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Standard Test Methods for Bulge-Forming Superplastic Metallic Sheet[1]

This standard is issued under the fixed designation E2712; 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 These test methods describe procedures for determining the biaxial formability of a superplastic metallic sheet in a circular die.

1.2 The intent of these test methods are primarily to be used as tests of superplasticity as measured by the ability to form to a prescribed depth in a die cavity without rupturing. These test methods can also be used to generate material for the measurement of cavitation in the formed part. These can be used as go/no go criteria for qualification to a specification.

1.3 These test methods have been used successfully with aluminum alloys. The use of these test methods on other metals should be verified.

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

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E2448 Test Method for Determining the Superplastic Properties of Metallic Sheet Materials

3. Summary of Test Method

3.1 Two methods of bulge forming are included in these test methods.

3.1.1 In the first test method, the sheet is formed into a die of a fixed depth as prescribed in a specification. If it touches the base of the die without rupturing, then it is considered to have met the specification.

3.1.2 In the second test method, the depth of the die is reduced so that the material fills the die. A portion excised from the center of the formed part may be examined for internal cavitation within the sheet.

4. Significance and Use

4.1 When a superplastic material is regularly being used in industrial production, it is often convenient to use the bulge test to qualify a batch or heat lot to an acceptance criterion. Comparing these test methods with Test Method E2448, the bulge test does not require a machined coupon, it is more convenient to perform, and it most closely simulates the multiaxial stresses and strains present in forming parts. These test methods do not measure the intrinsic superplastic properties of a material. Test Method E2448 should be used in that instance.

5. Apparatus

5.1 The bulge test consists of forming a sheet of material into a right circular cylindrical die using pressurized gas. The apparatus is shown in Fig. 1. The die cavity has a 100-mm diameter and a specified depth in a vessel suitably designed for the pressure and temperature envisaged for the test. The surface finish of the die cavity shall be R_A=0.4 µm.

5.2 The depth of the die (X in Fig. 1), may be varied by means of inserts or other methods to the depth set by the specification. For convenience, a series of inserts of different heights may be installed in the die to provide different depths according to the bulge test requirements.

NOTE 1—A depth of 55 mm has been successfully used on superplastic-forming (SPF) 5083 aluminum alloy.

5.2.1 The insert shall allow the free passage of gas around its periphery to the exhaust hole in the die.

5.3 The die entry radius is 5 mm. A lower plate with a control thermocouple may be moved to press against the die. The plate has a gas seal bead 0.7 mm high by 8 mm wide and a 136-mm inside diameter. A gas pressurization system with a gauge or other suitable means of measuring pressure and detecting sheet failure shall be provided at the lower plate to form the material into the cavity. The pressure tolerance up to 1 MPa shall be ±50 kPa, and above 1 MPa shall be ±5 % of pressure. An exhaust port in the die may be connected either to

[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] 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.

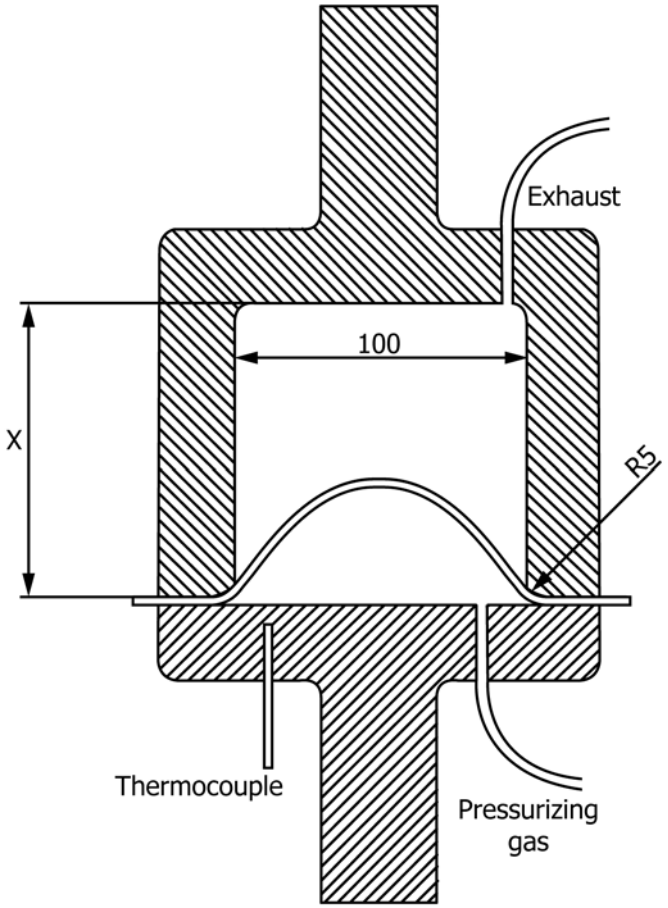

FIG. 1 Bulge-Forming Apparatus

the atmosphere or to a second gas pressurization system that provides a back pressure to the forming sheet.

5.4 The apparatus is provided with a means of heating it to the specified temperature for the material being tested. Usually, it is enclosed in a furnace equipped with doors opening in the front. The allowed tolerance between indicated and nominal test temperature is ±3°C up to 700°C and ±6°C above 700°C. The apparatus is provided with a means of moving the die or lower plate to insert and remove sheets of material and also to provide a force on the plate to counteract the force exerted by the pressurized gas. Usually, it is installed in a hydraulic press or clamping mechanism.

6. Procedure

6.1 *Dome Rupture Test:*

6.1.1 Clean a sheet of superplastic material sized at least 160 by 160 mm so that it is free of surface contaminants. The die and plate shall be clean and free of any lubricant. No lubricant shall be used in the test unless specifically required by the lot acceptance criteria. If desired, the rolling direction may be marked in one corner of the specimen.

NOTE 2—The presence of lubricant greatly affects the depth to which the material forms before rupturing. Although very important for production, lubricant adds an unnecessary variable to the test method, which is why it should not generally be used. It follows that the apparent superplasticity of a material in the bulge test is less than what can be accomplished in a production environment; however, the bulge test is only used as a pass/fail criteria, not as a quantitative test to replicate actual forming conditions.

6.1.2 Before testing, bring the vessel up to the desired temperature. Place the sheet onto the lower plate, and then mechanically clamped the plate to the die with sufficient force to prevent gas leakage or the sheet drawing across the seal during the test.

6.1.3 Start the test as soon as the thermocouple reaches the minimum temperature in the range specified, and record the time taken. The temperature shall be within the tolerance specified in Section 5 from the time from initiation of applying gas pressure until the termination of test or fracture.

NOTE 3—The SPF properties of some materials can be highly dependent on the thermal history before forming. In this case, a different heating profile may be specified, recorded, and controlled for the test to allow optimum forming conditions to be realized. This is especially true when recrystallization or other metallurgical phenomena occur.

6.1.4 Apply a specified gas pressure to the underside of the sheet. For convenience, the pressure is usually constant; however, a variable pressure/time profile may be specified if required. In general, maintain the pressure on the die side of the sheet (back pressure) at atmospheric pressure via the exhaust vent. In some cases, however, a constant or variable back pressure may be used. Record the forming and back pressures.

NOTE 4—The pressure is dependent on the alloy being tested, sheet

thickness, and other factors. A pressure of $0.15 \times t$ MPa has been used successfully on 5083 aluminum alloy at 773K, where t is the sheet thickness in millimetres.

NOTE 5—Backpressure minimizes cavitation in the sheet during forming and may be especially important for some aluminum alloys.

6.1.5 Continue the test until the sheet ruptures, as indicated by a sudden drop in pressure in the gas system. Release the forming pressure, back pressure, and clamp load immediately. The time taken to failure may be recorded. If after a suitable length of time, as determined by experience, the sheet has not ruptured, then it has deemed to have fully formed in the die.

6.1.6 Remove the coupon from the apparatus and allow it to cool on a flat surface.

6.2 *Cavitation Test:*

6.2.1 For this test, choose a sufficiently shallow die so that the sheet will form into the entire shape of the die without rupturing. The depth of the die determines the amount of superplastic strain the material undergoes measured at the center of the formed cup. Record the die depth on a certification of conformance.

6.2.2 The test procedure is the same as for the rupture test except in this case it is halted after a specified time, when the part has fully formed into the whole die cavity. The time may be established from computer analysis or prior testing of similar sheet, and is easily determined by those practiced in the art of SPF.

7. Analysis

7.1 *Dome Rupture Test*—Examine the dome for evidence that it touched the base of the die, indicated by the formation of a flat circular area on the crown of the dome. This area will normally not be the area of rupture. If it touched the base, it met the criteria; if it ruptured without forming a flat area at the crown, it is considered to have failed the criteria.

7.2 *Cavitation Test*—Exise a coupon 10 by 10 mm from the center of the formed cup. Examine it for cavitation. The method used to determine cavitation is not part of this test method and shall be specified on the bulge test acceptance criteria.

7.3 The superplastic strain of the sample is defined as:

$$e_{SPF} = \frac{(t_0 - t_1)}{t_1} \times 100\ (\%) \tag{1}$$

where:

t_0 = initial thickness measured at the center of the initial blank and

t_1 = final thickness measured in the same place on the formed cup.

8. Report

8.1 The following shall be reported:

8.1.1 Specimen identification,

8.1.2 Material certification,

8.1.3 Blank initial thickness and sheared size,

8.1.4 Temperature of the test,

8.1.5 Strain rate, variable pressure/time parameters, or the constant pressure used, and

8.1.6 Depth of the die (X in Fig. 1).

8.2 For the dome rupture test, the following should be reported:

8.2.1 Statement that the specimen passed or failed the specification height.

8.3 For the cavitation test, the following should be reported:

8.3.1 Method used to determine cavitation,

8.3.2 Amount of cavitation expressed as a volume percentage, and

8.3.3 Superplastic strain.

9. Precision and Bias

9.1 No information is presented about either the precision or bias of these test methods for bulge-forming superplastic materials since these tests are nonquantitative.

10. Keywords

10.1 constant strain rate; metallic materials; metallic sheet materials; superplastic forming; superplastic forming properties; superplastic properties; temperature; true strain; true stress