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**Metallic Materials - Tube - Determination of Biaxial
Stress-strain Curve of Tube by Hydro-bulging Test**

金属材料 管 测定双轴应力-应变曲线的液压胀形试验方法

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Metallic Materials - Tube - Determination of Biaxial Stress-strain Curve of Tube by Hydro-bulging Test

1 Scope

This Standard specifies the terms and definitions, symbols and descriptions, test principles, equipment, specimens, test procedures, calculation of biaxial stress-strain curves and test reports of the biaxial stress-strain curve hydro-bulging test for metallic material tubes.

This Standard is applicable to thin-walled metal tubes with a circular section (including seamless tubes and welded tubes) whose wall thickness is not less than 0.5 mm and diameter-to-thickness ratio is greater than 20.

2 Normative References

The following documents are indispensable to the application of this document. In terms of references with a specified date, only versions with a specified date are applicable to this document. In terms of references without a specified date, the latest version (including all the modifications) is applicable to this document.

GB/T 228.1 *Metallic Materials - Tensile Testing - Part 1: Method of Test at Room Temperature*

GB/T 15825.2 *Sheet Metal Formability and Test Methods - Part 2: General Test Rules*

3 Terms and Definitions

The following terms and definitions are applicable to this document.

3.1 Digital Image Correlation (DIC) Measurement System

Digital image correlation (DIC) measurement system refers to a measurement system which adopts the digital image correlation method to track the speckle image of the deformation of an object, and calculate the three-dimensional coordinates, displacement and strain of the whole field of the object surface.

3.2 Speckle

Speckle refers to a randomly distributed spot on the surface of a test specimen.

$$L = 2L_c + L_0 + 5 \quad \dots\dots\dots (1)$$

Where,

$L_0 = (1.0 \sim 3.0) D_0$; $L_0 = 1.5 D_0$ is recommended.

7.3 The end of the specimen shall be deburred and smoothly polished. There shall be no initial cracks, or relatively deep and sharp scratches. In addition, during the preparation of the specimen, it shall be ensured that the surface of the specimen is not damaged (defects like scratches and cracks, etc.).

7.4 The outer surface of the specimen shall be cleaned, so as to spray speckles. The specific spraying method and precautions are shown in Appendix B.

7.5 During the preparation of the specimen, the specimen shall be prevented from being deformed.

8 Test Procedures

8.1 During the test, the test temperature shall be recorded. The test is generally conducted at room temperature $10\text{ }^{\circ}\text{C} \sim 35\text{ }^{\circ}\text{C}$.

8.2 Measure the initial wall thickness and initial outer diameter of the specimen. Along the circumferential direction, measure 8 points at equal intervals. The resolution of the measuring tool shall be not lower than 0.01 mm.

8.3 Carry out necessary cleaning and examination of the molds and test devices used in the test. In addition, check whether the pressure control system can normally operate and whether the pressure line has any leakage.

8.4 Before the test, under no-load conditions, check whether the equipment can normally operate; check whether the plug head and the sealing section of the mold fit well.

8.5 Place the prepared specimen into the mold. After mold clamping, use the plug for flaring and sealing.

8.6 In accordance with the wall thickness distribution measured in 8.2, determine the area of the thinnest point and mark it, so that the intermediate point of the bulging zone can be found when the DIC measurement system is used to analyze the data.

8.7 Pre-fill liquid (emulsified liquid or hydraulic oil) into the specimen to remove the gas inside the specimen. Then, increase the plug thrust to achieve sealing of the tube end.

8.8 Use a pressure sensor to measure the liquid pressure during the test.

8.9 Use the DIC measurement system to synchronously measure the speckle image

of the surface of the specimen during the test with 8.8.

8.10 In accordance with the same time scale, record and save the pressure data in the specimen and the deformation data measured by the DIC measurement system. It is recommended to record at least 60 sets of data every minute. In order to ensure a sufficient data size, at least 100 images shall be taken during the bulging test.

8.11 In accordance with a certain pressure increase rate (0.05 MPa/s ~ 0.1 MPa/s is recommended), load until the specimen ruptures. Then, end the test; record the burst pressure value; save the test data.

8.12 In order to ensure that at least 3 valid test results are obtained, a sufficient number of specimens shall be prepared.

9 Method for Determining Radius of Curvature, Strain and Stress

9.1 Radius of Curvature (ρ_{zp} , $\rho_{\theta p}$)

The required radius of curvature is the axial and circumferential radius of curvature of the intermediate point of the bulging zone. When the specimen is bulged, the axial profile of the outer surface of the area near the intermediate point is elliptical, and the circumferential profile is circular. Take the intermediate point of the bulging zone as the center, within the DIC measurement range, select a local rectangular area for analysis, as it is shown in Figure 2. The length l_1 of the selected area is recommended to be $l_1 = (0.2 \sim 0.5) D_0$; the width l_2 is recommended to be $l_2 = (0.2 \sim 0.4) l_0$, or it may be adjusted in accordance with the actual window size. In the axial direction of the selected area, uniformly select several points (it is recommended to select at least 5 points; the distance among the points shall be greater than 2 mm); extract the coordinate information of the selected points. In accordance with the elliptic equation, use the least squares fitting method to determine the axial radius of curvature of the intermediate point of the bulging zone. In the circumferential direction of the selected area, uniformly select several points (it is recommended to select at least 5 points; the distance among the points shall be greater than 2 mm); extract the coordinate information of the selected points. In accordance with the equation of circle, use the least squares fitting method to determine the circumferential radius of curvature of the intermediate point of the bulging zone. If necessary, it may also be negotiated to adopt other fitting methods or calculation methods to determine the radius of curvature.

$$F > 1.3p\pi \left[\frac{(D_0 - 2t_0)}{2} \right]^2 \quad \dots\dots\dots (A.2)$$

A.4 The test equipment shall provide sufficient mold clamping force. The provided clamping force F_t shall satisfy Formula (A.3):

$$F_t > 1.2(D_0 - 2t_0)Lp + \frac{2F}{\pi} \quad \dots\dots\dots (A.3)$$

A.5 The test equipment shall be equipped with an internal liquid pressure measurement system of the specimen, or an indirect measurement system. Starting from 20% of the maximum measured pressure value, the measurement error shall be not greater than 1% of the actually measured value.

A.6 During the test, use the DIC measurement method to obtain the X, Y and Z coordinates of the speckles on the outer surface of the specimen. The test equipment shall ensure continuous measurement of the outer surface of the specimen during the test.

A.7 The mold and plug shall have sufficient rigidity. The plug is used to seal the end of the specimen and prevent the generation of axial sliding of the specimen during the bulging process. The thrust of the plug head shall be sufficient for the specimen end to be flared and sealed, but it shall not cause cracks at the end of the specimen during the flaring and sealing. It is recommended that the cone angle ψ of the plug is 30° , or it may be adjusted in accordance with the actual situation, so as to achieve the sealing effect.

A.8 The equipment shall have an exhaust function to remove the gas inside the specimen before the test, so as to prevent liquid splash caused by the instantaneous release of the gas when it ruptures.

A.9 It is recommended to place a glass plate in front of the lens and lamps, so as to prevent liquid splash from damaging the equipment when the specimen ruptures at the end of the test, which can further protect the DIC measurement system. The placed protective device shall not affect the measurement accuracy of the DIC measurement system.

A.10 The upper mold needs to leave an observation hole. The setting of the observation hole shall be convenient for the measurement of the DIC measurement system without affecting the overall rigidity of the mold.

A.11 The mold fillet radius R_d is selected based on the initial diameter and wall thickness of the specimen. In accordance with $R_d = D_0 t_0 / 20$, calculate and determine the range of R_d ; in accordance with Table A.1, determine the actual value of R_d .

A.12 The structure, shape and size of the test mold shall satisfy the test principle and

prevail. It is recommended to use matte self-painting for spraying. After the speckles are sprayed, the specimen shall be tested as soon as possible, so as to prevent the speckles from falling off when the specimen is deformed after being placed for a long time.

NOTE: the spray paint might contain toxic solvents. Please follow the warning on the spray paint can. DO NOT inhale the sprayed gas. Make sure to use the spray paint under good ventilation. Avoid the spray paint's contact with skin and eyes. The sprayed paint mist is generally flammable, so keep it away from fire sources. Before spraying, check whether the surface of the specimen is suitable for painting.

B.3 Quality Requirements for Speckles

The quality of speckles on the surface of the specimen would affect the measurement. Hence, the speckles sprayed on the surface of the specimen to be tested shall satisfy the following requirements:

- a) In order to obtain a high-contrast random gray-scale distribution image, the speckles sprayed on the surface of the specimen shall have random characters, so as to ensure that the pixel area in the reference image matches the corresponding pixel area in the target image;
- b) The used paint shall have sufficient elasticity and strength to prevent the coating from cracking or falling fall. The speckles shall be able to deform with the specimen without premature failure;
- c) The surface features of the specimen need to have a good contrast to ensure the accuracy of image matching;
- d) The speckle surface should not have a relatively large area of continuous strong light area, for example, large spots. Figure B.2 respectively shows disqualified speckles and qualified speckles.

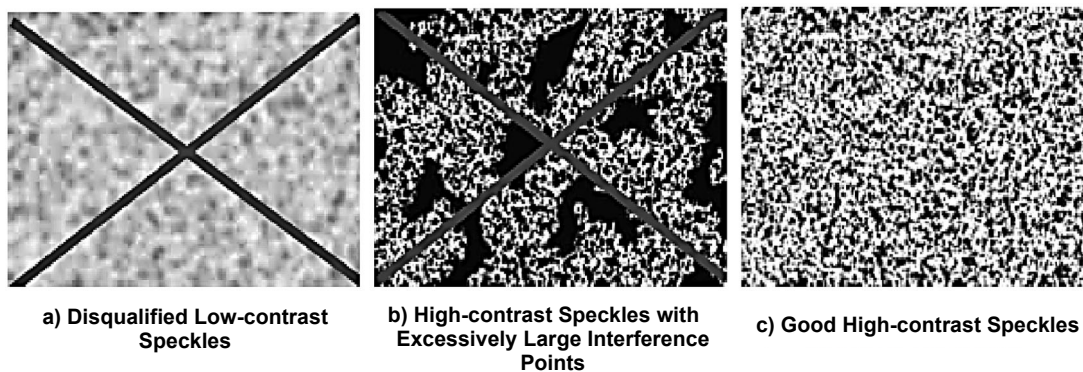


Figure B.2 -- Examples of Speckles

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