Ultraviolet Curing

Application Note 105

Introduction

Ultraviolet (UV) Curing is a process which utilizes light energy to increase the viscosity of a material after it has been applied to another surface. Generally, a liquid material is coated onto the surface and through a photopically driven chemical process. The process causes the liquid to undergo a phase transition to a solid state. Traditionally, this process has been accomplished utilizing purely chemical means. The material to be deposited is dissolved in a solvent which is applied to the surface. This solvent is then evaporated, leaving the material behind. These evaporated solvents are generally non-reactive and play no role in the finished, cured coating. They are most often disposed of after one use, adding a toxic burden to the environment. A great deal of effort has been invested into the development of clean technologies which eliminate the need for non-reactive solvent use in the film coating of materials. As of the 1960's, this push has resulted in a commercially viable film deposition process, based on several photochemical properties of ultraviolet light.

Photopolymerization

Photopolymerization is the chemical mechanism which facilitates the UV curing of surface coatings. Most generally, photopolymerization is the process in which relatively low molecular weight molecules are linked together to form larger chemical structures through the influence of some form of electromagnetic radiation. In most UV curing application the above process involves the presence of a photoinitiator. A photoinitiator absorbs a photon of a specific energy and enters an excited state. Due to its absorption of energy, the photoinitiator molecule forms an "initiator" product which interacts with the material to be coated; linking monomers to form polymers in a chain reaction. Schematically:

Photoinitiator + UV energy = Excited Photoinitiator

Excited Photoinitiator -> Initiator product

Initiator product + monomer = polymer

Additionally, scientists have found that the addition of a "photosensitizer" which adds energy to a photoinitiator when it receives light energy in a more practical bandwidth.

Ultraviolet Radiation Designations

Ultraviolet (UV) is a classification of electromagnetic radiation having a wavelength bandwidth of roughly 200 to 400 nanometers. Ultraviolet radiation comprises approximately 6% of the total sunlight irradiance. This 6% can be further broken down into UV-A and UV-B designations. Ninety percent of the UV spectrum is classified as UV-A and has an energy corresponding to wavelengths between 320 to 400 nm. The remaining 10% is UV-B radiation, occupying the 280 to 320 nm bandwidth.

Reasons for UV Curing

UV curing has a variety of applications. It is used to coat surfaces for a variety of reasons. Surface coating can act a as a barrier to chemical interactions, reduce the porosity of the target material, modify the surface's optical, mechanical , and electrical properties, and act as decoration or print. Coatings engineered to be cured by ultraviolet light come with their own set of benefits. When a coating's photoinitiators are synthesized to absorb specific electromagnetic radiation wavelengths rather than a wide band of heat energy, the curing process becomes much more efficient. This is especially true in a situation where a relatively thin section of material is to be coated on a much thicker substrate. In traditional curing systems where heat is utilized, time is required for the ovens to heat up and produce a uniform energy spectrum. This is not the case with UV curing where the polymerization process initiates instantaneously. Also, when dealing with heated materials, the product will need to be cooled before it can be handled, extending factory "dead" time. In 1977, Parrish made an analysis which reflected positively on the energetic efficiency of UV curing.

Historical Development of UV Curing Technology

The first patent to convert liquid to solid film was granted in the late 1940's. Although the process did work, the effectiveness of the procedure was hindered by the low output lamps used. With the advent of the medium pressure mercury vapor lamp first drew interest from the printing industry who were using the technique to print on wood substrates. Over time research, fuelled by environmental concerns over traditional printing practices, has advanced the sophistication of UV cured print. Today, it is very difficult to determine the difference of print cured by these two processes. Currently, the use of ultraviolet curing has extended out of the printing industry to many fields. Manufacturers of adhesives, coatings for metals, particles boards, fiber optic shielding, footwear, and circuit boards all have embraced this technology.

Equipment Involved

The ultraviolet source used to produce cured products in the above applications generally fall into two categories: Electrode and Electrodeless Lamps. The type of lamp with an electrode present is most often a medium pressure mercury vapor lamp. The lamp can be engineered to many different sizes and configurations to suit various applications, and is generally enclosed in a quartz tube with a diameter of 1 inch or 25 millimeters. The envelope is filled with an inert gas, (usually argon or xenon) and a small amount of mercury. A power supply connected to the lamp produces a voltage difference across the electrodes which produces an arc in the chamber. This arc vaporizes the mercury producing an emission of electromagnetic radiation in the ultraviolet, infrared, and visible spectrum. An electrodeless lamp produces a spectrum with a comparable profile, but the method differs completely. This type of lamp uses microwaves generated by magnetrons which produce a electromagnetic emission, the profile of which can be tweaked by the inclusion of different types of gas in the reaction vessel.

These lamps spectral output can be further altered by the inclusion of metal halides within the lamp's envelope. Tin doping produces a more uniform output in the ultraviolet band. Lamps doped with iron produce a spectrum that is shifted to the 350 to 450 nm range to facilitate the curing of pigmented coatings. Lead doping causes an intensity reinforcement in the 360 to 370 nm range. It should be noted that the addition of the above materials can adversely effect the operating lifetime of lamps due to their tendency to chemically react with electrodes and silica tube walls.

Lamp Maintenance

Ultraviolet radiation producing lamps require a moderate amount of maintenance to insure their effectiveness as a facilitate to the photopolymerization process. Ultraviolet lamps typically lose their effective output of energy over time. This is generally due to degradation of the lamp's quartz envelope (from wear and vitrification of the quartz via interaction with foreign materials), which acts to block radiation in the UV band. Common dirt and dust accumulation can also effect the lamp's output. As a result, cures may become uneven, non-uniform and result in a production of substandard products. Low output lamps will also lead to longer curing times. For these reasons, it is advisable to replace lamps as son as their power output drops below a specified level. Conversely, the replacement of lamps is a costly and time consuming process. In an attempt to overcome these problems, Solar Light Company has developed the PMA2112 High Intensity, UVA Probe. The PMA2112 is a UV-A radiometer sensitive to radiation in the range from 320 to 390 nm with the peak sensitivity around the 365nm mercury emission line. The radiation is captured by a diffuser mounted at the end of 18" "long probe and delivered to the sensor through a quartz light The irradiance (intensity of the UV radiation) is displayed in kW/m2 , W/cm2 or mW/cm2, user selectable. The conversion factor is:

1 W/m2 = 0.1 mW/cm2

High dynamic range of the detector allows measurement of signals as strong as 20W/cm2 and as weak as 0.1mW/cm2. Automatic tracking of the minimum, maximum and average built into the PMA2100 gives the opportunity to monitor the short term fluctuations of the UV source due to changing line voltage, equipment configuration or inherent instability of the UV sources operation.

Making the best use of the UV lamp requires precise knowledge of it's lifetime. It can be determined either by frequent spot-checks of the lamp's output or by setting the *PMA2100* in the automatic recording mode with the interval as long as 1 hour. The memory buffer can store up to 1024 data points, which is an equivalent of 42 days for 24 hour/day

The integral (dose) of the incident radiation can be automatically measured by the *PMA2100*. In order to start integrating the measured signal press the **START/STOP** button. The Integrated dose as well as the integration period will be displayed on the LCD below the main reading. A small running clock icon indicates the active integration. Pressing the **START/STOP** button again stops the integration, however the dose and time is still displayed on the LCD along with a halted clock icon. Pressing the **START/STOP** button again clears the dose integration information and the cycle can be repeated.

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