S5-1 Design and modelling of thermoformed displays for smart contact lenses

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Abstract

This paper explores the challenges regarding the thermoforming of a deformable guest-host liquid crystal display within a smart contact lens. Focus was given to the finite element modelling of its thermoforming, to find respective design rules. Such displays are thought to be used in vision correction applications (i.e. artificial iris).

1. Introduction

Nowadays, technological progress has been presented towards the development of the smart contact lens concept. The latter is foreseen to be applied in different fields ranging from biomedical control [1], signaling [2], and entertainment [3] to vision correction [4], among others. Within the vision correction applications, and besides the correction of focal length-related conditions (i.e. presbyopia), the development of an artificial iris operating in a dynamic way (i.e. emulating the function of a healthy eye) is currently being researched.

Figure 1 presents an illustration of a smart contact lens to be used as an artificial iris including potential components such as a microcontroller, an organic photovoltaic, a wireless interface and an electro-optic component at the center of the lens.

In this work, we present the smart contact lens platform with a guest-host liquid crystal display (GH-LCD) for iris conditions applications. Besides describing the different components in the system and their interactions, their thermoforming shaping from 2D to 3D was investigated and modeled using finite elements (COMSOL Multiphysics). An analysis of the stress/strain relationship during thermoforming was performed in order to understand the mechanical limitations of the platform/display and increase its robustness. The thermoforming method was proven to be a reliable way of fabricating such devices, especially when working with thermoplastic materials (i.e. polyethylene terephthalate, polyurethane, etc.) as main mechanical carriers. Besides a validated model of the thermoforming process, interesting trade-offs and design rules were extracted in order to determine maximum deformations at specific locations and final curvature of the lens, among others.

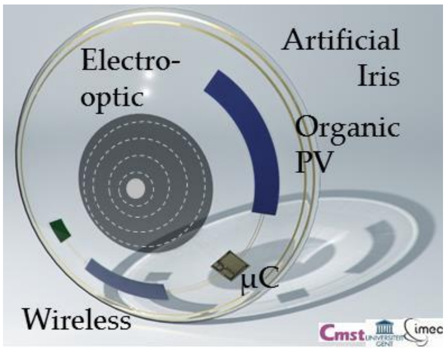

Fig. 1: Representation of the smart contact lens with an artificial iris LCD display, indicating the electro-optic component at the location of the iris.

2. Thermoformed displays

2.1 Guest-Host LCD Module

The development of a guest-host liquid crystal display (GH-LCD) on polymeric substrates has been explored at CMST [4, 5] in order to realize a device capable of dynamically modifying the light intensity at the pupil, being actuated by the changes in ambience illumination. Liquid crystal molecules act as the “host” material and a suitable dye acts as the “guest” in this guest-host LCD. The oblong-shaped dye molecules follow the orientation of the LC molecules influenced by electric fields, thus making tunable light absorption possible. The display would be located at the center of the contact lens platform with a hollow center (i.e. to allow for oxygen transmission) and a combination of a concentric rings array in order to control the illumination in a diaphragm way (i.e. similar to the normal iris functionality). The polyethylene terephthalate (PET) based display was thermoformed into a spherical cap in order to fit the curvature of the eye. The process flow as well as the challenges regarding the filling of the liquid crystal chamber are described in [4].

2.2 Thermoforming model

A finite element model (using the commercial software COMSOL Multiphysics) was developed to analyze the thermoforming of both the display and the mechanical carrier. The model will serve to extract design limitations and to predict lens curvature. Due to the viscoelastic nature of the polymers used (i.e. PET and TPU), the Generalized Maxwell viscoelastic model [6] and its constitutive equation (1) were used to represent the materials in the numerical simulations.

$$\sigma(t) = \epsilon \cdot \sum_{1}^{n} E_i \cdot exp\left(\frac{-t}{\tau_i}\right) \qquad (1)$$

Where, $\sigma(t)$ is the stress dependent on time, ε is the stretch value, E is the Young’s modulus and τ is the relaxation time, respectively.

3. Results

3.1 Thermoforming model

Figure 2 shows the comparison of measured and simulated strain values along the hoop direction (circumferential direction) of a thermoplastic disk at different temperatures. it is noted that there is a good agreement between the simulated data and the experimental data, which is one of the validation items of the model. The example shows a disk of 6.5 mm of radius with a maximum compressive strain (negative value) of -6% at the edge. The center of the disk experiences a tensile strain due to the contact with the mold (curvature of 8 mm).

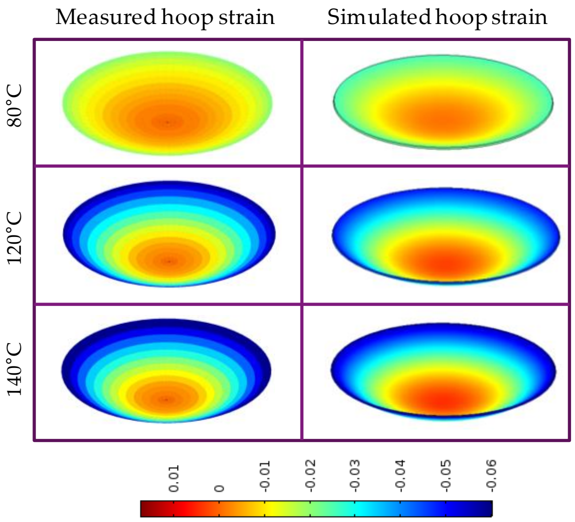

Fig. 2: Comparison of mesaured and simulated strain along the hoop direction for a disk of 6.5 mm of radius at different thermofomirng temperatures.

Figure 3 shows the implementation of the thermoforming FEM model in COMSOL, indicating the different materials and structures of the GH-LCD cell (blue for the PET substrate and green for the spacers and ring of glue). For visualization purposes the top layer of the mold and cell are not shown. Figure 3a shows the initial flat state of the lens on top of the metallic mold, while Figures 3b-d show the deformed state of the lens. Furthermore, the lens is modeled as freestanding on top of the mold, which represents the conditions of the thermoforming experiment.

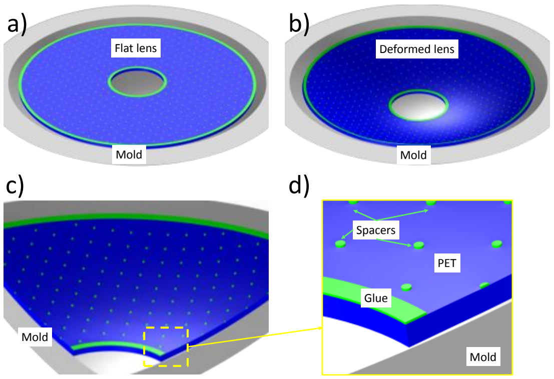

Fig. 3: Screen-shots from COMSOL. a) Initial flat position of the lens; b) Maximum deformation of the lens; c) ¼ symmetry of the deformed lens; and d) Close-up view of the deformed lens.

5. Conclusion

A finite element model was implemented and validated which predicts the mechanical behavior of the display during thermoforming. It was found that maximum tensile strain along the hoop direction was located at the center of the lens (1.5%), while a compressive strain on the spacers along the vertical direction was around -6%. These models could be applied for diverse types of thermoforming steps of soft materials in order to enhance the mechanical integrity and optimal component location.

Acknowledgements

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