FEATURE

Computer Simulation of 3-D UV Curing of Automotive Clearcoats

By Kevin Joesel

With the recent efforts of several coating manufacturers to develop full-body, dual cure automotive clearcoats, it became clear that the current process development technique would be unacceptable due to the high value of line time for automobile production. To overcome these challenges and minimize the time for process development, a computer simulation of UV curing 3-D objects has been developed and is being used as a practical application at several automotive manufacturing facilities.

UV curing of high-value, 3-D shapes, such as car bodies, presents considerable challenges. Successful UV-curing polymerization processes that consistently yield high-quality film properties require uniform irradiation of the coating. Minimizing shadow areas through the orientation of the part and lamps, and utilizing a source with a stable UV-spectral energy at wavelengths consistent with the coating formulation can accomplish this.

In developing a viable UV-curing process, manufacturing and production requirements must be considered.

- **Productivity**
  Usually given as parts/hour or unit area/hour.
- **Part Shape and Orientation**
  - Is the part conveyed vertically or horizontally?
  - What are the critical surfaces of the part?
  - What is the best orientation of the part and lamps to provide maximum illumination?
  - Can the orientation of the part or lamp be changed during the curing process?
- **UV Process Window**
  - What are the minimum and maximum UV intensity and energy required by the coating to cure?

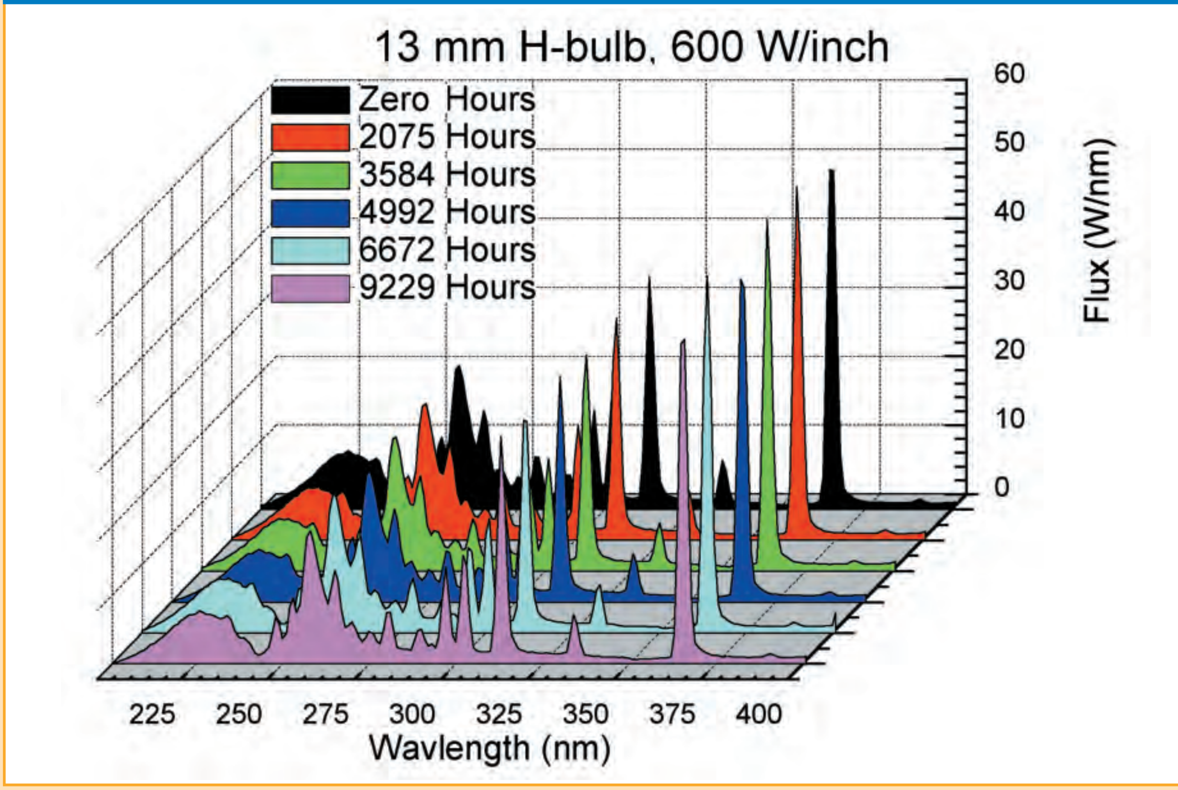
To date, fulfilling all these requirements has typically been accomplished on a "trial-and-error" basis. Lamps are positioned in a specific orientation, radiometric measurements are taken, and the measurements are evaluated against the minimum and maximum UV-energy requirements that define the UV-process window.[1] If they are outside the window, the orientation of the lamps and/or parts are changed and the whole process is repeated until a satisfactory solution is developed.

This process has been acceptable for smaller parts, such as headlamp lenses and reflectors. However, as the size of the parts and the subsequent lamp installations become larger, this iterative process can take many man-hours. It can possibly have a negative impact on productivity, if the finishing process is not available for needed production while taking measurements for process development.

With the recent efforts of several coating manufacturers to develop full-body, dual cure automotive clearcoats, it became clear that the current

FIGURE 1

Energy source used for computer simulation



process development technique, would be unacceptable due to the high value of line time for automobile production. To overcome these challenges and minimize the time for process development, a computer simulation of UV curing 3-D objects has been developed and is available for use.

The objective of the simulation is to develop a process solution that would include the minimum number of lamps needed to cure, the position of each lamp and power level at any time of interest, and the UV energy at each point of interest on the vehicle.

The information needed to obtain this solution requires a UV energy source model, the optical properties of the coating, a digital representation of the vehicle or part, and the physical constraints of the UV-curing area on the finishing line.

Once this information has been provided, the computer does the computations and sifts the information through various algorithms so the model can be run in the most efficient manner.

The computer simulation is time dependent, 3-D curable and multi-variable. The software runs with Windows® NT or 2000. The model is computational intensive requiring a fast computer configured with a Pentium® 4 microprocessor with a minimum of 1GB of memory.

Input Discussion

To obtain a precise and accurate radiant energy source model, one must start with a stable, reproducible UV source. In this case, the source is an electrodeless irradiator with a 13mm H bulb.[2] This is an ideal energy source due to its proven spectral stability over time, under various operating conditions.[3] (See Figure 1).

To develop the radiance model of the UV source, irradiance measurements were taken at various distances and power levels from the source. To test the validity of the model, a comparison was made between the measured irradiance values and irradiance values predicted by the simulation at distance not used to develop the UV source model. The difference was found to be within the error of the measuring equipment.

As mentioned earlier, a digital file of a vehicle is needed. One of the most common is the IGES format and in the subsequent graphics, a Volvo S70 was used.

FEATURE

FIGURE 2

Facets used in a simulation

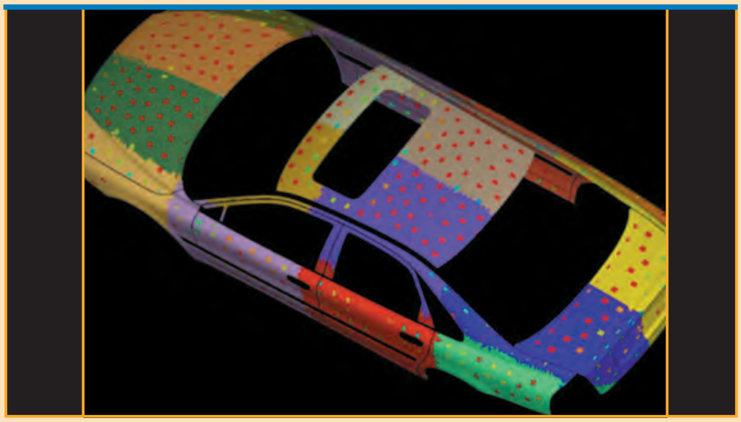
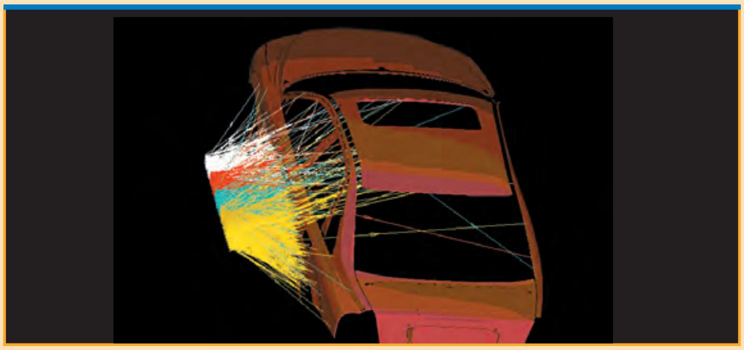


FIGURE 3

Ray tracing of five horizontal 10" irradiators to the IGES model of a vehicle



A CAD representation of the physical dimensions and components of the UV-curing area in the finishing line is required. The software uses this data when analyzing the movements of the lamps to assure that they will not collide or interfere with other components in the area. Other important variables that are needed relating to the finishing line are the line speed, starting position of the UV lamps, and position of the target relative to the UV lamps.

The next critical set of variables needed is the optical properties of the coating. These include the spectral absorption characteristics, refractive index and reflection of UV energy. To provide the most exact result, the properties should be provided for wet and dry films.

Finally, the minimum and maximum UV energy requirements are needed. Specifically, the irradiance (W/cm2) and energy (J/cm2) values of each specific UV band (UVA, UVB, UVC & UVV) are required. In addition to these parameters, it is critical to include the model of instrument used to develop these specifications.

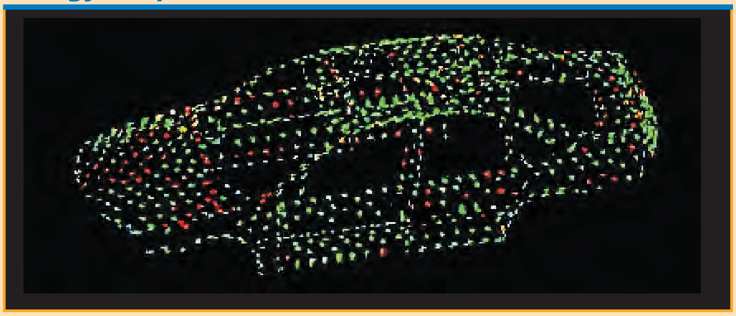
Software

Now that an energy source model, a digital representation of the vehicle and paint line are identified, and the UV-process window of the coating formulation is known—a discussion about the computations that the simulation needs to make can begin.

Each lamp has seven degrees of freedom used in the calculations. The orientation of the lamp in free space (x, y & z) accounts for three degrees of freedom. The solid angle rays of the UV energy, emitting from the aperture of the lamp (α, β & γ), accounts for three more degrees of freedom. The final degree of freedom is the power level of the lamp. Remember, multiple lamps are used. Thus, the simulation

FIGURE 4

Energy map



keeps track and calculates the position of each lamp relative to its origin when developing a solution.

Next, the simulation breaks the vehicle into a large number of facets (up to 3,000.) A facet is a two-dimensional area of known size and location. To manage the output of the simulation, facets of interest can be designated. Figure 2 illustrates the facets used on a vehicle in a simulation.

The UV-energy source model provides the data to trace solid angle rays from the lamp aperture to the target substrate. Figure 3 depicts the ray tracing of five horizontal 10" irradiators to the IGES model of a vehicle. Basically, the software computes the energy at a particular facet by summing all of the rays that strike it from all of the lamps.

Another algorithm compares each facet's irradiance values at each point in time and the final integrated energy values with the process parameters that were entered. When all of the irradiance values at each facet and at each point in time, are within the maximum and minimum UV-energy values, the simulation is complete. If any of the values on any facet are not within the process window, then a proprietary algorithm attempts to predict the lamp and object parameters that need to be changed to yield a result within the process window.

Figure 4 depicts the energy map at an intermediate point in the execution of the software. The facets that are within the energy process window are shown in green, facets above the maximum energy level are red, and facets below the minimum energy levels are shown in blue.

This depiction shows high-energy areas primarily on the hood and low energy near the bottom edges of the body. When a final solution is reached, all the facets should be green.

Conclusion

The development of this software supports the rapid development of UV-curing processes for automotive coatings. Specifically, the optimal number of lamps should be known early in the process design phase. The amount of labor and line time used for UV-process development will be significantly reduced and ultimately eliminated. In addition, the impact of changes in process conditions, parts or the finishing line at existing installations can be easily evaluated.

Acknowledgments

The author wishes to acknowledge the assistance of Jeff Okamitsu, vice president of research and development, Fusion UV Systems.

The author also wishes to acknowledge Volvo AG for their support and permission to use the IGES model of the S70 body.

References

1. Stowe, R.W.; "Practical Relationships Between UV Lamps and the UV Curing Process Window," Proceedings, RadTech North America 1994.
2. Fusion UV System electrodeless I600 irradiator with a 13mm H bulb.
3. Okamitsu, J. & Joesel, K.; "Emission Stability of a Microwave Powered Lamp System" Proceedings, RadTech Automotive Focus Group 2002.

—Kevin Joesel is director of automotive markets, Fusion UV Systems, Inc., Gaithersburg, Md.