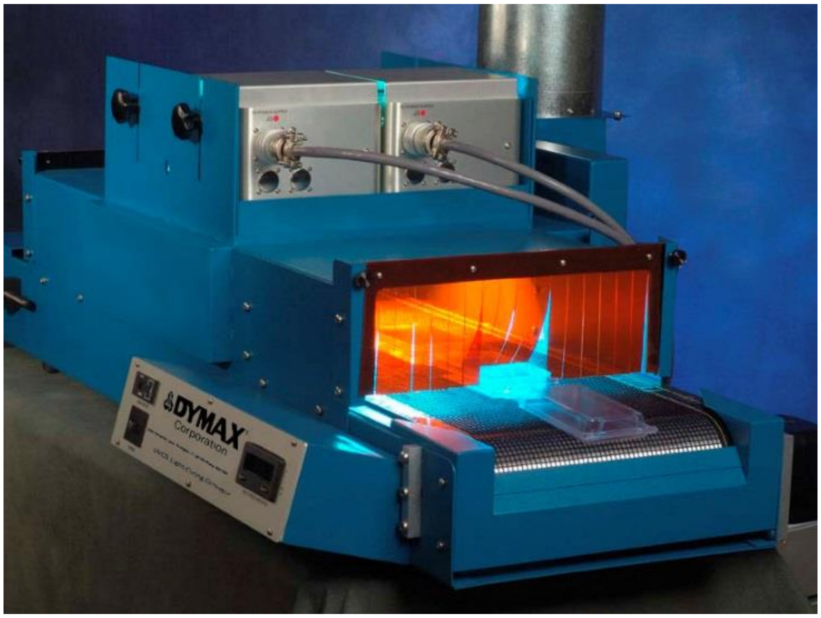
Validating a Conveyor Light-Curing Process

Ensure Your Light-Curing Process Will Perform Accurately Every Time



Since their initial introduction into manufacturing processes over 30 years ago, light-curable adhesives and coatings have continued to gain recognition as significant drivers for improved productivity and overall process cost reduction. In fact, they have become the preferred assembly method in many manufacturing industries. The basic components of a light-curing process include a light-curable adhesive, dispensing system, and curing energy source (spot, flood, or conveyor curing system). The key to a successful process is ensuring a compatible match among all components, therefore the best consultants are the companies that design, manufacture, and sell all three. They have the technical expertise to make sure the entire process is compatible and will run smoothly without any problems.

Once an adhesive, dispensing method, and curing system is selected, the process must be qualified prior to production start-up, and then steadfastly maintained during actual production. Validating a curing process is essential to its success, and validation is different for each style curing system. In this paper, we discuss how to validate a conveyor light-curing system.

Validating a Conveyor Light-Curing System

Once a manufacturer has identified the adhesive best suited for the application, the amount of adhesive in each bond, and the light-curing system they will be using, they will need to specify the exposure time and acceptable intensity range. The following process is suggested to determine the exposure time and intensity range required:

1. Define full cure

Identify a parameter (or group of parameters) that can be practically measured to indicate full cure. Physical properties of the cured adhesive or coating are most often used for measurement and correlation to full cure. Full cure is defined as the point at which additional cure time or additional intensity no longer improves these physical properties. Commonly used criteria include bond strength, hardness, and surface tack. Measurements are typically made on parts that have returned to room temperature after curing exposure cycle.

2. Determine minimum intensity and exposure time

Determine the minimum exposure time and intensity required to achieve full cure. Users can determine the minimum intensity and exposure time in one of two ways:

- ***Set exposure time and vary the intensity to determine the minimum intensity.*** Exposure time is selected first to avoid creating a bottleneck in the assembly process. This is also called the "takt time" with many manufacturers using LEAN practices. In most manufacturing processes, there is a rate-limiting step that dictates throughput. If exposure time is faster than the rate-limiting step, it will not be the bottleneck. If the minimum intensity associated with the chosen exposure time results in unacceptable bulb life, either a higher intensity curing system or multiple curing systems may be required.

- ***Set intensity and determine the minimum exposure time.*** The processing intensity is selected first to provide acceptable bulb life. This option would be selected if takt time was not as much of a concern as maximizing bulb life. If the minimum exposure time associated with the chosen intensity is considered too long, a higher intensity or multiple curing systems may be required. This tends to be a popular option when curing on conveyor systems. Since the intensity of the flood lamp is constant and only adjustable by changing the height to the bond line, increasing or decreasing belt speed to alter the duration of time the components are in the UV exposure area may be necessary.

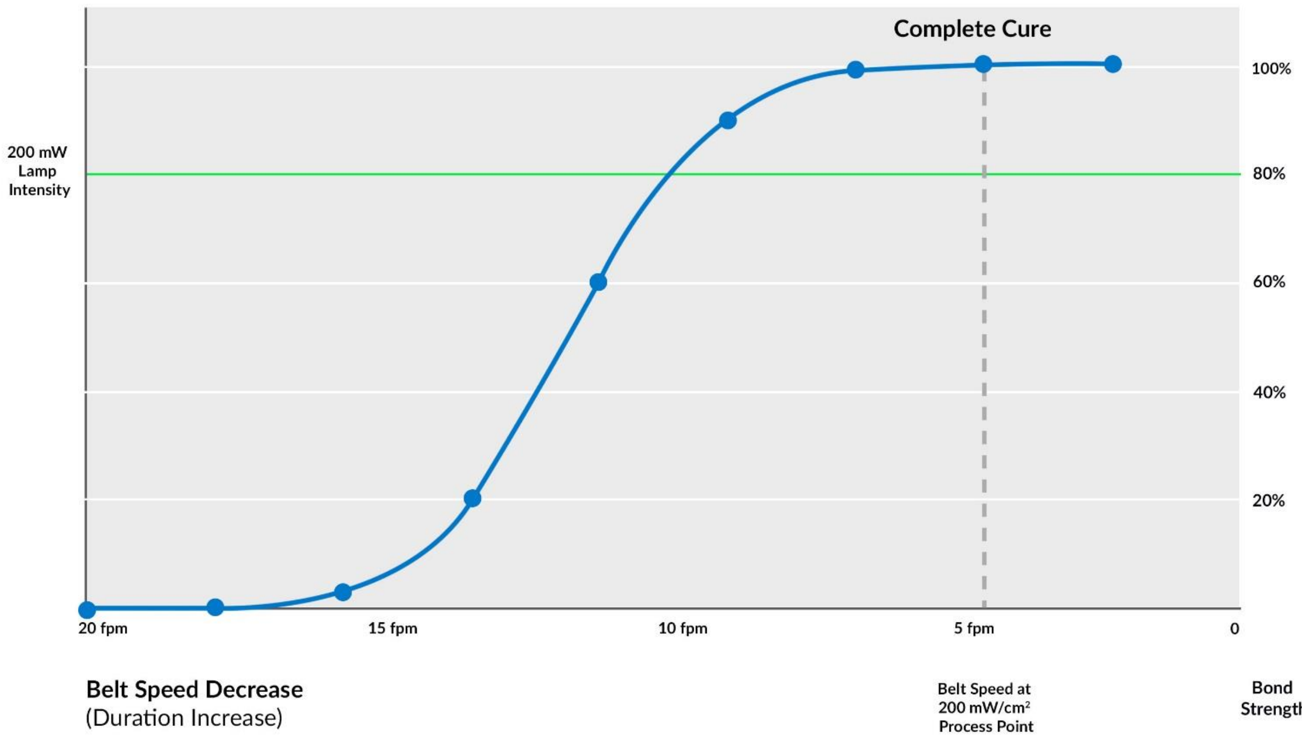
Regardless of which method is used to determine the minimum intensity, users should also keep the following points in mind:

- ***Distance must be a constant.*** The distance between the curing energy source and target cure area must remain a constant for all methods of measurement. This is a key factor in process control as curing energy levels quickly decrease over distance. As a bulb degrades, the distance to the bond line may need to be reduced to elevate the intensity (as explained during the *Process Control* section). Height adjustments made in the curing distance should be recorded and maintained.

- ***Validate a complete cure.*** Determining the minimum intensity required for full cure in a specific application requires empirical testing. This testing typically involves measuring some physical property indicative of cure (i.e. adhesion, hardness, etc.) while varying either exposure time or intensity. Figure 1 shows how this testing might be accomplished with a 5000-EC by setting intensity and varying the belt speed. Some of today's light-curing systems allow users to adjust intensity manually.

- ***Understanding the intensity mapping with your specific light source***. Not all flood units emit a consistent energy across the illuminated area. If you're curing multiple parts in a fixture or on a pallet, you should take several intensity readings to understand if there are high and low intensity points. This may mean defining minimum intensity based on the "low" areas. *Note – Dymax LED flood cure systems have much more consistent intensity output across the area than traditional broad-spectrum units.*

Figure 1. Curing Energy Profile (Intensity Held Constant)



3. Determine Your Safety Factor

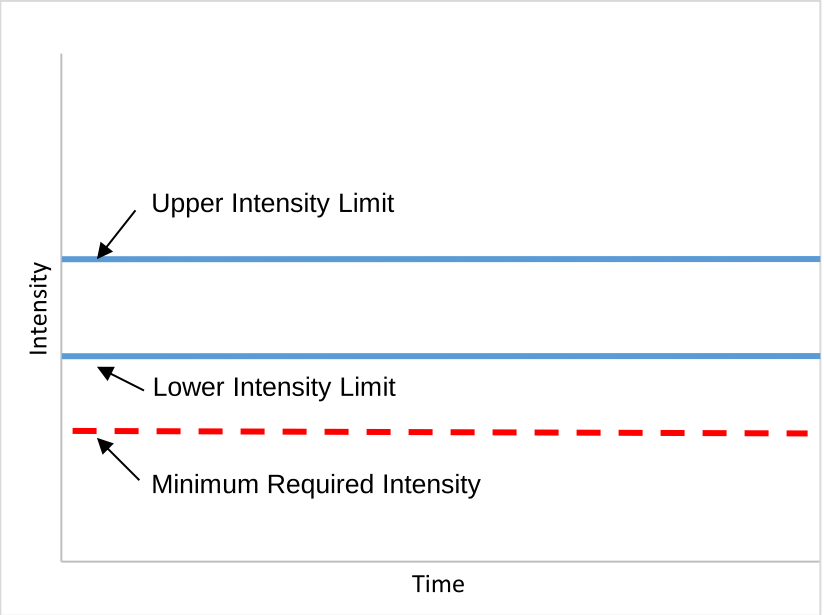
Apply a safety factor to the minimum intensity determined in Step 2 above to determine the lower intensity limit. For example, if the absolute minimum intensity required to cure an assembly within 5 seconds (takt time) is 75 mW/cm^2, the lower intensity limit would be 113 mW/cm^2 with a 50% safety factor. A safety factor helps to ensure that the UV curing process can withstand unavoidable variations in the parts and process. As applications and manufacturing environments can vary significantly, it remains the responsibility of the user to assess and establish the minimum intensity limits and safety factors.

4. Define the upper intensity limit

Determine the highest intensity that still produces acceptable parts within the specified time frame without causing damage to the bonded substrates or resins (typically caused by overheating). This intensity may or may not exceed the maximum intensity of the UV-curing system employed.

Your UV light-curing process now has both a lower and upper intensity specification and employs a safety factor as shown in Figure 2. By utilizing these four guidelines, a conveyor-cure system user can be very confident that the appropriate cycle time and curing intensity range has been established for the specific application under consideration.

Figure 2. A Controlled UV Curing Process



5. Set Exposure Rate (Duration)

The Dymax UVCS conveyor family features an adjustable belt speed from 0.9 to 32.0 feet per minute (fpm). This allows the user to dial in a UV dosage measured in J/cm^2 based on the intensity of the curing lamp (Joules (J) = Intensity x Time).

As seen in Figure 1, a product that cures at 5 fpm with 200 mW/cm^2 of intensity will collect 1.0 J/cm^2 of energy. At 5 fpm the component is under the 5000-EC for 5 seconds (1,000 mJ/cm^2 = 200 mW/cm^2 x 5 s). Now if the user wanted to decrease takt time, adding a second 5000-EC would allow for the belt speed to increase to 10 fpm while still collecting the 1.0 J/cm^2 dosage because the intensity delivered to the component was doubled.

Taking this a step further, the Fusion flood system has an intensity output of about 2,500 mW/cm^2. It would only take a fraction of a second to accumulate 1 J/cm^2 and thus increase the belt speed. If the substrate can withstand the momentary blast of intensity without damage, the process could increase component output.

Table 1. UVCS Speed and Duration

Speed		Seconds Per Exposure (Duration)			
Feet Per Minute	Inches Per Second	Fusion Flood Lamp	Single 5000-EC Flood Lamp	Dual In-Line 5000-EC Flood Lamp	Single LED Flood Lamp
1.0	0.2	5.00	25.00	50.00	25.00
2.0	0.4	2.50	12.50	25.00	12.50
3.0	0.6	1.67	8.33	16.67	8.33
4.0	0.8	1.25	6.25	12.50	6.25
5.0	1.0	1.00	5.00	10.00	5.00
6.0	1.2	0.83	4.17	8.33	4.17
7.0	1.4	0.71	3.57	7.14	3.57
8.0	1.6	0.63	3.13	6.25	3.13
9.0	1.8	0.56	2.78	5.56	2.78
10.0	2.0	0.50	2.50	5.00	2.50
11.0	2.2	0.45	2.27	4.55	2.27
12.0	2.4	0.42	2.08	4.17	2.08
13.0	2.6	0.38	1.92	3.85	1.92
14.0	2.8	0.36	1.79	3.57	1.79
15.0	3.0	0.33	1.67	3.33	1.67
16.0	3.2	0.31	1.56	3.13	1.56
17.0	3.4	0.29	1.47	2.94	1.47
18.0	3.6	0.28	1.39	2.78	1.39
19.0	3.8	0.26	1.32	2.63	1.32
20.0	4.0	0.25	1.25	2.50	1.25
21.0	4.2	0.24	1.19	2.38	1.19
22.0	4.4	0.23	1.14	2.27	1.14
23.0	4.6	0.22	1.09	2.17	1.09
24.0	4.8	0.21	1.04	2.08	1.04
25.0	5.0	0.20	1.00	2.00	1.00
26.0	5.2	0.19	0.96	1.92	0.96
27.0	5.4	0.19	0.93	1.85	0.93
28.0	5.6	0.18	0.89	1.79	0.89
29.0	5.8	0.17	0.86	1.72	0.86
30.0	6.0	0.17	0.83	1.67	0.83
31.0	6.2	0.16	0.81	1.61	0.81
32.0	6.4	0.16	0.78	1.56	0.78

Process Control

Once a process is validated, it is important for manufacturing to operate within the defined limits of the process. There are several concepts to consider when developing a controlled flood-curing process.

1. Monitor Intensity

Measuring intensity requires a radiometer, like the ACCU-CAL™ 50 (Figure 3) or ACCU-CAL™ 160 (Figure 4). A radiometer measures intensity over a specified range of wavelengths. The intensity of a flood system is best measured at the focal point of the lamp reflector. The focal point of a Dymax broad-spectrum flood lamp is 3.0" (76 mm) beneath the bottom of reflector. The focal point for a Fusion I300MB lamp is 2.1" (53 mm) below the bottom of the irradiator. The focal point on a Dymax LED flood lamp is 1.0" (25 mm) below the bottom of the LED array housing. Recording intensities is necessary to document the health of the curing system and the process is operating within the limits set during the validation.

2. Adjust Intensity

Since the intensity from arc-ignition lamps tends to drop with time, the intensity set-point should be set closer to the upper intensity limit threshold (Step 4 of validation), and should be periodically checked and re-adjusted. In the standard arc-ignition systems, the intensity adjustment is performed by moving the z-axis distance from the bond line. Increasing the distance from the UV source to the bondline will decrease the intensity. The technology in the new LED flood systems allows for adjustments in output intensity simply through the front panel display, leaving the lamp to bondline distance untouched.

Figure 3. ACCU-CAL™ 50 Radiometer

Figure 4. ACCU-CAL™ 160 Radiometer

3. Documentation

Documentation methods and measurements is a critical aspect of any manufacturing process. This documentation should be posted at the work station, not filed away. Documentation that is readily available is more likely to be followed, and the following items are strongly recommended. Table 2 below is an example of a UV-curing intensity record that incorporates items a through h.

a. Radiometer and Detector serial number, last calibration date, next calibration date
b. Expected Intensity measurement with maximum and minimum limits
c. Setup procedure
d. Belt speed
e. Distance from the part
f. Intensity measurement method and frequency
g. Intensity re-adjustment method and frequency
h. Bulb replacement method and bulb change history log

Table 2. Example of a Conveyor Curing Intensity Record

Station 1 – Conveyor Curing Intensity Record

Equipment – ACCU-CAL™ 160, SN:16545M (calibrated Sept. 9, 2017, calibration due Sept. 9, 2018)

Radiometer Settings – Mode – (Peak Intensity)

Frequency – 6:30 am and 4:30 pm daily. Allow UV Equipment 5 minutes warm-up before measurement.

Measurement Process - Use Fixture # L1-F-C15

Belt Speed – 12 fpm (feet per minute) **Lamp Height** – 3.0in (76mm)

Cure Limits – Minimum Intensity 135 mW/cm^2 / Maximum Intensity: 260 mW/cm^2

Daily Intensity Target – 185.0 mW/cm^2 – 220.0 mW/cm^2

Date	Time	Startup Intensity (mW/cm^2)	Bulb Replacement Required	New Intensity	Technician
15-May	7:28 am	187.5	No	N/A	AB
15-May	4:34 pm	184.7	Yes	219.6 mW/cm2	CD
16-May	7:35 am	219.4	No	N/A	EF

4. Eliminate or Understand Possible Variations

The more variation that is eliminated from a curing process, the more controlled the process will be. If a variation cannot be eliminated, it should be understood and worked into the process. We have already mentioned maintaining distance and intensity. Other sources of variation include:

- **Bulbs:** Natural variations in the components that construct the bulbs used in light curing systems will lead to variations in initial intensity output. This will be most noticeable when changing out an old lamp for a new lamp. Lamps also degrade at different rates, depending upon their initial intensity and pattern of usage, but all will exhibit similar degradation curves.

- **Radiometers:** ACCU-CAL™ 50 radiometers consist of a meter and detector. These two components are calibrated as a matched set. Interchanging a detector between meters will certainly lead to repeated inaccurate measurements that can be wildly out of range. Each detector comes with a graphed spectral response curve specific to that device like a fingerprint.

- **Radiometer Calibration:** For all radiometers, the calibration process individually calibrates each radiometer set to a single transfer standard within an acceptable deviation limit. When comparing two radiometers to each other, the stacking of deviations could indicate significant differences in measurement that may seem unacceptable, but each radiometer is in fact accurate when compared to the calibration standard. For this reason, it is strongly recommended for a single radiometer to be used when monitoring the daily activities of a production line. A second radiometer should only be used when the main radiometer is returned for calibration. The radiometers should be compared to understand what the deviation is between the two units. This will help the user to understand the difference in measurement they may begin to witness when using the secondary radiometer.

- **Measurement Location:** Depending on the flood lamp used in the conveyor system, the UV intensity delivered to the bond line can vary across both the X and Y axis (length and width) of the exposed area. Always placing the measuring radiometer in the same location will provide consistent measurements. One way to ensure consistent placement of the radiometer regardless of the technician is to create a fixture that would be used with the radiometer. In addition to consistent placement, it is also important to make sure the intensity measure is recorded at the same Z axis (height) as the bond line. A measurement taken with the radiometer detector 0.5" above or below the height of the bond line could produce energy levels drastically different to what the bond line is actually receiving.

Support

Dymax is always available to support manufacturers with their applications. Our Customer Support Team can provide pricing, lead time, and availability of curing, dispensing, and adhesive products. The Application Engineering Team can assist with curing, dispensing, and adhesive selections tailored to your specific application, as well as provide troubleshooting and process assistance. Please visit www.dymax.com/customer-service for support information, including local contacts in your area.

In addition to live support, we also have a large collection of educational Informative and documentation available for download on the Dymax website. Visitors can find comprehensive guides, videos, and other resources that will aid them in setting up and maintaining a successful UV-curing process.

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Dymax Corporation
+1.860.482.1010 | info@dymax.com | www.dymax.com

Dymax Europe GmbH
+49 611.962.7900 | info_de@dymax.com | www.dymax.de

Dymax Engineering Adhesives Ireland Ltd.
+353 21.237.3016 | info_ie@dymax.com | www.dymax.ie

Dymax Oligomers & Coatings
+1.860.626.7006 | info_oc@dymax.com | www.dymax-oc.com

Dymax UV Adhesives & Equipment (Shanghai) Co. Ltd.
+86.21.37285759 | dymaxasia@dymax.com | www.dymax.com.cn

Dymax UV Adhesives & Equipment (Shenzhen) Co. Ltd.
+86.755.83485759 | dymaxasia@dymax.com | www.dymax.com.cn

Dymax Asia (H.K.) Limited
+852.2460.7038 | dymaxasia@dymax.com | www.dymax.com.cn

Dymax Asia Pacific Pte. Ltd.
+65.6752.2887 | info_ap@dymax.com | www.dymax-ap.com

Dymax Korea LLC
+82.2.784.3434 | info_kr@dymax.com | www.dymax.com/kr