tension Test*—Test Methods [D412](#).

5.1.2 *Compression Set*—Test Methods [D395](#).

5.1.3 *Low Temperature*—Test Method [D1329](#).

5.1.4 *Density*—Test Methods [D297](#).

5.1.5 *Fluid Aging*—Test Method [D471](#).

5.1.6 *Heat Aging*—Test Methods [D865](#) and [D573](#).

5.1.7 *Hardness*—Test Methods [D2240](#) and [D1415](#).

5.2 In case of conflict between the provisions of these test methods and those of detailed procedures herein, the latter shall take precedence.

¹ These test methods are under the jurisdiction of ASTM Committee D11 on Rubber and Rubber-like Materials and are the direct responsibility of Subcommittee D11.37 on Coated Fabrics, Rubber Threads and Seals.

Current edition approved Oct. 1, 2022. Published December 2022. Originally approved in 1956. Last previous edition approved in 2015 as D1414 – 15. DOI: 10.1520/D1414-22.

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 Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

6. Test Conditions

6.1 The temperature of the testing room shall be $23 \pm 2^\circ\text{C}$ ($73.4 \pm 3.6^\circ\text{F}$). The specimens to be tested shall be kept in this room for a minimum of 30 min previous to the time of testing. For referee tests the minimum time for conditioning shall be 16 h. In cases where this temperature cannot be obtained, the actual temperature shall be reported.

7. Dimensional Measurements

7.1 Thickness:

7.1.1 The thickness or cross section shall be measured by a micrometer in accordance with Practice D3767, Procedure A.

7.1.2 The O-ring specimen shall be measured at four points equally distributed around the circumference in both the radial and axial direction. An average reading shall be used for calculation.

7.2 *Diameter*—A stepped cone or optical comparator may be used for measuring the inside diameter of small rings. The diametric intervals of the stepped cone shall not exceed 2 % of the diameter to be measured (see Fig. 1).

8. Tension Testing

8.1 *Testing Machine*—The testing machine shall conform to the requirements specified in Section 3 of Test Methods D412, with the exception of the grips. Grips for testing rings shall consist of ball-bearing spools at least 9 mm (0.35 in.) in diameter, and be capable of being brought within 19 mm (0.75 in.) center-to-center distance at closest approach. Stresses within the specimen shall be minimized by (1) rotating one

spool one full revolution for each 150 mm (6.0 in.) of travel of the power-driven grips or (2) lubricating the contact surface of the spools with castor oil. Grips for testing straight specimens may be of any type provided breaks do not occur in a portion of the specimen that has been at any time in contact with the grips. For specimens smaller than 25 mm (1 in.) in inside diameter, spools of smaller diameter and closer approach may be employed.

8.2 Test Specimen:

8.2.1 The test specimen shall consist of an entire O-ring except in the following cases: (1) when the diameter is too large to permit a break within the limits of travel of the testing machine, (2) when the specimen has been previously cut open to permit an aging test, and (3) when the specimen is unaged but is to be compared with an aged specimen as described in (2). For these cases a specimen cut from a ring shall be employed.

8.2.2 Specimens that exhibit obvious flaws at any point on the surface, such as might result from imperfect molding or flash removal, shall not be tested.

8.3 Procedure for Determination of Tensile Strength, Ultimate Elongation, and Tensile Stress:

8.3.1 Bring the grips close enough together so the specimen can be installed without stretching. Set the machine for a speed of 500 ± 50 mm (20 ± 2 in.)/min, set the chart recorder, and engage the clutch. (If a recorder is not used, note the spool center-to-center distance continually by means of a suitable scale). The stressed inside circumference, L , is equal to twice the distance between spools plus the circumference of one spool. Record the breaking force value, F , at the elongation specified for tensile stress and at the time of rupture. Measure the center-to-center distance between the spools at rupture to the nearest 2.5 mm (0.1 in.) and record as the value for D .

8.3.2 For the application of bench marks to segmented specimens as described in 8.2, hold the piece as straight as possible being careful not to apply excessive stress. Follow the procedure described in 8.3.1. Discard results for any specimen that breaks at a point that has at any time contacted the grip, and test an additional specimen. A suitable extensometer may be employed for elongation determination.

8.4 Calculations:

8.4.1 *Tensile Strength*—Calculate the tensile strength as follows:

8.4.1.1 For O-rings on spool grips:

$$T = F/A \quad (1)$$

where:

T = tensile strength,

F = breaking force, and

A = twice the cross-sectional area calculated from axial thickness, W , as follows:

$$A = \pi W^2/2 = 1.57 W^2 \quad (2)$$

therefore:

$$T = F/1.57 W^2 \quad (3)$$

8.4.1.2 For straight or single-strand specimens:

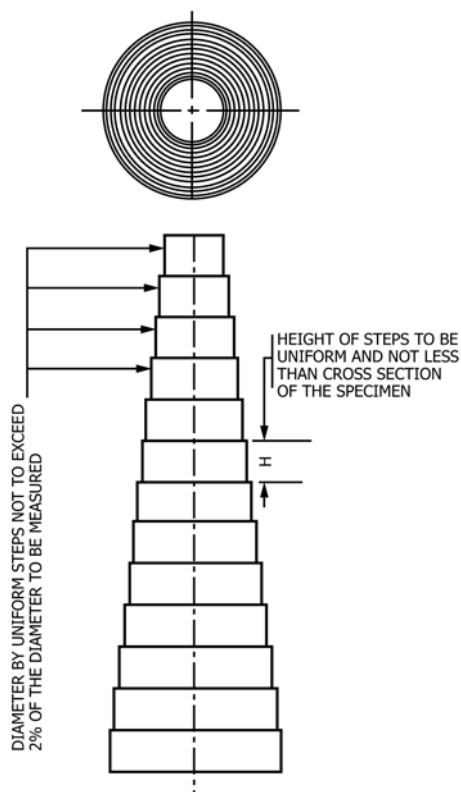


FIG. 1 Stepped Cone Gage

$$A = 0.785 W^2 \quad (4)$$

$$T = F/0.785 W^2 \quad (5)$$

8.4.2 *Ultimate Elongation*—Calculate the ultimate elongation as follows:

8.4.2.1 For rings:

$$\text{Ultimate elongation, \%} = [(2D + G - C)/C] \times 100 \quad (6)$$

where:

D = distance between centers of the spool grips at the time of rupture of specimen,

G = circumference of one spool (spool diameter \times 3.14), and

C = inside circumference of the specimen (or inside diameter \times 3.14).

8.4.2.2 For straight or single-strand specimen cut from an O-ring:

$$\text{Ultimate elongation, \%} = [(L - L_o)/L_o] \times 100 \quad (7)$$

where:

L = observed distance between bench marks of stressed specimen, and

L_o = original distance between bench marks.

8.4.3 *Tensile Stress*— Calculate the tensile stress as in the case of tensile strength except the stress is reported at a predetermined elongation below the ultimate elongation. Calculate the center-to-center distance of the spool grips, D , where the prescribed elongation, E , occurs, as follows:

$$D = 1/2[(EC/100) + C - G] \quad (8)$$

NOTE 1—This value of tensile stress at a predetermined elongation is based upon inside circumference and differs from that determined by Test Methods D412, which is based on the mean circumference.

8.5 *Characteristics of Sample Tested*—The median of the values for three specimens shall be taken as the characteristics of the sample tested, except that under the following conditions the median of the values for five specimens (two additional) shall be used:

8.5.1 If one or more values do not meet the specified requirements when testing for compliance with specifications.

8.5.2 If referee tests are being made.

8.6 *Report*:

8.6.1 The report shall include the following:

8.6.1.1 Results calculated as in 8.4,

8.6.1.2 Date of test,

8.6.1.3 Temperature of test room if other than provided for in Section 6,

8.6.1.4 Type of testing machine used, including diameter of spool grip if other than standard, and speed, if other than 8.3 ± 0.8 mm (20.0 ± 2 in.)/min, and

8.6.1.5 Type of specimen (ring or straight).

9. Tension Testing Precision and Bias

9.1 These precision statements have been prepared in accordance with Practice D4483. Refer to this practice for terminology and other statistical details.

9.2 *Precision*—The precision results in this precision and bias section give an estimate of the precision of these test methods with the materials (rubbers, carbon blacks, etc.) used in the interlaboratory program described in Table 1A and Table 1B. The precision parameters should not be used for acceptance or rejection testing of any group of materials without documentation that they are applicable to those particular materials and the specific testing protocols of these test methods.

9.3 A type 1 inter-laboratory precision program for tensile strength was conducted during the periods listed with the number of laboratories listed and the o-ring materials listed in Table 1A. In each laboratory, two single tests were performed on the o-rings by 2 different technicians on 2 different days for a total of four replicates. A test result is the value obtained from a single determination. Both repeatability and reproducibility represent short-term (daily) testing conditions. Acceptable difference values were not measured.

9.4 *Tensile Strength Repeatability*—The **relative** repeatability limits, (r), of this test method are as shown in Table 1A for each of the materials listed in the table. The difference between two single test results (or determinations) found on identical test material under the repeatability conditions prescribed for this test will exceed the repeatability value on an average of not more than once in 20 determinations in the normal and correct

TABLE 1 A Precision Parameters for Test Methods D1414, Tensile Strength (Type 1 Precision), Size 2-214 O-rings

Material	Period	Units Number of Laboratories (M/V) ^A	MPa		r	(r)	SR	R	(R)
			Mean Level	Sr					
FVMQ; MIL-DTL-25988C; T1, C1, G60	Sep 2020	6(0/0)	7.1	0.66	1.87	26.3	0.70	1.99	27.9
FVMQ; MIL-DTL-25988C; T1, C3, G75	Oct '19; Feb '20	7(0/1)	8.2	0.24	0.68	8.2	0.74	2.09	25.3
FKM; AMS7259E	April 2021	3(0/0)	12.1	1.98	5.61	46.4	2.22	6.30	52.0
NBR; AMS-P-5315B	Sep-Dec 2018	10(1/0)	12.2	0.45	1.28	10.5	0.54	1.54	12.6
FKM; AMS7287	May-Jun 2019	8(1/1)	12.5	0.80	2.28	18.3	0.80	2.28	18.3
Average Pooled Values			10.4		1.03	27.9	1.18	3.33	31.9

^A M=Mean outliers; V=Variability outliers

TABLE 1 B Precision Parameters for Test Methods D1414, Ultimate Elongation (Type 1 Precision), Size 2-214 O-rings (continued)

Material	Period	Units Number of Laboratories (M/V) ^A	Percent		r	(r)	SR	R	(R)
			Mean Level	Sr					
FKM; AMS7259E	April 2021	3(0/0)	165.2	22.61	63.97	38.7	23.54	66.63	40.3
FVMQ; MIL- DTL-25988C; T1, C3, G75	Oct '19; Feb '20	7(1/1)	176.9	8.98	25.41	14.4	11.72	33.17	18.8
FKM; AMS7287	May-Jun 2019	8(1/0)	233.8	19.07	53.97	23.1	19.07	53.97	23.1
NBR; AMS-P- 5315B	Sep-Dec 2018	10(1/1)	248.9	7.82	22.13	8.9	16.87	47.75	19.2
FVMQ; MIL- DTL-25988C; T1, C1, G60	Sep 2020	6(0/0)	285.6	21.94	62.10	21.7	27.23	77.05	27.0
Average			222.1						
Pooled Values				17.31	48.98	22.1	20.40	57.74	26.0

^A M=Mean outliers; V=Variability outliers

operation of the method. Two single test results that differ by more than the appropriate value from **Table 1A** or **Table 1B** must be suspected of being from different populations and some appropriate action taken.

NOTE 2—Appropriate action may be an investigation of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, etc., which generated the two test results.

9.5 Tensile Strength Reproducibility—The **relative** reproducibility limits, (R), of this test method are as shown in **Table 1A** for each of the materials listed in the table. The difference between two single and independent test results found by two operators working under the prescribed reproducibility conditions in different laboratories on identical test material will exceed the reproducibility value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results produced in different laboratories that differ by more than the appropriate value from **Table 1A** must be suspected of being from different populations and some appropriate investigative or technical/commercial action taken.

NOTE 3—Appropriate action may be an investigation in each laboratory of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, laboratories, etc., which generated the two test results. Technical/commercial actions are mutually resolved by the laboratories.

9.6 Bias—Bias is the difference between a test value and a reference value. However, for this test method, bias has not been determined.

9.7 A type 1 inter-laboratory precision program for ultimate elongation was conducted during the periods listed with the number of laboratories listed and the o-ring materials listed in **Table 1B**. In each laboratory, two single tests were performed on the o-rings by 2 different technicians on 2 different days for a total of four replicates. A test result is the value obtained from a single determination. Both repeatability and reproducibility represent short-term (daily) testing conditions. Acceptable difference values were not measured.

9.8 Relative versus absolute repeatability and reproducibility limits. For ultimate elongation, relative precision is statistically preferred. However, since the measurement units are in

percent and relative precision is a percent, the expression of relative precision would be calculated as a percent of a percent. This can be difficult to apply when evaluating the testing precision. Therefore, absolute precision is preferred for practical applications.

9.9 Ultimate Elongation Repeatability—The **absolute** repeatability limits, r, of this test method are as shown in **Table 1B** for each of the materials listed in the table. The difference between two single test results (or determinations) found on identical test material under the repeatability conditions prescribed for this test will exceed the repeatability value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results that differ by more than the appropriate value from **Table 1B** must be suspected of being from different populations and some appropriate action taken.

NOTE 4—Appropriate action may be an investigation of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, etc., which generated the two test results.

9.10 Ultimate Elongation Reproducibility—The **absolute** reproducibility limits, R, of this test method are as shown in **Table 1B** for each of the materials listed in the table. The difference between two single and independent test results found by two operators working under the prescribed reproducibility conditions in different laboratories on identical test material will exceed the reproducibility value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results produced in different laboratories that differ by more than the appropriate value from **Table 1B** must be suspected of being from different populations and some appropriate investigative or technical/commercial action taken.

NOTE 5—Appropriate action may be an investigation in each laboratory of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, laboratories, etc., which generated the two test results. Technical/commercial actions are mutually resolved by the laboratories.

9.11 Bias—Bias is the difference between a test value and a reference value. However, for this test method, bias has not been determined.

10. Tension Set Test

10.1 Procedure:

10.1.1 Stretch the O-ring specimens to 100 % elongation and hold at this strain for 10 min. At the end of this period release the specimen and allow it to recover for 10 min. At the end of this recovery period, measure the inside diameter with a step gage reference in 7.2 and shown in Fig. 1.

10.1.2 Apply the strain by (1) stretching the specimen over a tapered cone which has a step at the required 100 % elongation, or (2) by means of a tension test machine stopping the machine at 100 % elongation, or (3) by the use of any special fixture capable of holding the O-ring over two spools at constant distance between spool centers.

10.2 Calculation— Calculate tension set as follows:

$$\text{Tension set, \%} = [(L_1 - L_o)/L_o] \times 100 \quad (9)$$

where:

L_1 = diameter after testing, and
 L_o = original diameter.

10.3 Straight specimens cut from large O-rings may be tested and calculated in accordance with Test Methods D412.

11. Compression Set Test

11.1 Nature of Test— The compression set of O-ring specimens shall follow the general procedures of Method B of Test Methods D395, with the following exceptions:

11.2 Apparatus:

11.2.1 Spacers—The spacers shall be adjusted to within 0.025 mm (0.01 in.). This can be done by employing shim stock of various thickness.

11.2.2 Measurement— The cross section before and after test shall be measured in the same marked location with a ball-point (tubing) micrometer or other method as described in 7.1.

11.3 Test Specimen— The specimen shall be a suitable section cut from the sample O-ring. A52-mm (2-in.) section has been found to be satisfactory on sample O-rings of 17-mm (0.67-in.) or larger inside diameter. On smaller O-rings, a section of approximately 3 mm (1/8 in.) shall be cut from the sample and discarded.

NOTE 6—Testing a whole O-ring for compression set is always avoided because air trapped inside the O-ring results in a different set of conditions on the inside and outside surface of the specimen.

11.4 Procedure—Measure the actual specimen to within 0.025 mm (0.001 in.) and calculate the spacer to be 75 % of this thickness, to within 0.025 mm (0.001 in.). Close the plates, employing a sufficient number of bolts to prevent deflection upon heating. At the end of the heating period, release the plates as soon as possible and allow the specimens to cool to room temperature under the conditions described in Test Methods D395.

12. Compression Set Test Precision and Bias

12.1 These precision statements have been prepared in accordance with Practice D4483. Refer to this practice for terminology and other statistical details.

12.2 Precision—The precision results in this precision and bias section give an estimate of the precision of this test method with the materials (rubbers, carbon blacks, etc.) used in the interlaboratory program described in Table 2. The precision parameters should not be used for acceptance or rejection testing of any group of materials without documentation that they are applicable to those particular materials, test conditions, and the specific testing protocols of this test method.

12.3 A type 1 inter-laboratory precision program for compression set was conducted during the periods listed with the number of laboratories listed with the o-ring materials listed

TABLE 2 Precision Parameters for Test Methods D395, Method B, Compression Set (Type 1 Precision), Size 2-214 O-rings

Material	Period	Units Test Condi- tions	Percent Number of Laboratories (M/V) ^A	Mean Level	Sr	r	(r)	SR	R	(R)
FVMQ; MIL- DTL-25988C; T1, C1, G60	Sep 2020	Air; 23.9°C; 70 h	5(1/1)	8.4	1.54	4.37	52.0	1.54	4.37	52.0
FKM; AMS7287	May-Jun 2019	Air; 200°C; 22 h	8(1/1)	9.0	0.47	1.33	14.8	0.67	1.88	20.9
FKM; AMS7276H	Apr 2017	Air; 200°C; 22 h	8(0/0)	9.7	1.02	2.87	29.6	1.53	4.32	44.5
FVMQ; MIL- DTL-25988C; T1, C3, G75	Oct '19; Feb '20	Air; 175°C; 22 h	5(0/0)	10.9	1.28	3.61	33.1	1.75	4.96	45.5
FVMQ; MIL- DTL-25988C; T1, C3, G75	Oct '19; Feb '20	Air; 23.9°C; 70 h	5(0/1)	12.3	1.33	3.77	30.6	2.79	7.88	64.0
FVMQ; MIL- DTL-25988C; T1, C1, G60	Sep 2020	Air; 175°C; 22 h	5(0/0)	18.8	3.59	10.16	54.2	3.62	10.25	54.6
FKM; AMS7259E	April 2021	Air; 200°C; 22 h	3(0/0)	19.6	2.11	5.98	30.6	2.73	7.72	39.4
NBR; AMS-P- 5315B	Sep-Dec 2018	Air; 70°C; 70 h	10(1/0)	20.7	1.11	3.14	15.2	1.22	3.46	16.7
Average Pooled Values				13.7	1.79	5.07	37.1	2.18	6.17	45.1

^A M=Mean outliers; V=Variability outliers

and the test conditions listed in **Table 2**. In each laboratory, two single tests were performed on the o-rings by 2 different technicians on 2 different days for a total of four replicates. A test result is the value obtained from a single determination. Both repeatability and reproducibility represent short-term (daily) testing conditions. Acceptable difference values were not measured.

12.4 Relative versus absolute repeatability and reproducibility limits. For compression set, relative precision is statistically preferred. However, since the measurement units are in percent and relative precision is a percent, the expression of relative precision would be calculated as a percent of a percent. This can be difficult to apply when evaluating the testing precision. Therefore, absolute precision is preferred for practical applications.

12.5 *Compression Set Repeatability*—The **absolute** repeatability limits, *r*, of this test method are as shown in **Table 2** for each of the materials and conditions listed in the table. The difference between two single test results (or determinations) found on identical test material under the repeatability conditions prescribed for this test will exceed the repeatability value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results that differ by more than the appropriate value from **Table 2** must be suspected of being from different populations and some appropriate action taken.

NOTE 7—Appropriate action may be an investigation of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, etc., which generated the two test results.

12.6 *Compression Set Reproducibility*—The **absolute** reproducibility limits, *R*, of this test method are as shown in **Table 2** for each of the materials and conditions listed in the table. The difference between two single and independent test results found by two operators working under the prescribed reproducibility conditions in different laboratories on identical test material will exceed the reproducibility value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results produced in different laboratories that differ by more than the appropriate value from **Table 2** must be suspected of being

from different populations and some appropriate investigative or technical/commercial action taken.

NOTE 8—Appropriate action may be an investigation in each laboratory of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, laboratories, etc., which generated the two test results. Technical/commercial actions are mutually resolved by the laboratories.

12.7 *Bias*—Bias is the difference between a test value and a reference value. However, for this test method, bias has not been determined.

13. Compression Set in Liquids

13.1 Compression set may be conducted immersed in any liquid provided a suitable container is available. The container needs to be large enough to hold the plates and withstand the vapor pressure of the liquid at test temperature.

13.2 The specimen is prepared in accordance with **11.3**, and at the termination of the heating period the plates are released immediately and the specimens are allowed to cool to room temperature for 30 min in a fresh cool portion of the test liquid. Measurement and reporting are the same except the type of liquid is listed in the report.

14. Compression Set Test in Lubricants Precision and Bias

14.1 These precision statements have been prepared in accordance with Practice **D4483**. Refer to this practice for terminology and other statistical details.

14.2 *Precision*—The precision results in this precision and bias section give an estimate of the precision of this test method with the materials (rubbers, carbon blacks, etc.) used in the interlaboratory program described in **Table 3**. The precision parameters should not be used for acceptance or rejection testing of any group of materials without documentation that they are applicable to those particular materials, test conditions, and the specific testing protocols of this test method.

14.3 A type 1 inter-laboratory precision program for compression set in lubricants was conducted during the periods listed with the number of laboratories listed with the o-ring materials listed and the test conditions with lubricants listed in

TABLE 3 Precision Parameters for Test Methods **D395, Method B, Compression Set (Type 1 Precision), Size 2-214 O-rings**

Material	Period	Units Test Condi- tions	Percent Number of Laboratories (M/V) ^A	Mean Level	Sr	r	(r)	SR	R	(R)
FKM; AMS7259E	April 2021	AMS 3023 at 200°C for 70 h	2(0/0)	12.4	1.62	4.59	37.1	1.62	4.59	37.1
FVMQ; MIL- DTL-25988C; T1, C3, G75	Oct '19	AMS 3021 at 175°C for 70 h	4(0/0)	29.8	3.25	9.19	30.9	5.18	14.67	49.3
FVMQ; MIL- DTL-25988C; T1, C1, G60	Sep 2020	AMS 3021 at 150°C for 70 h	4(0/1)	31.1	2.53	7.15	23.0	8.37	23.67	76.2
Average Pooled Values				24.4						
					2.55	7.23	29.6	5.76	16.30	66.8

^A M=Mean outliers; V=Variability outliers

Table 3. In each laboratory, two single tests were performed on the o-rings by 2 different technicians on 2 different days for a total of four replicates. A test result is the value obtained from a single determination. Both repeatability and reproducibility represent short-term (daily) testing conditions. Acceptable difference values were not measured.

14.4 Relative versus absolute repeatability and reproducibility limits. For compression set in lubricants, relative precision is statistically preferred. However, since the measurement units are in percent and relative precision is a percent, the expression of relative precision would be calculated as a percent of a percent. This can be difficult to apply when evaluating the testing precision. Therefore, absolute precision is preferred for practical applications.

14.5 *Compression Set in Lubricants Repeatability*—The **absolute** repeatability limits, *r*, of this test method are as shown in **Table 3** for each of the materials and conditions listed in the table. The difference between two single test results (or determinations) found on identical test material under the repeatability conditions prescribed for this test will exceed the repeatability value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results that differ by more than the appropriate value from **Table 3** must be suspected of being from different populations and some appropriate action taken.

NOTE 9—Appropriate action may be an investigation of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, etc., which generated the two test results.

14.6 *Compression Set in Lubricants Reproducibility*—The **absolute** reproducibility limits, *R*, of this test method are as shown in **Table 3** for each of the materials and conditions listed in the table. The difference between two single and independent test results found by two operators working under the prescribed reproducibility conditions in different laboratories on identical test material will exceed the reproducibility value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results produced in different laboratories that differ by more than the appropriate value from **Table 3** must be suspected of

being from different populations and some appropriate investigative or technical/commercial action taken.

NOTE 10—Appropriate action may be an investigation in each laboratory of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, laboratories, etc., which generated the two test results. Technical/commercial actions are mutually resolved by the laboratories.

14.7 *Bias*—Bias is the difference between a test value and a reference value. However, for this test method, bias has not been determined.

15. Low-Temperature Test

15.1 *Nature of Test*— The TR-10 or Temperature Retraction Test shall be in accordance with Test Method **D1329** with the exceptions given in **15.2** to **15.4**.

15.2 *Test Specimen*— The test specimen shall be an O-ring of 1.5 to 3.8-mm (0.06 to 0.15-in.) cross-sectional diameter and of sufficient length to reach from clamp to clamp when the ring is cut and held in straight position.

15.3 *Procedure*—Stretch the mounted specimen 50 % as standard. If a greater or lesser stretch is used, report the actual stretch.

15.4 *Report*—The report shall include the following:

15.4.1 Testing elongation, in percent, and

15.4.2 Temperature at which the specimen retracts 10 %, designated as TR-10 and at other points, such as 30, 50, or 70 %, or all, if required.

16. Low-Temperature (TR10) Test Precision and Bias

16.1 These precision statements have been prepared in accordance with Practice **D4483**. Refer to this practice for terminology and other statistical details.

16.2 *Precision*—The precision results in this precision and bias section give an estimate of the precision of this test method with the materials (rubbers, carbon blacks, etc.) used in the interlaboratory program described in **Table 4**. The precision parameters should not be used for acceptance or rejection testing of any group of materials without documentation that

TABLE 4 Precision Parameters for Test Method **D1329, TR10, Retraction at Lower Temperature (Type 1 Precision), Size 2-214 O-rings**

Material	Period	Units Number of Laboratories (M/V) ^A	°C		<i>r</i>	(r)	SR	R	(R)
			Mean Level	Sr					
FVMQ; MIL-DTL-25988C; T1, C3, G75	Oct '19; Feb '20	4(0/1)	-63.1	0.29	0.82	-1.3	2.10	5.95	-9.4
FVMQ; MIL-DTL-25988C; T1, C1, G60	Sep 2020	2(0/0)	-60.5	0.38	1.08	-1.8	1.40	3.96	-6.6
NBR; AMS-P-5315B	Sep-Dec 2018	6(1/1)	-45.0	0.16	0.46	-1.0	0.93	2.64	-5.9
FKM; AMS7287	May-Jun 2019	6(1/1)	-29.9	0.19	0.54	-1.8	0.31	0.88	-2.9
FKM; AMS7259E	April 2021	2(0/0)	-19.2	1.70	4.82	-25.1	2.07	5.85	-30.5
Average Pooled Values			-43.5	0.80	2.26	-5.2	1.52	4.31	-9.9

^A M=Mean outliers; V=Variability outliers

they are applicable to those particular materials, test conditions, and the specific testing protocols of this test method.

16.3 A type 1 inter-laboratory precision program for low temperature test (TR10) was conducted during the periods listed with the number of laboratories listed with the o-ring materials listed in **Table 4**. In each laboratory, two single tests were performed on the o-rings by 2 different technicians on 2 different days for a total of four replicates. A test result is the value obtained from a single determination. Both repeatability and reproducibility represent short-term (daily) testing conditions. Acceptable difference values were not measured.

16.4 *Low Temperature (TR10) Repeatability*—The **absolute** repeatability limits, *r*, of this test method are as shown in **Table 3** for each of the materials and conditions listed in the table. The difference between two single test results (or determinations) found on identical test material under the repeatability conditions prescribed for this test will exceed the repeatability value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results that differ by more than the appropriate value from **Table 4** must be suspected of being from different populations and some appropriate action taken.

NOTE 11—Appropriate action may be an investigation of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, etc., which generated the two test results.

16.5 *Low Temperature (TR10) Reproducibility*—The **absolute** reproducibility limits, *R*, of this test method are as shown in **Table 4** for each of the materials and conditions listed in the table. The difference between two single and independent test results found by two operators working under the prescribed reproducibility conditions in different laboratories on identical test material will exceed the reproducibility value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results produced in different laboratories that differ by more than the appropriate value from **Table 4** must be suspected of being from different populations and some appropriate investigative or technical/commercial action taken.

NOTE 12—Appropriate action may be an investigation in each labora-

tory of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, laboratories, etc., which generated the two test results. Technical/commercial actions are mutually resolved by the laboratories.

16.6 *Bias*—Bias is the difference between a test value and a reference value. However, for this test method, bias has not been determined.

17. Relative Density Test

17.1 *Test Specimen*—Any O-ring, O-rings, or segment of an O-ring may be considered as the specimen. The minimum mass of the specimen shall be 0.005 N (0.5 gf). In the case of very small O-rings, two or more pieces may be used as the specimen to accomplish this total minimum mass.

17.2 *Procedure*—Employ the procedure outlined in Test Methods **D297**, density hydrostatic method.

NOTE 13—Extreme accuracy is required in making relative density determinations on small O-rings 0.001 N (1 g or less). The surface tension on the suspending wire is critical; this wire should be of the smallest diameter corrosion-resistant wire that will support the specimen weight. This surface tension on the wire and the elimination of small air bubbles on the surface of the specimen can be reduced by the addition of a few drops of wetting agent to the water in the weighing beaker.

18. Relative Density Test Precision and Bias

18.1 These precision statements have been prepared in accordance with Practice **D4483**. Refer to this practice for terminology and other statistical details.

18.2 *Precision*—The precision results in this precision and bias section give an estimate of the precision of these test methods with the materials (rubbers, carbon blacks, etc.) used in the interlaboratory program described in **Table 5**. The precision parameters should not be used for acceptance or rejection testing of any group of materials without documentation that they are applicable to those particular materials and the specific testing protocols of these test methods.

18.3 A type 1 inter-laboratory precision program for tensile strength was conducted during the periods listed with the number of laboratories listed and the o-ring materials listed in **Table 5**. In each laboratory, two single tests were performed on the o-rings by 2 different technicians on 2 different days for a

TABLE 5 Precision Parameters for Test Methods **D297, Density (Type 1 Precision), Size 2-214 O-rings**

Material	Period	Units Number of Laboratories (M/V) ^A	Mg/cm ³		<i>r</i>	<i>r</i>	SR	<i>R</i>	(R)
			Mean Level	<i>Sr</i>					
NBR; AMS-P-5315B	Sep-Dec 2018	10(0/1)	1.2665	0.00268	0.00758	0.5983	0.00584	0.01652	1.3040
FVMQ; MIL-DTL-25988C; T1, C1, G60	Sep 2020	5(1/0)	1.4783	0.00362	0.01024	0.6925	0.00362	0.01024	0.6925
FVMQ; MIL-DTL-25988C; T1, C3, G75	Oct '19; Feb '20	8(0/0)	1.5029	0.00346	0.00979	0.6512	0.00604	0.01709	1.1372
FKM; AMS7287	May-Jun 2019	9(1/1)	1.7654	0.00524	0.01483	0.8402	0.00941	0.02663	1.5083
FKM; AMS7259E	April 2021	3(0/0)	1.8406	0.00483	0.01365	0.7419	0.00483	0.01365	0.7419
Average			1.5707						
Pooled Values				0.00407	0.01153	0.7339	0.00625	0.01769	1.1264

^A M=Mean outliers; V=Variability outliers

total of four replicates. A test result is the value obtained from a single determination. Both repeatability and reproducibility represent short-term (daily) testing conditions. Acceptable difference values were not measured.

18.4 Relative Density Repeatability—The **relative** repeatability limits, (*r*), of this test method are as shown in **Table 5** for each of the materials listed in the table. The difference between two single test results (or determinations) found on identical test material under the repeatability conditions prescribed for this test will exceed the repeatability value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results that differ by more than the appropriate value from **Table 5** must be suspected of being from different populations and some appropriate action taken.

NOTE 14—Appropriate action may be an investigation of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, etc., which generated the two test results.

18.5 Relative Density Reproducibility—The **relative** reproducibility limits, (*R*), of this test method are as shown in **Table 5** for each of the materials listed in the table. The difference between two single and independent test results found by two operators working under the prescribed reproducibility conditions in different laboratories on identical test material will exceed the reproducibility value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results produced in different laboratories that differ by more than the appropriate value from **Table 5** must be suspected of being from different populations and some appropriate investigative or technical/commercial action taken.

NOTE 15—Appropriate action may be an investigation in each laboratory of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, laboratories, etc., which generated the two test results. Technical/commercial actions are mutually resolved by the laboratories.

18.6 Bias—Bias is the difference between a test value and a reference value. However, for this test method, bias has not been determined.

19. Immersion Test

19.1 Nature of Test—For determination of the changes in physical properties after liquid immersion, the definitions, standard test liquid descriptions, and general technique shall be in accordance with Test Method **D471**. The detailed procedure for O-rings, outlined in this section however, shall take precedence in case of conflict.

19.2 Apparatus:

19.2.1 The apparatus specified in Test Method **D471** for volatile liquids shall be used.

19.2.2 Standard Heating Device shall be an aluminum block heater or oil bath heater. The temperature shall be maintained within $\pm 1^\circ\text{C}$ (1.8°F).

19.3 Test Specimens—The test specimen shall consist of an entire O-ring when the outside diameter is small enough to permit installation in a test tube with the fluid level adjusted in accordance with **19.4.2**. For sizes too large in circumference to

insert as described, the O-ring shall be cut into segments. The specimen shall be a segment 90 ± 2 mm (3.5 ± 0.08 in.) in length. All tests for hardness, tension, elongation, and volume change shall be made in triplicate. The same three specimens may be used for all tests with hardness and volume determinations made prior to stress-strain tests. In the case of liquids that are volatile at room temperature, the specimen must be quickly placed back into the test liquid after hardness and volume test and prior to tension testing.

19.4 Procedure:

19.4.1 Suspend three specimens at one level in the test tube by the use of corrosion-resistant wire; separate the specimens by bending small loops in the wire or by the use of corrosion-resistant washers. For whole O-rings 6 mm (0.25 in.) in cross section and larger, place one specimen in each test tube. For cross-section sizes less than 4 mm (0.16 in.) place three specimens in each test tube.

19.4.2 Suspend the specimens vertically so that 25 mm (1.0 in.) of liquid is between the lower extremity of the specimen and the bottom of the tube. Add enough liquid to cover the specimens to a depth of 25 mm (1.0 in.) over the upper extremity of the specimens.

NOTE 16—For liquid mixtures, where the volume percent of the most minor constituent is known, the liquid volume of that constituent shall be 15 times the volume of the test piece.

For liquid mixtures where the volume percent of the most minor constituent is not known, then that volume is assumed to be 1 %, and the volume of the test liquid will be 1500 times the volume of the test pieces.

If the above procedure is used, operators should be aware that the test tube specified in Test Method **D471** may not be adequate and alternative containers and heating system may be required.

NOTE 17—A problem that can occur with large whole specimens is cracking at the point of maximum bend at the upper or lower portion, or both, of the specimen. When cracking is observed upon removal from the oil, or when breaks occur at these points during tension tests, a retest shall be made on segments cut from an O-ring.

19.4.3 Make volume change determinations on a minimum specimen weight of 0.005 N (0.5 gf). This may be accomplished by using two or more pieces for the specimen in the case of very small O-rings (see **Note 16**).

20. Immersion Test Precision and Bias

20.1 These precision statements have been prepared in accordance with Practice **D4483**. Refer to this practice for terminology and other statistical details.

20.2 Precision—The precision results in this precision and bias section give an estimate of the precision of these test methods with the materials (rubbers, carbon blacks, etc.) used in the interlaboratory program described in **Table 6A** through **Table 6H**. The precision parameters should not be used for acceptance or rejection testing of any group of materials without documentation that they are applicable to those particular materials and the specific testing protocols of these test methods.

20.3 A type 1 inter-laboratory precision program for volume change in lubricants was conducted during the periods listed with the number of laboratories listed with the o-ring materials the test conditions and lubricants listed in **Table 6A**. In each laboratory, two single tests were performed on the o-rings by 2

TABLE 6 A Precision Parameters for Test Method D471, Volume Change, Effect of Liquids (Type 1 Precision), Size 2-214 O-rings

Material	Period	Units Test Conditions	Percent Number of Laboratories (M/V) ^A	Mean Level	Sr	r	(r)	SR	R	(R)
FVMQ; MIL-DTL-25988C; T1, C3, G75	Oct '19	AMS3021 at 175°C for 70 h	4(1/1)	7.2	0.59	1.68	23.4	0.59	1.68	23.4
FVMQ; MIL-DTL-25988C; T1, C1, G60	Sep 2020	AMS3021 at 150°C for 70 h	4(0/1)	14.0	0.56	1.58	11.3	3.77	10.68	76.6
FKM; AMS7259E	April 2021	AMS 3023 at 200°C for 70 h	2(0/0)	14.0	1.41	4.00	28.6	1.41	4.00	28.6
FKM; AMS7287	May-Jun 2019	AMS3085 at 200°C for 70 h	6(0/1)	16.8	0.59	1.67	10.0	1.69	4.78	28.4
Average Pooled Values				13.0	0.87	2.46	18.9	2.20	6.24	48.1

^A M=Mean outliers; V=Variability outliers

different technicians on 2 different days for a total of four replicates. A test result is the value obtained from a single determination. Both repeatability and reproducibility represent short-term (daily) testing conditions. Acceptable difference values were not measured.

20.4 Relative versus absolute repeatability and reproducibility limits. For volume change in lubricants, relative precision is statistically preferred. However, since the measurement units are in percent and relative precision is a percent, the expression of relative precision would be calculated as a percent of a percent. This can be difficult to apply when evaluating the testing precision. Therefore, absolute precision is preferred for practical applications.

20.5 *Volume Change in Lubricants Repeatability*—The **absolute** repeatability limits, r, of this test method are as shown in **Table 6A** for each of the materials listed in the table. The difference between two single test results (or determinations) found on identical test material under the repeatability conditions prescribed for this test will exceed the repeatability value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results that differ by more than the appropriate value from **Table 6A** must be suspected of being from different populations and some appropriate action taken.

NOTE 18—Appropriate action may be an investigation of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, etc., which generated the two test results.

20.6 *Volume Change in Lubricants Reproducibility*—The **absolute** reproducibility limits, R, of this test method are as shown in **Table 6A** for each of the materials listed in the table. The difference between two single and independent test results found by two operators working under the prescribed reproducibility conditions in different laboratories on identical test material will exceed the reproducibility value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results produced in different laboratories that differ by more than the appropriate value from **Table 6A** must be suspected of being

from different populations and some appropriate investigative or technical/commercial action taken.

NOTE 19—Appropriate action may be an investigation in each laboratory of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, laboratories, etc., which generated the two test results. Technical/commercial actions are mutually resolved by the laboratories.

20.7 *Bias*—Bias is the difference between a test value and a reference value. However, for this test method, bias has not been determined.

20.8 A type 1 inter-laboratory precision program for volume change in fuels was conducted during the periods listed with the number of laboratories listed with the o-ring materials the test conditions and fuels listed in **Table 6B**. In each laboratory, two single tests were performed on the o-rings by 2 different technicians on 2 different days for a total of four replicates. A test result is the value obtained from a single determination. Both repeatability and reproducibility represent short-term (daily) testing conditions. Acceptable difference values were not measured.

20.9 Relative versus absolute repeatability and reproducibility limits. For volume change in fuels, relative precision is statistically preferred. However, since the measurement units are in percent and relative precision is a percent, the expression of relative precision would be calculated as a percent of a percent. This can be difficult to apply when evaluating the testing precision. Therefore, absolute precision is preferred for practical applications.

20.10 *Volume Change in Fuels Repeatability*—The **absolute** repeatability limits, r, of this test method are as shown in **Table 6B** for each of the materials listed in the table. The difference between two single test results (or determinations) found on identical test material under the repeatability conditions prescribed for this test will exceed the repeatability value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results that differ by more than the appropriate value from **Table 6B** must be suspected of being from different populations and some appropriate action taken.

TABLE 6 B Precision Parameters for Test Method D471, Volume Change, Effect of Liquids (Type 1 Precision), Size 2-214 O-rings (continued)

Material	Period	Units Test Condi- tions	Percent Number of Laboratories (M/V) ^A	Mean Level	Sr	r	(r)	SR	R	(R)
FKM; AMS7259E	April 2021	Fuel B at 23°C for 70 h	2(0/0)	1.0						
NBR; AMS-P- 5315B	Sep-Dec 2018	Fuel A at 23°C for 72 h	8(1/1)	2.4	0.43	1.21	49.8	0.57	1.61	66.3
FKM; AMS7287	May-Jun 2019	Fuel B at 23°C for 70 h	6(0/0)	2.8	0.42	1.20	43.1	0.52	1.47	52.8
FVMQ; MIL- DTL-25988C; T1, C3, G75	Oct '19	AMS2629 at 23.9°C for 22 h	6(1/0)	4.3	0.43	1.21	27.9	0.59	1.66	38.4
FVMQ; MIL- DTL-25988C; T1, C1, G60	Sep 2020	AMS2629 at 23.9°C for 22 h	6(1/1)	6.5	0.38	1.07	16.4	0.49	1.39	21.4
NBR; AMS-P- 5315B	Sep-Dec 2018	Fuel B at 23°C for 72 h	9(1/1)	30.0	0.76	2.15	7.2	1.31	3.71	12.4
Average Pooled Values				7.8	0.50	1.42	18.1	0.76	2.15	27.5

^A M=Mean outliers; V=Variability outliers

NOTE 20—Appropriate action may be an investigation of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, etc., which generated the two test results.

20.11 *Volume Change in Fuels Reproducibility*—The **absolute** reproducibility limits, R, of this test method are as shown in Table 6B for each of the materials listed in the table. The difference between two single and independent test results found by two operators working under the prescribed reproducibility conditions in different laboratories on identical test material will exceed the reproducibility value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results produced in different laboratories that differ by more than the appropriate value from Table 6B must be suspected of being from different populations and some appropriate investigative or technical/commercial action taken.

NOTE 21—Appropriate action may be an investigation in each laboratory of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples,

laboratories, etc., which generated the two test results. Technical/commercial actions are mutually resolved by the laboratories.

20.12 *Bias*—Bias is the difference between a test value and a reference value. However, for this test method, bias has not been determined.

20.13 A type 1 inter-laboratory precision program for hardness change in lubricants was conducted during the periods listed with the number of laboratories listed with the o-ring materials the test conditions and lubricants listed in Table 6C. In each laboratory, two single tests were performed on the o-rings by 2 different technicians on 2 different days for a total of four replicates. A test result is the value obtained from a single determination. Both repeatability and reproducibility represent short-term (daily) testing conditions. Acceptable difference values were not measured.

20.14 *Hardness Change in Lubricants Repeatability*—The **absolute** repeatability limits, r, of this test method are as shown in Table 6C for each of the materials listed in the table. The

TABLE 6 C Precision Parameters for Test Method D471, Hardness Change, Effect of Liquids (Type 1 Precision), Size 2-214 O-rings (continued)

Material	Period	Units Test Condi- tions	Percent Number of Laboratories (M/V) ^A	Mean Level	Sr	r	(r)	SR	R	(R)
FKM; AMS7259E	April 2021	AMS 3023 at 200°C for 70 h	2(0/0)	-7.6	2.07	5.86	-76.9	2.07	5.86	-76.9
FVMQ; MIL- DTL-25988C; T1, C1, G60	Sep 2020	AMS3021 at 150°C for 70 h	4(0/1)	-7.6	0.90	2.54	-33.6	2.37	6.71	-88.9
FVMQ; MIL- DTL-25988C; T1, C3, G75	Oct '19	AMS3021 at 175°C for 70 h	4(0/0)	-5.0	1.36	3.84	-77.4	2.05	5.79	-116.7
FKM; AMS7287	May-Jun 2019	AMS3085 at 200°C for 70 h	6(0/1)	-4.4	1.82	5.14	-117.3	2.06	5.82	-132.9
Average Pooled Values				-6.1	1.60	4.53	-73.8	2.14	6.06	-98.8

^A M=Mean outliers; V=Variability outliers

difference between two single test results (or determinations) found on identical test material under the repeatability conditions prescribed for this test will exceed the repeatability value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results that differ by more than the appropriate value from Table 6C must be suspected of being from different populations and some appropriate action taken.

NOTE 22—Appropriate action may be an investigation of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, etc., which generated the two test results.

20.15 *Hardness Change in Lubricants Reproducibility*—The **absolute** reproducibility limits, R, of this test method are as shown in Table 6C for each of the materials listed in the table. The difference between two single and independent test results found by two operators working under the prescribed reproducibility conditions in different laboratories on identical test material will exceed the reproducibility value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results produced in different laboratories that differ by more than the appropriate value from Table 6C must be suspected of being from different populations and some appropriate investigative or technical/commercial action taken.

NOTE 23—Appropriate action may be an investigation in each laboratory of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, laboratories, etc., which generated the two test results. Technical/commercial actions are mutually resolved by the laboratories.

20.16 *Bias*—Bias is the difference between a test value and a reference value. However, for this test method, bias has not been determined.

20.17 A type 1 inter-laboratory precision program for hardness change in fuels was conducted during the periods listed with the number of laboratories listed with the o-ring materials the test conditions and fuel listed in Table 6D. In each laboratory, two single tests were performed on the o-rings by 2 different technicians on 2 different days for a total of four replicates. A test result is the value obtained from a single determination. Both repeatability and reproducibility represent

short-term (daily) testing conditions. Acceptable difference values were not measured.

20.18 *Hardness Change in Fuels Repeatability*—The **absolute** repeatability limits, r, of this test method are as shown in Table 6D for each of the materials listed in the table. The difference between two single test results (or determinations) found on identical test material under the repeatability conditions prescribed for this test will exceed the repeatability value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results that differ by more than the appropriate value from Table 6D must be suspected of being from different populations and some appropriate action taken.

NOTE 24—Appropriate action may be an investigation of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, etc., which generated the two test results.

20.19 *Hardness Change in Fuels Reproducibility*—The **absolute** reproducibility limits, R, of this test method are as shown in Table 6D for each of the materials listed in the table. The difference between two single and independent test results found by two operators working under the prescribed reproducibility conditions in different laboratories on identical test material will exceed the reproducibility value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results produced in different laboratories that differ by more than the appropriate value from Table 6D must be suspected of being from different populations and some appropriate investigative or technical/commercial action taken.

NOTE 25—Appropriate action may be an investigation in each laboratory of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, laboratories, etc., which generated the two test results. Technical/commercial actions are mutually resolved by the laboratories.

20.20 *Bias*—Bias is the difference between a test value and a reference value. However, for this test method, bias has not been determined.

20.21 A type 1 inter-laboratory precision program for tensile strength change in lubricants was conducted during the

TABLE 6 D Precision Parameters for Test Method D471, Hardness Change, Effect of Liquids (Type 1 Precision), Size 2-214 O-rings (continued)

Material	Period	Units Test Conditions	Percent Number of Laboratories (M/V) ^A	Mean Level	Sr	r	(r)	SR	R	(R)
FVMQ; MIL-DTL-25988C; T1, C3, G75	Oct '19	AMS2629 at 23.9°C for 22 h	5(0/1)	-4.6	0.89	2.52	-55.4	1.50	4.24	-93.1
FVMQ; MIL-DTL-25988C; T1, C1, G60	Sep 2020	AMS2629 at 23.9°C for 22 h	5(1/0)	-3.1	0.70	1.99	-65.2	1.07	3.02	-98.9
FKM; AMS7259E	April 2021	Fuel B at 23°C for 70 h	2(0/0)	-0.5	1.29	3.65	-730.7	1.80	5.10	-1020.4
FKM; AMS7287	May-Jun 2019	Fuel B at 23°C for 70 h	6(1/1)	0.0	1.06	3.00	-7503.1	1.06	3.01	-7520.5
Average Pooled Values				-2.0	1.01	2.86	-140.3	1.39	3.94	-193.5

^A M=Mean outliers; V=Variability outliers

periods listed with the number of laboratories listed with the o-ring materials the test conditions and lubricants listed in Table 6E. In each laboratory, two single tests were performed on the o-rings by 2 different technicians on 2 different days for a total of four replicates. A test result is the value obtained from a single determination. Both repeatability and reproducibility represent short-term (daily) testing conditions. Acceptable difference values were not measured.

20.22 *Tensile Strength Change in Lubricants Repeatability*—The **absolute** repeatability limits, r, of this test method are as shown in Table 6E for each of the materials listed in the table. The difference between two single test results (or determinations) found on identical test material under the repeatability conditions prescribed for this test will exceed the repeatability value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results that differ by more than the appropriate value from Table 6E must be suspected of being from different populations and some appropriate action taken.

NOTE 26—Appropriate action may be an investigation of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, etc., which generated the two test results.

20.23 *Tensile Strength Change in Lubricants Reproducibility*—The **absolute** reproducibility limits, R, of this test method are as shown in Table 6E for each of the materials listed in the table. The difference between two single and independent test results found by two operators working under the prescribed reproducibility conditions in different laboratories on identical test material will exceed the reproducibility value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results produced in different laboratories that differ by more than the appropriate value from Table 6E must be suspected of being from different populations and some appropriate investigative or technical/commercial action taken.

NOTE 27—Appropriate action may be an investigation in each laboratory of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples,

laboratories, etc., which generated the two test results. Technical/commercial actions are mutually resolved by the laboratories.

20.24 *Bias*—Bias is the difference between a test value and a reference value. However, for this test method, bias has not been determined.

20.25 A type 1 inter-laboratory precision program for tensile strength change in fuels was conducted during the periods listed with the number of laboratories listed with the o-ring materials the test conditions and lubricants listed in Table 6F. In each laboratory, two single tests were performed on the o-rings by 2 different technicians on 2 different days for a total of four replicates. A test result is the value obtained from a single determination. Both repeatability and reproducibility represent short-term (daily) testing conditions. Acceptable difference values were not measured.

20.26 *Tensile Strength Change in Fuels Repeatability*—The **absolute** repeatability limits, r, of this test method are as shown in Table 6F for each of the materials listed in the table. The difference between two single test results (or determinations) found on identical test material under the repeatability conditions prescribed for this test will exceed the repeatability value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results that differ by more than the appropriate value from Table 6F must be suspected of being from different populations and some appropriate action taken.

NOTE 28—Appropriate action may be an investigation of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, etc., which generated the two test results.

20.27 *Tensile Strength Change in Fuels Reproducibility*—The **absolute** reproducibility limits, R, of this test method are as shown in Table 6F for each of the materials listed in the table. The difference between two single and independent test results found by two operators working under the prescribed reproducibility conditions in different laboratories on identical test material will exceed the reproducibility value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test

TABLE 6 E Precision Parameters for Test Method D471, Tensile Strength Change, Effect of Liquids (Type 1 Precision), Size 2-214 O-rings (continued)

Material	Period	Units Test Conditions	Percent Number of Laboratories (M/V) ^A	Mean Level	Sr	r	(r)	SR	R	(R)
FVMQ; MIL-DTL-25988C; T1, C3, G75	Oct '19	AMS3021 at 175°C for 70 h	4(0/0)	-54.9	6.74	19.09	-34.8	6.74	19.09	-34.8
FVMQ; MIL-DTL-25988C; T1, C1, G60	Sep 2020	AMS3021 at 150°C for 70 h	4(0/0)	-40.2	17.04	48.21	-120.0	18.56	52.53	-130.7
FKM; AMS7287	May-Jun 2019	AMS3085 at 200°C for 70 h	6(0/0)	-14.0	9.04	25.59	-183.4	9.91	28.04	-200.9
FKM; AMS7259E	April 2021	AMS 3023 at 200°C for 70 h	2(0/0)	-9.0	23.34	66.05	-733.9	34.76	98.38	-1093.1
Average Pooled Values				-29.5	15.51	43.89	-148.8	20.60	58.28	-197.5

^A M=Mean outliers; V=Variability outliers

TABLE 6 F Precision Parameters for Test Method D471, Tensile Strength Change, Effect of Liquids (Type 1 Precision), Size 2-214 O-rings (continued)

Material	Period	Units Test Condi- tions	Percent Number of Laboratories (M/V) ^A	Mean Level	Sr	r	(r)	SR	R	(R)
FVMQ; MIL- DTL-25988C; T1, C1, G60	Sep 2020	AMS2629 at 23.9°C for 22 h	6(1/0)	-14.5	17.09	48.37	-333.3	17.09	48.37	-333.3
FVMQ; MIL- DTL-25988C; T1, C3, G75	Oct '19	AMS2629 at 23.9°C for 22 h	6(0/1)	-13.7	6.83	19.33	-140.8	8.50	24.05	-175.1
FKM; AMS7287	May-Jun 2019	Fuel B at 23°C for 70 h	6(1/0)	-10.0	8.26	23.39	-235.1	8.26	23.39	-235.1
FKM; AMS7259E	April 2021	Fuel B at 23°C for 70 h	2(0/0)	-1.6	32.38	91.63	-5638.6	35.92	101.65	-6255.6
Average Pooled Values				-10.0	19.07	53.98	-542.3	20.75	58.73	-590.0

^A M=Mean outliers; V=Variability outliers

results produced in different laboratories that differ by more than the appropriate value from **Table 6F** must be suspected of being from different populations and some appropriate investigative or technical/commercial action taken.

NOTE 29—Appropriate action may be an investigation in each laboratory of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, laboratories, etc., which generated the two test results. Technical/commercial actions are mutually resolved by the laboratories.

20.28 *Bias*—Bias is the difference between a test value and a reference value. However, for this test method, bias has not been determined.

20.29 A type 1 inter-laboratory precision program for ultimate elongation change in lubricants was conducted during the periods listed with the number of laboratories listed with the o-ring materials the test conditions and lubricants listed in **Table 6G**. In each laboratory, two single tests were performed on the o-rings by 2 different technicians on 2 different days for a total of four replicates. A test result is the value obtained from a single determination. Both repeatability and reproducibility represent short-term (daily) testing conditions. Acceptable difference values were not measured.

20.30 Relative versus absolute repeatability and reproducibility limits. For ultimate elongation change in lubricants, relative precision is statistically preferred. However, since the measurement units are in percent and relative precision is a percent, the expression of relative precision would be calculated as a percent of a percent. This can be difficult to apply when evaluating the testing precision. Therefore, absolute precision is preferred for practical applications.

20.31 *Ultimate Elongation Change in Lubricants Repeatability*—The **absolute** repeatability limits, r, of this test method are as shown in **Table 6G** for each of the materials listed in the table. The difference between two single test results (or determinations) found on identical test material under the repeatability conditions prescribed for this test will exceed the repeatability value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results that differ by more than the appropriate value from **Table 6G** must be suspected of being from different populations and some appropriate action taken.

NOTE 30—Appropriate action may be an investigation of the test

TABLE 6 G Precision Parameters for Test Method D471, Elongation Change, Effect of Liquids (Type 1 Precision), Size 2-214 O-rings (continued)

Material	Period	Units Test Condi- tions	Percent Number of Laboratories (M/V) ^A	Mean Level	Sr	r	(r)	SR	R	(R)
FVMQ; MIL- DTL-25988C; T1, C3, G75	Oct '19	AMS3021 at 175°C for 70 h	4(0/0)	-46.1	8.49	24.03	-52.1	8.49	24.03	-52.1
FVMQ; MIL- DTL-25988C; T1, C1, G60	Sep 2020	AMS3021 at 150°C for 70 h	4(0/0)	-22.7	15.20	43.00	-189.3	16.96	48.01	-211.4
FKM; AMS7259E	April 2021	AMS 3023 at 200°C for 70 h	2(0/0)	-0.1	19.22	54.38	-43507.2	19.22	54.38	-43507.2
FKM; AMS7287	May-Jun 2019	AMS3085 at 200°C for 70 h	6(1/0)	11.8	14.24	40.31	341.3	14.24	40.31	341.3
Average Pooled Values				-14.3	14.79	41.86	-292.9	15.26	43.20	-302.3

^A M=Mean outliers; V=Variability outliers

method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, etc., which generated the two test results.

20.32 Ultimate Elongation Change in Lubricants Reproducibility—The **absolute** reproducibility limits, R, of this test method are as shown in **Table 6G** for each of the materials listed in the table. The difference between two single and independent test results found by two operators working under the prescribed reproducibility conditions in different laboratories on identical test material will exceed the reproducibility value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results produced in different laboratories that differ by more than the appropriate value from **Table 6G** must be suspected of being from different populations and some appropriate investigative or technical/commercial action taken.

NOTE 31—Appropriate action may be an investigation in each laboratory of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, laboratories, etc., which generated the two test results. Technical/commercial actions are mutually resolved by the laboratories.

20.33 Bias—Bias is the difference between a test value and a reference value. However, for this test method, bias has not been determined.

20.34 A type 1 inter-laboratory precision program for ultimate elongation change in fuels was conducted during the periods listed with the number of laboratories listed with the o-ring materials the test conditions and lubricants listed in **Table 6H**. In each laboratory, two single tests were performed on the o-rings by 2 different technicians on 2 different days for a total of four replicates. A test result is the value obtained from a single determination. Both repeatability and reproducibility represent short-term (daily) testing conditions. Acceptable difference values were not measured.

20.35 Ultimate Elongation Change in Fuels Repeatability—The **absolute** repeatability limits, r, of this test method are as shown in **Table 6H** for each of the materials listed in the table. The difference between two single test results (or determinations) found on identical test material under the repeatability conditions prescribed for this test will exceed the repeatability value on an average of not more than once in 20 determinations

in the normal and correct operation of the method. Two single test results that differ by more than the appropriate value from **Table 6H** must be suspected of being from different populations and some appropriate action taken.

NOTE 32—Appropriate action may be an investigation of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, etc., which generated the two test results.

20.36 Ultimate Elongation Change in Fuels Reproducibility—The **absolute** reproducibility limits, R, of this test method are as shown in **Table 6H** for each of the materials listed in the table. The difference between two single and independent test results found by two operators working under the prescribed reproducibility conditions in different laboratories on identical test material will exceed the reproducibility value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results produced in different laboratories that differ by more than the appropriate value from **Table 6H** must be suspected of being from different populations and some appropriate investigative or technical/commercial action taken.

NOTE 33—Appropriate action may be an investigation in each laboratory of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, laboratories, etc., which generated the two test results. Technical/commercial actions are mutually resolved by the laboratories.

20.37 Bias—Bias is the difference between a test value and a reference value. However, for this test method, bias has not been determined.

21. Heat Aging Test

21.1 Procedure—The general procedures for heat aging O-rings shall be in accordance with Test Method **D573**, with the following exception: When required by the material specification, or when agreed upon by the purchaser and the seller, the procedure shall be in accordance with Test Method **D865**. The report shall state which method was employed.

22. Heat Aging Test Precision and Bias

22.1 These precision statements have been prepared in accordance with Practice **D4483**. Refer to this practice for terminology and other statistical details.

TABLE 6 H Precision Parameters for Test Method D471, Elongation Change, Effect of Liquids (Type 1 Precision), Size 2-214 O-rings (continued)

Material	Period	Units Test Conditions	Percent Number of Laboratories (M/V) ^A	Mean Level	Sr	r	(r)	SR	R	(R)
FVMQ; MIL-DTL-25988C; T1, C3, G75	Oct '19	AMS2629 at 23.9°C for 22 h	6(0/0)	-4.2	9.41	26.64	-640.3	11.27	31.90	-766.6
FVMQ; MIL-DTL-25988C; T1, C1, G60	Sep 2020	AMS2629 at 23.9°C for 22 h	6(1/0)	-2.8	15.20	43.03	-1515.1	15.20	43.03	-1515.1
FKM; AMS7287	May-Jun 2019	Fuel B at 23°C for 70 h	6(0/0)	4.1	10.70	30.29	741.7	10.70	30.29	741.7
FKM; AMS7259E	April 2021	Fuel B at 23°C for 70 h	2(0/0)	7.3	15.01	42.47	585.8	15.01	42.47	585.8
Average				1.1						
Pooled Values					12.84	36.34	3355.5	13.21	37.38	3451.8

^A M=Mean outliers; V=Variability outliers

22.2 *Precision*—The precision results in this precision and bias section give an estimate of the precision of these test methods with the materials (rubbers, carbon blacks, etc.) used in the interlaboratory program described in Table 7A through Table 7D. The precision parameters should not be used for acceptance or rejection testing of any group of materials without documentation that they are applicable to those particular materials and the specific testing protocols of these test methods.

22.3 A type 1 inter-laboratory precision program for hardness change in air was conducted during the periods listed with the number of laboratories listed with the o-ring materials and the test conditions listed in Table 7A. In each laboratory, two single tests were performed on the o-rings by 2 different technicians on 2 different days for a total of four replicates. A test result is the value obtained from a single determination. Both repeatability and reproducibility represent short-term (daily) testing conditions. Acceptable difference values were not measured.

22.4 *Hardness Change in Air Repeatability*—The absolute repeatability limits, *r*, of this test method are as shown in Table 7A for each of the materials listed in the table. The difference between two single test results (or determinations) found on identical test material under the repeatability conditions prescribed for this test will exceed the repeatability value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results that differ by more than the appropriate value from Table 7A must be suspected of being from different populations and some appropriate action taken.

NOTE 34—Appropriate action may be an investigation of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, etc., which generated the two test results.

22.5 *Hardness Change in Air Reproducibility*—The absolute reproducibility limits, *R*, of this test method are as shown in Table 7A for each of the materials listed in the table. The difference between two single and independent test results found by two operators working under the prescribed reproducibility conditions in different laboratories on identical test material will exceed the reproducibility value on an average of not more than once in 20 determinations in the normal and

correct operation of the method. Two single test results produced in different laboratories that differ by more than the appropriate value from Table 7A must be suspected of being from different populations and some appropriate investigative or technical/commercial action taken.

NOTE 35—Appropriate action may be an investigation in each laboratory of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, laboratories, etc., which generated the two test results. Technical/commercial actions are mutually resolved by the laboratories.

22.6 *Bias*—Bias is the difference between a test value and a reference value. However, for this test method, bias has not been determined.

22.7 A type 1 inter-laboratory precision program for tensile strength change in air was conducted during the periods listed with the number of laboratories listed with the o-ring materials and the test conditions listed in Table 7B. In each laboratory, two single tests were performed on the o-rings by 2 different technicians on 2 different days for a total of four replicates. A test result is the value obtained from a single determination. Both repeatability and reproducibility represent short-term (daily) testing conditions. Acceptable difference values were not measured.

22.8 *Tensile Strength Change in Air Repeatability*—The absolute repeatability limits, *r*, of this test method are as shown in Table 7B for each of the materials listed in the table. The difference between two single test results (or determinations) found on identical test material under the repeatability conditions prescribed for this test will exceed the repeatability value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results that differ by more than the appropriate value from Table 7B must be suspected of being from different populations and some appropriate action taken.

NOTE 36—Appropriate action may be an investigation of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, etc., which generated the two test results.

22.9 *Tensile Strength Change in Air Reproducibility*—The absolute reproducibility limits, *R*, of this test method are as shown in Table 7B for each of the materials listed in the table. The difference between two single and independent test results

TABLE 7 A Precision Parameters for Test Method D573, Hardness Change, Deterioration in an Air Oven (Type 1 Precision), Size 2-214 O-rings

Material	Period	Units Test Conditions	Percent Number of Laboratories (M/V) ^A	Mean Level	Sr	r	(r)	SR	R	(R)
FVMQ; MIL-DTL-25988C; T1, C3, G75	Oct '19	Air at 225°C for 70 h	4(0/0)	0.8	0.63	1.78	224.3	1.50	4.24	534.0
FVMQ; MIL-DTL-25988C; T1, C1, G60	Sep 2020	Air at 200°C for 70 h	4(0/0)	2.0	0.67	1.90	93.0	0.93	2.62	128.3
FKM; AMS7259E	April 2021	Air at 270°C for 70 h	2(0/0)	3.6	1.86	5.26	145.2	1.86	5.26	145.2
Average Pooled Values				2.2	1.20	3.39	157.4	1.48	4.19	194.3

^A M=Mean outliers; V=Variability outliers

TABLE 7 B Precision Parameters for Test Method D573, Tensile Strength Change, Deterioration in an Air Oven (Type 1 Precision), Size 2-214 O-rings (continued)

Material	Period	Units Test Con- ditions	Percent Number of Laboratories (M/V) ^A	Mean Level	Sr	r	(r)	SR	R	(R)
FVMQ; MIL- DTL-25988C; T1, C3, G75	Oct '19	Air at 225°C for 70 h	4(0/0)	-21.2	7.61	21.53	-101.5	7.61	21.53	-101.5
FKM; AMS7259E	April 2021	Air at 270°C for 70 h	2(0/0)	-5.6	17.70	50.10	-902.7	25.83	73.10	-1317.1
FVMQ; MIL- DTL-25988C; T1, C1, G60	Sep 2020	Air at 200°C for 70 h	4(1/0)	-2.4	11.62	32.88	-1360.8	11.62	32.88	-1360.8
Average				-9.7						
Pooled Values					12.99	36.76	-377.9	16.93	47.92	-492.6

^A M=Mean outliers; V=Variability outliers

found by two operators working under the prescribed reproducibility conditions in different laboratories on identical test material will exceed the reproducibility value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results produced in different laboratories that differ by more than the appropriate value from **Table 7B** must be suspected of being from different populations and some appropriate investigative or technical/commercial action taken.

NOTE 37—Appropriate action may be an investigation in each laboratory of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, laboratories, etc., which generated the two test results. Technical/commercial actions are mutually resolved by the laboratories.

22.10 *Bias*—Bias is the difference between a test value and a reference value. However, for this test method, bias has not been determined.

22.11 A type 1 inter-laboratory precision program for ultimate elongation change in air was conducted during the periods listed with the number of laboratories listed with the o-ring materials and the test conditions listed in **Table 7C**. In each laboratory, two single tests were performed on the o-rings by 2 different technicians on 2 different days for a total of four replicates. A test result is the value obtained from a single determination. Both repeatability and reproducibility represent short-term (daily) testing conditions. Acceptable difference values were not measured.

22.12 Relative versus absolute repeatability and reproducibility limits. For ultimate elongation change in air, relative precision is statistically preferred. However, since the measurement units are in percent and relative precision is a percent, the expression of relative precision would be calculated as a percent of a percent. This can be difficult to apply when evaluating the testing precision. Therefore, absolute precision is preferred for practical applications.

22.13 *Ultimate Elongation Change in Air Repeatability*—The **absolute** repeatability limits, r, of this test method are as shown in **Table 7C** for each of the materials listed in the table. The difference between two single test results (or determinations) found on identical test material under the repeatability conditions prescribed for this test will exceed the repeatability value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results that differ by more than the appropriate value from **Table 7C** must be suspected of being from different populations and some appropriate action taken.

NOTE 38—Appropriate action may be an investigation of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, etc., which generated the two test results.

22.14 *Ultimate Elongation Change in Air Reproducibility*—The **absolute** reproducibility limits, R, of this test method are as shown in **Table 7C** for each of the materials listed in the table. The difference between two single and independent test

TABLE 7 C Precision Parameters for Test Method D573, Elongation Change, Deterioration in an Air Oven (Type 1 Precision), Size 2-214 O-rings (continued)

Material	Period	Units Test Con- ditions	Percent Number of Laboratories (M/V) ^A	Mean Level	Sr	r	(r)	SR	R	(R)
FVMQ; MIL- DTL-25988C; T1, C3, G75	Oct '19	Air at 225°C for 70 h	4(0/0)	-16.9	7.46	21.11	-125.0	7.96	22.53	-133.4
FVMQ; MIL- DTL-25988C; T1, C1, G60	Sep 2020	Air at 200°C for 70 h	4(0/0)	-4.5	9.31	26.35	-587.3	9.31	26.35	-587.3
FKM; AMS7259E	April 2021	Air at 270°C for 70 h	2(0/0)	0.0	11.24	31.82	127289.2	11.24	31.82	127289.2
Average				-7.1						
Pooled Values					9.47	26.79	-376.5	9.60	27.17	-381.9

^A M=Mean outliers; V=Variability outliers

results found by two operators working under the prescribed reproducibility conditions in different laboratories on identical test material will exceed the reproducibility value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results produced in different laboratories that differ by more than the appropriate value from Table 7C must be suspected of being from different populations and some appropriate investigative or technical/commercial action taken.

NOTE 39—Appropriate action may be an investigation in each laboratory of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, laboratories, etc., which generated the two test results. Technical/commercial actions are mutually resolved by the laboratories.

22.15 *Bias*—Bias is the difference between a test value and a reference value. However, for this test method, bias has not been determined.

22.16 A type 1 inter-laboratory precision program for weight loss in air was conducted during the periods listed with the number of laboratories listed with the o-ring materials and the test conditions listed in Table 7D. In each laboratory, two single tests were performed on the o-rings by 2 different technicians on 2 different days for a total of four replicates. A test result is the value obtained from a single determination. Both repeatability and reproducibility represent short-term (daily) testing conditions. Acceptable difference values were not measured.

22.17 Relative versus absolute repeatability and reproducibility limits. For weight loss in air, relative precision is statistically preferred. However, since the measurement units are in percent and relative precision is a percent, the expression of relative precision would be calculated as a percent of a percent. This can be difficult to apply when evaluating the testing precision. Therefore, absolute precision is preferred for practical applications.

22.18 *Weight Loss in Air Repeatability*—The **absolute** repeatability limits, *r*, of this test method are as shown in Table 7D for each of the materials listed in the table. The difference between two single test results (or determinations) found on identical test material under the repeatability conditions prescribed for this test will exceed the repeatability value on an average of not more than once in 20 determinations in the

normal and correct operation of the method. Two single test results that differ by more than the appropriate value from Table 7D must be suspected of being from different populations and some appropriate action taken.

NOTE 40—Appropriate action may be an investigation of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, etc., which generated the two test results.

22.19 *Weight Loss in Air Reproducibility*—The **absolute** reproducibility limits, *R*, of this test method are as shown in Table 7D for each of the materials listed in the table. The difference between two single and independent test results found by two operators working under the prescribed reproducibility conditions in different laboratories on identical test material will exceed the reproducibility value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results produced in different laboratories that differ by more than the appropriate value from Table 7D must be suspected of being from different populations and some appropriate investigative or technical/commercial action taken.

NOTE 41—Appropriate action may be an investigation in each laboratory of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, laboratories, etc., which generated the two test results. Technical/commercial actions are mutually resolved by the laboratories.

22.20 *Bias*—Bias is the difference between a test value and a reference value. However, for this test method, bias has not been determined.

23. Hardness Test

23.1 *Nature of Test*— It is difficult to obtain reliability in testing hardness of O-rings due to the curved surface and relatively small cross section thickness. With certain precautions and proper technique the following test methods may be employed. It is recommended that for O-rings of cross-sectional thickness less than 6 mm (0.25 in.) the microtester specified in Test Method D1415 be employed.

23.2 Procedure:

23.2.1 *Test Method D2240*—This procedure was developed to test rubber articles of 6-mm (0.25-in.) thickness minimum and employs an indenter point 2.5 mm (0.1 in.) in length. Use caution (*I*) to center the specimen so the point of the indenter

TABLE 7 D Precision Parameters for Test Method D573, Weight Loss, Deterioration in an Air Oven (Type 1 Precision), Size 2-214 O-rings (continued)

Material	Period	Units Test Conditions	Percent Number of Laboratories (M/V) ^A	Mean Level	Sr	r	(r)	SR	R	(R)
FVMQ; MIL-DTL-25988C; T1, C3, G75	Oct '19	Air at 225°C for 70 h	4(0/1)	0.034	0.134	0.380	1125.3	0.551	1.560	4623.0
FVMQ; MIL-DTL-25988C; T1, C1, G60	Sep 2020	Air at 200°C for 70 h	4(0/1)	0.073	0.029	0.082	111.7	0.449	1.271	1737.5
FKM; AMS7259E	April 2021	Air at 270°C for 70 h	2(0/0)	0.275	0.206	0.583	212.2	5.236	14.82	5387.9
Average Pooled Values				0.127	0.143	0.405	317.9	3.051	8.63	6782.1

^A M=Mean outliers; V=Variability outliers

reads on the center or thickest portion, and (2) to apply just enough pressure to bring the base of the instrument in close contact with the specimen without compressing the specimen. A holding fixture may be employed which will provide (1) limitation of travel of the durometer head and (2) a self-centering feature to eliminate alignment difficulties. A fixture that accomplishes these requirements is shown in Fig. 2. Any fixture or design principle that will accomplish the stipulations of (1) and (2) above may be employed. Do not make hardness determinations on the parting or “flash” line.

NOTE 42—The durometer as described in Test Method D2240 is not recommended for testing O-rings with cross section of less than 6 mm (0.25 in.). If hardness measurements are made with this instrument on O-rings of smaller cross section, the values obtained may be different from those obtained on a standard specimen. Fixtures as shown in 23.2.2 should be employed for such determinations. For O-rings of less than 3-mm (0.12-in.) cross section, the fixture should be designed, double depth, to hold vertically two cross-section thicknesses of the specimen. This is to increase the total thickness to greater than the length of the indenter point. The total depth of the groove must be adjusted to a depth that will reduce within ± 2 the hardness of a standard specimen of the same material.

23.2.2 Test Method D1415—This test method, using a micro tester (see 3.3 of Test Method D1415) permits the testing of very small specimens to 1-mm (0.04-in.) minimum thickness. This test method is recommended for determining the hardness of O-rings with a cross-sectional thickness of 6 mm (0.25 in.) and smaller.

NOTE 43—Values obtained with the micro hardness tester may differ from durometer values due to the difference in methods. The surface effect from aging or curing is more pronounced with the micro tester.

24. Hardness Test Precision and Bias

24.1 These precision statements have been prepared in accordance with Practice D4483. Refer to this practice for terminology and other statistical details.

24.2 Precision—The precision results in this precision and bias section give an estimate of the precision of these test methods with the materials (rubbers, carbon blacks, etc.) used in the interlaboratory program described in Table 8A through Table 8C. The precision parameters should not be used for acceptance or rejection testing of any group of materials without documentation that they are applicable to those particular materials and the specific testing protocols of these test methods.

24.3 A type 1 inter-laboratory precision program for durometer hardness type A was conducted during the periods listed with the number of laboratories listed and with the o-ring materials listed in Table 8A. In each laboratory, two single tests were performed on the o-rings by 2 different technicians on 2 different days for a total of four replicates. A test result is the value obtained from a single determination. Both repeatability and reproducibility represent short-term (daily) testing conditions. Acceptable difference values were not measured.

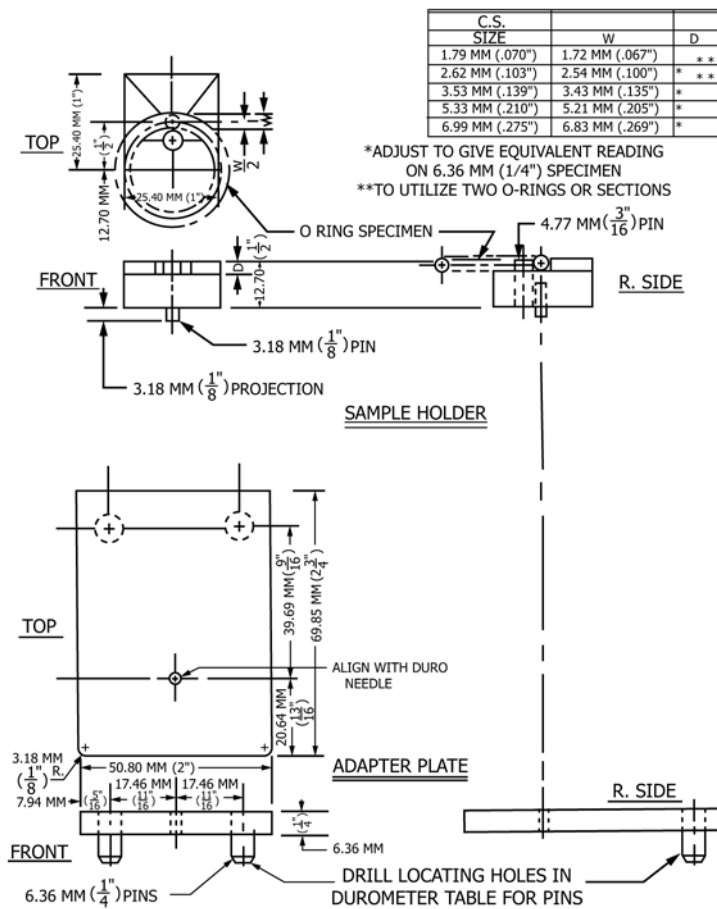


FIG. 2 Holding Fixture for Durometer in Hardness Test

TABLE 8 A Precision Parameters for Test Method D2240, Type A Durometer Hardness (Type 1 Precision), Size 2-214 O-rings

Material/ Specification	Period	Units Number of Laboratories (M/V) ^A	Durometer Units		r	(r)	SR	R	(R)
			Mean Level	Sr					
FVMQ; MIL- DTL-25988C; T1, C1, G60	Sep 2020	4(0/0)	63.8	0.45	1.29	2.0	4.06	11.49	18.0
NBR; AMS-P- 5315B	Sep-Dec 2018	9(0/1)	66.6	0.42	1.20	1.8	2.69	7.61	11.4
FKM; AMS7287	May-Jun 2019	9(0/1)	72.6	0.55	1.56	2.1	2.07	5.87	8.1
FVMQ; MIL- DTL-25988C; T1, C3, G75	Oct '19; Feb '20	7(0/0)	78.8	0.43	1.23	1.6	2.24	6.33	8.0
FKM; AMS7259E	April 2021	3(0/0)	86.9	1.44	4.09	4.7	1.44	4.09	4.7
Average			73.7						
Pooled Values				0.77	2.18	3.0	2.65	7.50	10.2

^A M=Mean outliers; V=Variability outliers

24.4 Durometer Hardness Type A Repeatability—The **absolute** repeatability limits, *r*, of this test method are as shown in **Table 8A** for each of the materials listed in the table. The difference between two single test results (or determinations) found on identical test material under the repeatability conditions prescribed for this test will exceed the repeatability value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results that differ by more than the appropriate value from **Table 8A** must be suspected of being from different populations and some appropriate action taken.

NOTE 44—Appropriate action may be an investigation of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, etc., which generated the two test results.

24.5 Durometer Hardness Type A Reproducibility—The **absolute** reproducibility limits, *R*, of this test method are as shown in **Table 8A** for each of the materials listed in the table. The difference between two single and independent test results found by two operators working under the prescribed reproducibility conditions in different laboratories on identical test material will exceed the reproducibility value on an average of

not more than once in 20 determinations in the normal and correct operation of the method. Two single test results produced in different laboratories that differ by more than the appropriate value from **Table 8A** must be suspected of being from different populations and some appropriate investigative or technical/commercial action taken.

NOTE 45—Appropriate action may be an investigation in each laboratory of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, laboratories, etc., which generated the two test results. Technical/commercial actions are mutually resolved by the laboratories.

24.6 Bias—Bias is the difference between a test value and a reference value. However, for this test method, bias has not been determined.

24.7 A type 1 inter-laboratory precision program for durometer hardness type M was conducted during the periods listed with the number of laboratories listed and with the o-ring materials listed in **Table 8B**. In each laboratory, two single tests were performed on the o-rings by 2 different technicians on 2 different days for a total of four replicates. A test result is the value obtained from a single determination. Both repeatability

TABLE 8 B Precision Parameters for Test Method D2240, Type M Durometer Hardness (Type 1 Precision), Size 2-214 O-rings (continued)

Material/ Specification	Period	Units Number of Laboratories (M/V) ^A	Durometer Units		r	(r)	SR	R	(R)
			Mean Level	Sr					
FVMQ; MIL- DTL-25988C; T1, C1, G60	Sep 2020	4(1/1)	70.6	0.43	1.22	1.7	1.51	4.27	6.0
NBR; AMS-P- 5315B	Sep-Dec 2018	10(1/1)	74.0	0.41	1.16	1.6	4.58	12.95	17.5
FKM; AMS7287	May-Jun 2019	7(1/1)	78.9	0.33	0.93	1.2	4.12	11.67	14.8
FVMQ; MIL- DTL-25988C; T1, C3, G75	Oct '19; Feb '20	6(1/1)	81.0	0.52	1.48	1.8	3.62	10.23	12.6
FKM; AMS7259E	April 2021	2(0/0)	91.5	0.68	1.92	2.1	1.24	3.52	3.8
Average			79.2						
Pooled Values				0.49	1.38	1.7	3.31	9.37	11.8

^A M=Mean outliers; V=Variability outliers

and reproducibility represent short-term (daily) testing conditions. Acceptable difference values were not measured.

24.8 *Durometer Hardness Type M Repeatability*—The **absolute** repeatability limits, *r*, of this test method are as shown in **Table 8B** for each of the materials listed in the table. The difference between two single test results (or determinations) found on identical test material under the repeatability conditions prescribed for this test will exceed the repeatability value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results that differ by more than the appropriate value from **Table 8B** must be suspected of being from different populations and some appropriate action taken.

NOTE 46—Appropriate action may be an investigation of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, etc., which generated the two test results.

24.9 *Durometer Hardness Type M Reproducibility*—The **absolute** reproducibility limits, *R*, of this test method are as shown in **Table 8B** for each of the materials listed in the table. The difference between two single and independent test results found by two operators working under the prescribed reproducibility conditions in different laboratories on identical test material will exceed the reproducibility value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results produced in different laboratories that differ by more than the appropriate value from **Table 8B** must be suspected of being from different populations and some appropriate investigative or technical/commercial action taken.

NOTE 47—Appropriate action may be an investigation in each laboratory of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, laboratories, etc., which generated the two test results. Technical/commercial actions are mutually resolved by the laboratories.

24.10 *Bias*—Bias is the difference between a test value and a reference value. However, for this test method, bias has not been determined.

24.11 A type 1 inter-laboratory precision program for international hardness type M was conducted during the periods listed with the number of laboratories listed and with the o-ring

materials listed in **Table 8C**. In each laboratory, two single tests were performed on the o-rings by 2 different technicians on 2 different days for a total of four replicates. A test result is the value obtained from a single determination. Both repeatability and reproducibility represent short-term (daily) testing conditions. Acceptable difference values were not measured.

24.12 Relative versus absolute repeatability and reproducibility limits. For international hardness type M, relative precision is statistically preferred. However, since the measurement units are in percent and relative precision is a percent, the expression of relative precision would be calculated as a percent of a percent. This can be difficult to apply when evaluating the testing precision. Therefore, absolute precision is preferred for practical applications.

24.13 *International Hardness Type M Repeatability*—The **absolute** repeatability limits, *r*, of this test method are as shown in **Table 8C** for each of the materials listed in the table. The difference between two single test results (or determinations) found on identical test material under the repeatability conditions prescribed for this test will exceed the repeatability value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results that differ by more than the appropriate value from **Table 8C** must be suspected of being from different populations and some appropriate action taken.

NOTE 48—Appropriate action may be an investigation of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, etc., which generated the two test results.

24.14 *International Hardness Type M Reproducibility*—The **absolute** reproducibility limits, *R*, of this test method are as shown in **Table 8C** for each of the materials listed in the table. The difference between two single and independent test results found by two operators working under the prescribed reproducibility conditions in different laboratories on identical test material will exceed the reproducibility value on an average of not more than once in 20 determinations in the normal and correct operation of the method. Two single test results produced in different laboratories that differ by more than the appropriate value from **Table 8C** must be suspected of being

TABLE 8 C Precision Parameters for Test Method D1415, Type M International Hardness (Type 1 Precision), Size 2-214 O-rings (continued)

Material/ Specification	Period	Units Number of Laboratories (M/V) ^A	IRHD Units		<i>r</i>	(r)	SR	R	(R)
			Mean Level	Sr					
FVMQ; MIL-DTL-25988C; T1, C1, G60	Sep 2020	4(0/0)	56.3	1.20	3.39	6.0	1.79	5.06	9.0
NBR; AMS-P-5315B	Sep-Dec 2018	9(1/1)	62.9	0.39	1.10	1.8	0.88	2.50	4.0
FKM; AMS7287	May-Jun 2019	7(1/0)	70.1	0.42	1.19	1.7	0.63	1.79	2.6
FVMQ; MIL-DTL-25988C; T1, C3, G75	Oct '19; Feb '20	5(0/1)	77.5	0.63	1.79	2.3	2.27	6.43	8.3
FKM; AMS7259E	April 2021	1(0/0)	87.7	0.44	1.25	1.4			
Average Pooled Values			70.9		1.94	2.7	1.54	4.37	6.2

^A M=Mean outliers; V=Variability outliers

from different populations and some appropriate investigative or technical/commercial action taken.

NOTE 49—Appropriate action may be an investigation in each laboratory of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, laboratories, etc., which generated the two test results. Technical/commercial actions are mutually resolved by the laboratories.

24.15 *Bias*—Bias is the difference between a test value and a reference value. However, for this test method, bias has not been determined.

25. O-Ring Mold Shrinkage Test

25.1 *Nature of Test*—This test method involves the molding of various rubber materials in cavities of standard dimensions representative of typical O-ring configurations. The specimens are then measured for inside diameter and cross-sectional thickness within 0.025 mm (0.001 in.) to determine actual mold shrinkage as a means of process control.

25.2 Apparatus:

25.2.1 *Shrinkage Mold*—Most critical is the shrinkage mold. Great care must be taken in both the manufacture and maintenance of this mold. Care must be taken not to dent, scratch, or otherwise damage the cavity. The mold cavities must be kept clean. Harsh mechanical or chemical methods that would dull the “cut off” or increase the cavity size must be avoided. The surface finish must be the best commercial practice.

25.2.2 *Calipers and Micrometers*—Cavity measurement shall be made by the use of vernier calipers and depth micrometers as follows:

25.2.2.1 Align the edges of the vernier with the inside diameter of the cavity “with magnification.” Take a reading that is the outside diameter of the cavity.

25.2.2.2 Open the calipers to align the outside diameter of the cavity. This gives the width of the cross section.

25.2.2.3 Use depth micrometers to check the depth of the cavity. Check each half for depth. The total of the two halves gives the total depth of the cavity.

25.2.2.4 Dimensions for the cavity of a recommended test size are 3.6-mm (0.142-in.) cross section by 25-mm (1.0-in.) inside diameter.

NOTE 50—Other test sizes varying the cross section and inside diameter may be preferred and are permitted. This size is recommended merely as the median standard cross section in a diameter easily molded and measured. Some laboratories may prefer a larger size, the important consideration being that the seller and the manufacturer use the same or comparable size for control work. It has been found important to use a test mold cross-section size as close as possible to the cross-section size of the production mold being considered.

25.3 Test Specimen:

25.3.1 Preparation of preforms is by the die-cut method unless otherwise specified. Sample stock shall be prepared by sheeting on a standard laboratory mill to a thickness of approximately 20 to 25 % greater than the cavity depth. Milling time should be the minimum required to obtain a smooth sheet. The sheet shall be allowed to rest for 30 to 60 min after which preforms shall be cut out with a suitable die. Other types of preforming, such as a spliced extrusion or slice

from a tube may give slightly different results. If an alternative method is used it must be noted in the report.

25.3.2 The preforms shall be placed in the shrinkage test mold which is maintained at curing temperature $\pm 2^{\circ}\text{C}$ ($\pm 3.6^{\circ}\text{F}$) in a suitable press. The mold shall be closed quickly and brought to a pressure equal to a minimum of 3.4 MPa (500 psi) across the mold for the optimum curing time of the material being tested. This curing time and temperature shall be noted in the report. Curing time and especially temperature are very critical in shrinkage consideration.

25.3.3 After curing is complete the specimens shall be allowed to rest for a minimum of 16 h at a temperature of $23 \pm 2^{\circ}\text{C}$ ($73.4 \pm 3.6^{\circ}\text{F}$). Flash removal shall be done individually and carefully so as not to disturb the basic dimensions of the specimen. An abrasive paper or sand-stick of fine grade is usually employed for the operation. Excess flash on the inside diameter must be avoided since this will alter the inside diameter measurement.

25.3.4 Specimen rings obtained must be free of all major defects, such as nonfills, backrind, etc., as these factors may affect true shrinkage determination. Care must be exercised to ensure proper closing of the mold to prevent erroneous cross-section shrinkage results.

25.4 Procedure:

25.4.1 Measure the cross section by the use of tubing micrometers or other method as described in 7.1. Determine actual shrinking by subtracting the average or mean cross section of the specimen from the actual mold cavity size. Measurement of the cross section in inside diameter, outside diameter, and side-to-side axes is desirable. This provides a check on the accuracy of the mold cavity radius and true roundness of cross section. Some materials, such as silicones, may create an imbalance on the two cross-section axes due to inherent shrinkage characteristics, thus producing an out-of-round cross section.

25.4.2 Measure inside diameter by the use of a suitable step gage as shown in Fig. 1, or a suitable taper gage (see 7.2). One or more gages may be necessary to cover a wide range of shrinkage. Take care not to force the specimen on the step gage. Use only enough pressure to be certain the inside diameter is in intimate contact with the gage. Determine actual linear shrinkage of the inside diameter by subtracting the average or mean inside diameter value of the specimens from the actual mold cavity inside diameter. The resultant value divided by the mold inside diameter and multiplied by 100 is the percent shrinkage. An alternative method of expression is in units such as millimetres per millimetre or inches per inch.

25.4.3 An alternative method of measuring the inside diameter and cross section is the shadowgraph or comparator. This instrument is very accurate, but if the O-ring is unsupported the diameter must be taken in two directions and averaged. To prevent any out-of-roundness, a special cone can be used in conjunction with the comparator. The comparator is also used to determine roundness of cross section by measuring thin slices of the cross-sectional area.

25.5 *Report*—The report shall include the following:

25.5.1 Method of preforming.

25.5.2 Number of specimens measured, and

25.5.3 Average shrinkage, expressed as a percentage.

26. Corrosion Test

26.1 This test is intended to give a fast and relatively reproducible rating of the corrosion potential for an O-ring.

26.2 Apparatus:

26.2.1 The apparatus shall consist of any chamber that is corrosion-proof, can be sealed, and is of convenient size for the work load.

NOTE 51—A laboratory desiccator jar is commonly used.

26.2.2 The test panels unless otherwise specified shall be made of SAE-1020 steel. The panels shall be made in accordance with the drawings in Fig. 3.

26.2.3 Relative humidity of 100 % is maintained by the use of a solution of 85 % distilled water and 15 % USP glycerin. This solution should be added to a depth equal to at least 20 % of the depth of the chamber.

26.2.4 A corrosion-proof shelf shall be employed to hold the fixtures close above but not touching the solution.

26.3 *Test Specimen*— The test specimens shall consist of two segments 38 mm (1.5 in.) in length, cut from the sample O-ring. If the sample O-ring is smaller than 38 mm in circumference, two whole O-rings may be used.

26.4 Procedure:

26.4.1 Clean the panels with toluene or other solvent system that will produce a clean dry surface free from film.

26.4.2 Remove the cover and place the individual specimens and test panels into the open chamber for 1 h of preconditioning.

26.4.3 After this 1 h preconditioning, assemble the specimens with panels as shown in Fig. 3. Apply sufficient pressure to cause a deflection of 15 % of the original cross-sectional diameter of the specimens.

26.4.4 Place the assembled fixture on a watchglass and insert it into the test chamber.

26.4.5 Cover the chamber and allow it to stand for 96 h at $23 \pm 2^\circ\text{C}$ ($73.4 \pm 3.6^\circ\text{F}$).

26.4.6 Remove the specimens, wash the panels with toluene or other suitable solvent system, and wipe with a lint-free cloth. If superficial rust or adhering particles from the specimen are still present, a light buffing with crocus cloth, steel, or brass wool is permitted.

26.5 Compare the results to the examples shown in Fig. 4. The rating shall be nil, moderate, or severe.

27. Precision and Bias

27.1 The precision and bias tables and statements for each test method are given in a precision section following the procedural section for each test method. See the section for the test method of interest for the applicable precision and bias information.

28. Keywords

28.1 aging tests; o-rings; physical properties

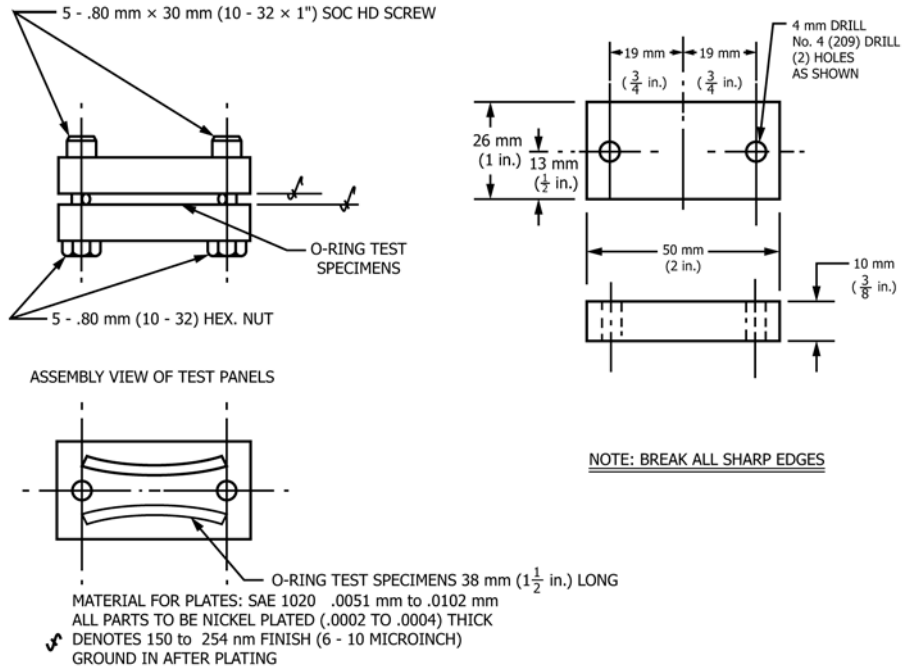


FIG. 3 Corrosion Test Panels

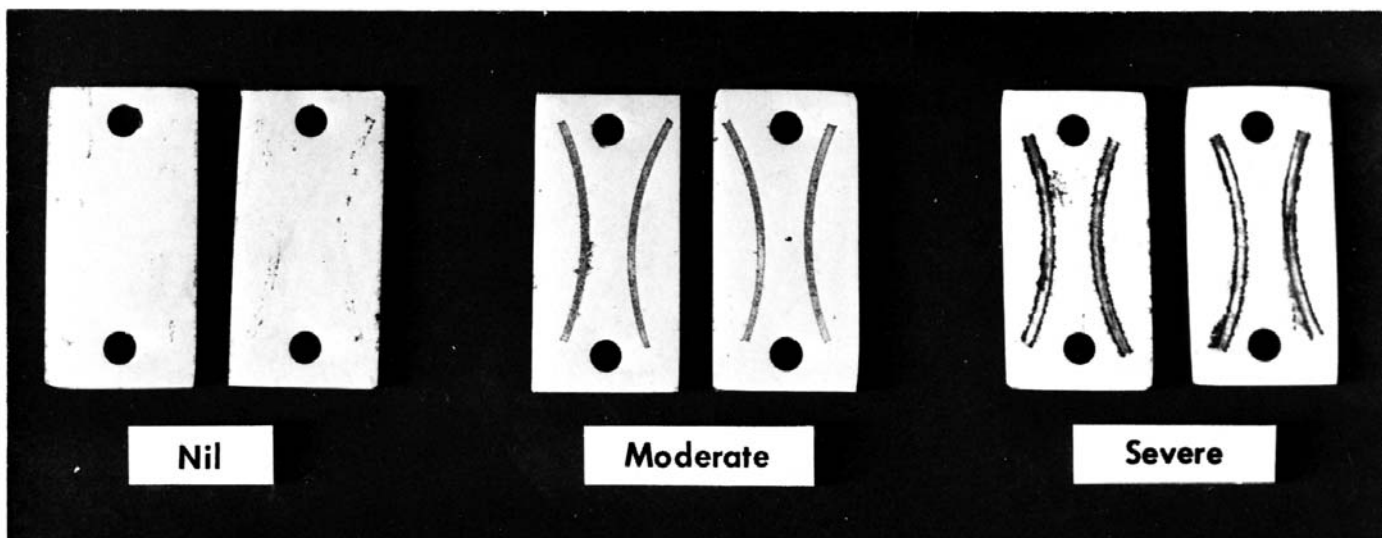


FIG. 4 Examples of Corrosion Test Results

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