DYMAX®

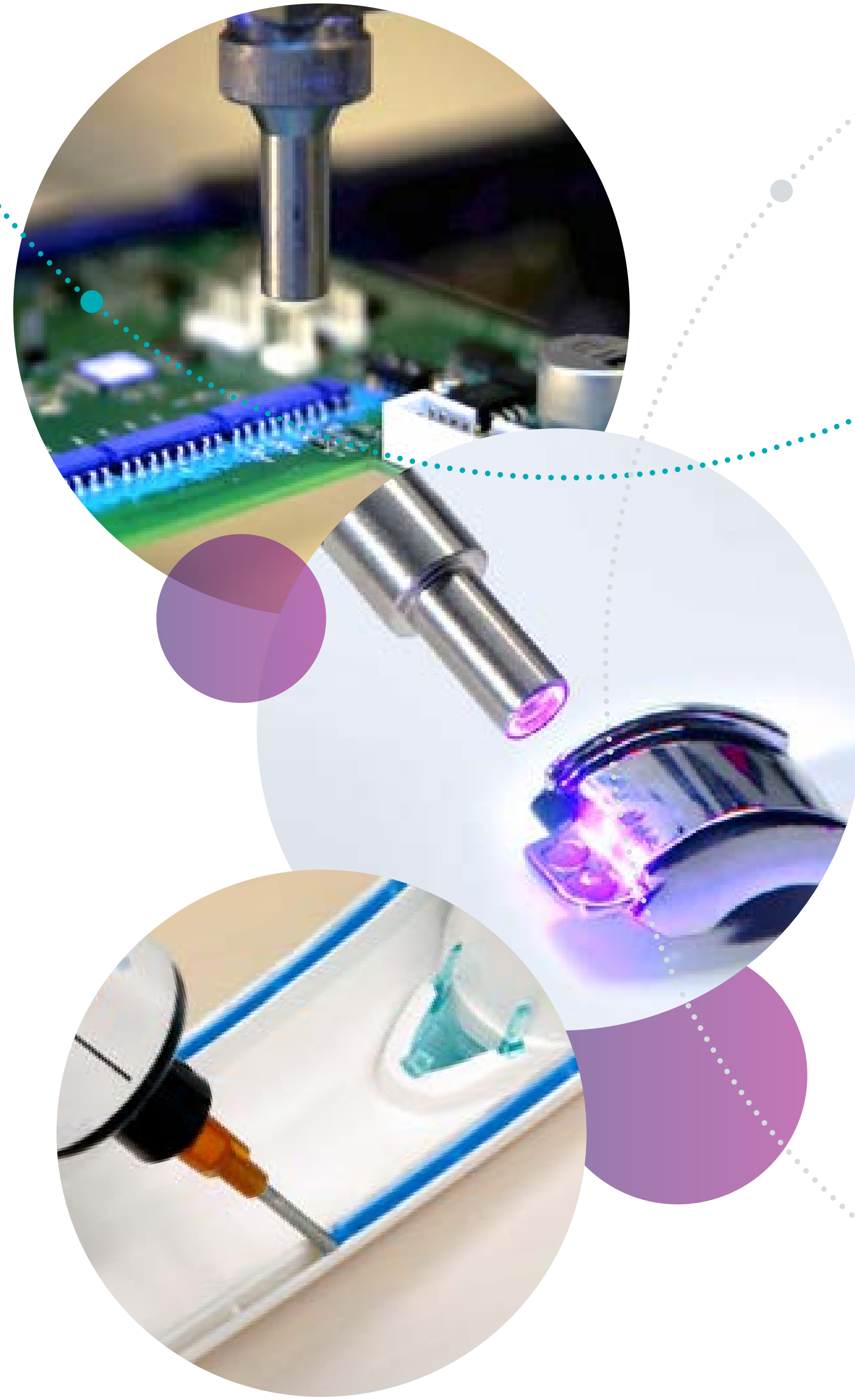
An Introduction to UV Light-Curing Technology

Contents

What is Light-Curing Technology?

Ultraviolet (UV) light-curing technology was originally developed in the 1960s as an alternative to solvent-based, heat- and air-drying processes and slow-curing silicones, epoxies, urethanes, pressure-sensitive tapes, cyanoacrylates, modified acrylics, and other methods of joining. It wasn't until the early 1980s that UV curing became popular in industrial manufacturing applications. Today the technology has been widely adopted in many industries including automotive, appliance, aerospace, telecommunications, medical device, military, consumer electronics, and graphics arts.

UV curing is a process in which high-intensity ultraviolet and visible light are used to initiate a photochemical reaction that generates a crosslinked network of polymers. Using light instead of heat, liquid monomers and oligomers are mixed with a small percent of photoinitiators, that when exposed to light-curing energy, instantly cure or harden UV-curable inks, coatings, and adhesives. Offering many advantages over traditional drying methods, UV curing increases production speed and product throughput, decreases work-in-progress and scrap, enables 100% in-line inspection, and because it is a solvent-free process, reduces environmental pollutants.

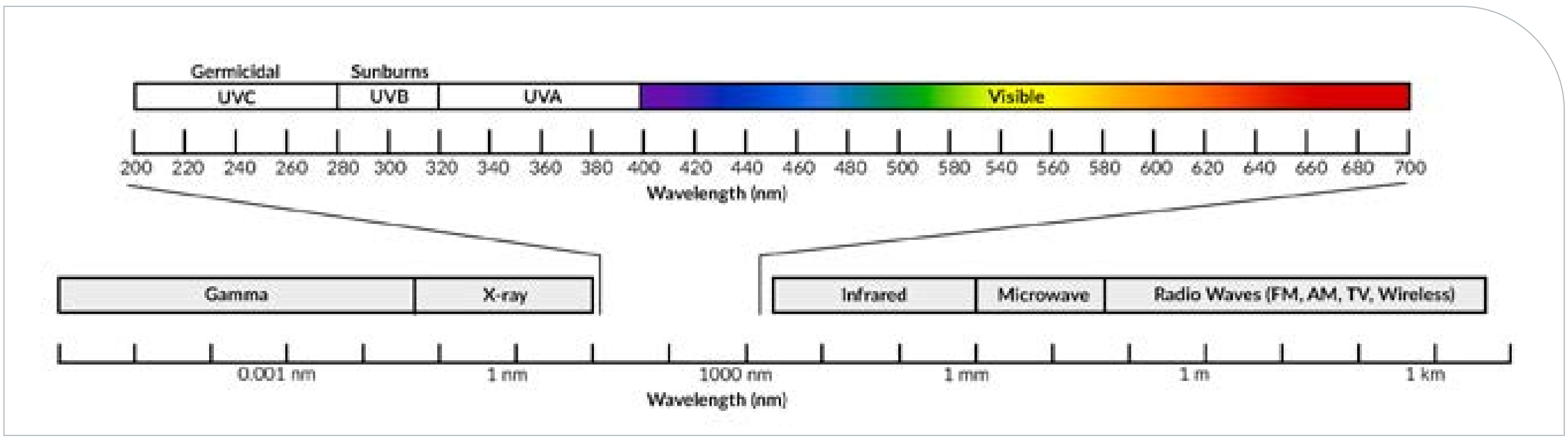


The Science Behind Light Curing

The Electromagnetic Spectrum

The electromagnetic spectrum is the collective term for all known frequencies and their linked wavelengths of the known photons (electromagnetic radiation). The spectrum is an extremely wide range of radiation that travels at the speed of light and is divided into different regions based on wavelengths that extend from radio waves (~1 m - 11 km), through visible and UV (~300-800 nm), to gamma rays (~0.001 nm).

UV light is the portion of the electromagnetic spectrum between X-Rays and visible light, and the range of shorter wavelengths adjacent to the visible-light spectrum. Visible light is the only portion of the electromagnetic spectrum that the eye can see. Wavelengths in these regions are commonly measured in nanometers (nm). A nanometer is a billionth of a meter or a thousandth of a micron. The UVA range is generally considered the safest of the three UV ranges (UVA, UVB, and UVC). Light-curable materials (LCMs) typically require UVA light (320-400 nm) and/or (blue) visible light (400-450 nm) for curing.



Electromagnetic Spectrum

Fundamentals of Light-Curing Technology

Key concepts to know for a successful light-curing process.

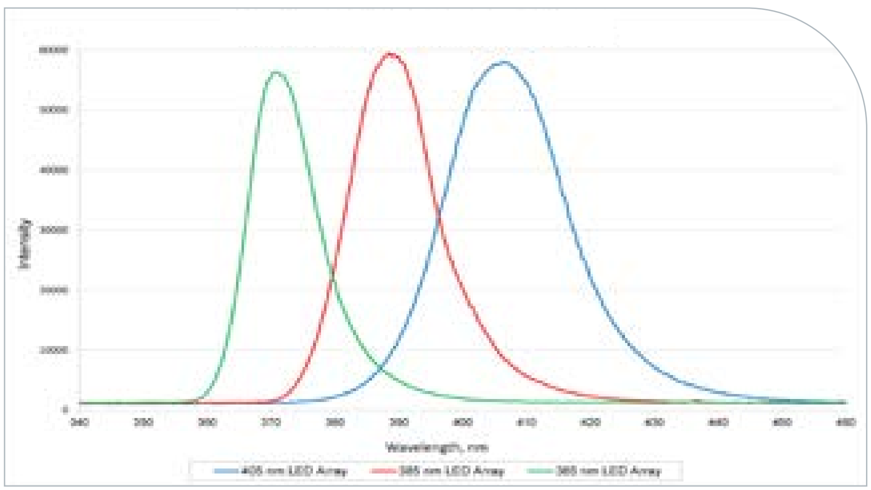
Spectral Output

Spectral output is the radiant output of a lamp versus wavelength, and is commonly charted out as output watts plotted against wavelength. Curing bulbs vary in their spectral output. Sometimes filters modify the spectral output of a curing system. It is important to remember that the output of a curing lamp must be matched to the absorption of the photoinitiator in the LCM. If they are not matched, the LCM will not cure properly and may result in a failed bond. Light-curing systems with spectral outputs at 365 nm, 385 nm, and 405 nm are common.

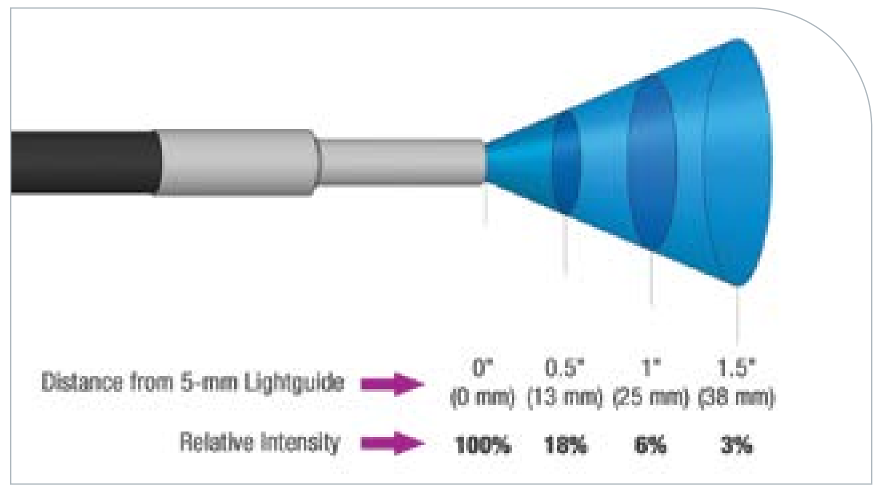
Intensity

Intensity is the light energy reaching a surface per time and it is often measured in milliwatts per centimeter squared (mW/cm^2). When using the term "intensity", it is important to define which wavelength is being referred to. Higher intensity light (of the proper wavelength) will generally provide a faster cure.

Intensity is always affected by the distance from the light-curing lamp to the surface. Intensity decreases with increasing distance from both spot lamps and flood lamps, especially spot lamps. Intensity decreases with increasing distance from the focal point for focused-beam systems.



Example of a Light-Curing System Spectral Output Chart

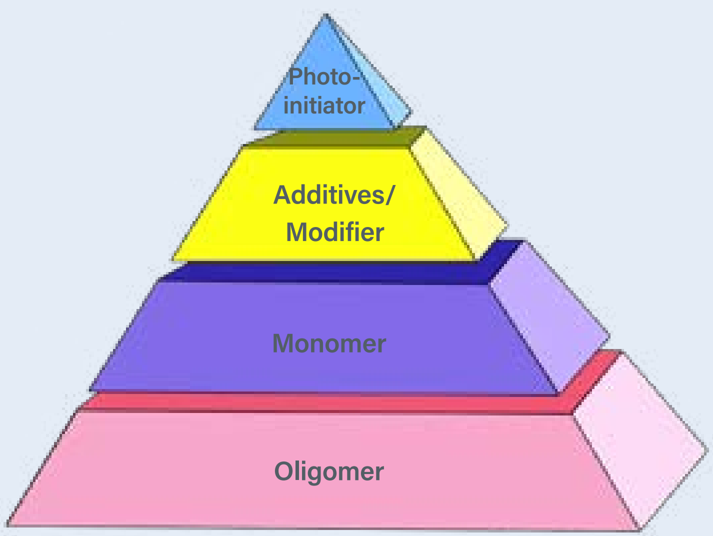


The Effect of Distance on Intensity

The Composition of Light-Curable Materials

Light-curable materials (LCMs) are typically composed of four main ingredients that are tailored to suit specific applications. Those ingredients include:

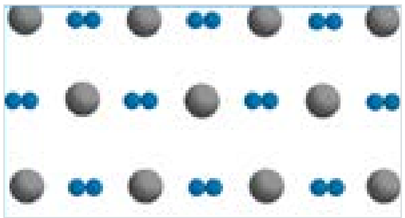
- **Oligomers** - medium-length polymer chains that give the formulation its basic mechanical properties, i.e. elongation, shrinkage, hardness, etc.
- **Monomers** - give formulations their specific properties
- **Additives/Modifiers** - added to fine tune formulations and provide unique features such as fluorescing or color
- **Photoinitiators** - chemicals that fragment into free radicals when exposed to light



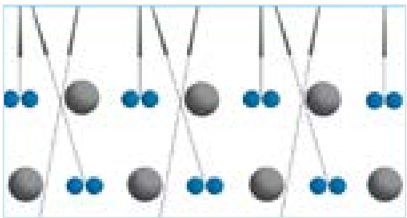
The Polymerization Process

Light-curable materials use energy provided by ultraviolet (UV) or visible light to start a curing reaction. When the photoinitiator in an LCM is exposed to a light-energy source of the correct spectral output, the curing process begins. LCMs utilize photoinitiators sensitive to different ranges of light. Because of this, it is important to match the material being cured with the source of light being used to cure it. Most LCMs used for assembly and thick layer curing, from 0.003" - 0.25+" (.05 mm - 6+ mm), use a broad spectrum of UV light with a concentration in the UVA range to achieve cure. Some materials also use visible (blue) light for cure.

Once light is introduced, it excites and fragments the photoinitiators, resulting in the generation of free radicals. The free radicals begin to attach themselves to the acrylates that make up the LCM, resulting in polymeric chain radicals. This process is repeated until all free radicals are attached, resulting in polymer termination (cured material).

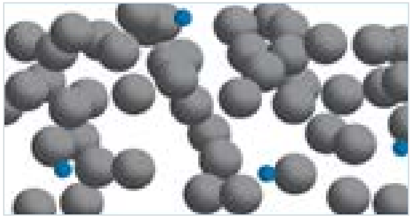


1 - Liquid Unreacted State



2 - Photoinitiators Generate Free Radicals

3 - Polymer Propagation



4 - Polymer Termination

Designing a Light-Curing Process

What are the components that make up a light-curing system?

The typical light-curing system consists of a light-curable material, a dispensing mechanism, and a means of curing the LCM. In order for the process to work effectively, all of the components must be optimized to work together.

Light-Curable Materials

There are a variety of light-curable materials that manufacturers use to bond their components. These products range from epoxies, to silicones, to acrylate systems. Products can be one- or two-component and may cure with UV and/or visible light only or have additional curing mechanisms such as secondary heat or moisture curing.

Dispensing Equipment

To apply an LCM to a component or substrate surface, a dispensing system is required. Types of dispensers include hand-held, machine-mounted, robotic and rotary systems. Methods of application include manual or automated dispense from syringes, valves, or spray guns.

Light-Curing Equipment

In order to bond components together with an LCM, a light-curing source is required. There are “traditional” broad-spectrum systems that utilize bulbs for curing as well as “newer” LED systems that cure with LED arrays. Light-curing systems are available in a number of different configurations, the most popular being spot, flood, and conveyor-style systems.

The Basic Types of Light-Curable Materials

There are two basic types of light-curable materials: acrylates and epoxies.

Acrylate Systems

The term "acrylate" is a shorthand term for a wide range of materials that includes acrylates, methacrylates, and similar functional groups. Acrylate systems react when exposed to UVA light (always) and visible light (in many cases). The materials exhibit a very broad range of properties. Depending on additives, acrylate systems can be produced which are colored (i.e., red, blue, or black), opaque, fluorescing (often a requirement for in-line inspection), or thermally conductive. The physical properties of acrylates include adhesion, viscosity, durometer, and appearance. Since acrylates can be made to cure with visible light, fluorescing and red or blue formulations are common.

Cure speeds with acrylate resins depend on formulation specifics, and of course, on the intensity and nature of light used to cure them. Practical cure speeds range (mostly) between 0.5 - 15 seconds. Depth of cure also varies with formula and process specifics. Typical cure depths range from 0.10 in - 0.59 in (2.5 mm - 15 mm).

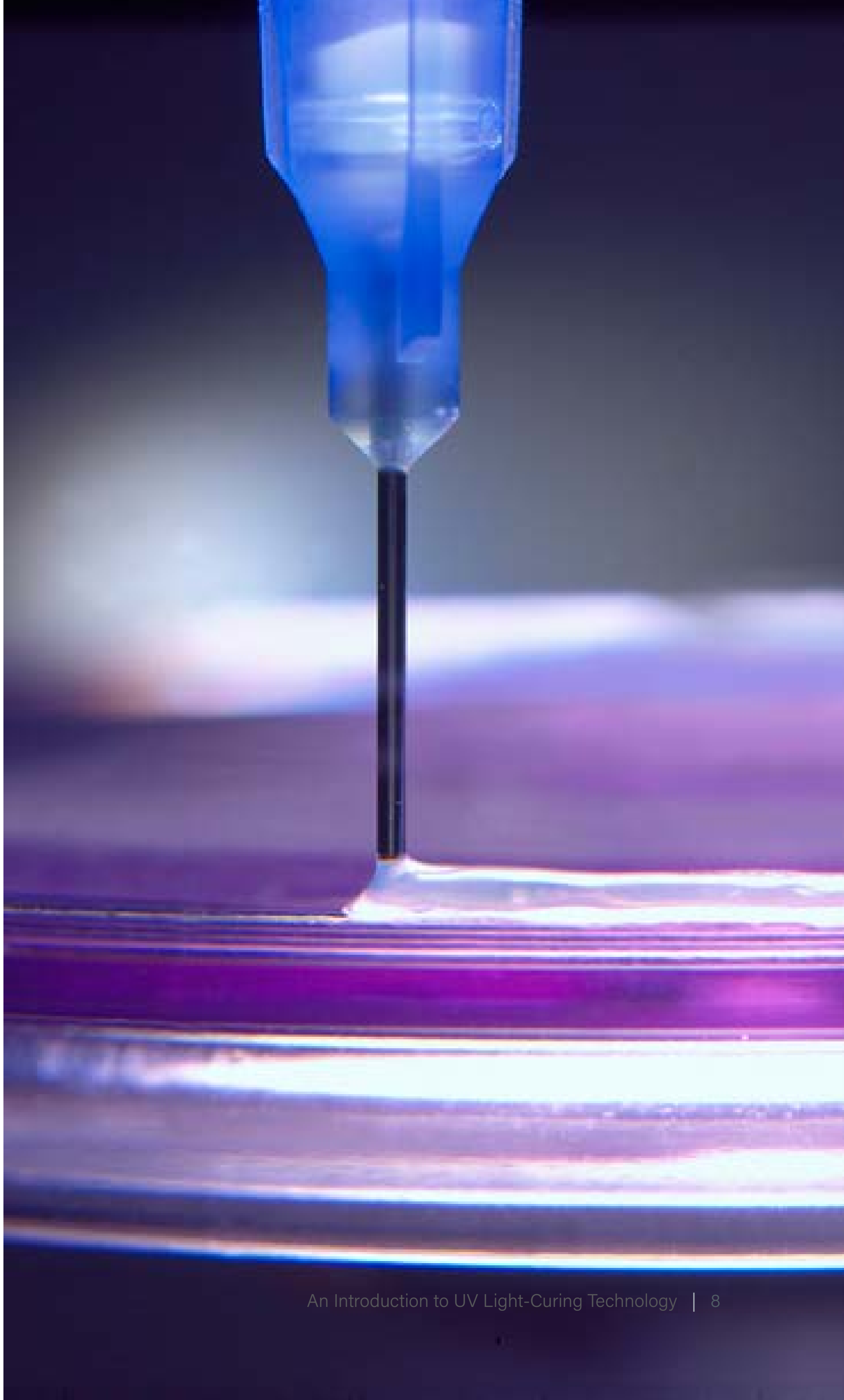
Acrylate LCMs can also be made to react with heat or activator. This is useful when light cannot be used to cure the material due to the presence of a "shadow." Acrylate LCMs typically cannot be cured with moisture or air.

Surface tack is sometimes observed with acrylate LCMs. Surface tack is caused by the interference of atmospheric oxygen with the free radical cure mechanism on the surface of the resin. In most cases, surface tack can be eliminated by altering the curing process (greater light intensity, longer cure time, or a slight adjustment in the wavelength of light used). On the other hand, there are some acrylate LCMs that will not cure tack-free even with these alterations. Most of these products were designed for applications where the LCM is not exposed to air, i.e., in bonding applications between two substrates.

Epoxy (Cationic) Systems

Epoxy LCMs, sometimes called "cationic systems" by virtue of the type of photoinitiator employed as opposed to the chemical make-up of the resin, comprise the second main class of light-curable materials. The range of properties which can be achieved with epoxy LCMs is somewhat narrower than with acrylate LCMs. Nevertheless, epoxy LCMs can be formulated to exhibit a few advantages over some acrylate LCMs, including tack-free cures (no oxygen inhibition) and superior adhesion to certain substrates.

A point of difference between epoxy and acrylate LCMs is that the development of full properties often takes longer for light-curable epoxies, so heat is sometimes used to accelerate the cure. In addition, the curing of cationic LCMs is impeded by moisture/humidity.



Alternative Bonding Technologies

How they compare to light-curable adhesives

Cyanoacrylates

Commonly referred to as superglue, cyanoacrylates cure in the presence of moisture. They offer high shear strength but often see blooming and stress cracking.

One-Part Epoxies

Epoxies are a class of substances made from epoxide-containing polymers. One-component grades do not require mixing like their two-component versions, but they do require moderate heat to cure.

Two-Part Epoxies

Two-part epoxies are comprised of two components, a resin and a hardener, that must be mixed before dispense. They excel in applications that require extreme chemical resistance.

Two-Part Urethanes

Two-part urethane adhesives cure chemically once mixed. Polyurethanes offer a good balance of strength and flexibility.

Hot Melt Adhesives

Holt melts are typically composed of thermoplastic resin and require heating to activate their adhesion properties. When heated they become a high-viscosity liquid and return to a solid when cooled to room temperature.

One-Part Silicones

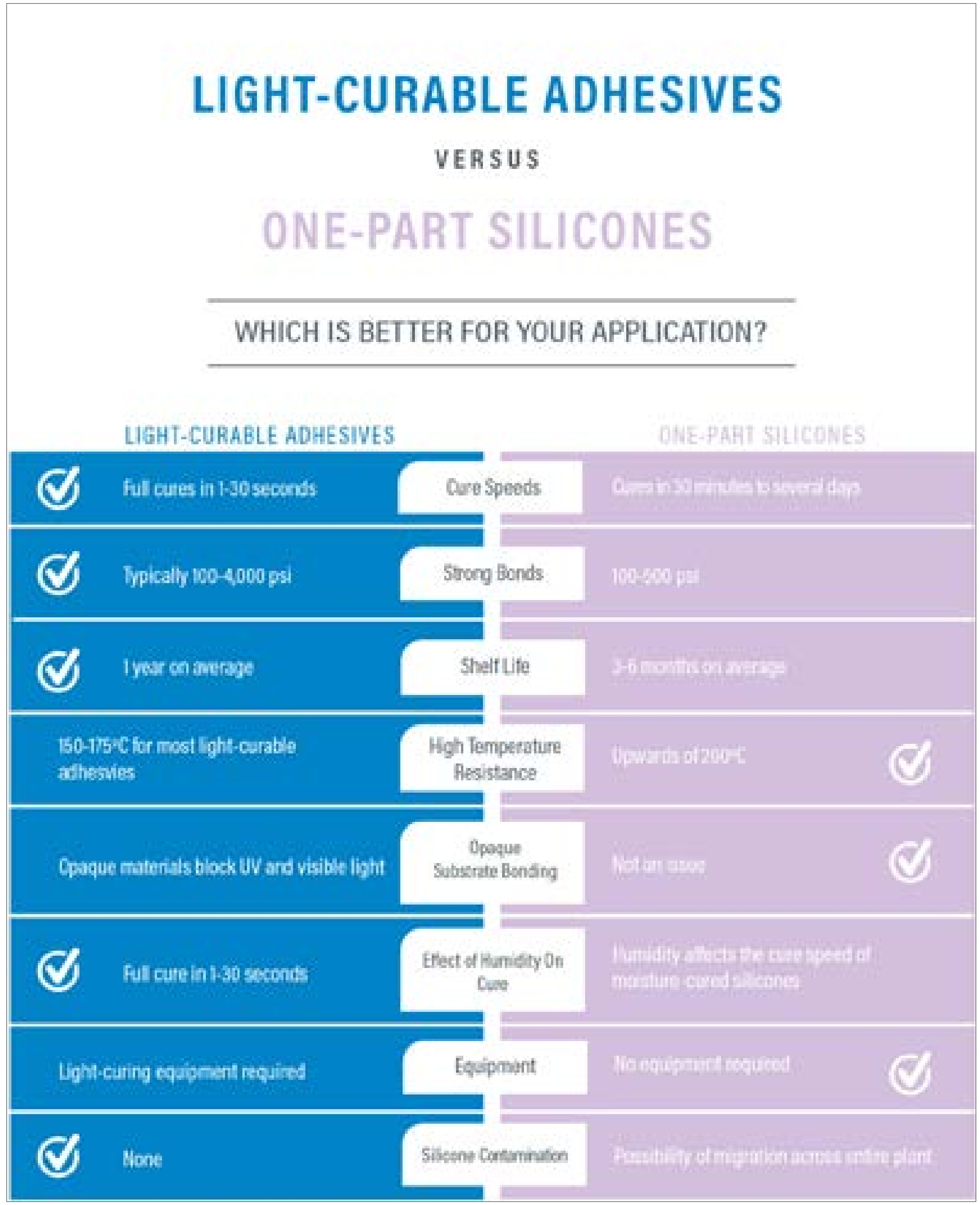
Single-component silicone adhesives require humidity to cure. They remain highly elastic at low temperatures and have good temperature stability but their bonds can only be subjected to small mechanical loads.

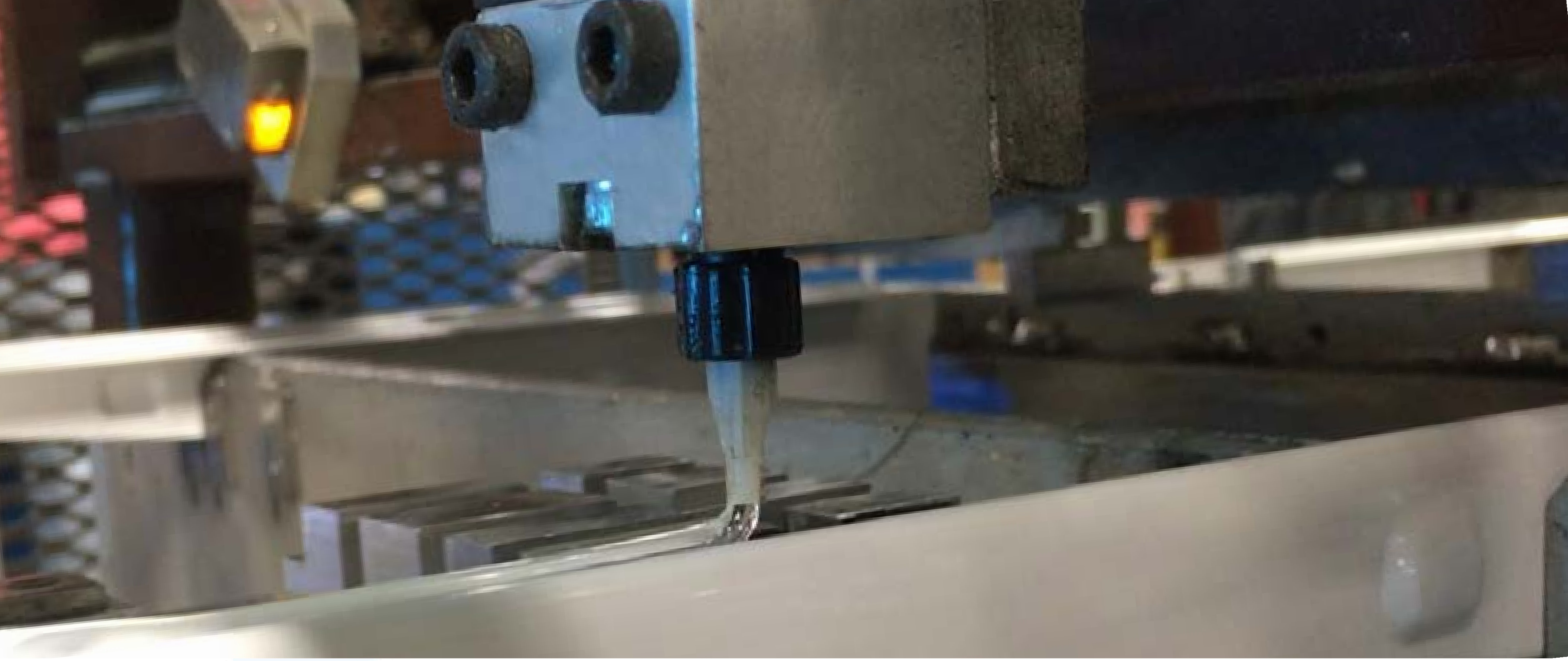
Solvent-Based Adhesives

These adhesives are typically hard polymers that are dissolved and softened with a solvent. As this solvent evaporates, the adhesive re-hardens and forms a strong bond.

Hover on the thumbnails below to
enlarge the infographic.

Please Note: The points noted on these infographics are a general comparison of the adhesive chemistries. It is always recommended that the proper testing be done for each specific application before selecting an adhesive.





The Basics of Dispensing Light-Curable Materials

Dispensing methods, equipment, features, and applications

Selecting the right equipment is critical to creating a successful LCM dispensing process. Important features to consider are whether the system will be manual or automated, the type of fluid container and applicator needed, the shot size required (dots or beads), and material viscosity.

Dispensing Methods

The three main types of fluid dispensing are:

1. **Dispense:** Dispense-only units are either manual or power-driven and do not mix or have any monitoring capabilities. Most LCMs are single component and use a traditional dispense only.

2. **Mix and Dispense:** Mix and dispense units combine two or more fluids at a determined ratio and then dispense the material.

3. **Meter, Mix, and Dispense:** Meter, mix, and dispense systems use a predetermined mix ratio and shot size.

Machine-Mounted Dispensing System for Packaging Application

Dispensing Equipment

Dispensing equipment includes:

- Hand-held systems
- Machine-mounted systems
- Robotic and rotary systems

Material Application

There are a variety of dispensers used to apply LCMs such as syringe dispensers, valves, and spray guns.

Syringe dispensers utilize pre-packed disposable syringes for accurate and consistent fluid deposits and eliminate the risk of contamination during dispense.

Diaphragm valves are used for reactive materials because the internal valve design prevents fluid from coming in contact with the valve's actuating components. Needle valves deliver precise dots or very fine beads of low- to medium-viscosity fluids. Some needle valves feature stroke adjustment which allows for fine-tuning of the dispense volume, ensuring precise and consistent fluid deposits. Spool valves for automated dispensing systems are designed to accurately dispense a variety of medium- to high-viscosity fluids by using suck-back and adjustable flow controls.

Standard and high-flow spray valves are used in automated dispensing systems and as spray guns for manually spraying materials. High- to super-flow spray gun systems are used in applications where a significantly higher flow rate is required, such as high-volume, large part coating and masking.

LCM Dispensing

The typical LCM dispensing system is made up of a number of components including the reservoir, a controller or regulator, and an applicator. The container, which holds the LCM, can be a syringe, cartridge, or larger reservoir such as a bottle drop-in reservoir or pressure pot. A controller and/or regulator is paired with the container and can be used to adjust dispensing time, material volume, and air pressure. LCMs are applied through a variety of manual and automated methods including syringes, valves, and spray systems.

Additional Features

Dispensing systems can incorporate a variety of features such as foot controls, multiple dispense capability, disposable fluid paths, and suck back controls. A foot pedal can control the rate of material flow. There are also systems that can dispense from multiple nozzles simultaneously. Disposable fluid paths carry materials from the material reservoir to the dispense tip, sealing fluids in the fluid path, preventing the fluid from coming in contact with the valve's inner components and ensuring a contaminate-free dispensing process. Suck back control is a mechanism that prevents the dispensing nozzle from leaking between intended shots.

Material Viscosity

Viscosity is a measure of a fluid's resistance to flow. The type of applicator used to apply an adhesive will often be determined by the viscosity of the material and the type of surface or components the adhesive or coating is being applied to. Adhesive viscosities range from very low (thin) to very high (thick). Low temperatures increase an adhesive's viscosity and decrease flow, while higher temperatures reduce viscosity and increase flow.

The Basics of Light-Curing Equipment

Light Sources

Mercury-Arc Lamps

Mercury-arc lamps typically provide 50-1,000 mW/cm^2 of UVA light at the curing surface. They are appropriate for lower-volume applications where conveyor speeds of 1 to 5 feet per minute are acceptable. These systems have a lower capital cost, but bulb degradation must be monitored with a radiometer to ensure a controlled process.

Electrodeless Lamps

Electrodeless lamps generally provide 1,000 - 3,000 mW/cm^2 of UVA light at the curing surface and is recommended for medium- to high-volume applications. These systems cure faster for greater throughput. While capital costs are higher, total cost of ownership is lower due to longer bulb life, less maintenance, and better energy efficiency.

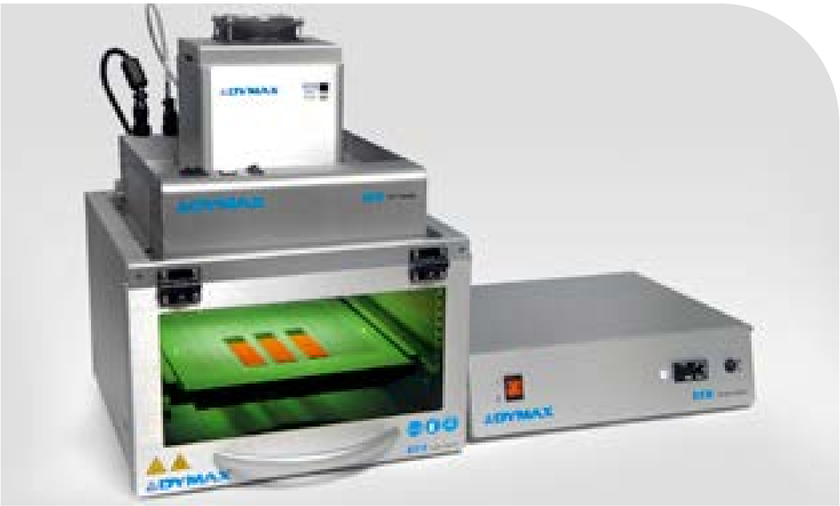
Light-Emitting Diodes (LED)

In the past decade, LED light-curing systems have become increasingly popular due to their many advantages over traditional mercury-arc lamps. They are semiconductor energy sources that use an array of surface-mounted LEDs to emit very discrete wavelengths of energy, resulting in a single, narrow, bell-shaped emission spectrum. It is imperative to understand if your chemistry is LED compatible before considering a switch to LED.

Light-Emitting Diode

Curing System Configurations

Light-curing systems are available in a number of different configurations, allowing users to select a system that best fits their budget and manufacturing needs. The three main configurations of light-curing systems include spot lamps, flood lamps, and conveyor systems.



Spot Lamp Systems

Spot-cure systems deliver optimized curing energy to a very precise location. They can be used manually by an operator in a turnkey benchtop system or incorporated into a high-speed automated assembly line. They are ideal for curing small areas quickly in R&D laboratory environments as well as low- and high-volume production applications in the medical, industrial, electronics, automotive, and optical industries.

Flood Lamp Systems

Flood-lamp curing systems usually provide moderate to high-intensity light over a larger cure area than a spot lamp. They have the advantage of being able to cure a tray of parts, or parts with large bonded or coated areas. Flood-curing lamps are available in handheld and bench-top configurations but they are most commonly integrated into existing manufacturing processes by mounting them above high-speed assembly lines.

Conveyor Systems

Light-curing conveyor systems are ideally suited for curing LCMs on larger parts or on large quantities of smaller parts. Parts are loaded onto a motorized belt and carried through a tunnel of curing lamps.

Hybrid Light-Curing Systems

Some companies also offer hybrid systems that are a mix of two configurations, i.e., a spot lamp that can also be used as a flood lamp. These systems can be useful in settings where applications are constantly changing and curing flexibility is needed.

Why Choose a Light-Curing Process?

Speed

Many users choose a light-curing process because of the speed of cure. Most UV light-curable materials cure fully in 1-30 seconds. Speed provides dramatic cost reducing benefits including:

- Shorter cycle times – Less work-in-progress and shorter lead times.
- Increased capacity – Assembly steps that may have been bottlenecks with slower systems are no longer bottlenecks.
- Less floor space – Elimination of ovens, humidity chambers, conveyors and racks.
- Simple and better automation – Indexing time on a line is reduced, inspection can be completed on-line, and the complexity of fixturing during the curing process is reduced.

One-Component Formula

Often overlooked, but many times more significant than speed, the one-component nature of light-curable materials provides additional cost reducing benefits, including:

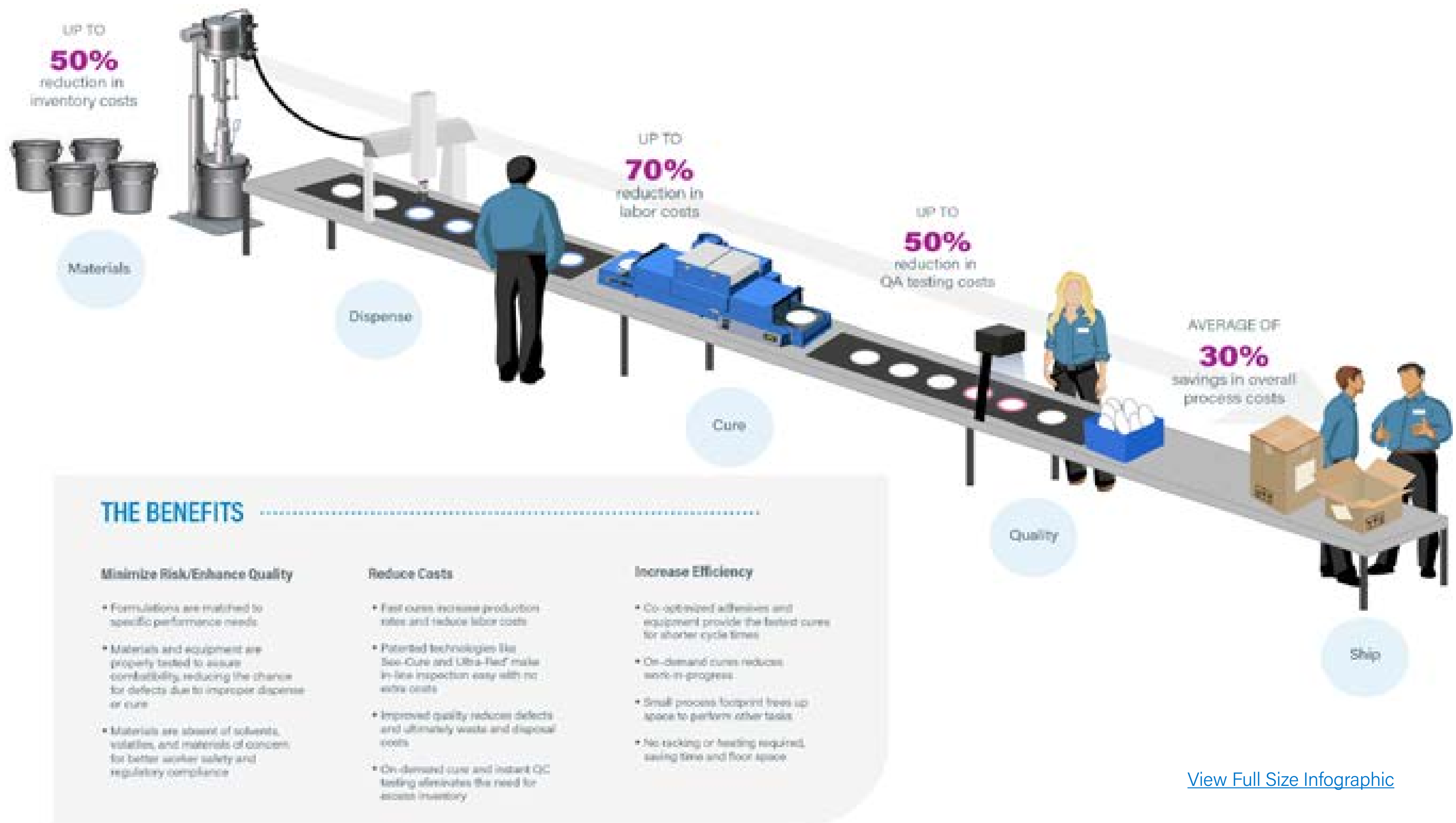
- Lower capital costs – Dispensing systems for one-component materials cost significantly less than systems for two-component materials.
- No pot life problems – Two-component systems generally have pot lives (the time between when a multiple component system is mixed and when it is dispensed or thrown away) measured in minutes or hours. Two-part systems that cure in less than 30 minutes have pot lives of less than 10 minutes. As a result, two-component systems, especially those with shorter cure times, require frequent purge cycles and often result, regardless of operational precautions, in clogged mixing elements.
- No hazardous waste – Material purged from a system that remains uncured is usually classified as hazardous waste. The A and B components of a two-component system are hazardous when not fully cured.

Product Performance

Product performance is another critical factor in selecting between different bonding technologies. LCMs offer greater adhesive strength to a wider range of substrates and exhibit a wider range of other physical properties than other comparative technologies.

Overall Benefits of an Integrated Light-Curing Process

To achieve the full benefits of light-cure technology, it is critical to design a system where all elements work in optimized harmony with one another. Integrated system solutions take into consideration all elements of the assembly process to deliver a system where chemistry and equipment work seamlessly together to increase process efficiency, improve product quality, and lower assembly costs. The graphic below demonstrates some of the areas where efficiencies may be realized.



View Full Size Infographic

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- White papers
- Webinars
- Articles
- Application case histories
- Videos
- And more!

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