The CASE for Extreme Intensity in U V Curing

Ultraviolet Light (UV) curing of adhesives, coatings, inks, masks and potting materials has long been established as one of the fastest, most environmentally responsible, and cost effective of production curing methods. Where applicable, many materials (monomer – oligimer mixes) can be completely cured (polymerized) in, quite literally, a split second! Process engineers familiar with UV curing generally understand that consistent, complete curing is dependent upon the UV dosage (more properly called *energy density or radiant flux density*) applied. Many, however, are not as familiar with the impact of UV light <u>intensity</u> (more properly called *effective irradiance*) on cure strength.

Dosage or Intensity?
UV dosage or energy density, normally measured in joules or millijoules, is the product of the UV intensity/irradiance applied and the total time that the UV light is applied. For example, 3 Joules of UV energy can be applied by exposing a monomer to UV irradiance of 300 mW for 10 seconds, or by exposing that monomer to irradiance of 3000 mW (or 3 W) for just 1 second. Which is preferred? UV lamp systems invariably deliver heat in the form of Infrared (IR) energy along with the UV energy. Since substrate materials are often heat-sensitive, many photopolymer chemists and process engineers believe that lower intensity for longer exposure time is the best way to handle heat-sensitive applications. In fact, the opposite is true, when the correct "multicure" approach is employed. But thermal considerations aside, is bond or cure strength equal for both high intensity short cures and low intensity long cures?

The landmark study by Dr. S. Jonsson et al several years back dramatically underscored the fact that very high intensity (but short exposure time) cures were most often far stronger and more completely polymerized than longer, low intensity cures of the same dosage. In a model evaluation system*, he confirmed that increasing intensity 10 to 20 times increased the polymerization rate by almost 50%. The results of his testing implied that "by using high intensity irradiators one can increase the production speed by a factor of 20 and still be able to obtain 25% higher degree of conversion". Dr. Jonsson attributed the majority of demonstrated cure improvement to a phenomenon we now call Dark Cure, which is the cure that continues after the UV light is extinguished. "Especially for the shorter exposure times at higher intensities, it is now obvious that the dark portion of the polymerization is responsible for more than 90% of the total conversion!" Perhaps oversimplifying but for clarity's sake, let's look at an analogy of a straw piercing a potato. If you apply mild pressure or speed on a straw, you may not be able to pierce more than a few millimeters, even if the pressure is sustained for quite a while. But if you apply extreme pressure or speed for just an instant, you might find that the straw has pierced the entire mass of the potato. Extreme intensity penetrates deeply.

Surface Tack and Oxygen Inhibition
Another major benefit of extreme intensity UV application for free radical initiator

*HDDA monomer with 1% Irgacure651 photoinitiator chemistries (the most common) is in mitigating surface cure problems due to oxygen inhibition. In short, in addition to "punch through" deep cure mechanisms, extreme intensity effectively seals the surface instantly, preventing unwanted oxygen diffusion into the film afterwards. The effects of this high intensity mitigation were shown dramatically and documented by Jonsson. When very high intensities were used in a comparative study, initial rates of polymerization in air were the virtual equal of those cured in a Nitrogen purged environment!** This was not the case, of course, with low intensity irradiance.

Temperature Control

Temperature-sensitive substrates and chemistries are common problems in medical device manufacturing, a variety of coating processes, and myriad other applications. The first step in heat control is optimal IR filtering, usually accomplished at the UV cure lamp itself. Dichroic filters & reflectors, and good lamp design go a long way here. But with even the best IR filtration, substantial heat will always accompany extreme UV intensity. Enter "MultiCuring". LESCO has pioneered this novel approach to the thermal rise challenge. Multicuring allows the same accumulated Joule dosage in a slow, low intensity process to be applied in a multi-pass, short time but extreme intensity format. Maximum polymerization, minimum thermal rise. It's discussed in detail in LESCO White Paper No. 107.

Special Applications

More and more, process speeds are on the rise in quest for higher throughputs and lower costs. In disk drives, ink jet cartridge manufacture, PCB lines, and so many other processes, the need for speed seems unquenchable. With extreme intensity UV spot curing, sufficient power can be brought to bear to allow special multi-furcated fiber light delivery of that UV light to multiple, discrete cure sites on a high speed line. The result is sub second cures, benefiting from dark cure strength improvement and polymerization continuation, full temperature control, and all oxygen inhibition issues. Since much of the intensity initially generated at the source is lost to lightguide delivery losses and furcation splits, it is critical that the spot cure unit itself be the highest intensity possible to begin with. In fact, for certain process cures, particularly though involving metallic substrate bonds, adequate bond strength from UV cure is simply not possible without extreme intensity and the dark cure which follows.

Conclusions

Very high intensity UV curing is clearly headed for mainstream as more and more users become familiar with its benefits as compared to low intensity techniques. Although very high intensity UV lamp systems do cost a bit more initially, complete payback within the first year of operation are not unusual. Studies such as those cited support the clear advantage in vastly improved process speed, improved cure strength, and improved thermal control.

**Secrets of the Dark, Dr. S. Jonsson et al