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Characterization of an acrylic polymer under hygrothermal aging as an optically clear adhesive for touch screen panels

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ABSTRACT

Optically clear adhesives (OCAs) are key components of touch screen panels (TSPs). It is important that OCAs do not affect the transparent electrodes in TSPs because OCAs are contacted to the transparent electrodes. Therefore, N-vinyl caprolactam (NVC) was incorporated in the composition of an acrylic pressure sensitive adhesive (PSA) with excluding an acidic component to maintain the cohesion for OCA preparation. With increasing amounts of NVC, the tack and peel strength of UV-cured PSA increased, but high amounts of NVC led to decreased peel strength. The UV-cured PSA films were placed in a high temperature and humidity chamber for 8 weeks to investigate the durability and corrosion property under hygrothermal conditions. In this study, the corrosion test method using copper foil was suggested as a simple and economical method and was used to evaluate the effect of NVC on the corrosion property of PSA. This method helped identify suitable OCAs that do not have corrosive property. PSA films containing more than 20 wt% of NVC promoted the corrosion of copper foil under hygrothermal aging conditions. The caprolactam ring was opened by moisture, and the PSA structure morphed into a polar structure during the aging process. This change caused a glass transition shift, an increase in the storage modulus at the rubbery plateau, and an increase in peel strength. The surface free energy of the PSA films also increased due to the increase in the polar property. However, high amounts of NVC caused a decrease in the peel strength after 8 weeks of aging because of increased molecular interactions.

1. Introduction

Touch screen panels (TSPs) are common input tools, the application of which in electronic devices is currently expanding. TSPs comprise a cover window, transparent electrodes, and a display module. These constituents are attached to one another with optically clear adhesives (OCAs). In this study, "optically clear" infers that more than 90% of visible light can transmit through the adhesive. This property is essential for displaying the images passing through each component of the TSP on the display module. Generally, an OCA is contacted on the cover window and transparent electrodes, especially in capacitive-type TSPs (Fig. 1), which are commonly used in recent electronic devices [1]. Therefore, it is important for OCAs not to influence the transparent electrode because the electrode is a key component driving the TSP.

Acrylic adhesives were mostly chosen as OCAs due to their fast UV curability and excellent clarity and economical aspect. These adhesives usually contain an acidic component, which is representative of acrylic acid (AA), to improve the cohesion and supply the remaining reaction site with a curing agent. However, if this acidic component was added to the OCA, it can corrode the transparent electrode contacted to the OCA [2]. Therefore, the acidic component should be excluded from the OCA; however, it is essential to incorporate an alternative material into the OCA to maintain the cohesion.

N-vinyl caprolactam (NVC) can be a good replacement for AA. The nitrogen atom in an NVC structure has high electronegativity; therefore, NVC can help enhance the cohesion of OCAs. NVC has been employed in other studies for medical pressure sensitive adhesives (PSAs) [3,4], self-adhesive products, such as labels [5,6], drug delivery systems [7], and dental materials [8].

Several studies on OCAs have been published. Acrylic OCAs for color filters in liquid crystal displays have been reported by Chang and Holguin. OCAs were applied to color filters and changed to a near-structural adhesive by UV and thermal curing [9]. Titanium oxide [10], hafnium carboxyethyl acrylate [11], and zirconium carboxyethyl acrylate [12] blended acrylic PSAs have also been

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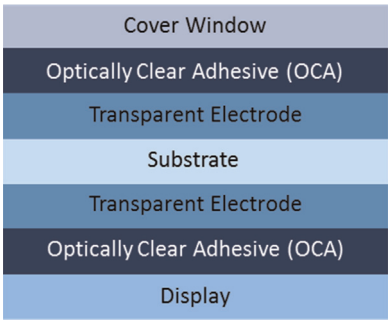

Fig. 1. Capacitive type TSP structure and OCA application.

studied for OCA applications; the main property of those blends being a high refractive index, which can contribute to clearer images on the display. Various companies have applied for several patents on OCA (pressure sensitive adhesive (PSA) type) or optically clear resins (OCRs, liquid resins) [2,13–16].

A more important property of OCAs compared to the refractive index is the anti-corrosion property towards transparent electrodes. The refractive index of a generic acrylic adhesive is adequate to produce a clear image. In addition, the above-mentioned papers studied AA-containing PSAs as OCAs. Therefore, acrylic PSAs without AA and with an anti-corrosion property need to be studied for application in OCAs. Studies on PSAs that do not have an acidic component and on the corrosive property of PSAs toward a substrate, in this case, a transparent electrode (conductive substrate), have not been published. Accordingly, it is necessary to study this topic – acid-free acrylic PSAs and their properties.

The purpose of this research is to characterize an acrylic OCA, with NVC being incorporated in the main polymer backbone, which will protect the transparent electrodes from corrosion by the OCA. Therefore, a PSA-type OCA was prepared with varying amounts of NVC, and its adhesion performance was measured. The durability of the OCA is also important because TSPs will be more widely used in long-term electronic products, such as white goods or automobiles. However, this property has not yet been studied; therefore, the durability of the PSAs prepared in this study should be assessed, as well. Hygrothermal aging is generally used as a test method to determine the suitability of an OCA before any actual application by intentional exposition to a harsh environment. Consequently, the prepared OCA was submitted to property tests including adhesion performance and corrosion property after exposition to hygrothermal aging conditions. Additionally, a method for detecting the corrosive property of PSA toward the transparent electrode was suggested as a simple and economical one.

2. Experimental

2.1. Materials

2-Ethylhexyl acrylate (2-EHA, Samchun Pure Chemical, Republic of Korea), isobornyl acrylate (IBOA, Sigma-Aldrich, USA), and N-vinyl caprolactam (NVC, Sigma-Aldrich, USA) were used to prepare the monomer premix. 1,6-Hexanediol diacrylate (HDDA, Miwon Specialty Chemicals, Republic of Korea) was used as a crosslinking agent. The photoinitiator for the premix preparation and UV-curing was α,α-dimethoxy-α-phenylacetophenone (Irgacure 651, BASF, Germany). All reagents were used without any further purification.

Table 1
Monomer ratio for premix preparation by UV irradiation.

	#1	#2	#3	#4	#5
2-EHA (wt%)	60	60	60	60	60
IBOA (wt%)	40	35	30	20	0
NVC (wt%)	0	5	10	20	40
T_g of cured PSA film (°C)[a]	−40.8	−32.1	−28	−16.6	−22.6

[a] Measured by ARES.

2.2. Monomer premix preparation

A 300 mL round-bottomed flask was equipped with a mechanical stirrer, thermometer and N_2 purging tube. Then, each monomer was charged into the flask, in concentrations given in Table 1. The amount of photoinitiator used was 0.04 phr. Five monomer premixes with different amounts of NVC were prepared by UV-irradiating 2-EHA, IBOA, NVC, and the photoinitiator mixture using a UV-spot cure system (SP-9, USHIO, Japan) of 40 mW/cm^2 intensity under a N_2-rich atmosphere for approximately 3 min. The average viscosity of all the monomer premixes after UV irradiation was approximately 870 cPs, as measured with a Brookfield viscometer using a No. 4 spindle under 750 rpm at room temperature. The molecular weight of each monomer premix was detected by gel permeation chromatography. The monomer premix was diluted with tetrahydrofuran to 1%. The instrument was Agilent 1100 S (USA) and 5-μm polystyrene column was used.

2.3. Coating and curing

Each premix was blended with 0.1 phr of HDDA and 0.15 phr of additional photoinitiator using a paste mixer (Daewha Tech Co. Ltd, Republic of Korea) for 5 min under 1000 rpm. The heat generated during blending was not considered. These mixtures were coated on a PET film for peel strength measurements and the dry-thickness of the coated PSAs was 175 μm. The mixtures were also coated on a release film for viscoelastic property measurements and the dry-thickness of the coated PSAs was 500 μm. The coated samples were UV-cured using conveyor belt type UV-curing equipment with 1000 mJ/cm^2 doses and formed the PSA film after UV-curing.

2.4. Gel fraction

To measure the gel fraction of each sample, the UV-cured PSA films were soaked in toluene for 24 h at 50 °C after weighing each sample. After eliminating the toluene, the swelled PSA films were fully dried for 24 h at 50 °C. After drying, the samples were weighed, and the gel fraction was finally determined. The gel fraction of the cured PSA films was calculated from the following equation.

$$\text{Gel fraction}(\%) = (W_1/W_0) \times 100$$

where W_0 is the initial weight of the sample and W_1 is the solvent extracted weight [17].

2.5. Transmittance

A UV/visible spectrophotometer (Cary 100 UV–vis, Agilent Technologies, USA) was used to evaluate the visible light transmittance of the PSA films used as OCAs in this experiment. The wavelengths of the measurements ranged from 400 to 700 nm. The UV-cured PSA films, which were coated on the PET film, were