OPTIMIZATION OF THE UV ACRYLIC COATING AND CURING PROCESSES

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I. Introduction

UV curable pressure sensitive adhesives (PSAs) are 100% solids acrylic polymers which are cured in-line using photo-initiators and UV emitting lamps. With these products, acrylic polymers can be coated with hot melt coating equipment, avoiding the line speed constraints and processing costs associated with shipping, handling, and flashing off solvent or water. This paper details best practices for processing, coating, and curing of these adhesives, and compares these conditions relative to coating a traditional rubber-based hot melt PSA. The recent development of cationic curing is compared to the established free radical mechanism, and three experiments are detailed that explore product cure and performance robustness.

II. Module 1: Product Performance and Handling

Performance

Acrylic-based polymers are naturally resistant to yellowing and generally exhibit good chemical resistance. Several UV acrylic PSAs are highlighted in this report, some employing the cationic cure, others the free radical. The products studied in this paper are:

Adhesive A – Free radical cure, base resin
Adhesive B – Cationic cure, tackified
Adhesive C – Free radical cure, tackified

These UV products exhibit a wide range of performance, displayed in Table 1.

Table 1: 1 mil Performance on Stainless Steel

Test (Units)	Adhesive A	Adhesive B	Adhesive C
Peel 24h dwell (ozf/in)	37	65	89
Shear, 4.4 psi (h)	5	23	7
Looptack (ozf/in)	47	65	74

As a result of this adhesive performance range, this technology can be used in multiple PSA markets; including, but not limited to, tapes, labels, and graphics as displayed in Figure 1.

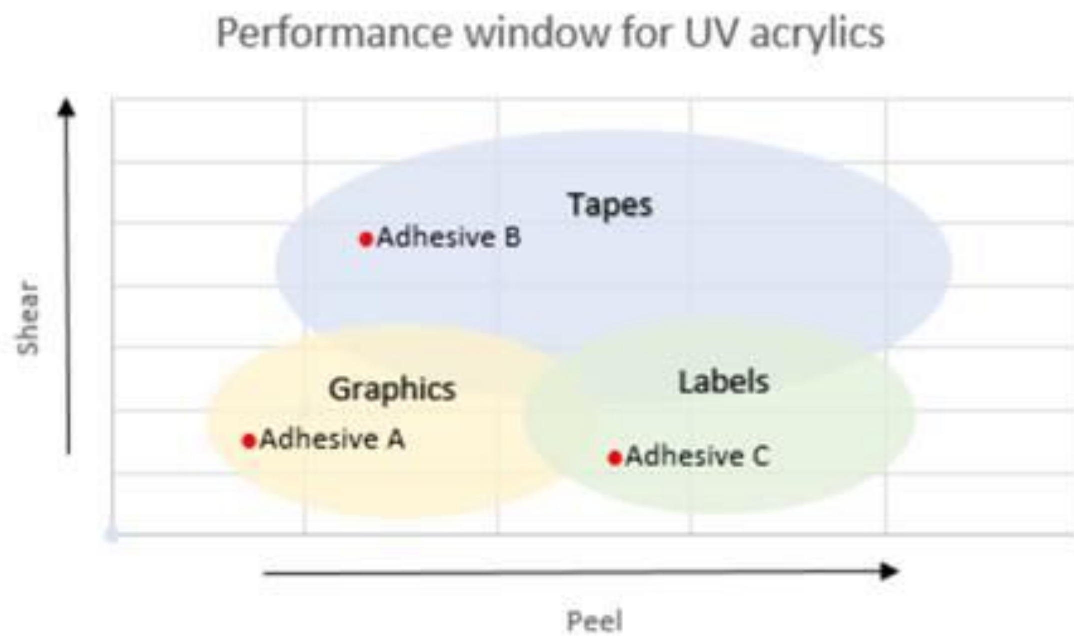


Figure 1: UV Acrylic Product Performance

Physical Properties
Although the adhesives are supplied in 100% solids form, the flow characteristics are completely different from that of a 100% solids rubber-based hot melt. The uncured product has little to no cohesive strength so it strings extremely easily, flows at room temperature, and is coated at a lower application temperature than rubber hot melts. Suggested coating temperature for this set of UV acrylics is 270-280°F. Due to the lower recommended coating temperatures, UV-curable PSAs are much higher viscosity during application than traditional hot melts, which are generally recommended to be coated at 325°F. Figure 2 shows that the viscosity curves of these two technologies are very similar.

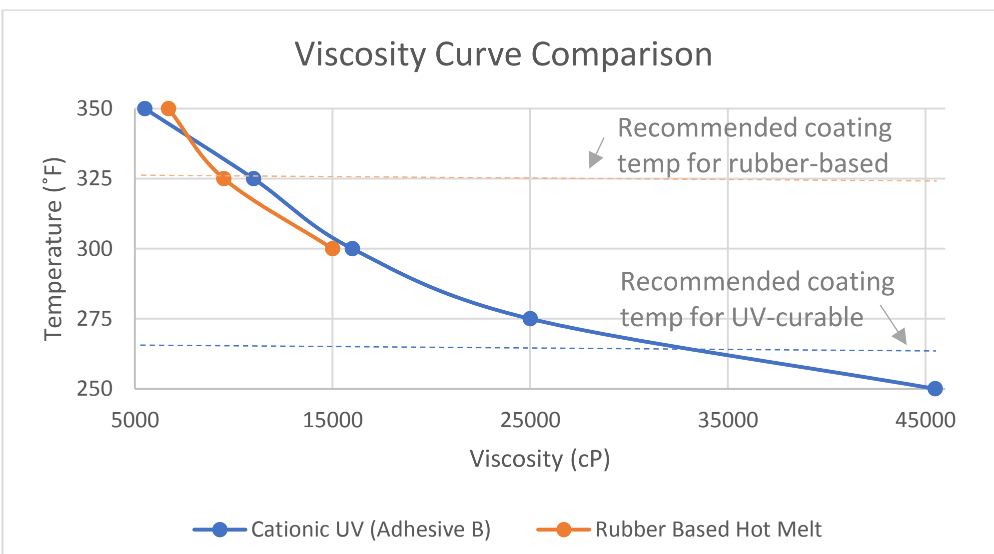


Figure 2: UV Acrylic and Rubber Based Hot Melt Viscosity Comparison

The relatively low coating temperature for the UV acrylic polymers is for thermal stability purposes; this is covered in more detail in the next section.

Thermal Stability

Due to the reactive nature of UV-curable acrylics, consideration must be given to the thermal stability. Extended periods of elevated temperature can cause char in traditional hot melts. Conversely, viscosity increase and gelling is the concern for UV-curable acrylics. These two potential undesirable responses are the result of preemptive curing, catalyzed by the excessive thermal energy. Typical thermal stability of the two chemistries is illustrated in Figure 3.

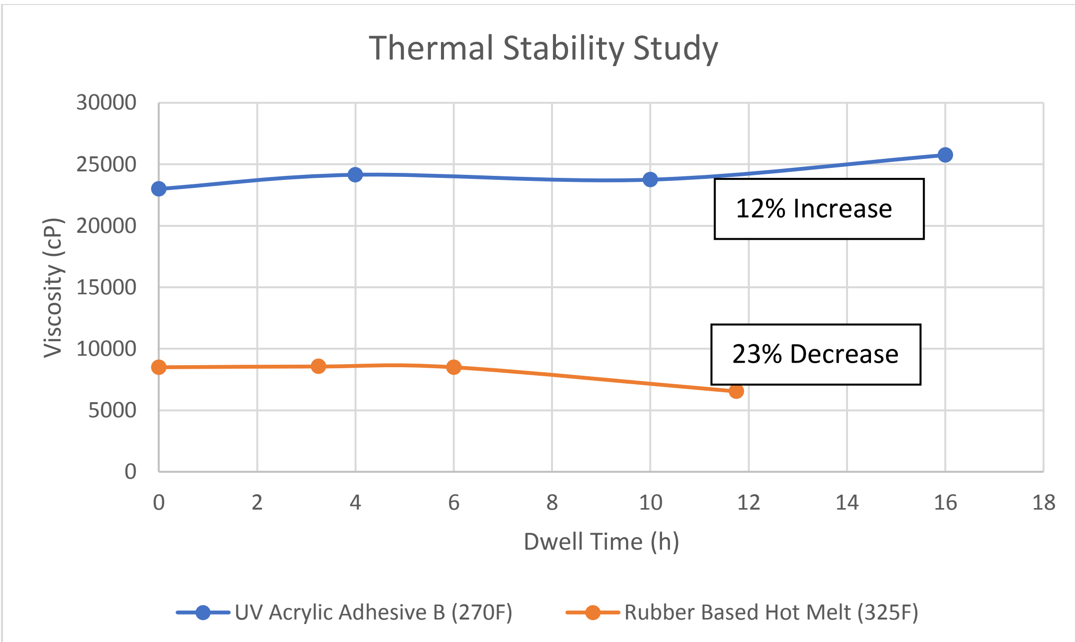


Figure 3: Thermal Stability Study

Thermal stability in UV acrylics is influenced primarily by the functional monomer content as well as the photo-initiator levels; both of which give the adhesive crosslinking potential. Greater level of either (or both) results in greater reactivity, thus decreasing thermal stability. Extra care must be taken to control and limit elevated temperature exposure to maintain a stable operating window during coating. When coated at recommended temperatures, such as 270°F, the UV-curable stability window is in excess of 20 hours with minimal viscosity increase. In addition to temperature control, equipment hygiene contributes to stability and will be highlighted in the next section.

Melt Tank Design and Hygiene

Greater consideration for melt tank hygiene must be taken when working with reactive systems. When choosing a melt tank consider that the more surface area there is inside the tank, the more places adhesive can get trapped. Trapped UV material can eventually gel and hinder the flow of the melt tank. As a result, pre-melt grids are not suggested when working with UV acrylics. A wider, shallower melt tank is preferred so that the bottom (or very close to the bottom) of the tank can easily be seen visually.

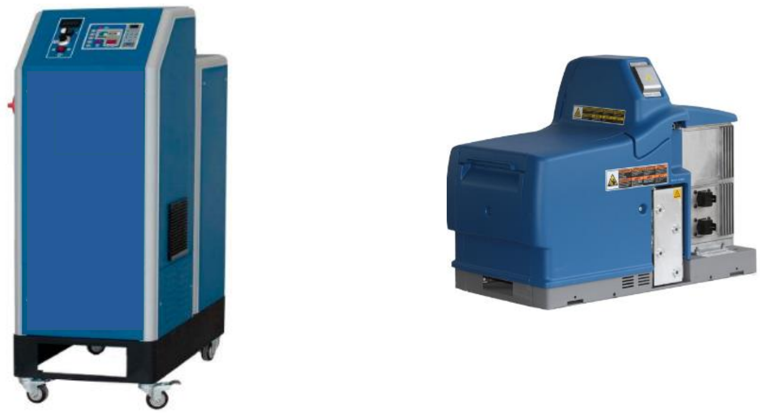


Figure 4: Undesirable tall, deep melt tank design (left) vs. preferred shallow, wide melt tank design (right)

Along that same line of thinking, best practice melt tank hygiene, when working with UV acrylics, involves purging with cleaner. Purge material should be run through the system (melt tank, hose, coating head) before changing over to a new adhesive to rid the system of any trapped UV adhesive. Purging forces out trapped material as well as prevents contamination. Contamination was explored in depth to see if residual rubber-based material, as well as UV-curable material with a different curing chemistry, has an impact on thermal stability. To mimic typical residual material during changeover, 5% contamination was added, and Brookfield viscosity was monitored over time at a typical application temperature for UV PSAs. Table 2 shows that there is little/no effect seen on the product's thermal stability with up to 5% contamination.

Table 2: Contaimation Study – Viscosity Readings at 270F (cP)

Product	Contamination	Total 270F Dwell			% Change
		5 Hours	10 Hours	15 Hours	
Adhesive B (Cationic UV)	None	24,750	22,250	25,000	1.00%
	5% Rubber Hot Melt	24,500	23,500	26,700	9.00%
	5% Free Radical UV	24,000	22,000	25,000	4.20%

As for the purging method, there are two general approaches. In either case, the first step is to pump the current adhesive out of the tank. For the next step, one option is to add a high viscosity material to physically push the residual adhesive out of the melt tank and hose. The other method is to circulate hot oil through the tank and hose to soften the adhesive to dislodge and flow the adhesive out of the system.

III. Module 2: Coating and Curing Considerations

Coating Setup

UV acrylics are coated very similarly to traditional rubber based hot melts; the prevalent difference is the addition of the in-line curing step. Between the coating head and the lamination nip, the primary substrate is fed through a UV lamp station as seen in Figure 5.

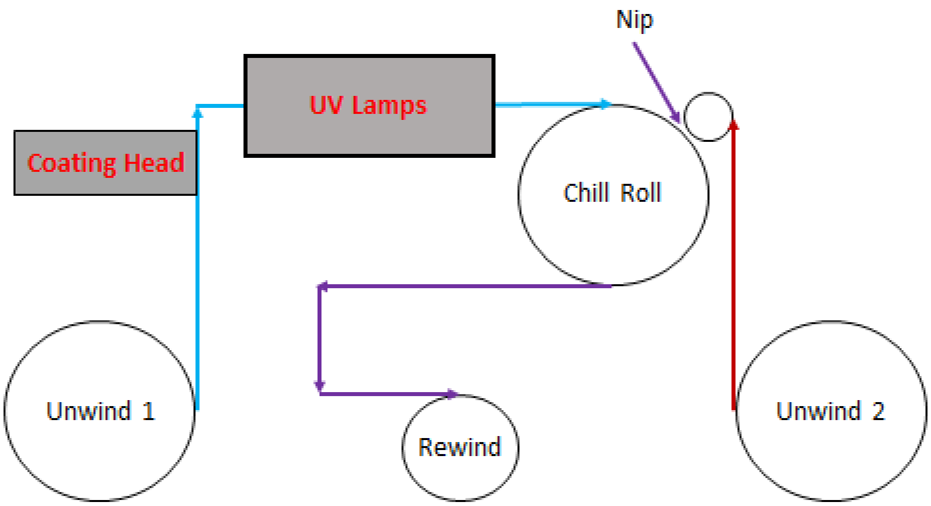


Figure 5: UV Acrylic Hot Melt Example Coating Setup

UV Lamp Operation and Measurement

These UV lamps utilize H or H+ bulbs (among others) and a movable shutter covers the lamps when exposure isn't necessary. H and H+ bulbs utilize high voltage to vaporize the mercury to emit the UV spectrum. The most common photo-initiators used in these adhesives cure at 250-260nm wavelength exposure. The total level of UVc exposed to the sample is determined by the intensity of the lamps, as well as the length of time that the sample is being exposed. The intensity of the lamps is controlled by the user, and is presented as a percent of its maximum output. The exposure time can be controlled by adjusting line speed. The UVc exposure can be measured experimentally using a radiometer; some are manufactured thin enough to send through a lamp system. This way the radiometer can be sent through the lamps on the primary substrate at the chosen line speed and lamp output to simulate the exact travel path and speed of the adhesive, whilst detecting the amount of UV exposure in mJ/cm^2 for the pass. Field experience has shown that the amount of UVc exposure does not differ noticeably on the edges of the web vs the center, even in wide web operations.

Generally, UV lamps are kept in the ON position constantly during operation, with blowers constantly running to control the temperature of the lamps. Some substrates, including many films, are unable to withstand this extreme heat exposure, even for its short dwell time. Paper materials are generally able to withstand the heat, but only for a brief time. The lamps are also equipped with shutters that open and close. In the closed position, the shutters block UVc exposure, as well as a large amount of heat from the web. If the web is stopped whilst the lamps remain on, the stationary paper quickly catches fire. For safe operation, any machine with a UV lamp system should have the UV lamp shutters immediately close any time the line stops, including emergency-stop (E-Stop).

Figure 6: Web Entering H Lamp System

The ability to detect the level of UVc light exposure is important; the amount of UVc exposure can have a noticeable effect on adhesive performance. The curing process turns the stringy uncured material into a cross-linked polymer with greatly increased cohesive strength. But what UV dose is necessary to make that change? To answer this, the adhesive coat weight needs to be considered. As the coat weight increases, the UV dose necessary for cure is increased. Cure exposure suggestions are measured in $mJ/cm^2/gsm$, but will be referred to as mJ/gsm.

The Cure Mechanisms

Free Radical – suggested cure exposure: 1.2-1.5 mJ/gsm. In this cure mechanism, the photo-initiators decompose into free radicals upon the exposure to UV light, causing rapid polymer chain growth. As a result, when the samples are no longer being exposed to UV, the free radicals stop being created, and the curing stops. Therefore, this curing mechanism takes place during exposure to the UVc light, but stops almost immediately after exiting the lamps.

Cationic – suggested cure exposure: 0.6-0.8 mJ/gsm. The cationic curing mechanism doesn't require as much UVc energy as the free radical mechanism due to its ability to continue the curing process after the UVc exposure has stopped. In cationic curing, the UVc exposure begins the curing process; the process then continues off-line in the finished coated roll.

The significant difference in suggested cure exposure levels between free radical and cationic can have a significant effect on the resulting processing conditions. Table 3 shows experimental data from running at different line speeds, while keeping the lamp output the same, to see its effect on total exposure.

Table 3: Line Speed's Effect on Exposure

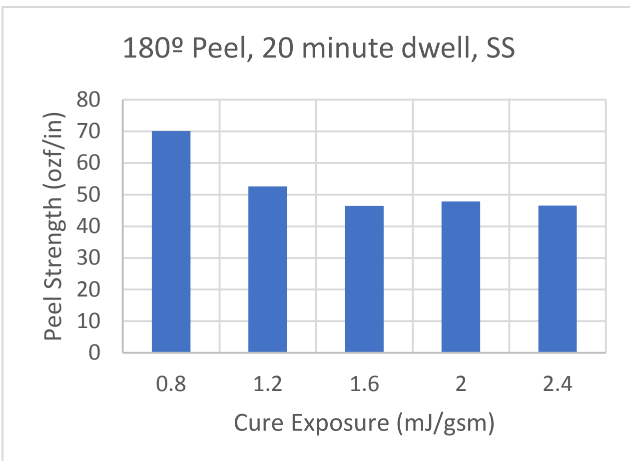
Line Speed (fpm)	Exposure (mJ/cm2)	2 mil Exposure (mJ/gsm)
23	100	2
35	75	1.5
70	60	1.2
94	50	1
115	40	0.8
137	30	0.6
161	20	0.4

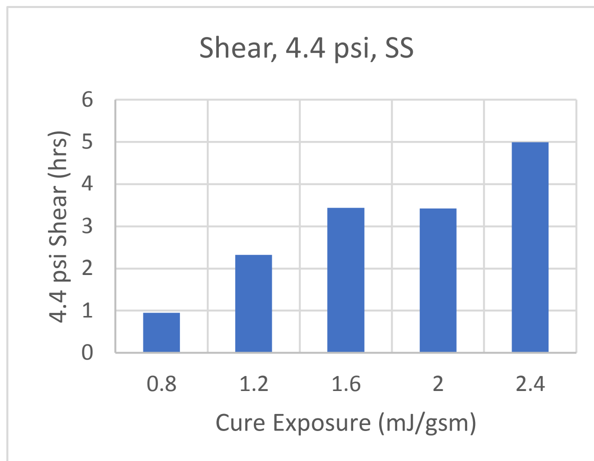
In this example, to reach the suggested cure exposure for free radical, the line would have to run between 35 and 70 feet per minute (fpm). However, if running a cationic adhesive, the line speed could be increased to over 100 fpm.

Cure exposure can be impacted by many factors, including bulb life and UV shield design, and should be validated based on the end use performance of the material, covered in Module 3.

IV. Module 3: Cure Exposure's Effect on Performance

Experiment 1: Cure Exposure Ladder
In general, the UVc light increases the adhesive's modulus through the curing process. The amount of exposure can make a noticeable impact on just how stiff the modulus becomes. As the modulus increases, the adhesive gains cohesive strength while losing some adhesion at the surface of the substrate. This is illustrated in Figures 7 and 8, illustrating performance of the free radical base resin Adhesive D.





Figures 7 and 8: Free Radical Base Resin (Adhesive D) Cure Exposure Study

It can be observed that the decrease in adhesion noticed in the 180º peel testing is relatively low within a wide range of cure exposures; the shear is a far more positive correlation. The typical practice for choosing the optimal UV energy is to look for stable peel values (on the cure exposure plateau) and to choose a cure exposure that meets the targeted shear performance minimums.

Experiment 2: Light and Dark Side
One phenomenon that has yet to be discussed is the light side and the dark side of the adhesive coating. When curing UV adhesives, one side of the adhesive film directly faces the UV bulbs; referred to as the light side. On the opposite side of the film, closest to the substrate, the adhesive gets exposed via the UVc light that has traveled through the coating. This is highlighted in Figure 9.

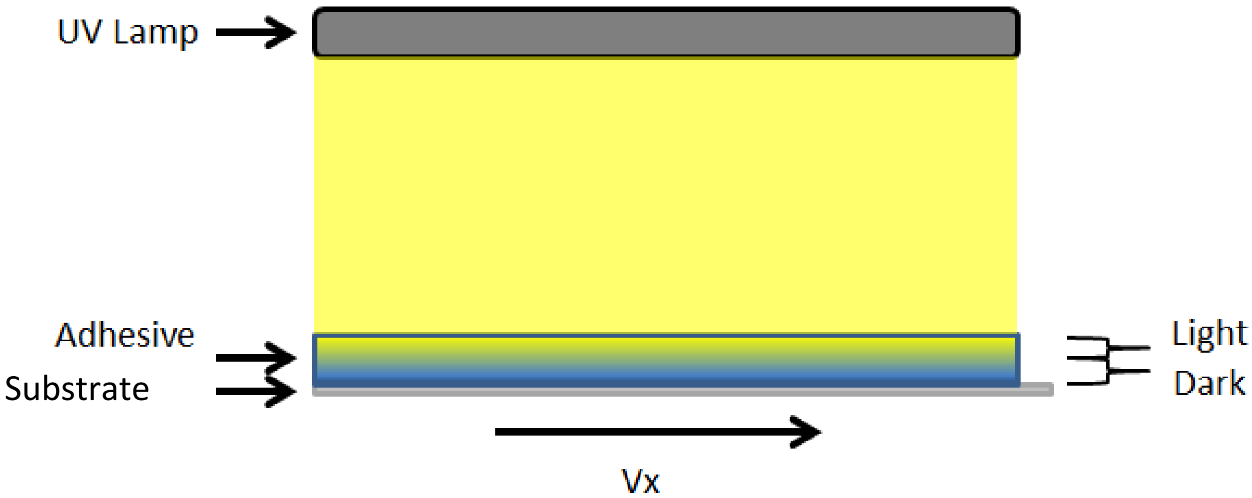


Figure 9: Light and Dark Adhesive Film Sides

To clarify, Figure 10 below represents testing the "light" side of the adhesive, Figure 11 represents testing the "dark" side. The rationale is that the "side" of the adhesive film that is contacting the substrate (in this case, stainless steel) determines the name.

Figure 10: "Light" Side Testing

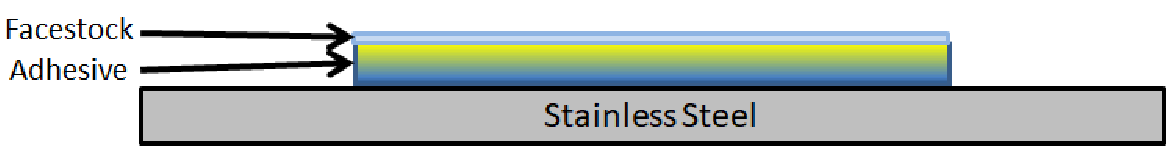


Figure 11: "Dark" Side Testing

Studies on the light and dark side performance were conducted on relatively thick coatings of 5 mil coat weight. The light and dark side peel performance on stainless steel panels is compared in Table 4.

Table 4: 5 mil Light vs Dark Side 180 Peel Strength (ozf/in)

Cure Exposure (mJ/gsm)	Adhesive B (UV Cat)		Adhesive D (UV FR)	
	Light	Dark	Light	Dark
1.5	28	24	13	32
2	26	22	13	21
2.5	20	24	14	17

This table shows one significant differentiation between the two cure technologies: free radical technology has through-cure limitations versus cationic for higher coat weights. Cationic coatings exhibit robustness in shear data as well as seen in Table 5.

Table 5: Adhesive B (UV Cat) 7 mil Shear Results

Side	4.4psi Shear (h)	Average
Light	3.98	3.81
	3.68	
	3.76	
Dark	3.28	3.63
	3.62	
	3.99	

Conclusion

Processing and coating UV-curable acrylic PSAs require a greater level of care and attention than that of a traditional rubber-based hot melt. Considerations such as application temperature, equipment hygiene, and UV-curing conditions must be given. However, with the addition of a bank of UV lights, existing hot melt coating and progressing equipment can be utilized with minimal additional operator training. UV-curable technology enables the advantages of acrylic chemistry to be utilized in a 100% solids form, enabling faster liner speeds, and higher coat weights than with solvent and water-based systems.