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Characterization of polypropylene PPC7712 using the Bulging Test

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Abstract – The bulge test is a multi-dimensional test used to characterize the mechanical properties of sheet metal under biaxial tension. A major advantage of the bulge test over the more conventional uniaxial tensile test is that the stress-strain curve extends to the range of effective strain found in many forming processes. It is clamped in place and inflated with hydraulic pressure. This paper describes mechanical behaviour of a copolymer polypropylene (PPC7712) under bulge test. Special equipment has been used for deforming the thin circular specimen. The measurement of the strain and stress fields applied to the specimen during the test is provided by a high-resolution 3D camera system based on the image correlation technique. The experimental obtained results were compared to Rankin and Hill theoretical models.

Key words: bulge test / polypropylene / 3D camera system / mechanical properties.

1 Introduction

The bulging test has been developed for giving more information on material behavior when the material is under biaxial loading. Within this test, carried out with circular die, the true stress-strain curve can be obtained.

There are two main possibilities for post-processing the experimental results of the bombing test. A first one follows a very simple experimental path using analytical models. Another one, based on DIC (digital image correlation), requires more time and a more expensive device.

The aim of the present study is to investigate the mechanical behavior of bulge testing for polymer sheet PPC7712 and to compare the two experimental routes for the post-processing of the experimental results obtained by the bulging test carried out on polymer PPC7712.

2 Bulge test background

Figure 1 shows a two-dimensional diagram of a typical bulge test set-up [1]. The specimen is placed firmly on the lower die which has a cavity containing an incompressible fluid. The specimen is then clamped between the upper and lower dies. A locking bead in the die prevents the sheet sample from sinking into the die cavity.

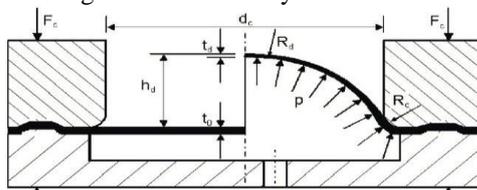


Figure 1. Geometry of the bulge test

The principle of the test is as follows: when the lower punch rises, it pushes the piston at a predetermined speed, and causes a gradual increase of the pressure on the specimen.

3 Experimental Study

a. Materials

The material tested is a copolymer polypropylene grade PPC7712 supplied by Total Petrochemicals in the form of granules [2]. Test experiments have been performed using circular specimen of 80 mm in diameter (D) and 1.8 mm thick. In this case, the specimen is painted with a speckle pattern black on white.

b. Experimental device

The device used for the hydraulic bulge test was built on an Instron tensile machine 8803 equipped with a 5kN load cell at room temperature with a DIC. The DIC system composed of two 3D cameras (Figure 3). The bulge tests are carried out with a cross-head speed of 3 mm/min.

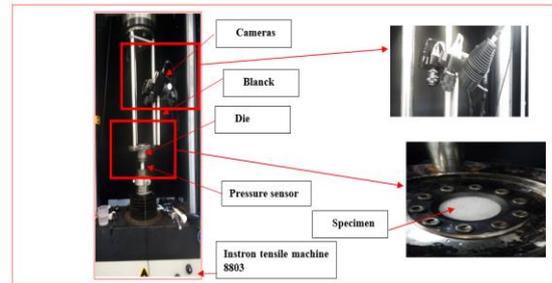


Figure 2. Bulge-test device

The simple experimental route consists of measuring the internal pressure P and the bulge height at the dome of the specimen h_d . A pressure sensor measures the pressure inside the cavity of the lower die and the displacement at the center of the specimen was measured by means of the 3D cameras. The final shape of the plates is shown in the next figure:

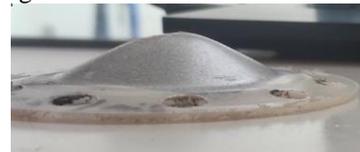


Figure 3. The specimen after bulging test

4 Theory of Stress and Strain measurement

a. Measurement with DIC system

The membrane theory can be used to compute stress, strains and pressures, as will be discussed in the next section. We can get the true stress-strain curve with the help of analytical models found in the literature [3]:

$$\sigma = \frac{PR}{2t} \quad (1)$$

where R : Radius of curvature (measured during the test by the DIC)

The current thickness t is evaluated in terms of the initial thickness t_0 and the current thickness strain ϵ . In bulging an isotropic sheet, the surface strains at the pole, by symmetry, are equal. where $\epsilon_1 = \epsilon_2 = \epsilon$, the membrane strain, and $\epsilon_3 = \epsilon_t$ is the thickness strain. We assume that the volume is constant during plastic deformation. Therefore,

$$\epsilon_t = -(\epsilon_1 + \epsilon_2) \quad (2)$$

ϵ_1 : Major strain (DIC) ; ϵ_2 : Minor strain (DIC)

The thickness t :

$$t = t_0 \exp(\epsilon_t) \quad (3)$$

5 Theoretical measurement

a. Radius at the top of the dome

The radius at the top of the dome can be calculated by assuming that the dome is spherical and that there is not a fillet in the cavity of the die [4]:

$$R_{Hill} = \frac{r_c^2 + h_d}{2h_d} \quad (4)$$

where r_c is the diameter of the cavity, and h_d the dome height.

The radius of the dome can be calculated by Panknin method [5]:

$$R_{Pankin} = \frac{(r_c + r_f)^2 - 2h_d r_f + h_d^2}{2h_d} \quad (5)$$

b. Thickness at the apex of the dome

Hill [4] investigated analytical methods to describe the deformation in the hydraulic bulge test.

$$t_{Hill} = t_o \left(\frac{1}{1 + \left(\frac{h_d}{r_c}\right)^2} \right)^z \quad (6)$$

With the stereo correlation technique, the strain components and the current thickness are directly evaluated through the displacement field. It is then important to compare the curvature radius and the current thickness obtained by the analytical models and the digital images processing with experimental measures. The resulting stress-strain curves are also compared.

6 Experimental results

Figure 4 shows the comparison between the evaluated curvature radius and the dome height obtained by the analytical models and the DIC system. The curve shows clearly the difference between the two methods of measurement.

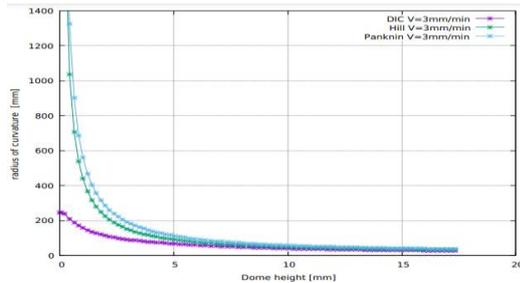


Figure 4. Evolution of the curvature radius obtained by analytical models and DIC system.

Figure 5 shows the thickness reduction of the specimen under bulge test obtained by experimental and theoretical methods.

Finally, we illustrate in Figure 6 the implication of a post-processing of the sheet bulging test on the resulting Stress/Strain curves obtained with circular die.

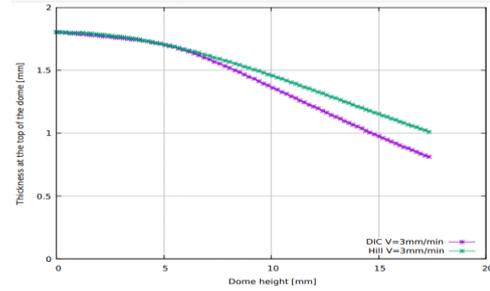


Figure 5. Evolution of the thickness reduction vs the dome height obtained by analytical models and with the DIC for bulging test.

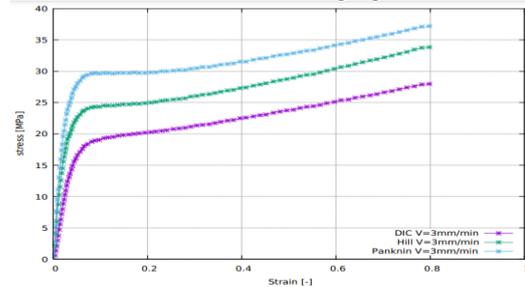


Figure 6. Stress/Strain curves obtained by analytical models and with the DIC for bulging test.

7 Conclusion

In this paper, a bulge test apparatus for testing the PPC7712 polymer was developed. Once the bulge height, the internal pressure and the thickness at the pole are obtained experimentally, the effective stress and effective strain can be determined. The post-processing of the experimental results of such a test is more complicated. During bulging test, the stress-strain curve is different for the three methods (DIC, Hill, Panknin). In conclusion, the DIC has to be preferred for post-processing experimental results of the bulging test.

8 References

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