WINDOW FILMS FOR ENERGY CONSERVATION: DESIGN AND PRODUCTION CHALLENGES

Raghu Padiyath and Gregory King

Renewable Energy Division, 3M Company, St. Paul, MN 55144

Presented at the 15th International Coating Science and Technology Symposium, September 13-15, 2010, St. Paul, MN[1]

Introduction

Energy conservation can play an important part in meeting the growing global demand for energy. Buildings account for 39% of the energy consumption in the United States and heating and cooling them take up 40% of the energy used. While the walls and ceilings in the building envelope can be made of good insulating materials having R-values ranging from 10 – 50, most windows are very energy inefficient with R-values between 2 and 3. In addition, solar heat gain through the windows is often a significant problem not to mention excess glare from a poorly chosen glazing.

For several decades, window films have been in use for reducing solar heat gain, glare, and fading of furnishings and have evolved from a primarily semi-transparent metalized film to highly sophisticated spectrally selective ones that are visually transparent but infrared and UV blocking. As these films have become more acceptable in the marketplace, the expectations have risen in scope and complexity. Today's quality and performance expectations pose significant challenges in both technical specifications and manufacturing operations.

Since a significant portion of the incident solar radiation is in the visible portion of the electromagnetic spectrum, window films absorb this radiation using either pigments or dyes incorporated into the film or in the coatings. Similarly, the infrared portion of the solar spectrum can be either reflected or absorbed with multi-layer polymeric films or sputtered inorganic/metal pairs. Almost all window films also have UV absorbers incorporated into the film or adhesive or both. Due to the wide ranging products and applications, product developer, manufacturing engineer and field service representatives often encounter problems that are difficult to understand and time-consuming to resolve. In this paper, we present challenges unique to the window film related to both design and production.

Window film constructions

The simplest type of window film construction available in the marketplace has a hardcoat, typically a UV cured acrylate coated on a dyed or pigmented PET film. Solvent borne pressure sensitive adhesive is coated on the opposite side that is wetted with soapy water, applied to the glazing and 'squeegeed' to obtain smooth, bubble free application. A vast majority of the products use pigments and/or dyes that absorb only visible light as shown in the spectra in Figure 1. In some cases, the film may be coated with metal (Al, Ni, Ag, Cu and their alloys) while in others a separate metalized film may be laminated to the first one. In some high performance window films, hundreds of polymeric layers of differing refractive indices result in transparency in the visible and high reflectance in the IR region. Sputter coated stacks of alternating dielectric (Indium Oxide, Indium Tin

Oxide, Titanium Oxide, Indium Zinc Oxide, etc.) and Silver (or Silver alloys) are also used for window films having high visible light transmission and high IR reflectance. In the following sections, challenges associated with manufacturing window films of different constructions are discussed in detail.

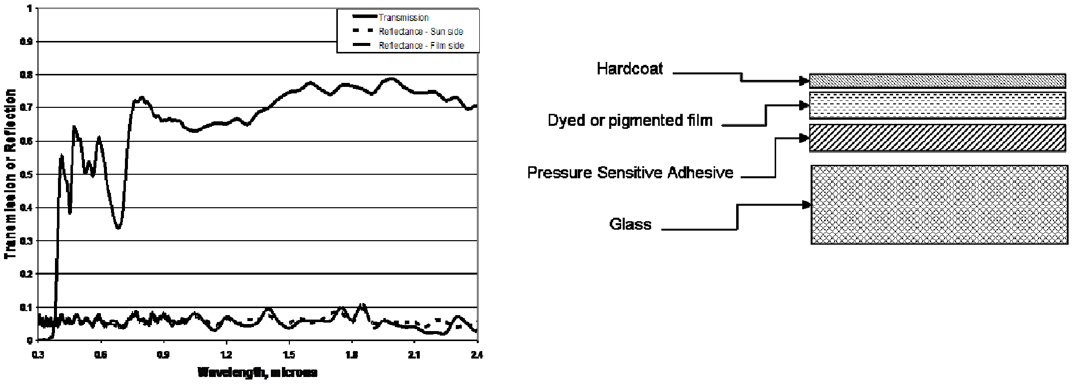

Figure 1. A typical window film construction and solar transmission/reflection spectra

Hardcoats

In addition to abrasion resistance, the hardcoat must meet key customer requirements such as color, haze, and transmission. For externally applied films, weatherability of the hardcoat is also critical while maintaining the abrasion resistance and other desirable properties. Secondary attributes such as slip (i.e. “stickiness”), antireflection, and easy-clean functionality are also taken in to account while formulating the hardcoat for window films. A high degree of correlation is usually obtained between lab scale and factory experiments. Often, a tradeoff between abrasion resistance and curl must be considered for UV cured acrylates that are used in window film constructions. In hardcoats containing pigment particles and/or dyes, achieving the right balance of these factors while targeting the desired transmission is very challenging. Furthermore, local coating thickness variation of the order of 0.1 microns or less can lead to defects rejected by the end-users.

Because coating defects are only apparent at the full usable product width of 40 – 72 inches, product quality often can only be optimized at the final manufacturing location. Tuning the solution formulation to work with existing coating and drying equipment is also more often than not a necessity. The % solids of the coating formulation is the most common control handle to achieve stable coating bead at the desired production speed and coating thickness. In the drying stage, surface tension of the solution, drying rate of the solvent(s), miscibility of the hardcoat components in the solvent(s), and viscosity of the dried, but uncured solution, all are important factors to consider. These are typically controlled by modifying surfactants, solvents, and oligomeric thickeners. Coatings that are highly mobile prior to the UV curing process can be vulnerable to iridescence, dewets, or windblown mottle. A common tradeoff at this stage is adding enough viscosity to stabilize the dried (but uncured) coating but not so much that the wet coating window shrinks to unmanageable gap sizes or unacceptably low line speeds.

Adhesives

Again, a careful consideration of key customer requirements is the starting point for formulating the adhesive in the lab. These include peel strength, optical clarity, and stiffness. As the films are sometimes left on the glazing for 10 – 25 years, it must be durable and UV absorbers, anti-oxidants and stabilizers are added to the adhesive. For films designed for automotive applications, a common trade off with pressure-sensitive adhesives is conformability to patterns on the glass (e.g. heater wires) versus ability to resist deformation by external forces (e.g. window gaskets, window stickers).

Coating process windows for adhesives are general y more robust than for hardcoats because adhesives are more viscoelastic and are coated at higher wet thickness. However, high solvent loading required for coatability combined with the high coat weights often result in linespeeds that are limited by drying capacity. Both as applied and dried, coating quality must be excellent and even minor levels of orange peel, streaking, and gels in the coating are rejected by the end users. These common coating and drying defects must be addressed by proper design and maintenance of the coating equipment. Pump sizing to avoid bubbles, line cleanliness to avoid gels, and coater cleanliness to avoid streaks are often more critical than the exact components of the adhesive itself. Solvent blend is often chosen to ensure that drying is not so fast that oven flammability limits are exceeded or that evaporative cooling causes condensation blushing. Solvents may also be chosen to overcome defects due to the electrostatic charges often induced due to corona treatment used to obtain required levels of adhesion to the substrate.

Substrate

Normally selected for its optical properties and adhesion to the coatings, the input substrate often dictates overall product quality and manufacturing yield. Many of the substrate attributes important to quality are difficult to measure, therefore difficult to specify. Caliper variation (including buckles, hardbands, edge flare, or dimples) can lead to coating thickness variations or non-uniform drying. These are often subtle variations that may not be detectable in the wound input roll or that may appear and/or diminish as the run proceeds. General film cleanliness of the substrate is often not specified but point defects and / or metallization voids are detected after significant value has been added and high amount of cost have been incurred. Similarly, micro scratching and primer patterns that are difficult to inspect in the incoming raw films may become enhanced by coatings, particularly those containing pigments. This difficulty in quantifying input film quality metrics and getting vendors to agree on what you can accept in manufacturing (particularly if they have no test method in place to measure a problem) is key to making a profitable product. In our experience, a well-written and explicitly negotiated RM specification along with incoming film inspection process aligned to the customer needs must be put in place for all of the substrates used in window film manufacturing.

Polymeric multi-layer optical films pose additional challenges of on and off-axis color uniformity. In these types of films, hundreds of alternating polymeric layers must be co-extruded and stretched to produce film having layers with a highly controlled thickness gradient to avoid aesthetically unpleasing product. These issues specific to multi-layer optical film will be presented.

Conclusions

While the window films are primarily designed and installed to reduce solar heat gain and reduce cooling costs for buildings and provide comfort in automobiles, it is not the functional aspects of the film that pose a challenge. It is often secondary issues related to the raw materials, substrates and coating and drying that result in rejected product and increased overall cost.