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Standard Test Method for Measuring Shrinkage from Mold Dimensions of Molded Plastics[1]

This standard is issued under the fixed designation D 955; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method is intended to measure batch-to-batch uniformity in initial shrinkage from mold to molded dimensions of either thermoplastic or thermosetting materials when molded by compression, injection, or transfer under specified conditions.

1.2 This test method does not provide for the measurement of shrinkages that may occur as molded materials age, after the first 48 h out of the mold.

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 618 Practice for Conditioning Plastics and Electrical Insulating Materials for Testing[2]

D 647 Practice for Design of Molds for Test Specimens of Plastic Molding Materials[2]

D 788 Specification for Poly(Methyl Methacrylate) (PMMA) Molding and Extrusion Compounds[2]

D 796 Practice for Compression Molding Test Specimens of Phenolic Molding Compounds[2]

D 883 Terminology Relating to Plastics[2]

D 956 Practice for Compression Molding Specimens of Amino Molding Compounds[2]

D 1896 Practice for Transfer Molding Test Specimens of Thermosetting Compounds[2]

D 1897 Practice for Injection Molding Test Specimens of Thermoplastic Molding and Extrusion Materials[2]

D 1898 Practice for Sampling of Plastics[2]

D 3419 Practice for In-Line Screw-Injection Molding Test Specimens from Thermosetting Compounds[3]

D 4066 Specification for Nylon Injection and Extrusion Materials[3]

D 4181 Specification for Acetal (POM) Molding and Extrusion Materials[3]

D 4549 Specification for Polystrene Molding and Extrusion Materials (PS)[4]

D 4976 Specification for Polyethylene Plastics Molding and Extrusion Materials[4]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[5]

3. Terminology

3.1 *General*—Definitions of terms applying to this test method appear in Terminology D 883.

4. Significance and Use

4.1 *Compression Molding*—In compression molding, the difference between the dimensions of a mold and of the molded article produced therein from a given material may vary according to the design and operation of the mold. It is probable that shrinkage will approach a minimum where design and operation are such that a maximum of material is forced solidly into the mold cavity or some part of it, or where the molded article is hardened to a maximum while still under pressure, particularly by cooling. In contrast, shrinkages may be much higher where the charge must flow in the mold cavity but does not receive and transmit enough pressure to be forced firmly into all its recesses, or where the molded article is not fully hardened when discharged. The plasticity of the material used may affect shrinkage insofar as it affects the retention and compression of the charge.

4.2 *Injection Molding*—In injection molding, as in compression molding, the difference between the dimensions of the mold and of the molded article produced therein from a given material may vary according to the design and operation of the mold. The difference may vary with the type and size of molding machine, the thickness of molded sections, the degree and direction of flow or movement of material in the mold, the size of the nozzle, sprue, runner, and gate, the cycle on which the machine is operated, the temperature of the mold, and the length of time that follow-up pressure is maintained. As in the

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[2] *Annual Book of ASTM Standards*, Vol 08.01.

[3] *Annual Book of ASTM Standards*, Vol 08.02.

[4] *Annual Book of ASTM Standards*, Vol 08.03.

[5] *Annual Book of ASTM Standards*, Vol 14.02.

case of compression molding, shrinkages will approach a minimum where design and operation are such that a maximum of material is forced solidly into the mold cavity and where the molded article is hardened to a maximum while still under pressure as a result of the use of a runner, sprue, and nozzle of proper size, along with proper dwell. As in compression molding, shrinkages may be much higher where the charge must flow in the mold cavity but does not receive and transmit enough pressure to be forced firmly into all of the recesses of the mold. The plasticity of the material used may affect shrinkage indirectly, in that the more readily plasticized material will require a lower molding temperature.

4.3 *Transfer Molding*—In transfer molding, as in compression or injection molding, the difference between the dimensions of the mold and of the molded article produced therein from a given material may vary according to the design and operation of the mold. It is affected by the size and temperature of the pot or cylinder and the pressure on it, as well as on mold temperature and molding cycle. Direction of flow is not as important a factor as might be expected, although it can have some bearing on results.

5. Sample Preparation

5.1 Some materials require special treatment before they are molded. For example, thermoplastics which absorb moisture must be dried before molding. Materials to be tested shall be prepared for molding in accordance with the manufacturer's recommendations. The preparation given to the material prior to molding shall be recorded and reported.

6. Apparatus

6.1 *Compression Mold*—A single bar, single-cavity positive mold having a cavity cross-section 12.7 by 127 mm (½ by 5 in.) and a loading depth sufficient to obtain a molded bar 12.7 mm (½ in.) in thickness, or for diametral shrinkage, a single cavity positive 102-mm (4-in.) disk mold. Both shall conform to Practice D 647.

6.2 *Injection Mold*—For shrinkage parallel to flow, an impact bar mold having a cavity 12.7 by 127 mm (½ by 5 in.). The thickness shall be 3.2 mm (⅛ in.), unless otherwise agreed upon by the seller and the purchaser. The mold shall have at one end a gate 6.4 mm (¼ in.) in width by 3.2 mm (⅛ in.) in depth (Note 1). For diametral shrinkage, where shrinkage both parallel to flow and transverse to flow are to be measured, the mold shall have a cavity 102 mm (4 in.) in diameter by 3.2 mm (⅛ in.) in thickness with a gate, placed radially at the edge, 12.7 mm (½ in.) in width by 3.2 mm (⅛ in.) in depth.

NOTE 1—If, for any reason, a test specimen of thickness greater than 3.2 mm (⅛ in.) is agreed upon, the depth of the gate may be greater than 3.2 mm (⅛ in.) and must be reported.

6.3 *Transfer Mold*—An impact bar mold having a cavity 12.7 by 12.7 by 127 mm (½ by ½ by 5 in.) and having either an end gate or top gate at one end 6.4 by 1.52 mm (⅛ by 0.060 in.) in depth.

6.4 *Compression Press*—A suitable hydraulic press that will deliver a pressure of 20 to 35 MPa (3000 to 5000 psi) to the material in the mold.

6.5 *Injection Press*—A suitable injection-molding machine that will fill the test molds when it is operated in the range from one half to three fourths of its rated shot capacity at melt temperatures recommended by the material supplier. Different screw and barrel configurations are required for thermoplastic and thermoset materials.

NOTE 2—If injection machines of appropriate capacity are not available, the requirement of 6.5 may be met in machines of larger capacities by providing test molds with multiple cavities to be filled from a common sprue, so that the total weight of the shot, including sprue and runner will fall within the specified limits.

6.6 *Transfer Press*—A suitable hydraulic press that will deliver a pressure of 70 to 140 MPa (10 000 to 20 000 psi) on the material in the pot of the die or the cylinder of the press.

6.7 *Balance*—A balance for weighing compression-molding charges.

6.8 *Measuring Tools*—Measuring tools (micrometers, vernier calipers, etc.) accurate to 0.02 mm (0.001 in.) for measuring the molds and the test specimens.

7. Test Specimens

7.1 *Compression-Molding Materials*—For mold shrinkages of compression-molding materials, the test specimens shall be bars, 12.7 by 12.7 by 127 mm (½ by ½ by 5 in.), or a disk 3.2 mm (⅛ in.) in thickness and 102 mm (4 in.) in diameter, made in a positive mold in such a way as to minimize lateral movement of the plastic during the molding.

7.2 *Injection-Molding Materials*—For mold shrinkage of injection-molding materials, specimens of two types shall be used: (*1*) bars 12.7 by 3.2 by 127 mm (½ by ⅛ by 5 in.), gated at the end to provide flow throughout the entire length, shall be used for measurements of shrinkage in the direction of flow, and (*2*) disks, 3.2 mm (⅛ in.) in thickness and 102 mm (4 in.) in diameter, gated radially at a single point in the edge, shall be used for measurements of shrinkages of diameters parallel and perpendicular to the flow.

7.3 *Transfer-Molding Materials*—For shrinkage of transfer-molding materials, specimens 12.7 by 12.7 by 127 mm (½ by ½ by 5 in.), gated at the end or at the top near one end, so as to provide flow throughout their entire length, shall be used for measurement of shrinkage in the direction of flow. A disk specimen 3.2 mm (⅛ in.) in thickness and 102 mm (4 in.) in diameter gated radially at a single point in the edge, shall be used for measurements of shrinkages of diameters parallel and perpendicular to the flow.

8. Conditioning

8.1 *Conditioning*—Conditioning of molded specimens shall be done in the Standard Laboratory Atmosphere, 4.2, of Practice D 618 for various lengths of time as discussed in 9.3.

8.2 *Test Conditions*—Conduct tests in the standard laboratory atmosphere of 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 percent relative humidity, unless otherwise specified in the test methods or in this specification. In cases of disagreement, the tolerances shall be ±1°C (±1.8°F) and ±2 percent relative humidity.

9. Procedure

9.1 Measure the length of the cavity of the bar mold, or the diameter of the cavity of the disk mold parallel and perpendicular to the flow, to the nearest 0.02 mm (0.001 in.). Make

the measurements at standard laboratory temperature as defined in 4.1 of Practice D 618.

9.2 Mold at least five sound test specimens from the sample to be tested, under such conditions of pressure, temperature, time, etc., as the manufacturer and the purchaser may agree are suitable for the material. In the absence of other definite recommendations, the following are suggested as suitable molding procedures for plastics of various types:

9.2.1 *Thermoplastics Molded by Compression*—For thermoplastics, such as cellulose acetate, load the mold evenly at room temperature with the requisite quantity of granular material, also at room temperature, and place the mold in a hydraulic press such that a pressure of 20 to 35 MPa (3000 to 5000 psi) on the projected area of the mold cavity can be applied and the mold can be heated to 121 to 129°C (250 to 265°F) in 5 to 10 min. Apply heat and pressure, within these ranges, to mold the specimen. Cool the mold to room temperature under pressure and discharge the specimen. The rate of heating, the maximum temperature reached, and the rate of cooling do not seem critical, but the temperature of the mold at the time of discharge should be definitely controlled.

9.2.2 *Thermoplastics Molded by Injection*—Molding of thermoplastic materials should be carried out in accordance with Practice D 1897. The molding machine used should be such that it is operated without exceeding one half to three fourths of its rated shot capacity. The temperature of the heating cylinder should be maintained at a point which will on a cycle selected, produce a melt at a temperature within the range recommended by the manufacturer of the material. The mold should be maintained at a temperature recommended by the material manufacturer and should be maintained within 3°C (5°F) of the prescribed temperature.

9.2.3 *Thermoplastics Molded by Transfer*—The press used for transfer molding thermoplastics should be of a size that will permit operation under a pressure on the stock pot or cylinder of from 70 to 140 MPa (10 000 to 20 000 psi). The temperature of the cylinder and of the die should be maintained at a point that will yield smooth pieces.

9.2.4 *Thermosetting Materials Molded by Compression*:

9.2.4.1 *Urea Type*—Molding of thermosetting materials of the urea type should be carried out in accordance with Practice D 956.

9.2.4.2 *Phenolic Type*—Molding of thermosetting materials of the phenolic type should be carried out in accordance with Practice D 796.

9.2.4.3 *Epoxy Type*—Molding of thermosetting materials of the epoxy type to make physical and electrical test specimens should be carried out as follows:

Item	Molding Condition
Charge	powder
Preheating	none
Molding temperature	149 to 178°C (300 to 350°F)
Pressure	4 to 14 MPa (500 to 2000 psi)
Molding time	5 min

9.2.5 *Thermosetting Materials Molded by Transfer*—The press used should be such that pressure in the stock pot or cylinder can be maintained in the range between 55 and 140 MPa (8000 and 20 000 psi). The temperature of the cylinder should be such that the entire charge can be forced into the die before premature curing can take place, which would be evidenced by roughness and poor finish.

NOTE 3—Soft flow epoxy molding materials require a press suitable to deliver 4 to 14 MPa (500 to 2000 psi) to the material in the pot. See also Practice D 1896.

9.2.6 *Thermosetting Materials Molded by Injection*—The molding machine used shall be such that the injection pressure can be controlled between 70 and 140 MPa (10 000 to 20 000 psi). The capacity shall be adequate to produce a shot within one half to three fourths of the rated capacity. The cylinder and mold heating systems shall be capable of heating the shot and the mold to the temperatures required by the material specification. The molding should be carried out in accordance with Practice D 3419.

9.3 After molding, allow the specimens to cool in the Standard Laboratory Atmosphere prescribed in 4.2 of Methods D 618 before being measured. Standard shrinkage measurements shall be made to determine the “48-h” or “normal” mold shrinkage. Shrinkage occurring during shorter periods of time designated “initial” molding shrinkage or “24-h shrinkage” as defined below are optional and may be made upon agreement between the buyer and the seller. The period of storage for “initial molding shrinkage” for specimens 3.2 mm (⅛ in.) in thickness shall be from 1 to 2 h; for specimens 6.4 mm (¼ in.) in thickness, 2 to 4 h; and for specimens 12.7 mm (½ in.) in thickness, from 4 to 6 h. Measure the length or diameter of each specimen at Standard Room Temperature to the nearest 0.02 mm (0.001 in.) and then return the specimens to storage in the Standard Laboratory Atmosphere. Measure the specimens again not less than 16 nor more than 24 h after molding, in order to obtain the “24-h shrinkage,” and again not less than 40 nor more than 48 h after molding, in order to determine the “48-h” or “normal” mold shrinkage.

10. Calculation and Report

10.1 Calculate the shrinkage per millimetre (or inch) by subtracting the dimension of the specimen from the corresponding dimension of the mold cavity in which it was molded and dividing the difference by the latter.

NOTE 4—Expansion per millimetre (or inch) is calculated by subtracting the dimension of the mold from the corresponding dimension of the specimen and dividing by the former. The positive value thus obtained must be specifically reported as expansion.

10.2 The report shall include:

10.2.1 Details of any special preparation, such as drying, which the material received before molding.

10.2.2 The molding procedure used.

10.2.3 For compression molding, the form and distribution of the mold charge and the molding pressure, temperature, and time.

10.2.4 For injection molding, the temperatures of the cylinder, the mold, and the plastic from the nozzle, the type and size of the nozzle, the molding pressure, the molding cycle, and the make, type, and size of the machine used.

10.2.5 For transfer molding, the temperature of the pot or cylinder, the mold temperature, the pressure on the pot, and the molding cycle.

TABLE 1 Shrinkage from Mold Dimensions of I.M. Bars[A]

Material[B]	Average	S_r	S_R	r	R
1	0.00513	0.00008	0.00124	0.00022	0.00347
2	0.04108	0.00022	0.00754	0.00062	0.02111
3	0.00474	0.00021	0.00127	0.00059	0.00356
4	0.02107	0.00013	0.00280	0.00036	0.00784
5	0.01731	0.00017	0.00389	0.00048	0.01089

[A] Values expressed in mm/mm (in./in.).

[B] 1 = Polystyrene Specification D 4549 PS110B56152
2 = Polyethylene Specification D 4976 PE235
3 = PMMA Specification D 788 PMMA0131V0
4 = Acetal Specification D 4181 POM213
5 = Nylon (Polyamide) Specification D 4066 PA111

TABLE 2 Shrinkage from Mold Dimensions of I.M. Disks Flow Direction[A]

Material[B]	Average	S_r	S_R	r	R
1	0.00463	0.00008	0.00124	0.00022	0.00347
2	0.03799	0.00035	0.00923	0.00098	0.02584
3	0.00420	0.00018	0.00170	0.00050	0.00476
4	0.02327	0.00021	0.00294	0.00059	0.00823
5	0.01941	0.00028	0.00348	0.00078	0.00974

[A] Values expressed in mm/mm (in./in.).

[B] 1 = Polystyrene Specification D 4549 PS110B56152
2 = Polyethylene Specification D 4976 PE235
3 = PMMA Specification D 788 PMMA0131V0
4 = Acetal Specification D 4181 POM213
5 = Nylon (Polyamide) Specification D 4066 PA111

TABLE 3 Shrinkage from Mold Dimensions of I.M. Disks Cross Direction[A]

Material[B]	Average	S_r	S_R	r	R
1	0.00403	0.00010	0.00162	0.00028	0.00454
2	0.02040	0.00019	0.00247	0.00053	0.00692
3	0.00427	0.00013	0.00142	0.00036	0.00398
4	0.02528	0.00037	0.00471	0.00104	0.01319
5	0.02068	0.00047	0.00506	0.00132	0.01417

[A] Values expressed in mm/mm (in./in.).

[B] 1 = Polystyrene Specification D 4549 PS110B56152
2 = Polyethylene Specification D 4976 PE235
3 = PMMA Specification D 788 PMMA0131V0
4 = Acetal Specification D 4181 POM213
5 = Nylon (Polyamide) Specification D 4066 PA111

10.2.6 The "48-h" shrinkage, and the "initial" and "24-h shrinkage", if these were to be obtained, shall be expressed in millimetres per millimetre (or inches per inch) with each value representing the mean of values obtained on five or more specimens.

11. Precision and Bias

11.1 *Precision*:

11.1.1 Tables 1-3 summarize data from a round robin[6] conducted in 1988 involving five thermoplastic materials tested by eight laboratories. Each material was supplied in granular form to each of the testing laboratories by a single supplier. The resins were handled in accordance with the suppliers instructions and were molded in accordance with Practice D 1897. Each test result is the average of five individual determinations from successive injection molding cycles. Each laboratory obtained one test result for each material.

11.1.2 Repeatability estimates S_r and r were made by treating the five individual determinations from successive injection cycles as test results. Poorer precision (larger values of S_r and r) would be expected if the same operator were to shutdown and then restart the injection molding machine on the same day with the same mold, material, and operating setpoints. Repeatability under such circumstances was not evaluated. The repeatability estimates may, however, be used to judge individual members of the five sample sets as described in 11.1.3.

NOTE 5—**Caution:** The following explanations of r and R (11.1.3-11.1.3.3) are only intended to present a meaningful way of considering the approximate precision of this test method. The data in Tables 1-3 should not be rigorously applied to acceptance or rejection of material, as those data are specific to the round robin and may not be representative of other lots, conditions, materials, or laboratories. Users of this test method should apply the principles outlined in Practice E 691 to generate data specific to their laboratory and materials, or between specific laboratories. The principles of 11.1.3-11.1.3.3 would then be valid for such data.

11.1.3 *Concept of r and R*—If S_r and S_R (standard deviations) have been calculated from a large enough body of data, and for test results that were averages from testing five specimens:

11.1.3.1 *Repeatability*, r (comparing two test results for the same material obtained by the same operator using the same equipment on the same day)—The two test results should be judged not equivalent if they differ by more than the r value for that material.

11.1.3.2 *Reproducibility*, R (comparing two test results for the same material obtained by different operators using different equipment on different days)—The two test results should be judged not equivalent if they differ by more than the R value for that material.

11.1.3.3 Any judgment made in accordance with 11.1.2.1 and 11.1.2.2 has an approximate 95 % (0.95) probability of being correct.

11.1.4 *Results*—The r and R values are obviously a function of each material and its molding characteristics. It would be incorrect to assume values from Tables 1-3 for any new material.

11.2 *Bias*—It is known that the test result is as dependent on the experimental conditions as on the material itself. It is the intent of this method to control and document as many of these variables as possible. There are no recognized standards by which to estimate the bias of this test method.

[6] Supporting data are available from ASTM Headquarters. Request RR: D-20-1158.