



Instrumented film-insert injection compression molding for lens encapsulation of liquid crystal displays



Isik Isil Nugay¹, Miko Cakmak*

Polymer Engineering Department, The University of Akron, 250 S Forge St., Akron, OH 44325, United States

ARTICLE INFO

Article history:

Received 29 March 2014

Received in revised form 2 January 2015

Accepted 5 January 2015

Available online 19 February 2015

Keywords:

Injection compression molding

Film insert injection molding

LCD

Thermoplastic polyurethane

Lamination

Thermal characterization

ABSTRACT

A film-insert injection compression molding process was introduced to encapsulate cholesteric liquid crystal displays with flexible and rigid lens for full protection of displays to replace the currently used time consuming hand lamination technique. For this purpose, a new interchangeable cavity instrumented hot runner mold was designed and constructed. This complex method was carefully optimized considering challenges arising from an insert multilayer display with +80% liquid crystal content as well as different thermal expansion coefficients between the layers and the lens material as a high potential of delamination and warpage. Concerning the desired physical properties including transparency, low melt viscosity and melting temperature as well as a wide range of hardness grades from soft (flexible) to hard (rigid), three different hardness grades of thermoplastic polyurethanes were found to be the best candidates for this lens application. During proposed lens encapsulation, the pressure changes were evaluated with screw and mold movements using position detection via displacement transducers attached to track the mold closure and screw forward motion. The quality of encapsulation and shrinkage related problems, as well as their elimination, were all discussed. Display substrate material selection criteria for lower warpage were defined with supporting thermal characterizations. Among the process parameters, tested also by applying the design of experiments with Taguchi method, mold temperature was found to be the most influential parameter on warpage, followed by pin gate opening time, packing pressure, and cooling time.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

Full color, reflective, bistable, lightweight and flexible cholesteric liquid crystal displays are introduced to the market offering numerous applications such as electronic skins with real time switchable colors for consumer device cases, walls and windows. They add an ultimate personalization feature to the application area and device by providing a discrete color with the advantage of low power consumption. For the current use, plastic/glass film lenses are hand laminated on the displays with a pressure sensitive optical adhesive for increased protection and ease of application. However, this process is a labor intensive process, increasing the production time and failing to encapsulate the edges of the displays as it involves only adhesion of the lens on the display. Therefore, there is a need for a more economically viable process to create fully protective display encapsulations allowing use in rigid and flexible applications. The injection molding process can be

considered as a good candidate for encapsulating the displays, although the process complexity is likely to cause challenges to be resolved. Encapsulation application demands for the film-insert injection molding technique however, the traditional injection molding would generate over the limit pressure values on the delicate display elements.

In the film-insert injection molding (FIM) process, the molten polymer is injected into the mold cavity where one side of the mold wall is insulated by a pre-attached film. FIM is a cost and time-effective technique eliminating various post-processing procedures (screen printing, spray painting, laminations etc.) and improving surface quality as well as durability. Many products such as automotive interior parts, cellular phone cases, logo designs on plastic products are produced using FIM method [1,2]. Adhesion between the film and the substrate may be enhanced using this process as the injected hot molten resin can partially melt the film [3].

Disadvantages of the FIM process include the possibility of washing off the printed ink on the film, unexpected weld line, wrinkling of the film, warpage, and uneven part shrinkage [1]. Traditional injection molding process creates residual stresses due to

* Corresponding author.

¹ Present address: Apple Inc. Panel Process and Optics, 1 Infinite Loop, Cupertino, CA 95014, United States.

shear and extensional flows within the process. During packing, high pressure and during solidification and cooling, thermal stresses are imposed on the part as previously mentioned; and thus, it causes deformation. The FIM process interrupts heat transfer in perpendicular direction to the cavity wall, which causes very severe residual stresses on the part. This asymmetric residual stress distribution is shown to result in extreme warpage and non-uniform shrinkage [1,4]. The effects of injection molding conditions such as injection speed, melt temperature, mold temperature, packing time, and pressure on viscoelastic behavior and deformation of film insert molded parts, were investigated in many studies [1,2,4]. Beak et al. reported their work on warpage of polycarbonate, acrylonitrile–butadiene–styrene (ABS) substrates, and polymethylmethacrylate (PMMA) films [5]. Film inserts were annealed at higher temperatures to minimize the effects of thermal shrinkage and residual stress on warpage of the final parts; the thermal expansion coefficients were calculated and compared for annealed and non-annealed films [1,2,5]. Effects of film and substrate thicknesses on warpage were investigated in detail [4]. In the above mentioned studies, warpage reversal phenomenon (WRP) was also observed and presented as the combined effect of the thermal shrinkage of inserted film and the relaxation of residual stresses in FIM part during annealing. Annealing was found to affect warpage variation more than any other injection molding parameter [5]. It is clear that warpage will be a major problem for the rigid lens encapsulation of displays. As a solution to this problem, injection compression molding (ICM) process was introduced to reduce the pressures exerted on the part.

In recent years, manufacturing of precision plastic optical parts for high-quality parts such as lenses and disk substrates by injection–compression molding processes gained popularity. These are a combination of the traditional injection molding process and the compression molding process. There are many devices produced by traditional injection molding, from automotive parts to medical sensors; however, there are disadvantages involved in using this technique for making optical parts, such as high injection and packing pressure, uneven shrinkage, warpage, residual stress, and sink marks [6]. Optical birefringence is an outcome that significantly reduces optical performance (e.g. double-vision) of an optical electronic device –for instance, liquid crystal display– due to residual stresses brought about during the process. In the compression molding process, the molten polymer is compressed by the moving platen to flow into the cavity. The pressure produced in this process is more uniform along the cavity wall, and lower for post filling stage, and therefore results in less residual stress as well as less part warpage [6,7]. Drawbacks for this method include low productivity due to the time-consuming charging step, and the limitation for producing large complex shaped parts. The injection compression molding differs from traditional injection molding in terms of cavity filling, where there is further melt flow and reduction of cavity volume during the packing step. The compression stage after the partial melt filling of the cavity decreases the mold pressure and clamp tonnage by 20–50%, and reduces the cycle time and residual stresses [8]. The process is also reported to allow even packing, and thus, lower uneven shrinkage and warpage [9]. High-precision optical parts manufacturing via injection compression molding is presented in both experimental and numerical forms in the literature for various cases [10–13]. Studies conducted on molding optical lenses concluded that the parts had better quality compared to the traditional injection molded parts at the same cooling time [10,11]. The injection compression molded disks (e.g. CD-R) are shown to have enhanced dimensional accuracy on the direction perpendicular to the compression, as well as improved conformity to cavity profile and reduced warpage [12,13].

The objective of this research is to introduce a new combination of processing method, film-insert injection compression molding

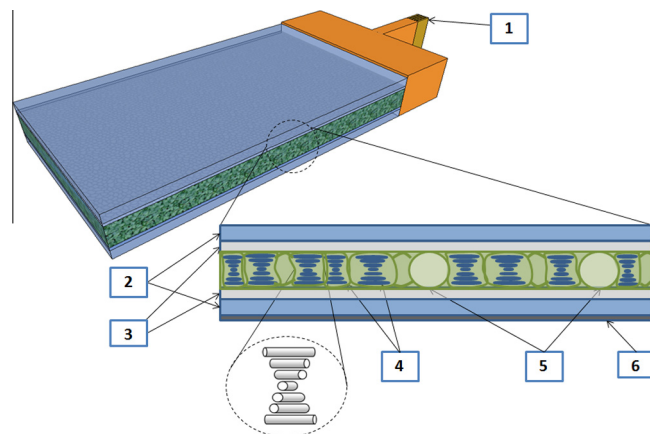


Fig. 1. Components of the LCD display: cross-sectional view of rectangular (8×4 cm) display with one has electronic “tab” for electronic switching (1), PET (2) and conductive layer (3), acrylate encapsulated cholesteric LC(4), separator beads (5) and absorbing carbon black coating (6).

(FICM) for lens encapsulating displays and to investigate the process effect on transparent polyurethane lens encapsulation of cholesteric liquid crystal displays (Fig. 1). The displays are composed of an electrical tab with Kapton tape, a PET layer, a conductive coating, polymerization induced phase separated LC layer, a conductive coating, a PET layer and a thin layer of carbon coating for light absorption. A hybrid method developed to encapsulate displays is considered to reduce production time and allow full protection of the display, including display edges, as a better alternative to the currently used hand lamination technique. The goal is to encapsulate displays with a lens without delamination or damage to the liquid crystal layer and the electronics of the display. Therefore, our primary focus is to optimize processing conditions while maintaining the integrity of potentially compressible display layer of +80% liquid crystal domains. For this purpose, a highly instrumented interchangeable cavity mold was designed and built; the effect of different process conditions on final part quality was investigated along with the design of experiments for warpage optimization. A variety of grades for polyurethane lens encapsulations are presented to find use among the current rigid market applications and to foster flexible future applications of these liquid crystal displays. The potential display substrates, PET and PEN, and their thermomechanical properties were also discussed to explain lower warpage results.

2. Experimental

2.1. Materials

2.1.1. Display

The display PET layers were heat stabilized and supplied by Dupont. The $51 \mu\text{m}$ PET film was used as substrate material in all displays except the optional $127 \mu\text{m}$ PEN substrate displays. In some displays, $178 \mu\text{m}$ PET or $127 \mu\text{m}$ PEN was laminated for extra protection of the liquid crystal layer. The conductive coating on the substrate layers, the back side carbon black with binder coating, and the acrylate encapsulated cholesteric LC with spacers for the entire display device assembly, were prepared by Kent Displays Inc. The substrate layers were laser singulated for complete sealing of the device.

2.1.2. Injection molding materials

In order to encapsulate the LCD display, a range of thermoplastic polyurethane from flexible to rigid was used as lens material.

Download English Version:

<https://daneshyari.com/en/article/540543>

Download Persian Version:

<https://daneshyari.com/article/540543>

[Daneshyari.com](https://daneshyari.com)