Assessment of the elongational properties of HIPS membranes based on full-field strain measurements during positive thermoforming

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Abstract.

In the field of experimental mechanics, interest is more and more attributed to designing original single multiaxial tests which can exhibit heterogeneous mechanical responses for parameters identification. In fact, classical identification procedures of biaxial thermoplastic properties which rely on simple isotropic behavior obtained from uniaxial mechanical tests generally lack precision. Such aspect is mostly confirmed by the inaccuracy of the mechanical behavior when the same parameters identified from uniaxial loads are used in multiaxial cases. Membrane inflation constitutes one particular example of biaxial loading tests. It is characterized by imposing combined but different stretching levels along the principle directions [1,2]. The pole region is submitted to equibiaxial stretching whereas the regions near the base of the spherical shape are submitted to planar tension. As reported in literature, with the use of optical measurement techniques such as stereo digital image correlation (S-DIC) analysis of strain full-fields, the identification of material parameters of elastomers [3] or biological tissues [4] has become more reliable. Moreover, biaxial load configurations have various forms and can even be performed during the shaping of plate sheets via the thermoforming process. As recently reported by *Van Mieghem et al*., S-DIC has the potential to monitor large out-of-plane deformations taking place during thermoforming. The authors provided an original experimental procedure for validation of plastic-processing simulation packages based on thickness distribution under the assumption of material incompressibility [5,6].

In the present study, by investigating a different case from the previously stated authors, we shed more light on the potential of stereo digital image correlation (S-DIC) and positive thermoforming for identification of elongational properties of a high impact polystyrene (HIPS) at different temperatures (higher than its glass transition). In this context, an industrial thermoforming machine (Illig Ed100) is used. A thin thermoplastic sheet is pre-heated and pre-stretched at the rubbery state by applying an air-flow to form a spherical bubble of almost 55 mm radius within 1.5 seconds duration. Then, the pre-stretched sheet is further deformed by using a large wooden positive mould (Figure 1). This mould has a particular form which imposes a large out-of-plane displacement level of 250 mm at less than 2 seconds. During the mechanical deformation the sheet surface temperature is monitored using multiple thermocouples. Complementarily, a pressure sensor (of the type JUMO AP-30) is used to measure the air pressure during the inflation phase. Material deformations during the whole thermoforming cycle are monitored by using a S-DIC system from LaVision equipped with two 4M pixels cameras that allow detection of a set of pair images at 150 fps at a full resolution of (2048×2048 pixels).

Only the full-field strain data evaluated during the plate membrane inflation step will be presented (up to 55 mm /250 mm), in the current study. First, the displacement profiles during the mechanical load along the principle directions will be used to confirm the axisymmetry of the problem. Second, the full-field experimental data at the polar region will be used for identification of the material elongational parameters of a hyperelastic model such as the Mooney-Rivlin model (classically used for HIPS) by using a Finite Element Model Updated (FEMU) procedure [7,8]. Boundary conditions and preliminary results of the identification procedure will be presented. Finally, with respect of the assumption of material incompressibility, the validation procedure will be based on the comparison between numerically calculated and experimental measured thickness distributions along the major axes of the HIPS sheet.

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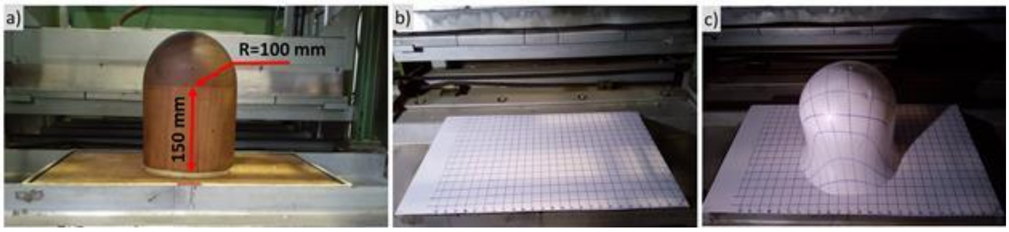

Fig 1. a) Characteristic dimensions of the used mould. b) 1.5 mm thick HIPS plate before deformation. c) Final shape obtained by the adopted mould.

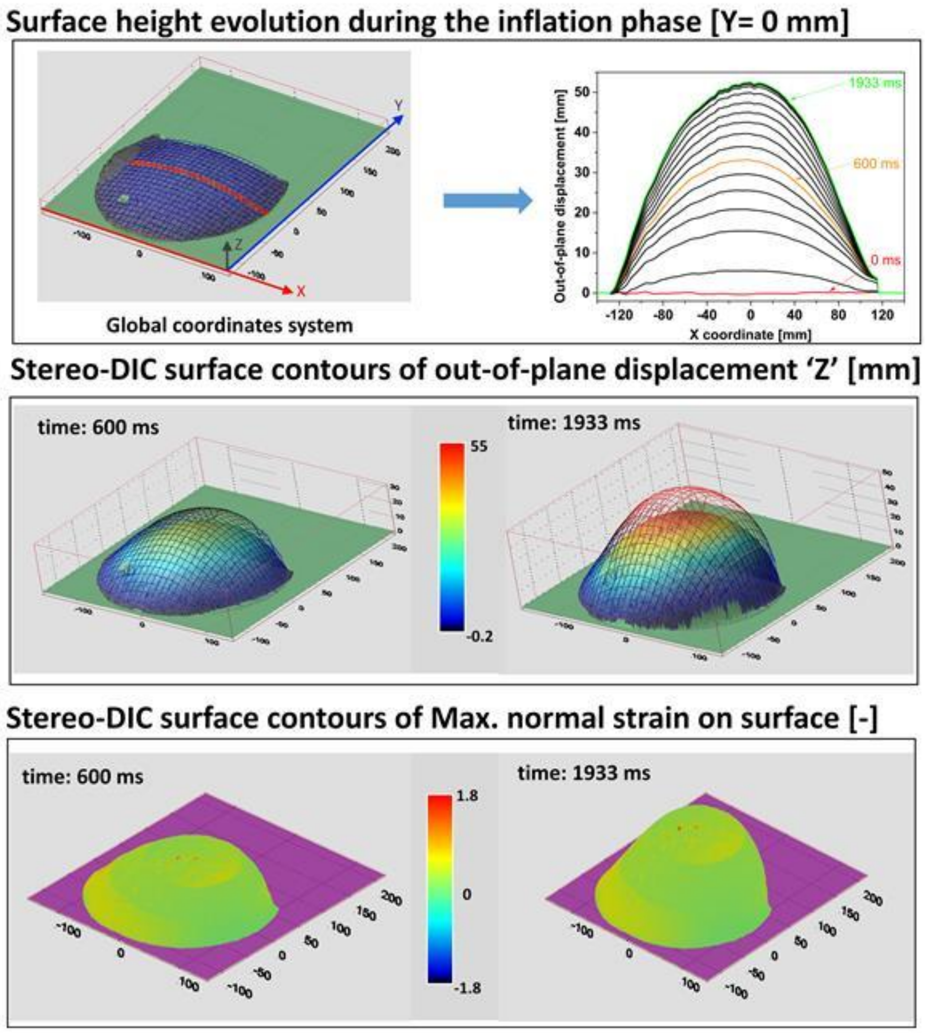

Fig. 2. Stereo-DIC based results related to the sheet out-of-plane deformation during the inflation step of the positive thermoforming process.

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