Standard Test Method for Evaluating Springback of Sheet Metal Using the Demeri Split Ring Test[1]

This standard is issued under the fixed designation E2492; 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 provides a means of evaluating the springback behavior of metals in a test that simulates a stretch-draw forming process. The test method can also be used to calibrate computer simulation codes by selecting appropriate control parameters to achieve satisfactory correlation between simulation and test results.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

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

2. Terminology

2.1 *Definitions:*

2.1.1 *springback*—the difference between the final shape of a part and the shape of the forming die.

2.1.2 *Demeri Split Ring Test*—a test that measures the springback behavior of sheet metal by comparing the diameter of a ring extracted from the wall of a flat bottom cup and the diameter of the same ring split to release residual stresses.

3. Summary of Test Method

3.1 The test method consists of four steps: *(1)* deep draw a cylindrical cup from a circular blank with a constant clamp or blankholder force, *(2)* cut a circular ring from the mid-section of the drawn cup, *(3)* split the ring along a certain direction to release residual stresses caused by the stretch-draw operation, and *(4)* measure the opening of the ring (springback).

4. Significance and Use

4.1 The formability of materials is affected by springback, the difference between the final shape of a part and the shape of the die that formed it. Materials having a large amount of springback create difficulties for the die designer and make die rework much more likely and complicated. This can add months and great costs to the achievement of successful dies. While dealing with springback in traditional metals is largely overcome by experience, new metals often have so much springback that they can only be used after much trial and error. The quantification and prediction of the tendency of metals to springback is addressed by this test method.

4.2 The magnitude of the springback is a convolution of the elastic modulus, the flow stress of the metal of interest, the sheet metal thickness and the amount and type of cold work introduced by the forming process. Since the cup forming process contains features of many forming operations, the amount of springback measured by the Demeri split ring test is indicative of the behavior of the metal in many stamping operations.

4.3 The amount of springback that occurs in this test is very large compared to other approaches. This improves measurement accuracy and reduces experimental error in all types of formable metals.

4.4 This test does not require measurement fixtures or any sophisticated profiling equipment for accurate measurement of springback. Conventional length measuring instruments are all that is needed to perform the required measurements.

4.5 This test can be used to rank materials according to their tendency to springback after a forming operation (see Refs **1-3**).[2] Since springback depends on the sheet thickness, metals should be compared at the same thickness. Experience has shown that the test can also be used in conjunction with an appropriate analysis to predict quantitatively the amount of springback occurring after a forming operation (see Refs **2-9**).

4.6 This test provides a method to compare springback predictions by various numerical simulation codes. Test results can be used to calibrate computer simulation codes by selecting proper control parameters and appropriate material models to achieve satisfactory correlation between simulation and test

[1] This test method is under the jurisdiction of ASTM Committee E28 on Mechanical Testing and is the direct responsibility of Subcommittee E28.02 on Ductility and Formability.

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[2] The boldface numbers in parentheses refer to the list of references at the end of this standard.

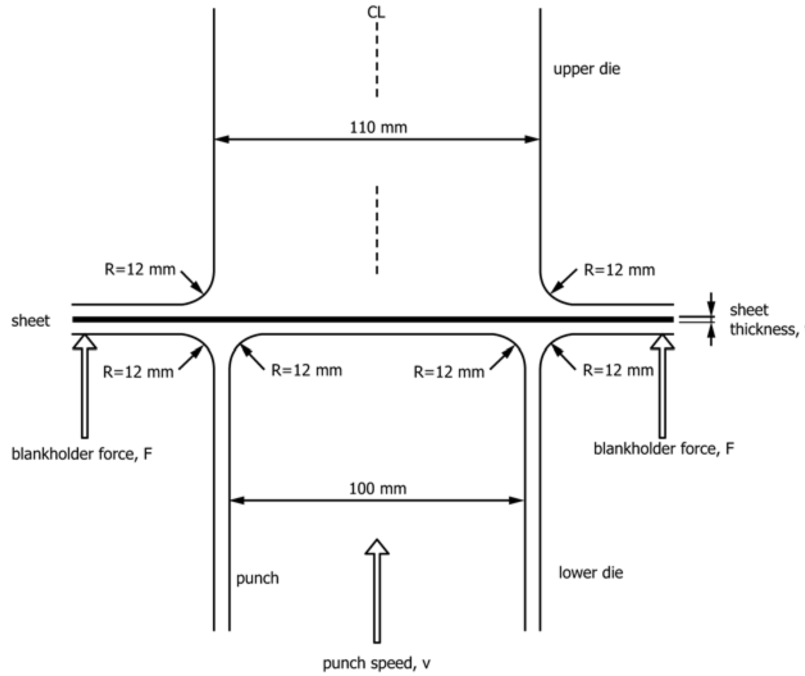

FIG. 1 Cross Section Through the Experimental Setup Used for Cup Drawing

results. Test data can be used to evaluate and improve current forming and simulation capabilities.

4.7 The experimental setup and test procedure are simple, and test results are highly repeatable.

5. Apparatus

5.1 *Cup Forming Apparatus*—A die set and punch are needed to form the cup from circular sheet metal blanks for subsequent testing. The die set consists of upper and lower tools with centrally located circular holes. The sheet is held between these and formed into a cup by the action of a punch that fits through the hole in the upper and lower dies. This arrangement is shown in Fig. 1. The apparatus can be part of a double acting press where the clamp force on the upper tool of the die is generated hydraulically, followed by movement of the punch to make the cup. Alternatively, the upper tool can be held down by a combination of bolts and Belleville spring washers to achieve a constant force. In this case, the cup can be formed in a universal or compression testing machine.

5.2 *Ring Slicing Apparatus*—The cutting equipment, used to slice the ring from the cup and split it, must not change the worked state of the ring, as this will affect the result. Good results have been obtained with laser cutting equipment, electro discharge machining (EDM), and slow speed diamond wheels. Shears have been shown to badly distort the ring and leave burrs that affect the result. Other methods are acceptable if they can be shown to agree with one of the successful methods.

5.3 *Dimensional Measurement Apparatus*—Methods of measuring the location of the ring to be extracted from the cup (h_o) (see Fig. 2), the initial ring diameter (D_o), the ring height (h), the ring wall thickness (t_w) and the final diameter of the split open ring (D_f) are required. Most methods having the required accuracy and precision are acceptable for the first three measurements. Only a non-contacting method, such as an optical micrometer, traveling microscope, or comparator, should be used for measuring the final diameter as this is very sensitive to the presence of additional forces.

6. Hazards

6.1 Forming equipment can be dangerous. Care must be taken to keep hands away when forming the cups.

6.2 Cutting and slicing equipment can also cause injury if care is not taken in their use.

6.3 Sheet metal generally has sharp edges and burrs. Precautions, such as gloves and safety glasses should be worn. When the ring is split open, it is required to be restrained in some way to avoid artifacts due to sudden springback. If it is not restrained, harm to the person splitting the ring may result.

7. Sampling, Test Specimens, and Test Units

7.1 Samples for testing shall be from the same lot or heat as the material of interest except where the measurement of springback is being made to rank different types of materials for future reference. In this latter case, it will suffice to use material typical of the specification.

7.2 Test units shall be in SI units.

8. Procedure

8.1 The dimensions used in this section are defined here for convenience. The depth of the drawn cup is d (see Fig. 2). The height of the ring extracted from the cup is h (see Fig. 2). The wall thickness of the cup is t_w. The diameter of the unsplit ring is D_o, measured to the midthickness (see Fig. 3). D_o is equal to the average of the outside and inside diameters ($OD/2 + ID/2$)

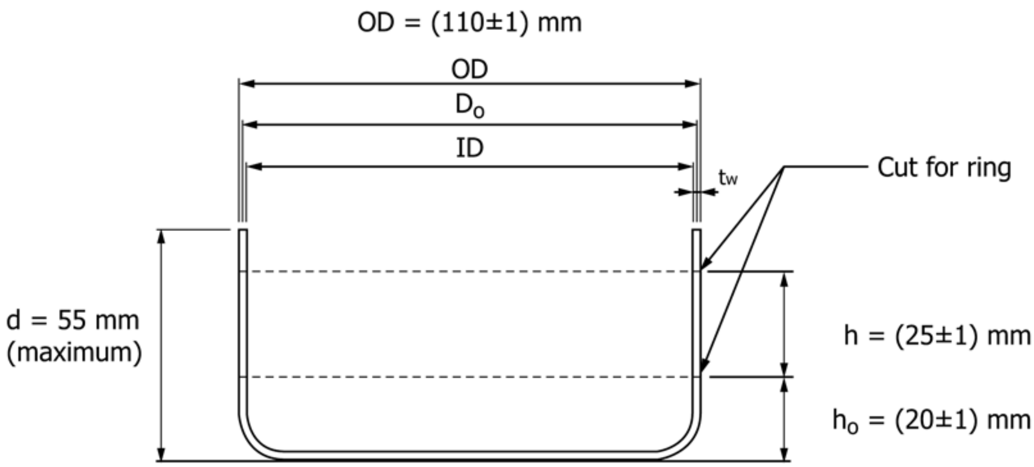

FIG. 2 Ring Location in a Drawn Cylindrical Cup

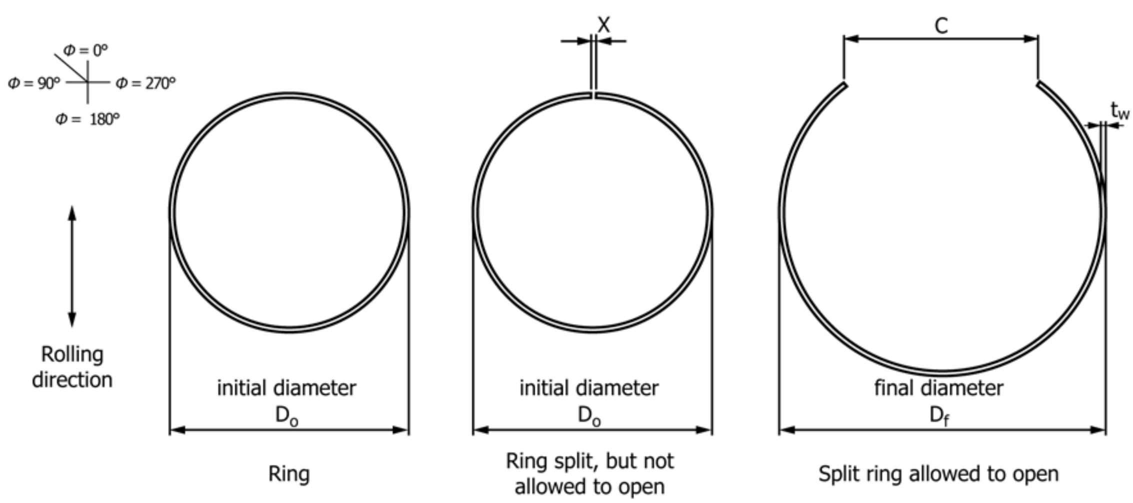

FIG. 3 Steps in Splitting a Test Ring

or the outside diameter minus the wall thickness ($OD - t_w$). The diameter of the split ring at midthickness is D_f (see Fig. 3) and may be determined in the same way as for the unsplit ring. The chord length measured between the midthickness tips of the split ring is C (see Fig. 3). The length of the section of the circumference removed by the splitting operation is X (see Fig. 3).

8.2 The initial step in obtaining samples for this test is to form cylindrical cups from (200 ± 2) mm diameter, drawing oil-lubricated, circular blanks to a maximum depth, d, of 55 mm. Cups of this depth have been routinely made from formable aluminum and steel sheet. To minimize friction, a sheet of solid lubricant is applied to the die side of the blank. The tooling used for this test is shown in Fig. 1. Sheet metal blanks are to be centered in the die to an accuracy of ±2 mm. The punch and die radii shall be both (12.0 ± 0.1) mm and the die gap (5.0 ± 0.1) mm. Due to the die gap requirement, this method is only applicable to sheet metal having a maximum thickness of 3 mm. Since the lubrication and surface finish of the dies, punch, and sheet metal can affect the springback, these details must be known and reported (see Section 10) even if they conform to conventional forming practice. Surface roughness of the tools should be typical of good practice (~0.8 µm). Punch speed shall be kept constant at (5 ± 1) mm/second. Clamp (or blankholder) force shall be kept constant at a known value to produce wrinkle and split free cups. A clamp force of 88 kN has produced successful cups from DS, A6022-T4, BH210, HSLA50, DP600 and TRIP600 sheet metals. The clamp (or blankholder) force is about one-third the punch (drawing) force.

8.3 Rings from the formed cups shall be cut (20 ± 1) mm from the bottom of the cup as shown in Fig. 2. The rings shall be (25 ± 1) mm high (h) and have an external diameter OD of (110 ± 1) mm. The wall thickness (t_w) shall be measured in three positions (top, middle, and bottom) in two locations (rolling and transverse) to an accuracy of 0.02 mm, and averaged. The diameter D_o shall be measured in the same positions and to an accuracy of 0.1 mm, and averaged. The diameter D_o shall be measured from the midthickness (that is, neutral axis) of the ring. The height of the ring, h, shall be measured at (0, 90, 180, and 270) degrees around the ring where (0 and 180) degrees coincide with the rolling direction. The ring height, h, shall be measured to an accuracy of 0.02 mm at each location and averaged.

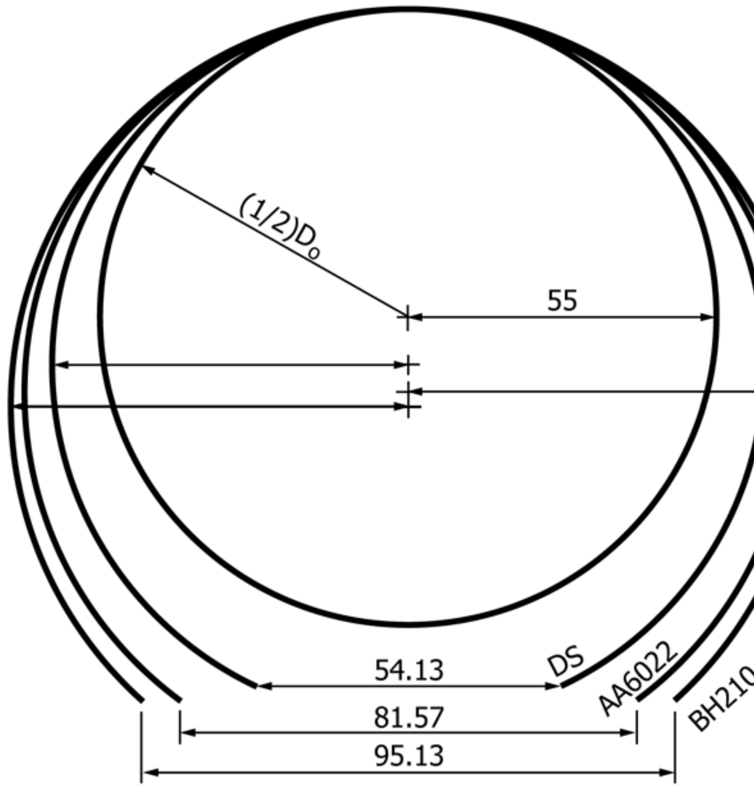

FIG. 4 Traces of Split Rings for Three Sheet Metals

8.4 The prepared rings shall then be split along the rolling direction to allow them to open up and to springback as shown in Fig. 3. The amount by which the diameter of a ring changes from its original unsplit diameter is a measure of the released residual stress and the resulting springback.

8.5 Examples of the diameter of the rings before and after splitting are shown in Fig. 4 for three sheet metals: drawing quality steel (DS), bake hardenable steel (BH33) and aluminum alloy (A6022).

8.6 It is necessary to restrain the rings during the splitting process to avoid dynamic effects on the springback. After splitting, the restraint must be removed gradually. The chord length of the open ring shall be measured at three locations (top, center, and bottom) to an accuracy of 0.1 mm and averaged. The average chord length is a measure of the resulting springback. It is uniquely related to the difference in diameters of the unsplit and split rings as shown in Section 9. Alternatively, the diameter of the split ring may be measured at three locations (top, center, and bottom) to an accuracy of 0.1 mm and averaged. Measurements of diameter, D_f, and chord length, C, shall be measured from the midthickness (or neutral axis) of the ring.

9. Calculation or Interpretation of Results

9.1 Assuming that the open ring is circular, the final diameter and chord of the split ring are related exactly by the following expression:

$$D_f = D_o + 2D_f \arcsin\left((C - X)/D_f\right) \tag{1}$$

where:

D_f and D_o = average diameters of the split and unsplit rings, respectively,
C = chord length of the split ring, and
X = length of circumference removed by the cutting process that split the ring.

NOTE 1—This equation can be solved implicitly to any degree of accuracy desired.

9.2 Alternatively, the following approximate expression can be used to calculate D_f from C to an accuracy of better than 1%:

$$D_f = D_o\left(0.0635A^3 - 0.0475A^2 + 0.3416A + 0.9983\right) \tag{2}$$

where:

A = $(C - X)/D_o$.

10. Report

10.1 The report shall contain a description or identification of the material tested together with the thickness of the original sheet and the diameter of the circular blank.

10.2 The report shall include all relevant details of cup forming, such as the binder force, the punch speed, lubrication, surface finish of dies, punch, and sheet metal, and the geometry of the die and punch. Additional information on the resulting cup may include changes in wall thickness along the wall and any evidence of asymmetry in forming, wrinkling or tearing.

10.3 The location of the ring in the cup, h_o, its diameter, D_o, wall thickness, t_w, height, h, and the method of extraction shall be included.

TABLE 1 Statistical Data for Springback in Six Metals in Terms of Chord Length, *C*

Material	Sheet Thickness	Average Chord Length	Repeatability Standard Deviation	Repeatability Limit
	t (mm)	C (mm)	S_r (mm)	r (mm)
AA6022	0.93	81.57	2.29	6.41
BH210	0.78	95.13	6.00	16.79
HSLA340	1.54	46.40	0.55	1.53
TRIP600	1.58	62.30	0.77	2.16
DP600	1.60	49.70	1.05	2.95
DS	1.01	54.13	1.23	3.45

10.4 The means of splitting the ring and the final diameter, D_f, and/or chord length, C, shall be reported. If only the chord length is reported, the amount of material removed by the splitting operation, X, must also be reported.

10.5 The springback may be reported as either the diameter difference ($D_f - D_o$), or the true chord length ($C + X$).

11. Precision and Bias[3]

11.1 The precision of this test method is based on an interlaboratory study of E2492 Test Method for Evaluating Springback of Sheet Metal Using the Demeri Split Ring Test, conducted in 2004. One laboratory tested six different materials. Four test results, or replicates, were produced for five of the materials, and seven test results were measured for the sixth material (DS). Each test result reported was the result of a single analytical determination.

11.1.1 *Repeatability*—Two test results obtained within one laboratory shall be judged not equivalent if they differ by more than the "*r*" value for that material; "*r*" is the interval representing the critical difference between two test results for the same material, obtained by the same operator using the same equipment on the same day in the same laboratory.

11.1.1.1 Any judgment in accordance with this statement has an approximate 95 % probability of being correct.

11.1.2 *Reproducibility*—The interval representing the difference between two test results for the same material, obtained by different operators using different equipment in different laboratories. The reproducibility is being determined and will be available within five years (November 2012).

11.2 *Bias*—At the time of the study, there was no accepted reference material suitable for determining the bias for this test method, therefore no statement on bias is being made.

11.3 The precision statement was determined through statistical examination of 27 results, from one laboratory, on 6 materials.

12. Keywords

12.1 accepted reference value; accuracy; bias; cup drawing; Demeri Split Ring Test; drawability; formability; forming; interlaboratory study; precision; precision conditions; repeatability; reproducibility; springback; standard deviation; stretch-draw forming

[3] Supporting data are available from ASTM International Headquarters. Request RR:E28-1024.

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