Next Generation Exterior Durable Hard Coats for Plastics

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Abstract

UV curable hard coats have been used successfully in the automotive industry for over twenty years. The latest generation of this coating technology is now entering markets other than automotive. Coatings with exceptional scratch and abrasion resistance coupled with exterior durability are making inroads in the film industry. These advances are allowing for greater penetration in the optical display, building materials, and the solar energy markets.

Introduction

Plastic usage has been increasing for many years. Plastics can offer excellent impact resistance and clarity and most attractively, they allow for design freedom and thus allow for some very aesthetically appealing appearances that were once inconceivable. Despite the many benefits that plastics offer, they have a major drawback in that they don't always provide the desired degree of chemical, scratch, mar and abrasion resistance and in the case of polycarbonate, weatherability. UV curable coatings are being utilized to improve the durability and longevity of these plastics.

The automotive lighting market has seized upon the advantages of polycarbonate protected with a UV curable hard coat with a vengeance. These coatings are exposed to very stringent testing – 5 to 7 year weatherability, taber, steel wool and falling sand resistance, hot to cold cycle testing, water immersion and humidity resistance – to name a few of the requirements. These tests are similar to those required in the film market. Logic would imply that the same formulas could be used in both markets. However, there are differences between forward lighting and film applications. These differences will dictate the direction for the formulation of hard coats for plastic films.

Automotive vs. Film Markets

Both the automotive and film markets require weatherability, chemical resistance and scratch resistance. However, the most obvious difference between a PC lens and a PC film is the geometry. A head lamp lens is three dimensional which will require the coating to be cured out of focus. The UV energy will be higher than the UV intensity because of the geometry of the part. Depending on how the UV lamps are positioned, different areas of the lens may see different levels of energy. With PC film, the substrate is flat. To obtain the optimum cure parameters, the UV lamps should be run in focus. This will allow a more uniform energy distribution as well as potentionally providing higher UV intensity than UV energy.

A PC lens can be more rigid and thicker than most PC films. The lack of rigidity makes the film more susceptible to heat distortion. Shorter flash times at lower temperatures need to be used as well as heat dissipation techniques during the UV cure. With the shorter, lower temperature flash conditions, interpenetration of the coating into the substrate cannot be relied upon to achieve adhesion.

Automotive headlamp lenses will generally have a hard coat film build of 8 to 18 microns. Hard coats for films are generally much lower; 2 to 6 microns being the typical target thicknesses.

These are just a few differences between a lens and film; further discussion will show what these differences mean to the formulation of hard coats for the film markets.

Processing

Automotive head lamp lenses are either coated by spray, flow coating or dip coating. Although films could be coated via spraying, the transfer efficiency is lower than other methods. If both sides of the film need to be coated, dip coating could be utilized with higher transfer efficiency. The coating would have to be formulated to have the proper rheology to coat evenly without heavy edges or inconsistent film builds. The most common application method currently being utilized is gravure or roll coating. This allows for high transfer efficiency, consistent coating film build and high speed applications.

Film builds for a roll or gravure coated coating can be controlled either mechanically by the choice of cylinder and / or by the solids level of the coating. The higher the solids, the thicker the film build. By combining the coating head and the solids level, process flexibility can be very broad.

As stated earlier, because films are flat, coatings applied to films are best cured with the lamps in focus **(Illustration 1)**. With a focused reflector, the intensity of the UV energy is much higher. With higher intensity, line speeds can be increased. The faster the line is run, the less heat is transferred to the substrate. With thin, heat sensitive substrates, this fact is critical to successful processing. In order to run the faster speeds, oligomers with quick conversion times must be used so that performance is not sacrificed. **Table 1** shows some differences between UV energy and UV intensity.

Illustration 1: Focused vs. Unfocused Reflector

Focused Reflector   Unfocused Reflector

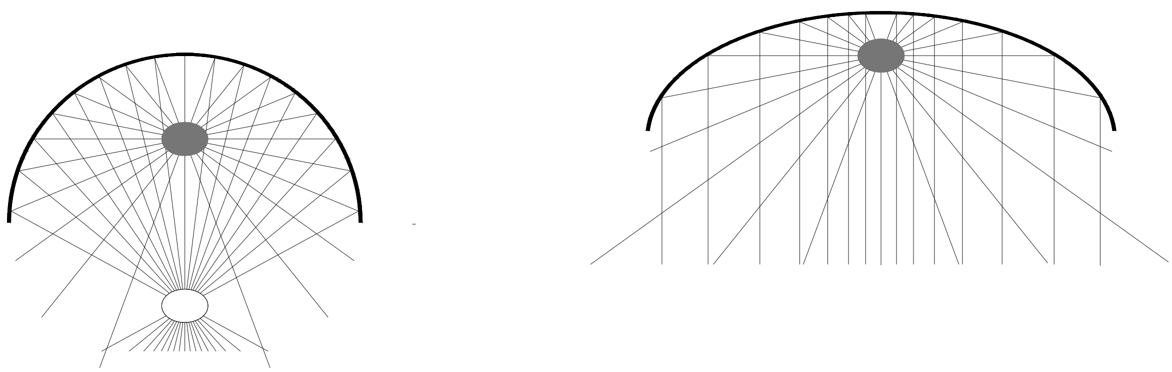

Table 1: Energy and Intensity Effects on Abrasion Resistance

UV Energy	UV Intensity	Taber % Haze
6000 mJ/cm2	181 mW/cm2	8.6
4000 mJ/cm^2	511 mW/cm^2	4.2
750 mJ/cm^2	1372 mW/cm^2	4.4

Desired Properties

Scratch Resistance

A coated PC headlamp lens must withstand many rigors in its day to day functions. Since polycarbonate is not abrasion resistant on its own, a hard coat is necessary to improve its durability. Automotive OEMs have many tests to determine a coating's durability. Taber, steel wool, falling sand, and Abrex are but a few. In the film market, taber abrasion is the most commonly used. Simply put, a taber test involves mounting a coated panel under an abrasive wheel. Various weight amounts can be placed on this wheel. The wheel is then rotated at a set speed in the opposite direction that the panel is rotated. This test can be run for any amount of cycles. One hundred cycles is considered a standard test. For transparent substrates and coatings, a post haze reading can be taken to compare and contrast similar coatings; the lower the haze, the more abrasion resistant the coating. A haze of less than 10%, with less than 6% being ideal, is the target for most scratch resistance coatings.

Since long term weatherability is just as critical as abrasion resistance for the automotive OEMs, optimum scratch resistance is sometimes sacrificed for longer durability. In the film market, most applications desire scratch resistance over weatherability. Therefore, harder, higher crosslinking oligomers can be used in the formulations to provide this improved scratch resistance.

Pencil Hardness

Most Automotive OEMs do not call out pencil hardness as a standard test. For the film market, it is commonly requested. However, pencil hardness can be subjective. The substrate will have a tremendous effect on the reading – the softer the substrate, the softer the coating will read **(Table 2).** To overcome this variable, all coatings should be compared on the same substrate. If specific pencil hardness is requested, the testing must be done on the specified substrate, grade and thickness. The required pencil hardness will depend on the application, but typically, most coating / substrate combinations need to be 2H or higher.

Table 2: Pencil Hardness Variability with Substrate

Substrate	Pencil Hardness without Coating	Pencil Hardness with Coating
Glass	9H	6H
PET	2H	4H
Polycarbonate	5B	3H

Weathering

Polycarbonate and polyester, if uncoated, will quickly degrade upon UV exposure; hence the need for a protective coating. Automotive OEMs typically call for a hard coat for forward lighting to withstand 5 to 7 years in the elements. With the exception of the solar market, weathering requirements in the film market can vary from 6 months to 3 years. Although the duration may be shorter, the formula must still be robust. The film build on a head lamp lens can be two to three times thicker than that on a film application. Even at the lower film builds, the coating is required to provide substrate protection to prevent the plastic from degrading. To be able to protect at this lower film build, the proper UV absorbers and levels must be chosen.

The solar market would be the exception to the lower weathering requirements. For this market, ten years is the minimum that a coating must pass. Many solar applications use acrylic as the substrate. Acrylic is an exterior durable plastic; however, it will scratch easily. These applications require a hard coat to prevent scratching that would lower the efficiency of the unit. But in this case, the coating does not need to protect the plastic from photodegradation; the coating needs to keep from yellowing, cracking and losing adhesion in the field.

Stain and Chemical Resistance

Head lamp lenses must pass some chemical resistance testing – typically those that would be used to clean and protect a vehicle. Since the end uses of coated films are widely varied, the chemicals that the hard coat will be exposed to are more numerous than those in the automotive sector. **Table 3** lists some of the most common chemicals that a hard coat for film must be able to withstand – both at room temperature and an elevated screening (50°C). Since the elevated temperature can force the chemicals further into the coating, it is a much harsher test. On this list, Hydrochloric Acid, coffee, mustard, tea and grape juice tend to be the most stubborn. The proper formulation requires a tight crosslink density in order to keep the chemicals from penetrating into the coating matrix and must act as a stain repellant to prevent any visual defects from forming.

Table 3: Common Chemicals Used for Stain Resistance Testing

HCl	*Tea*	Ketchup	Methyl Ethyl Ketone	Fantastik
Coffee	Vinegar	Tomato Juice	Isopropanol	Mr. Clean
Mustard	Lemon Juice	Tide	Brake Fluid	Windex
Grape Juice	Milk	Armor All	Sunscreen	Bleach (20%)

Appearance

All hard coats for the automotive lighting market are high gloss, transparent coatings. For the film market, there is a demand for high gloss and low to semi-gloss coatings as well. By adding silica to a high gloss coating, the gloss can be lowered to the requested level. However, if an improper silica is used, complications arise. An increase in viscosity, hard settling of the silica, an increase in yellowness, surface marring, embrittlement of the coating, and even loss of adhesion can be seen with the wrong selection. By combining the proper silica with the right additive package(s), and modifying the base formula, a coating can be made that will still pass weathering, pencil hardness and stain resistance.

Conclusion

Currently, film markets are using UV curable hard coats to enhance the properties of plastics. However, improvements are still needed. Commercial coatings that do not yellow upon exterior exposure lack optical clarity and are soft and easy to mar. Coatings that have good chemical resistance are not durable enough to use in an exterior environment. Low gloss coatings do not have adequate chemical resistance and /or mar too easily. The next generation of coatings are improving in these areas and increasing the useful life of the finished products. Extended weatherability, improved scratch and mar resistance as well as chemical resistance are available without sacrificing one property for another.

Hard coats for the automotive and film markets have similar substrates and requirements; however, because of the differences in geometries and film builds, the coating formulations need to be modified to be successful. By using the automotive market as a reference, a new generation of hard coats is being introduced that is improving weathering, scratch resistance and chemical resistance of coatings in the film markets. These improvements will expand the use of thin films in a multitude of existing markets and allow penetration into new and emerging areas.