FEATURE

UV Curing in the Plastic Components Industry

By Dawn Skinner

UV is rapidly becoming the technique of choice for curing coatings in the plastic components industry, but it's not been all plain sailing. Complex part shapes, temperature sensitive substrates and demanding finish quality are just some of the challenges faced by chemistry suppliers and equipment manufacturers alike. This article reviews the development of UV-curing chemistries and techniques for plastic components, their current uses and potential.

In order to develop UV curing into a feasible and reliable production process for the plastics industry, chemistry suppliers and equipment manufacturers have had to work together to create effective, workable solutions to these and other issues.

Then and Now

Until recently, coaters and decorators of plastic components had no option but to paint or coat pieces using water or solvent-based products and then to dry them all thermally in large curing ovens. Though effective, the water-based coatings required very high energy input to drive off the water content, the VOC emissions from drying solvent-based formulations required expensive containment or treatment equipment and the drying ovens simply took up a huge amount of space.

Identifying and developing a drying technology that could eliminate some or all of these problems would obviously revolutionize the production process and massively enhance the potential for coated plastic components.

UV curing was an obvious contender. Introduced commercially in the 1970s for flat, web-type applications, the technology was already proven to practically eliminate all VOC emissions, offer energy and space savings in comparison with large curing ovens, provide faster curing times and even the ability to cure on heat sensitive substrates with UV-resistant coatings.

However, could UV-curable coatings provide the quality and range of visual and textural finishes required, especially for the modern, fashion-conscious teletronics industry? In addition, would it work for the complex 3-D shapes frequently found in plastic components?

The Development Process

The principle of UV curing is based on initiating a chemical polymerization inside a liquid coating using direct UV irradiation to create a cross-linked, dry, solid coating. There are two elements to a successful UV-curing system—the UV-curable coating and the UV-curing lamps with their support systems.

The finished properties of a UV-cured coating—hardness, scuff and scratch resistance, gloss or matt appearance, UV stability, chemical resistance, etc.—are dictated by the initial chemical composition of the coating, the "match" of the UV lamp's spectral output, intensity and dose with that chemistry and the optimum physical sitting of the UV lamps.

In order to develop UV curing into a feasible and reliable production

FIGURE 1

Coatings comparison for plastics

Property	Water-Based	Solvent-Based	UV Curable
Solids content	40-60%	60% (clear coatings) 20-30% (pigmented)	40-95% Few at 100%
Soft feel	Easy to apply and achieve	Easy to apply and achieve	Difficult to achieve because UV tends to produce hard surface cure.
Visuals (gloss/matt etc.)	All gloss range possible	All gloss range possible	All gloss range possible. Very low matt can be more difficult.
Durability	Moderate	High	High
Advantages	• "Easy" switch from solvent-based systems to reduce VOC emissions • Range of textures/ appearances possible	• Known technology • Wide range of suppliers • Lower cost capital equipment	• Small compact plants • High production rates • Reduced reject rates
Disadvantages	• Energy/time costs to remove water prior to thermal cure	• High VOC levels	• Some solvents to be removed • New technology • New capital equipment required

process for the plastics industry, chemistry suppliers and equipment manufacturers have had to work together to create effective, workable solutions to these and other issues.

Chemistry

While the concept of a coating that is free of organic solvent carrier, but which retains the performance properties of a solvent-based coating, is very attractive, designing such a product has proved to be a challenge.

UV coatings are very different from conventional solvent or water-based liquid and paste coatings. They are up to 100% solids, containing little or no solvent or water carrier, but formulated from monomers, oligomers, pigments, additives and photoinitiators. When exposed to high-intensity UV light the photoinitiators start a chain reaction to polymerize the formulation, producing a dry, solid coating.

Challenges and Solutions

For the chemistry formulators, there were two initial challenges when creating UV-curable coatings for plastics:

- To create coatings which could be applied using standard application methods.
- To compensate for the lack of solvent content which, in conventional coatings, aids adhesion to the substrate.

The commonly used application methods, such as spray coating, dip coating and flow coating, all presented problems for 100% solids UV formulations. Hence, UV-curable coatings for the plastics industry are likely to contain some solvent or water content, to allow the coating to be applied by the chosen method.

There are some 100% solids sprayable UV systems available commercially, but these are very limited. The inclusion of low-viscosity cross-linkable materials to enable effective application may compromise the final properties of the cured coating. Thus, these 100% UV systems tend to be used in "less demanding" applications—as decorative coatings for the cosmetic container industry, for example, where high durability or scratch resistance are not critical factors.

However, the exception is UV-curable powder coatings. Though still requiring further research and development work to bring these 100% solids formulations within the reach of many of today's plastic coating operations, current UV-curable powders are bringing the possibility of powder coating plastics a little nearer.

Unlike traditional powder coatings, UV-powder coatings only require the application of infrared (IR) or convection heat for the melt/flow process, and are then cured by low temperature UV-radiation curing. This reduces the heat required from a typical range of 160-200°C to 80-120°C and the dwell time at these temperatures from 20-60 minutes to only 2-10 minutes—depending on part size and shape.

Melt temperatures will have to be reduced further for many plastics applications and the advantages will need to offset the costs of special storage and handling. However, UV-curable powder coatings can be applied using the same methods as for conventional powder coatings and provide exceptionally high-quality finished coatings.

Therefore, UV-curable coatings have been formulated to meet standard application requirements, but they also need to adhere to the substrate.

The wetting (spread) of the coating on the surface and the adhesion of the dried (cured) coating to the surface of the substrate depend on the tension at the boundary surface. For sufficient wetting and adhesion of a coating, the surface tension of the substrate must be higher than that of the coating. In most cases, the surface tension of the coating can't be changed so that of the substrate must be increased, which is usually achieved with an oxidizing flame, corona discharge or UV pre-treatment.

The surface treatment results in a physically and chemically modified surface with increased surface tension, enhancing the wetting of the coating and producing better adhesion.

The solvent used in conventional coatings to aid application can also be used to enhance wetting and chemically attack the surface of the substrate to increase the adhesion of the coating. UV coatings do not necessarily contain such solvents and may not have the opportunity to physically "anchor" themselves in this way. Therefore, it is important to check the surface tension, and modify if necessary, when using UV coatings.

An additional challenge to coatings formulators has been the achievement of specific finished properties such as soft feels or low matt finish, both of which are in demand for modern consumer teletronics products and which can be difficult to achieve with UV-curable coatings.

Figure 1 (on page 20) shows an overview comparison of the three main coating technologies. Solvent-based coatings are the known, "tried and tested" systems, which have served the industry well for many years. However, the drive to reduce the use and emission of solvents leads manufacturers to look at water-based coatings. This is seen as an "easy" technology switch, but water-based coatings do require special consideration when it comes to the drying operation to ensure the coating is fully cured.

No one technology is the perfect solution for all applications and coating requirements, but UV-curable coatings certainly have many important features and benefits. The high durability of the coatings coupled with the significant improvements in production speeds and reduction of finished product reject rates are the key driving forces for implementing UV-curing technology in many plastic coating operations. Development work continues to increase the range of UV-curable coatings with new soft feel, low matt and one-coat high gloss, pigmented systems coming into the market.

With all these factors and options, plastics coaters are making their choice of coating on an "application-by-application" basis. No one coating is sweeping across the board; rather, the choice of coating is usually driven by economics, with coaters choosing the most cost-effective system that will deliver their required performance characteristics.

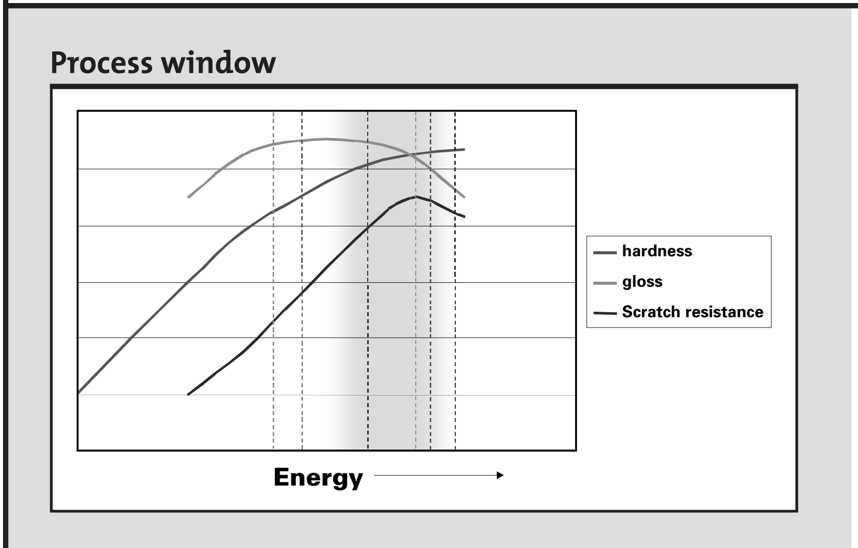
UV-Curing Equipment

Existing UV-curing technology could be easily adapted for flat plastic component applications, with installations incorporating the latest in-line modular UV-curing units, variable power supply and electrodeless bulbs. However, creating UV systems to cure coatings on 3-D plastic components presented far more of a challenge.

3-D Curing

Many plastic components are complex 3-D structures containing frequent undercuts that create "shadow" areas. If UV curing was to be

FIGURE 2



successfully applied to plastic components, then the problem of achieving optimal cure in these "shadow" areas had to be solved.

The optimal characteristic profile of a coating can only be achieved if the parameters of the individual manufacturing steps are situated within certain boundaries—the process window (Figure 2).

For two-dimensional parts the UV dose can be adjusted simply by changing the power of the UV lamp or the line speed; however, for 3-D parts, due to their complexity, it is more critical to achieve an even energy distribution over the whole surface. Intensity, dose and UV spectrum must be combined to provide a cured coating with the optimum combination of properties required.

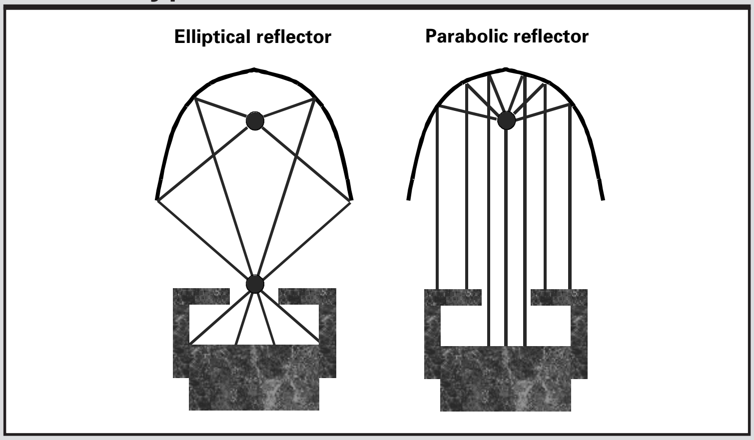
Following intensive R&D involving laboratory experimentation and pilot testing, a variety of solution concepts have been developed to eliminate "shadow." These are often combined in production to obtain optimal results:

- A programmed robot can move either the lamp over the surface of the part, or in reverse, the part in front of the UV lamp.
- Short and modular UV lamps can be placed at different angles around the geometry of the part.
- A variable power supply alters the power of the lamp, and therefore, the dose supplied.
- Additional installation of reflectors ensures optimal utilization of the irradiation.
- Distance between the lamps and the part to be cured can be altered.
- Installations can be made with a UV lamp on a flexible arm.
- The installation of elliptical reflectors rather than parabolic reflectors improves the curing of former shadow areas (Figure 3).

Of all these solutions, robotics is the probably the most exciting, but also the one that presented the most problems.

FIGURE 3

Different types of reflectors



A robot used for UV curing must be designed to meet specific requirements. Depending upon the UV irradiation unit used, the robot must have a carrying capacity between 8-16kg. Precision and speed are not necessarily primary characteristics, depending upon the geometry and size of the part to be cured; however, many degrees of freedom and a large work radius is important. UV stable supply cables and gaskets must be used.

The UV lamps also have to be adapted for robotic use. Traditionally, UV lamps were designed to be mounted almost exclusively in a fixed position. To cure 3-D plastic components from a moving robot, the lamps had to be adapted to cope with the new environment.

Internal components insensitive to vibrations were developed to overcome problems caused by rapid movements, sudden changes in direction and sudden stopping. The construction and cooling of the UV lamps also had to be re-designed to ensure that the lamps would not overheat.

Robot mounted UV-curing lamps are now being used successfully in a variety of production installations throughout Europe by companies such as DIAM of France. In production, using robots for UV curing has been found to provide process flexibility and high productivity. Optimized programming of robots has even made the UV curing of extreme geometries possible. However, there is still much development that can be done to refine and improve the technique.

The Future

UV-curable coatings are now commonly used for plastics applications that experience very harsh environments where high levels of scratch/scuff resistance are required, such as consumer teletronics products and automotive polycarbonate headlamp lenses.

Despite this success and to widen the usage of UV-curable coatings in the plastics industry, there are some technical issues still to be resolved. Environmental, legislative and economic pressures necessitate ongoing research and development programs.

Customers are beginning to look beyond the simple "solids content" or VOC issues, to evaluate the coating process "in the round"—taking into account performance and cost drivers and the implications for their plant processes and procedures when making a choice of coating system.

The constant drive for reduced solvent content in coatings formulations will remain a major influencing factor; however, progress in this area is likely to be limited by the viscosity rheology requirements of the application process. Will this lead to new application techniques in the future?

Acknowledgments

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