Heraeus

UV Curing: Cure on Demand for Filament Winding

by *Susan A. Mitchell*
formerly Business Development Manager, Heraeus Noblelight America, LLC

Abstract:

Ultraviolet (UV) curing is a photochemical polymerization process that is used commercially to cure gel coats and laminate layers. This paper describes how filament winders of composite parts can apply UV curing to their fabrication process. After a brief introduction to UV curing and the benefits, there is a discussion of UV curing equipment, resins, factors to consider and typical processing equipment set-ups.

Introduction

UV curing is used commercially to cure gel coats and laminate layers of resin and fiberglass and some carbon fiber in open molding, filament winding, pultrusion, and most recently 3D printing applications. Typically, when a composites fabricator uses a UV curing process, productivity increases dramatically, resulting in a clear competitive advantage. For this reason not much is shared publicly and there is often the perception in the marketplace that UV curing is not being used. While we cannot divulge company names and specific processing details, this paper does share information about what the benefits are, the UV curing equipment and resins, factors to consider, and how to configure automated lines. There are many different types of fiberglass fabrication methods where UV curing is applied. However, the focus here is on automated filament winding processes.

Background

UV curing is a photochemical polymerization process. A wide variety of industrial processes use UV curing to cure inks, adhesives and coatings on products ranging from CD/DVDs to cell phone cases, medical devices and cosmetic bottles. As it applies to fiberglass composites, a thermoset resin which contains a small percentage of photoinitiator will cure in a matter of seconds when exposed to UV energy. UV curing has been known and proven to work with fiberglass composites for many years. The introduction of BAPO (bisacylphosphine oxide) photoinitiators, which are long wavelength absorbing photoinitiators (360-405nm), made it possible to cure laminate sections up to ½ inch thick. Another driver is the increasingly stringent environmental regulations requiring reduced styrene emissions. Fabricators are searching for ways to reduce emissions and UV curing provides an option.

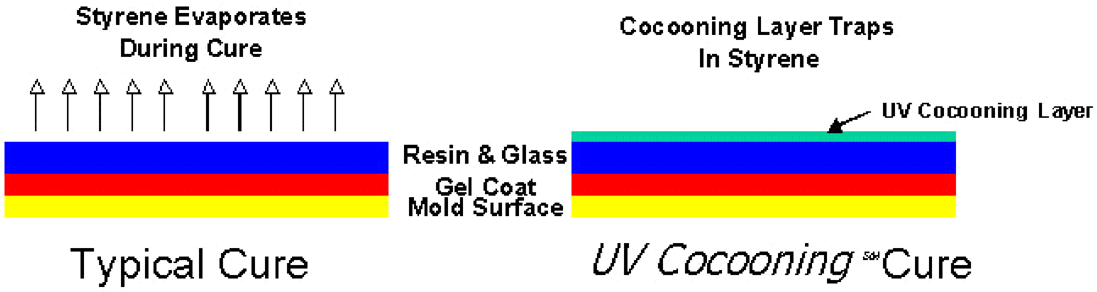
UV curing is a line-of-sight process, so any shadow areas on a part will not cure. However, this does not mean that three-dimensional parts cannot be UV cured. Three-dimensional parts can rotate or move in front of precisely positioned UV lamps so that even seemingly impossible parts can be cured. In cases where it is not possible to cure due to part geometry, a dual-cure resin, which has both a catalyst such as peroxide and photoinitiators, enables faster curing than peroxide alone and reduces styrene emissions.

UV Curing Benefits

The major benefit of UV curing is increased productivity. Increased mandrel utilization and part production rates are important benefits for the composite fabricator. Mandrels are expensive and unless they become integral with the part, another part can't be wound until the cured part is pulled off the mandrel. Even if the mandrel is integral with the part, the faster the resin sets up the quicker the part can be moved off the winding machine and the next part started.

Another benefit is the reduced floor space requirements. Since part production is quicker, there are less mandrels sitting around waiting for the part to cure. This can be a significant factor, especially for a fast growing business or new plant.

UV curing can also reduce styrene emissions because typically while the part is curing it continues to emit styrene. With UV curing, the surface cures very fast, eliminating the styrene from escaping into the environment.



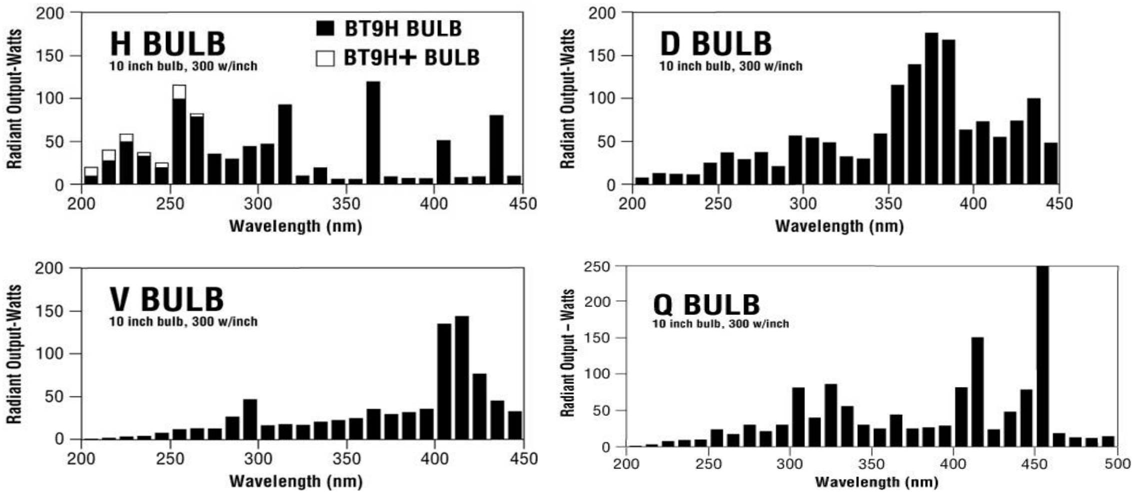
Initial testing using high-powered UV lamps to scan over a part surface, called "UV cocooning" indicates that as much as 40% of styrene emissions may be eliminated. The shape of the part, the amount of photoinitiator used, the number of UV lamps and orientation to the part, and type of resin all impact the emission reduction possible. Of course this also reduces the styrene smell in the workspace and surrounding community. So employee retention may improve and community complaints may decrease.

Less waste and faster winding speeds are possible with UV B-stage curing because the B-staged resin isn't slung off during winding or drip off the rovings. In fact, higher approach angles are possible because the roving now sticks in place on the mandrel.

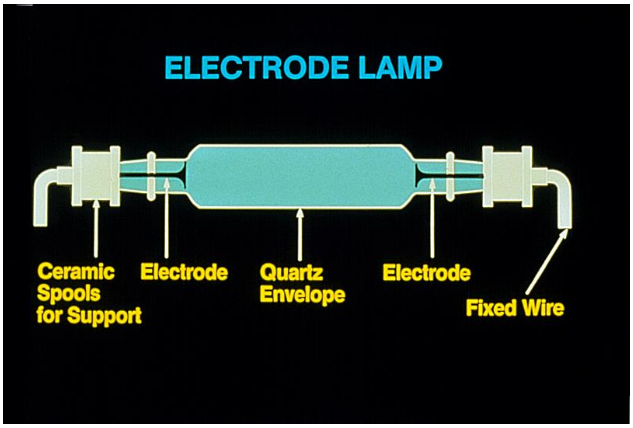
UV Curing Equipment

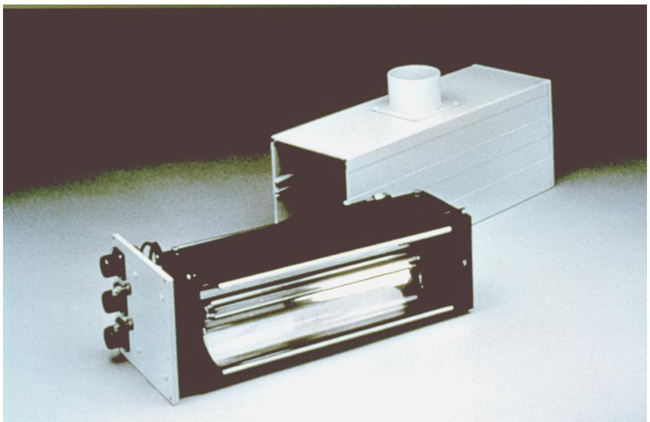
Traditional UV curing systems consist of a lamp head, or irradiator, which contains the bulb and reflector. The lamp head is controlled by a power supply or ballast, which is connected to the lamp head via electrical cables. For proper operation, the lamp head must be cooled, so there is also some type of cooling mechanism such as a blower or cooling water to maintain bulb temperatures. More recently, UV LED curing systems are also available offering the added benefits of long life and small form factor for easy integration into existing filament winding machines.

The type of UV curing equipment, mercury arc lamps, microwave-powered, or UV LED, specific bulb type, and orientation to the part will depend on the chemistry, overall process design, and maintenance considerations. Most laminate resins and gel coats cure best with a long wavelength, iron or gallium additive (350-430nm, often referred to as “D” or “V”) type bulbs for efficient through cure. If only short wavelength photoinitiators are used, typical in emission reduction applications, then a short wavelength mercury bulb (250-300nm, often referred to as “H”) type is best. Below are examples of bulb spectra.

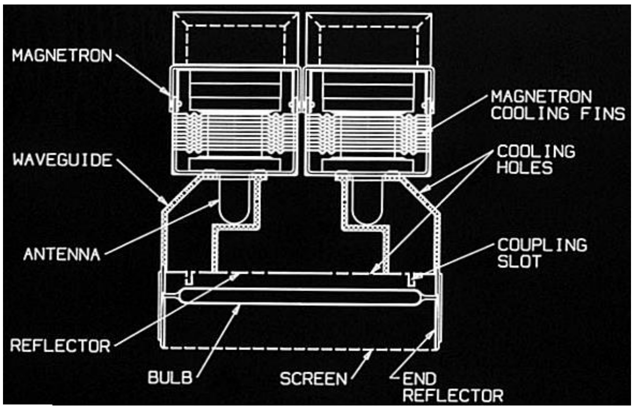


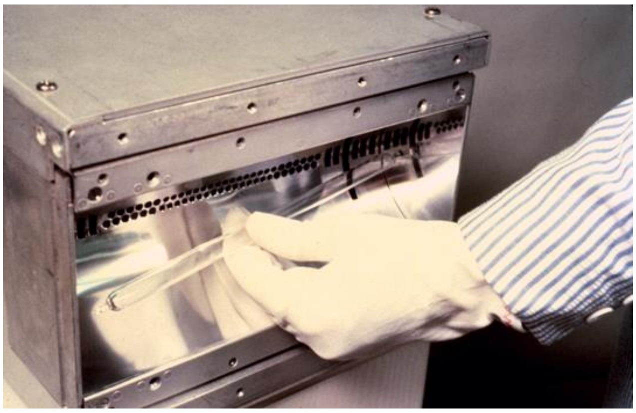
Mercury arc lamps (also referred to as electrode type) have electrodes at either end of a quartz tube.





Microwave-powered lamps (also referred to as electrodeless type) are simply a totally enclosed quartz tube. Instead of striking an arc between two electrodes to excite the gasses in the bulb, microwave energy penetrates the quartz to excite the gasses.

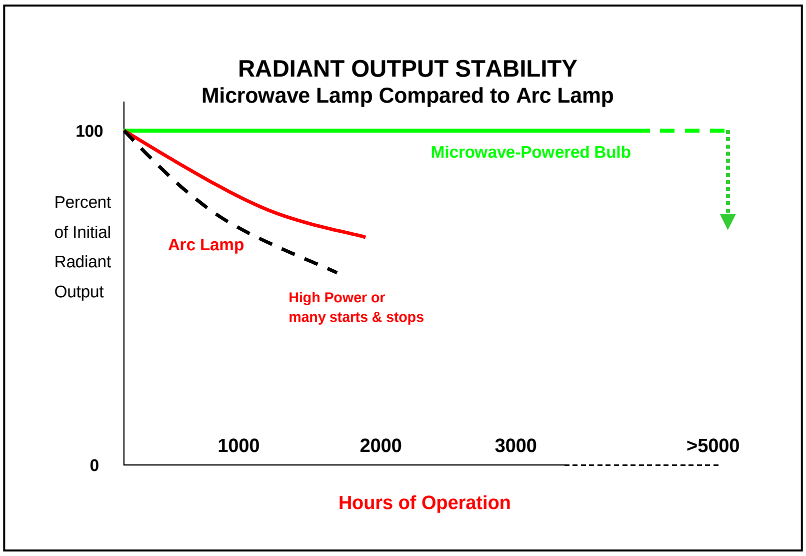




UV LED curing systems, commercial since the mid 2000’s, use light emitting diode technology to emit essentially monochromatic UV energy at 365, 385, 395 or 405 nm wavelengths. Individual LEDs are packed into arrays behind an emission window of a UV LED curing system. For efficient operation and long life the LEDs must be cooled, but it’s significantly less compared to traditional technologies and often self-contained inside the small form factor and light weight lamp heads.

The choice between UV curing technologies depends on several factors. Arc lamp systems are generally the least costly, but do not last as long or have stable output over their short life as illustrated in the chart below. This is especially true for the longer wavelength, additive bulbs used for most composites applications. The microwave-powered bulbs are guaranteed for typically six to ten times the life of an arc type bulb and a UV LED system operates 20,000 plus hours.

Arc lamps generally have longer restrike times, so shutters are used when a process requires lamps be shut off for short periods, such as when an automated line stops intermittently or unexpectedly. Microwave-powered lamps restart in seconds and UV LED lamps are instant on/off, so shutters are not required. Shutters can require additional maintenance, especially in dirty environments.



Microwave-powered and UV LED systems are available in modular units that fit easily into filament winding machines. UV LED systems offer the smallest form factor without the need for bulky cooling systems and are the most energy efficient, but they can be more expensive for a given application. UV LEDs offer long wavelength output suitable for composite applications. However, because their energy output drops significantly at increased working distances, they may not be suitable for curing three-dimensional composite parts.

Characteristic	Mercury Arc	Microwave-powered	UV LED
Life	500-2,000 hours	3,000-8,000 hours	20k+
Stable Wavelength Output	No	Yes	Yes
Stable Energy Output	No	Yes	Yes
Shutters	Yes	No	No
Cooling	Air or water, external	Typically air, usually external	Air, self-contained
Energy Efficiency	Least	Better	Best
Form Factor	Largest	Smaller, Modular	Smallest, Modular

All UV lamp systems require cooling air, but some arc lamps pull air from the substrate past the bulb and out the top of the housing. This is likely to significantly reduce the life of the bulb and overall performance of the system since fiberglass and resin is likely to be pulled onto the bulb and reflector degrading their effectiveness. Only “push” type systems, which push cooling air into the lamp housing and out of the lamp face onto the substrate, should be specified for filament winding applications.

Resins for UV Curing

A variety of resins and gel coats can be UV cured. In some cases the fabricator may choose to mix his own chemistry. Commercially formulated products are also available and especially recommended for pigmented gel coats. A discussion of laminate resins and gel coats follows.

Laminate

The majority of continuous laminating, pultrusion and many filament wound products are made with unsaturated polyester, vinyl ester or urethane resins. These resins are widely available and inexpensive. Several suppliers offer formulated UV curable resins.

Many composite fabricators use fillers in the laminate resin. Sometimes the fillers simply provide cost reduction, but some products require fillers for fire retardancy, opacity, or other properties. Typical fillers include calcium carbonate, calcium sulfate, and aluminum trihydrate. Aluminum trihydrate does not interfere with the UV cure, however the calcium fillers block the transmission of UV and must be reduced significantly or eliminated for successful cure. Although most laminate layers do not have pigments in them, if they do they may interfere with UV curing. Often dyes can eliminate or replace pigments.

Another option, especially for three-dimensional parts with shadow areas or those with heavy filler loading, is to use a hybrid cure. Photoinitiator, typically just the shortwave type, can be added to a promoted and catalyzed resin. When exposed to UV, the curing process begins quickly and then the traditional peroxide cure finishes the cure.

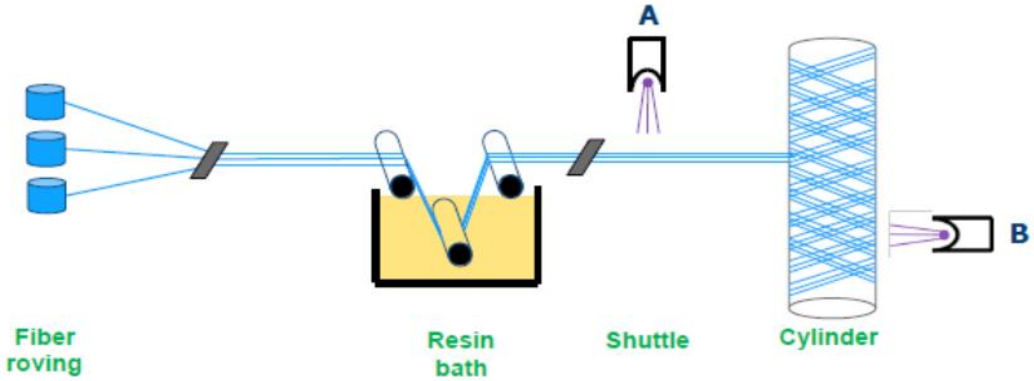
Many filament wound products are made of epoxy resins. UV curable epoxy resins are commercially available for some applications.

Gel Coat

Gel coat curing via UV has traditionally been difficult because the pigments and fillers both absorb and block the UV energy. This makes it difficult for the UV energy to penetrate through the entire gel coat thickness, which is typically 250-760 microns. Just adding photoinitiators and UV curing results in a badly wrinkled gel coat. Initial lab testing indicates that using a filter to cut off the short wavelength energy, and a combination of a long wavelength ‘V’ bulb with the long wavelength photoinitator prevents surface wrinkling while curing the pigmented gel coat. Since UV LED does not emit short wavelengths of UV energy, it may be ideal for this application, though testing still needs to be performed to prove this hypothesis. Clear UV-curable gel coats are available commercially.

UV Lamp Configurations

UV curing is used commercially for filament winding a variety of parts including oxygen and LP cylinders, baseball bats, and piping. The filament winding process lends itself quite naturally to UV curing since parts rotate on a mandrel and UV light can easily reach the surface area. And since UV curing happens in only a few seconds, it fits easily into the high production filament winding operation. There are several ways in which UV curing is applied to filament winding processes including B-stage cure, complete cure and gel coat cure.



UV lamps can often be retrofitted to existing filament winding machines. For B-stage curing, traditional UV or UV LED lamps are placed above and/or below the rovings, either glass, aramid or carbon, immediately after the resin bath (position A shown above).

Below is a photo of a commercial machine for B-stage curing. This machine uses one microwave-powered lamp above the rovings for B-staging resin onto carbon fibers. The B-stage cure is not a complete cure, but partially cures the resin to a tacky stage. In addition to reducing the total cure time, other benefits include:

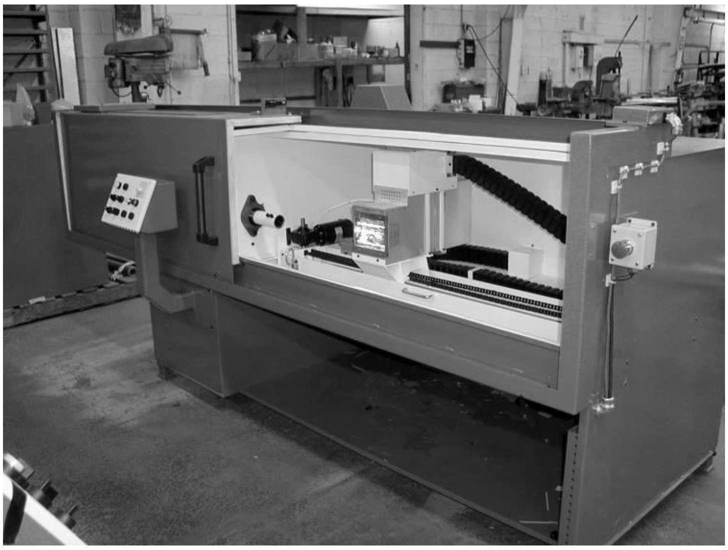
- the ability to wind at high approach angles because the roving is tacky
- faster winding speed because resin no longer flies off the mandrel during winding
- more consistent part throughout the wall thickness because resin is no longer forced out of the rovings closest to the mandrel as the part is wound
- less waste because the resin gels quickly so there is less dripping during winding and curing

Unsaturated polyester, vinyl ester and epoxy resins can all be B-staged using UV.

For complete cure, the lamps can be mounted onto a track so that the lamps can travel the length of the mandrel either as the part is wound or after the part has been completely wound (shown in position B above). Typically a part can be cured with one or two lamps since the part rotates. However, using more lamps increases cure speed.

Fabricators of filament wound cylinders, golf shafts, etc. that require a smooth, attractive appearance can UV cure the gel coat. A UV curable topcoat or gel coat is an ideal way to give the part a scratch resistant, durable topcoat, in a consistent, high production process. Gel coats on filament wound parts are usually manual or spray applied and then the part is exposed to UV. Again, only one or two

lamps are needed since the part rotates as the lamp travels the length of the mandrel.



The photo shown at left is a gel coat UV curing station built for curing a clear gel coat onto SCBA tank cylinders used by fire fighters, scuba divers, etc. After application of the gel coat, the cylinder is placed into the unit and one microwave-powered UV lamp traverses the length of the part while the part spins.

If a new filament winding operation is being set up, then the UV lamps can be incorporated into the overall winding machine. Light shielding must be constructed to ensure worker safety. In addition, controls should be integrated to provide proper operation and safety.

Summary

UV curing is ideal for converting batch processes to automated processes or for retrofitting onto automated lines. UV curing is already used in filament winding processes for producing a variety of parts. In addition to productivity gains, UV curing requires small floor space, improves mandrel utilization, reduces styrene emissions, increases winding speeds and reduces waste. Fabricators interested in the feasibility of UV curing for their operations should contact UV equipment manufacturers and resin suppliers who can team with them to develop a commercial process. Typical process development includes evaluation of UV cured lab samples to ensure property requirements, followed by UV curing tests in the plant to work out processing details and commercial feasibility.

www.heraeus-noblelight.com

Deutschland
Heraeus Noblelight GmbH
Heraeusstraße 12-14
63450 Hanau
Phone +49 6181 35 4499
Fax +49 6181 35 164499
hng-info@heraeus.com

USA
Heraeus Noblelight America LLC
910 Clopper Road
Gaithersburg, MD 20878
Phone +1 301 527 2660
Fax +1 301 527 2661
info.hna.uvp@heraeus.com

China
Heraeus Noblelight (Shenyang) Ltd.
Shanghai Branch
2F, Building 5th,
No. 406, Guilin Rd, Xuhui District
Shanghai 200233
Phone +86 400 080 2255
Fax +86 21 3357 5333
info.hns@heraeus.com

Japan
Heraeus K.K.
Noblelight Division
Sumitomo Fudosan Otowa
Bldg. 1F, 2F, 5F
2-9-3 Otsuka, Bunkyo-ku,
112-0012, Tokyo
Tel +81 3 6902 6602
Fax +81 3 6902 6613
info.hkk@heraeus.com

Technical data is subject to modification.
HNG UVP131/EN/01.19