

Negative C-plate Coated Compensation Film

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ABSTRACT

Thin Birefringent Films (TBFs) with negative C-plate retardation function produced by coating technology have been prototyped on glass and TAC substrates. The TBF compensation films demonstrate a wide range of retardation values (up to 500nm). The key concepts of the manufacturing process and characteristics of the compensation films are discussed.

1. INTRODUCTION

LCD compensation films (retarders) based on coatable Lyotropic Liquid Crystal (LLC) materials [1, 2] provide substantial advantages and opportunities for LCD industry. There is a great potential for reducing the cost of a wide variety of retardation films covering almost all needs in optical compensation of LCD [3]. Technology provides options for tuning N_z factor [4] and spectral dispersion of refractive indices as well as retardation [5], and other performance parameters to achieve the optimum optical property.

Technology has advanced to pilot production stage. In this paper we describe pilot scale manufacturing of compensation films by coating negative C-plate on glass by casting and on TAC substrate by slot die roll-to-roll process.

2. COATABLE NEGATIVE C-PLATE RETARDER

2.1 Properties of CN-LT-1000 coating solutions

Crysoptix proprietary negative C-plate material CN-LT-1000 described earlier [6] is based on water soluble rigid-rod polymer, having phenylene groups in the main chain, which provide high level of birefringence.

As opposed to coatable LLC materials, able to form in-plane anisotropic optical films ($\pm A$, B_A -plates), CN-LT-1000 material when dissolved in water, forms transparent solutions with no tendency to LLC phase formation even at high concentrations. However, the solutions show shear induced phase transition: flow birefringence is detected when orienting molecules by the action of shear forces. The effect of shear induced birefringence is clearly seen, when the solution is observed in crossed polarizers.

Rheological properties of aqueous coating solutions of CN-LT-1000 material have been examined. Flow measurements were performed using Rheometer AR 550. The 'cone-and-plate' geometry of the measuring unit was used. Shear viscosity vs. shear rate/stress was measured in the steady-state flow regime.

Figure 1 shows shear viscosity curves of solutions of different concentrations at 25°C. The solutions show a slight pseudo-plastic flow characteristic, and they are close to Newtonian liquids in the region typical for the normal coating conditions (shear rate 15-100 s^{-1}).

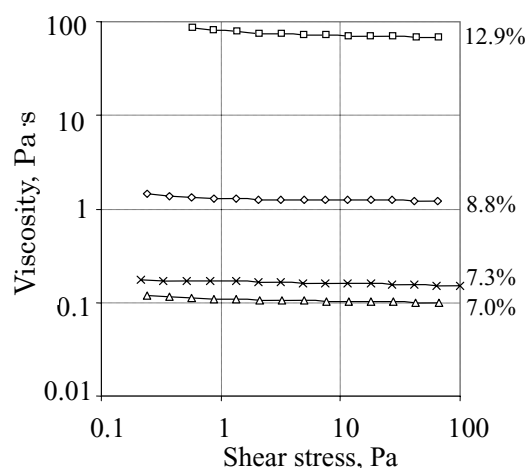


Fig. 1. Viscosity as a function of shear stress for CN-LT-1000 aqueous solutions of different concentrations at 25°C

Rheological behavior of the negative C-plate retarder material is quite different from the coatable LLC materials, such as previously described $\pm A$ -plate and biaxial B_A -plate materials, which show a pronounced shear-thinning effect and 2 orders of magnitude drop in viscosity at similar shear rates [4]. Coating of shear-thinning liquids is more complex, quality and uniformity of in-plane anisotropic film strongly depends on coating parameters such as coating speed, gap; at the same time coating of $-C$ -plate is more tolerant to these factors. The distinction arises from different mechanisms of aligning. In case of shear-thinning $\pm A$ - and B_A -plate materials the domains of lyotropic liquid crystal become macroscopically ordered along the coating direction under the action of shear stress in coating. On the contrary, in agreement with data presented in Figure 1, CN-LT-1000 material is coated without exercising any noticeable alignment. The alignment stage takes place during a wet film drying, when the polymeric molecules get arranged in the plane of the film with their long axes parallel to the substrate

plane but without any preferential orientation. This assumption is confirmed by direct measurements of out-of-plane retardation of the films: the out-of-plane retardation is negligible right after coating and increases as the film dries.

Quality and thickness of coatings obtained under the same coating conditions depend on the effective viscosity of the coating material, which in turn depends on concentration and temperature. Figure 2 shows the dependence of the shear viscosity of CN-LT-1000 aqueous solution on concentration. Such dependence can be approximated by an exponential function (shown in the figure).

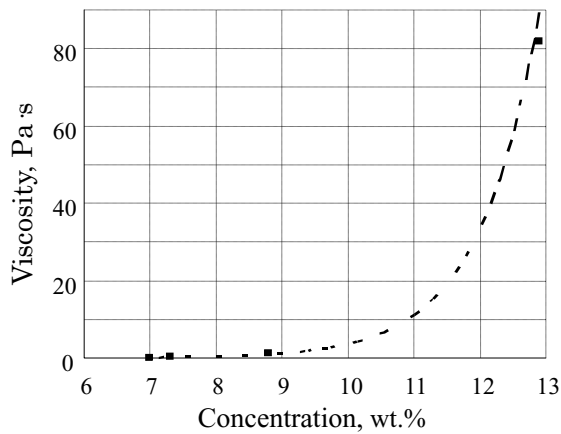


Fig. 2. Viscosity (at shear stress of 1Pa) as a function of concentration of solids in CN-LT-1000 aqueous solutions at 25°C

Viscosity of CN-LT-1000 aqueous solution as a function of temperature was studied for concentration of solids of 7.3 wt.%. The dependence is shown in Figures 3 and 4.

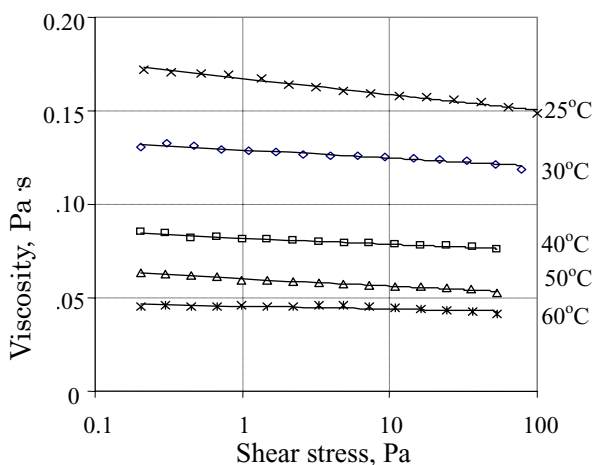


Fig. 3. Effect of temperature on viscosity (C = 7.3 wt.%)

By changing temperature of the coating material from

25 to 60 degrees C, the viscosity is changed by a factor of 3. Temperature of the material was fixed at 45 degrees C, which gave effective viscosity of ~0.07 Pa·s. These parameters characterize the standard solution for film manufacturing.

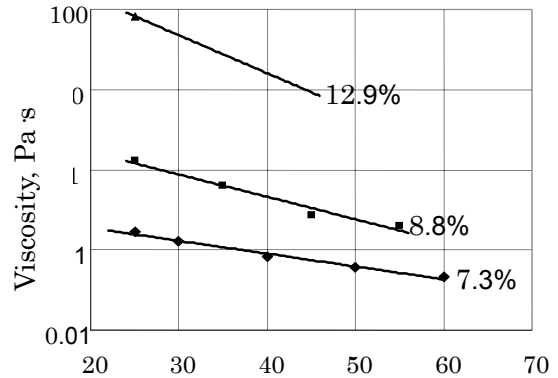


Fig. 4. Viscosity (at shear stress of 1Pa) as a function of temperature at different concentrations of CN-LT-1000 solutions

2.3 Coating on glass by applicator

Coatings were made using an Erichsen film applicator with heat plate accessory and variable gap (Zehntner ZUA 2000/220 Universal applicator). Coatings were made on glass plates of 230x380 mm size. Coating regimes were optimized using the fixed material formulation at 7.35 wt.% concentration and 45 degrees C temperature of the coating solution and substrate.

Thickness of the obtained films was measured with a surface profilometer Dektak 3ST. Thickness uniformity is the most important parameter as it determines retardation of the film. CN-LT-1000 material has a very high birefringence ($\Delta n \sim 0.125$), and a very small deviation of thickness is required.

In this work the maximum allowable variation (error) of retardation was limited to 5% of the target value. Two different retardation values were targeted – 250nm and 500nm. Thus the allowable thickness variation was less than 100nm for the dry retardation film.

A very basic coating process was used. The material was deposited on the substrate with a pipette at the starting line along the applicator, and then it was spread with the applicator over the substrate. Thickness of the coated film depends on the applicator gap, which is a distance between the applicator and substrate surface, and a speed of the applicator movement.

Figure 5 shows the results of obtained dry film thickness depending on the applicator gap at the coating speeds of 2.5 and 5.0 mm/sec. The speed of the applicator movement affects the thickness value of the resulting wet film, defects and uniformity. At a slow speed (2.5 mm/sec) we observed a “healing” of some of

the defects appearing in the film during coating, which does not happen at higher speeds. However, we observe a longer “starting region” at a slow speed where thickness value gradually reaches its terminal value (the stable maximum value). Increasing the applicator speed shortens the starting region, but at the same time this leads to an increased risk of defect precipitation in the coating.

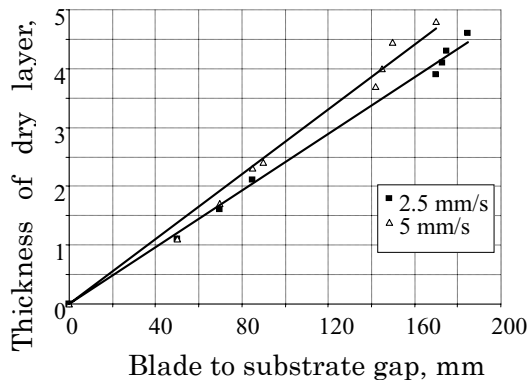


Fig 5. Effect of the applicator gap (blade to substrate) on thickness of a dry layer

We found that the optimum applicator speed for the applied coating method was in the range of 5-10 mm/sec. At this speed we observe thickness reaching its steady desired value after about 50-70mm from the starting line.

The length of the starting region is mainly determined by the kinetics of wetting of the substrate and applicator by the coating material. In order to improve wetting, the surfactants (wetting agents) can be used. By adding 0.01% of a surfactant viscosity of the material dropped by ~25% and shortened the starting region from 50-70 mm down to ~20 mm. Adding of the surfactant has also reduced the appearance of defects in coatings.

The coated films were dried in open air at approximately 45 degrees C. No special arrangement was necessary for this stage.

2.4 Coating on TAC by slot-die roll-to-roll

The CN-LT-1000 material was coated on TAC substrate using a slot-die roll-to-roll technique. Width of coated samples was 300mm, and length was not limited as quality of coating was uniform along the entire length of the film. The coating parameters were chosen to produce uniform dry coatings of 1.5, 2.0 and 2.5 micrometers thickness. This was achieved by tuning the flow rate of material and speed of the substrate. The solution and supply line of the coater were heated to 40 degrees C.

For illustrating potential productivity of the coating method we strived to maximize the web speed (speed of substrate movement). The substrate speed was maximized within the current limits of the coating machine, and we could reach 200 feet per minute. Samples produced at 200 feet per minute showed standard

deviation of the film thickness (measured along and across the samples) not higher than 3%.

2.5 Coated retarder characterization

Coatings made on the glass substrate were optically characterized with the described earlier procedure [4]. The refractive index spectral dependences are presented in Figure 6.

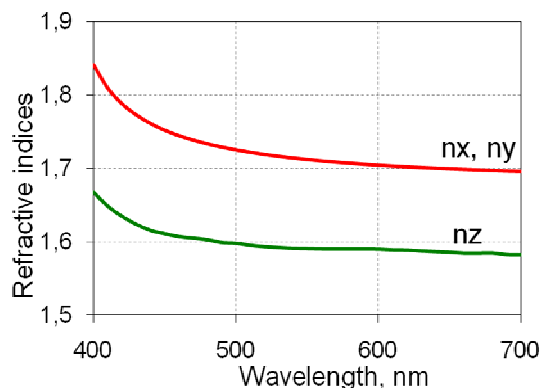


Fig 6. Three-dimensional refractive index of the CN-LT-1000 TBF™ coated on a glass plate vs. wavelength

A measurement of retardation of the film consisting of TAC substrate and the coated layer does not allow separating the optical properties of the coated layer - so the measured retardation corresponds to the coated layer on the TAC substrate. However, we have also measured R_{th} and R_o of the TAC alone, which gives us a reliable reference point to evaluate our results.

Measurements of R_{th} were performed using Axometrics equipment and shown in Figure 7.

The in-plane retardation (R_o) of the coated TAC is equal to TAC itself accurate within measurement error.

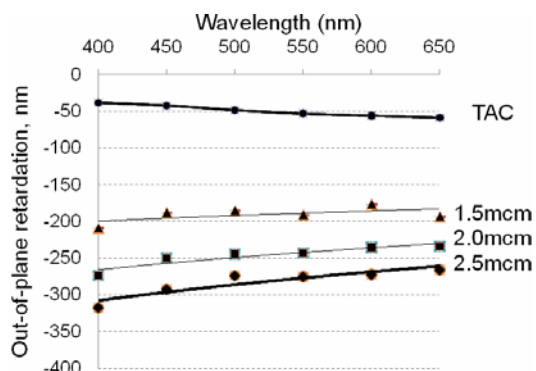


Fig 7. Out-of-plane retardation of CN-LT-1000 TBF™ coated on TAC vs. wavelength

An interference pattern can be observed on the surface of the resulting film, when viewed at certain angles. In our case the film shows pink reflection. Similar behavior is typical to other products coated with thin

layers. For example, camera lenses often have blue reflection.

We have performed thermostability tests of the samples coated onto glass, and the coated films showed no degradation if heated up to 250 degrees C. Coated films exhibit 100% adhesion to both display glass and TAC.

Conclusion

Negative C-plate retarder functional coating technology has matured to the manufacturing stage. Excellent optical properties and cost efficiency make new retarders a material of choice for LCD applications. Retarders are manufactured on the glass and plastic TAC substrate.

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