



**NATIONAL STANDARD OF THE
PEOPLE'S REPUBLIC OF CHINA**

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**Metallic materials - Sheet and strip - Biaxial stress-strain curve
by means of bulge test - Optical measuring systems**

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1 Scope

This standard specifies the symbols and descriptions, principles, test equipment, optical measurement systems, specimens, test procedures, apex curvature deformation and strain evaluation method for the optical measurement method for the biaxial stress-strain curve bulging test of sheets and strips of metallic materials, as well as the calculation and test report of biaxial stress-strain curve.

This standard applies to the determination of biaxial stress-strain curve of the metallic sheet and strip which has a thickness of less than 3 mm during the pure bulging process.

Note: The term "biaxial stress-strain curve" in this standard is abbreviated. The test determines the "biaxial true stress-true strain curve".

2 Symbols and descriptions

The symbols and descriptions used in this standard are as shown in Table 1.

Table 1 -- Symbols and descriptions

Symbol	Descriptions	Unit	ddie	Diameter of concave die (inner diameter)	mm	dBH	Diameter of blank holder (inner diameter)	mm	R1	Fillet radius of concave die (internal)	mm	h	Height of drawn specimen (external surface)	mm	t0	Initial thickness of specimen (unprocessed)	mm	t	True thickness of specimen	mm	p	Cavity pressure	MPa	rms	Standard deviation (root mean square)	-	rho	Radius of curvature	mm	r1	Radius of curved surface for determining	
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curvature mm r_2 Radius of curved surface for determining strain mm r_{1_100} Radius of curved surface determined by 100 mm concave die mm coordinate of a grid point on the surface of the bulged specimen, thereby calculating the shape change and true strain curve of the bulging center area of the specimen.

4.3 During the test, the system shall be able to determine the XYZ coordinates (non-contact) of the grid points on the surface of the bulged specimen through the optical system; use these coordinates to calculate the true strain ϵ_1 and ϵ_2 of each grid point in the selected area, the thickness direction strain ϵ_3 , as well as the curvature radius ρ of the dome of the bulging specimen.

4.4 The system should be equipped with a fluid pressure measurement system or an indirect measurement system. Starting from 20% of the maximum range of the system, the accuracy of the measurement system should meet level 1 requirements.

4.5 The concave die, blank holder and liquid cavity shall have sufficient rigidity, to ensure the minimum deformation of these parts during the test. The blank holding force shall be high enough to ensure the tightness of the blank holder.

The specimen shall not move between the blank holder and the concave die.

Usually during the test, the bulging pressure will weaken the blank holding force.

When determining the blank holding force required for the test, it shall consider the effect of this effect on the blank holding force.

4.6 The fluid medium for pressurization shall be in full contact with the surface of the specimen (no bubbles), to prevent the occurrence of high energy pressure release or oil splash due to the energy storage effect of the compressed air bubbles at the moment of energy release or rupture. During the test, until the specimen ruptures, the fluid shall not leak through the blank holder, concave die, or plate and anywhere else.

4.7 It is recommended to use calendering ribs (or devices with similar shapes on a round surface) to prevent material flow. The use of calendering ribs shall not cause the material to crack. The position of the calendering rib can be located between the concave die and the blank holder. The size of the calendering ribs should avoid blocking the material from flowing during the test, thereby causing excessive bending and wrinkling of the material.

4.8 It is recommended to place a glass plate in front of the lens and lighting equipment, to ensure that when the specimen is broken, the splash of test oil will not affect the optical measurement system. The glass plate can be fixed on the blank holder (thick glass) or placed in front of the lens and lighting system (thin glass), as shown in Figure 3. This plug-in protection device shall not affect the measurement quality of the optical measurement system. After each test, the glass plate shall be wiped clean to avoid damage or scratches; Meanwhile it shall be accurately placed back to the original position so that no recalibration of the measurement system is required. In order to obtain better measurement

5 Optical measurement system In order to determine the radius of curvature ρ of the specimen surface, as well as the true strains ϵ_1 and ϵ_2 , it is recommended that the optical measurement system have the following characteristics:

- a) Optical sensors based on 2 or more cameras.
- b) The measurement range shall be greater than $1/2$ of the concave die's diameter. The measurement area used should be a concentric circle of the blank holder; its diameter shall be greater than half the diameter of the blank holder. Throughout the forming process, this area can be observed at any height of the drawn specimen.
- c) Local resolution (distance between two individual grid points): The distance g_{max} between two adjacent measurement points on the undeformed specimens shall meet the following requirements:
- d) The determination of the curvature requires that in the concentric circle area of the blank holder with a diameter of $1/2 d_{die}$, the measurement accuracy can be verified by testing the optical measurement system, as shown in Appendix A. The accuracy of the z-axis coordinate shall meet:

Note: Strain measurement accuracy: $rms(\epsilon_1) = 0.003$, $rms(\epsilon_2) = 0.003$.

For each of the true strain values as mentioned in the root mean square above, the acceptable measurement range is as follows:

- $\epsilon_{real} = 0$, acceptable measurement range: $-0.003 \sim 0.003$;
- $\epsilon_{real} = 0.5$, acceptable measurement range: $0.479 \sim 0.503$.
- e) Lost measurement points: In order to avoid curvature discontinuities, in concentric circles with a diameter half the diameter of the blank holder, only measurement points that do not exceed 5% (not including interpolated points) are allowed to be lost. If two adjacent points are lost, the point shall not be fitted into the circle.

6 Specimen

6.1 General

7.2 Measure the initial thickness of the specimen, accurate to 0.01 mm.

7.3 Press the specimen through the blank holder and concave die. During the test, air bubbles shall be avoided between the specimen and the hydraulic fluid medium, to prevent the compressed air from splashing the hydraulic oil when the specimen ruptures.

7.4 It is recommended to use a constant strain rate of 0.05 s^{-1} for the deformation area of the specimen. If a constant strain rate cannot be achieved, it should keep the constant speed of the punch or hydraulic fluid medium. In the process of measuring the biaxial stress-strain curve, in order to avoid a greater impact on materials that are sensitive to temperature or strain rate, the bulge test should be completed within 2 min ~ 4 min.

7.5 During the test, measure the pressure of the hydraulic fluid medium.

7.6 During the test, measure the XYZ coordinates of the grid points on the specimen surface. Among them, the origin of coordinates shall be located at the center of the blank holder. The XY plane is parallel to the surface of the blank holder (parallel to the metal plate pressed before the test). Moreover, the X-axis direction corresponds to the rolling direction. The Z-axis shall be perpendicular to the surface of the clamped metal sheet specimen and face the direction of the optical sensor.

7.7 Pressure data and forming data shall be measured and saved simultaneously. It is recommended to measure at least 100 sets of data during the test. In order to show the entire strain and pressure changes, it is recommended to record at least 100 pictures of the bulge test.

7.8 When the crack completely penetrates the thickness direction of the specimen, the specimen shall be considered to have failed. That is, cracks in the thickness direction of the specimen can be judged by detecting the drop in fluid pressure.

7.9 Prepare enough specimens, to ensure that at least three valid test results are obtained.

8 Evaluation method of apex curvature deformation and strain

8.1 In order to better explain the following calculation methods of curvature and strain, it is necessary to assume a spherical surface (best fit spherical surface)

near the apex. In a picture before the failure of the specimen, as defined in 7.8, select the arc top area with the largest deformation; define it as the location where the true stress and true thickness strain ϵ_3 . In order to obtain a stable

9.3 The ratio of the diameter of the concave die and the thickness of the specimen shall be larger within a reasonable range, so as to ensure that the specimen is under a thin-walled stress state, meanwhile it may ignore the influence of bending. For tests where the ratio of the concave die's diameter to the specimen thickness is less than 100, it is recommended to check whether the bending strain is sufficiently small compared to the actual thickness strain ϵ_3 . The formula for determining the bending strain is as shown in formula (9):

Note: The biaxial stress-strain curve was obtained without using any assumptions based on the yield criterion. The biaxial stress-strain curve can be used to determine the yield locus of equiaxed stress, and to estimate the work hardening curve of the material before it reaches uniform extension.

9.4 Appendix C gives the recommended method for obtaining the yield criterion of equal biaxial stress points and the method for extrapolating the equivalent stress-strain curve based on uniaxial tensile specimens from the biaxial stress-strain curve obtained by hydraulic bulge test.

10 Test report The test report shall contain at least the following information: