Optimization of UV Curing Process for Adhesive Bonding in Medical Device Assembly

Chris LeConte, Business Development Manager, EXFO Photonic Solutions
Ben Yacobi, Department of Materials Science and Engineering, University of Toronto
Kevin Davis, Market Development Manager, EXFO Photonic Solutions
Manfred Hubert, PhD., VP Research, EXFO Photonic Solutions

UV cured adhesive bonding facilitates an economical automated assembly of medical devices. Current generations of the advanced UV curing systems, solvent-free UV adhesives that cure in seconds, and adhesive dispensing systems permit an effective and economical means for the formation of consistent and repeatable bonds for assembling medical devices.

The optimization and control of the UV curing process are essential in the manufacturing of reliable medical devices. The use of UV-cured adhesives offers several advantages such as lower energy requirements, savings on both the curing time and floor space, improved production rates, and ease of automation.

UV-cured adhesives are commonly employed for bonding and sealing medical devices, which in general are required to have uppermost quality and maximum reliability.

Adhesive bonding is typically employed in the assembly of medical devices in cases requiring joining of (i) dissimilar materials (or those with incompatible mechanical properties), (ii) materials that are not sufficiently thick for welding, and (iii) premanufactured subassemblies.

In the past, UV-cured adhesives were considered to have limitations, (as compared to heat curing adhesives) due to the shadowing effects in certain applications, CTE mismatch, and shrinkage on cure. With the developments of both; new types of UV curing systems and improved adhesive formulations (e.g., delay-cure adhesives), many of these issues have been resolved. The current generation of light curing sources, e.g., spot curing systems incorporating light guides, can typically prevent shadowing effects by distributing focused UV radiation from different angles to the areas to be joined.

Some of the examples of medical devices include

- Anesthesia masks (see figure 1)
- Syringes (see figure 2)
- Catheters
- IV delivery systems
- Angioplasty accessories
- Endoscopes
- Arterial locators
- Tubing drainage sets
- Endotracheal tubing
- Blood oxygenators
- Hearing aids
- Sensing, monitoring, and imaging devices

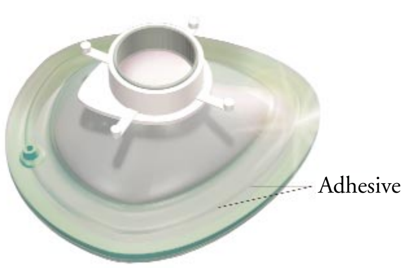

Figure 1

Figure 2

Adhesive bonding offers a versatile means for joining different materials, with the abilities of filling rough surfaces and forming a seal between two substrates. The main advantages of adhesive bonding include:

(i) adhesives provide a continuous bond, with uniform distribution of load over wider areas;
(ii) adhesives can bond irregularly shaped surfaces;
(iii) adhesive bonding can be more resilient to stress and to mechanical vibrations.

Adhesive bonding is especially suitable for the assembly of miniature components. One of the effective methods of adhesive bonding is that of UV curing based processes. In such a case, the bond design of the assembly must permit UV light to reach the adhesive.

The main advantages of using UV adhesive bonding in various applications, (including medical devices) are:

- Instant cure
- Cure-on-demand
- Economical (saves time and cost in production)
- Solvent free
- Lower energy requirements
- Increased production speed
- Ease of automation
- Accurate alignment of components (followed by instant cure)

Adhesives

Adhesives that are employed in various medical device applications include (i) light-curable acrylics (e.g., needle assembly, anesthesia masks, oxygenators), (ii) cyanoacrylates and light-curable cyanoacrylates (e.g., catheter components, tube-set bonding), (iii) polyurethanes (e.g., bonding of tips onto various components and assembling components requiring considerable flexibility), (iv) UV/ moisture-curable silicones (e.g., bonding and sealing of silicone-based assemblies and coating of components and assemblies), and (v) epoxies (e.g., needle assembly). Typically, a variety of formulations of adhesives with varying viscosities, cure times, temperature resistance, and strength properties are available for specific applications.

In general, UV-cured adhesives are characterized with relatively low process temperatures and relatively high polymerization rates (from several seconds to about 60 seconds). Combining the ultraviolet with a visible light cure is advantageous, since ultraviolet curing of thick materials can lead to a cure gradient, and by using an UV/visible adhesive, it is possible to attain a more consistent cure profile.

Optical radiation curing

Light-based systems are able to deliver faster cures for adhesives than traditional assembly methods. Efficient delivery of energy from a lamp source to the material is achieved by using either a light guide with a narrow diameter or a focusing lens. The technique is referred to as spot curing, and in this case, the light energy is deposited in a localized area where the adhesive has been dispensed. The lamp source is selected to provide the appropriate wavelength range of light to cure the material. Control of the exact dose of light delivered to the material through the measurement and setting of the intensity and duration of the exposure, in addition to the wavelength of light used, allows for customization of the curing profile for a particular application. Repeatability of the curing procedure can then be achieved using spot-curing methods, giving rise to consistent properties of the cured material.

A cure gradient might be obtained with inadequate penetration of light into the bulk of the material. In this case, the cure depth depends on: (i) the wavelengths of light used to treat the adhesive and (ii) absorption properties of the adhesive material and thickness of the adhesive bond.

The combination of UV and visible light provides improved cure speeds and depths, and permits a wider range of applications. In addition, curing of miniaturized components or devices with focused radiation minimizes the effects of irradiation on the surrounding areas

In typical applications, optical radiation curing offers great advantages and improved manufacturing efficiencies, since such curing methods readily render an in-line and in situ processing step that can directly follow or precede other processing or fabrication steps.

UV light curing, which is the most widespread type of light-induced curing of adhesives, can be employed with either a continuous wave or pulsed wave irradiation. Pulsed UV light is a rapid curing method that allows control of cure at low average power and low temperatures. It is important that the spectral output (i.e. the intensity of light at each wavelength over the whole wavelength range emitted by the lamp) is matched with the absorption characteristics of the photoinitiator. Some important wavelength regions include 250 nm associated with surface cure, those greater than 350 nm that improve depth cure, and the range between 400nm and 435 nm that employs visible photoinitiators to absorb light and to provide even greater depth of cure. In general, in order to match a light source to the UV-curable adhesive, one must determine: (i) the photoinitiator system that is incorporated in the adhesive and (ii) the transmission characteristics of the substrate.

A UV cure can be achieved in as little as 5 seconds or less. There are two types of UV curing systems: flood curing and spot curing. Spot curing systems deliver precise doses of UV energy to a specific cure site. This energy may be delivered in a "spot" of light, or a customized line or shape delivered though customized optics. Some commercially available UV spot curing systems have internal software features that allows the user a level of control and repeatability that is not achievable with flood cure UV systems or heat cure systems. An example of a repeatable, controllable and precise UV spot curing unit is the Exfo Novacure 2100 (shown in Figure 3).

Figure 3

Optimization of curing process

There are several control variables in the curing process. These include the time–intensity profile of the applied illumination, the spectral range of light used, the number and profile of curing steps, the positioning of the piece (being cured) relative to the light, and the method of distribution of light onto the piece. All the above should also be related to the characteristics of both the piece being cured and the adhesive. Such interdependence between the variables of the light-based curing process necessitates its optimization providing: (i) more control over the process (ii) improving its yield and throughput. Such an optimization for some adhesives may entail, for example: (i) an initial slow curing at low powers, (ii) a pause for a given period of time, followed by (iii) curing at a higher power level, which can contribute to a greater mechanical stability of the cured joint. In particular, employing such multi-step curing profiles for controlling the curing process can help minimize shrinkage and thus help to facilitate alignment between components throughout the curing process. The optimization of the curing process through multistep curing profiles can be accomplished by using a computer program related to a number of separate curing steps, each with its specific cure time, irradiance, and rest interval. Such programmable cure profiles provide a valuable means for optimizing a curing process. The results indicate that employing such programmed cure profiles provides reliable cures in the shortest possible time and with improved adhesive bond properties that meet stringent standards.

The self-directed methods developed for curing of various materials in different applications are based on: (i) monitoring of information during the curing and repetitive analysis of the temperature in order to maintain a predetermined cure temperature; (ii) generating and storing the set of a cure constant for different compounds in the computer database, so that these can be used later for optimizing cure of a specific compound; (iii) the comparison of actual characteristics to predicted values derived from computer simulations of the cure cycles; or (iv) using the program code for deriving the gradients related to process parameters; this method allows the monitoring and control of processes by determining the rate and direction of change of variables in relation to other process variables.

Application cases

1. *Catheter assembly*. Adhesives used in catheter assembly (balloon bonding) applications are required to withstand severe conditions related to temperature and pressure. Cyanoacrylate formulations are well suited to catheter applications. The bonding of balloon catheters must be performed at 360-degree irradiation of the catheter. In addition, cure of both ends of the balloon-catheter interface at the same time is highly advantageous. It can be advantageous to use custom designed curing accessories to deliver 360-degree irradiation. An example is shown in Figure 4. The finished product showing an inflated latex balloon attached to a catheter is presented in Figure 5.

Figure 4

Figure 5

2. *Syringe Production*. Syringe manufacturers producing 100-500 syringes per minute rely on precise, repeatable dosages of UV radiation to assemble a quality product. Adhesive is typically dispensed in the hub automatically, the cannula is then inserted in the hub and then fixtured in place by the curing of the adhesive.

Figure 6

If you would like to learn more about optimizing the UV curing process for bonding in medical device assembly, please contact the experts at EXFO.

CORPORATE HEADQUARTERS	465 Godin Avenue	Vanier (Quebec) G1M 3G7 CANADA	Tel.: 1 418 683-0211 . Fax: 1 418 683-2170
EXFO PHOTONIC SOLUTIONS INC.	**2260 Argentia Road**	**Mississauga (Ontario) L5N 6H7 CANADA**	**Tel.: 1 905 821-2600 . Fax: 1 905 821-255**
EXFO AMERICA	1201 Richardson Drive, Suite 260	Richardson TX 75080 USA	Tel.: 1 800 663-3936 . Fax: 1 972 907-2297
EXFO EUROPE	Le Dynasteur 10/12, rue Andras Beck	92366 Meudon la Forêt Cedex FRANCE	Tel.: +33.1.40.83.85.85 . Fax: +33.1.40.83.04.42
EXFO ASIA-PACIFIC	151 Chin Swee Road, #03-29, Manhattan House	SINGAPORE 169876	Tel.: +65 333 8241 . Fax: +65 333 8242
EXFO CHINA	Beijing New Century Hotel Office Tower, Room 1754-1755 No. 6 Southern Capital Gym Road	Beijing 100044, P. R. CHINA	Tel.: +86 (10) 6849 2738 . Fax: +86 (10) 6849 2662
TOLL-FREE (USA and Canada)	Tel.: 1 800 663-3936	www.exfo.com • info@exfo.com	

ISO 9001

www.exfo.com