Dow Corning Demonstrates Ability to Accurately Simulate Forward Roll Coating Process

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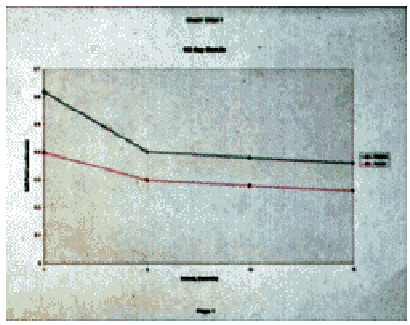
As a major supplier of silicone release coatings, Dow Corning frequently needs to validate the performance of its materials on a new application. Currently, this is an expensive and time-consuming process that often requires testing as many as ten different materials on a pilot coater. For this reason, Dow Corning recently attempted to validate the simulation of the forward roll coating process using NEKTON fluid flow modeling software from Fluent Inc., Lebanon, New Hampshire. The results from the model for the film split side as well as the combined inlet-outlet system produced by Dow Corning engineers correlated closely with experimental measurements on a lab coater. As a result, Dow Corning is moving ahead to implement new simulation-based techniques for validating coating applications and expects to achieve substantial gains in development cost and time and coating performance.

Silicone release coatings are applied on a super calendered paper or a plastic film where many sticky organic pressure-sensitive adhesive labels are laminated together. The release liner is removed as the label is applied on a substrate. These coatings are typically applied using the forward roll coating process. The demand for new formulations is increasing as label manufacturers continually increase the line speed at which coatings are applied and reduce coating thickness to lower their manufacturing costs. At the same time, new applications for release coatings are regularly being developed. To keep pace with these changes, Dow Corning is intensifying their effort to develop new and better coating materials.

At the present time, a lengthy trial and error process is required to validate the performance of the company's materials on each new application. Since the new application usually includes new base coating fluids and formulations, the rheological property of the new coating must be different from that of the existing ones. To obtain the optimum coating conditions for the new coating, a series of tests need to be performed: adjusting nip pressure, speed ratios between rollers, oven temperature, line speed, and so on. Evaluating each formulation requires a considerable amount of expense including renting time on a pilot coater, running experiments and, in the case of new formulations, developing and producing the material itself. Fluid flow simulation has the potential to eliminate some of this cost. Simulation would also allow many more materials to be evaluated for a particular application, thus making it possible to significantly improve coating performance. The major obstacle in simulation is the complexity of the forward roll coating process. This process uses a narrow deformable gap and rollers moving at very high speeds. Until recently, there was no commercially available software capable of simulating this process.

The introduction of NEKTON, a fluid flow analysis software package specifically designed to meet the needs of materials processing and optimization, altered the situation. NEKTON is based on the spectral element method which is a high-order, weighted-residual finite element technique. The spectral element method combines the common features and competitive advantages of low-order finite element methods with the accuracy and rapid convergence of higher order techniques. The software also allows for rapid mesh generation by building unstructured grids using a few large elements that are sufficient to capture the flow physics involved in the problem.

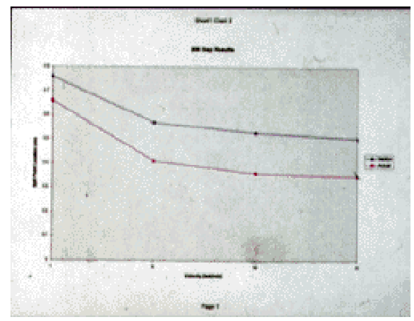
We decided to evaluate this software and began by building a lab coater that we used to correlate the predictions of the simulation software. The coater was designed and built with the assistance of the Center of Interfacial Engineering Coating Fundamentals Program - headed by Professor Scriven - at the University of Minnesota. It is about 3 feet long, 1 foot wide and 2 feet tall. This coater has two counter-rotating rollers. The bottom of the lower roller sits in a tub of material that adheres to the roller as it turns. The rollers are about 6 inches long and 5 cm in diameter. The gap between the rollers can vary in width. In these experiments, gaps of 100 and 200 microns were used. Roller speed was varied between 0.5, 1, 5, 15 and 30 feet per minute.



The lab coater was designed for full visualization. High speed video was used to produce a VHS tape of the lab coater. Using the tape footage, split point location was measured to validate the simulation. The split points were selected because they could be easily measured on the high speed video footage. The three points, marked with X on the accompanying illustrations, include the split point at which the coating material separates between the upper and lower rollers and two more points that are used to calculate the film thickness of the coating. The film thickness measurement was not included because at the low speeds the measurement could not be trusted due to settling of the liquid.

Two different types of models were created with the NEKTON software. First, the film split side of the forward roll coater was modeled at identical conditions to the lab coater for correlation purposes. The film split side model includes only the outlet portion of the fluid flow from the place where the gap between the two rollers is at its smallest. This type of model was used because it has fewer elements and thus takes less time to set up and converge. We also produced a combined inlet-outlet model (which represents the full system, both upstream from the nip point [smallest gaps] as well as the downstream side) in order to validate the inlet velocity conditions that were used as boundary conditions in the split side model.

For the film split model, a parabolic velocity distribution was selected as the inlet boundary condition at the nip boundary. This velocity profile was selected based on an examination of current literature. It was later correlated with the combined inlet-outlet model and found to be accurate. The surface of the material beyond the split point is represented as a free surface which can move and change in thickness. A truncate power law viscosity function was used as the rheological model to represent SYL-OFF 7676 silicone fluid used on the lab coater. This material has Newtonian properties until a 4111 reciprocal-second shear rate is reached, at which point shear thinning takes place. These properties were based on physical testing of 200 grade silicone fluid.



The split side model correlated closely with the physical measurements. The simulation predicted a split point location of about 25 percent larger than measured. But the trend line of the simulation matched the measurements almost exactly. The most likely causes of the offset are, in my opinion, measurement error and ribbing. Measurement error is probable because the high speed video equipment that we used was only available for a very short period of time. There wasn't time to generate paper plots so measurements had to be made directly from the video. Also, there was some doubt as to the precise amount of magnification of the camera.

Ribbing was another possible factor in the offset. Ribbing consists of small raised sections in the coating material across the width of the rollers in the gap area. Since the models that we created were all two dimensional, ribbing was not taken into account. Ribbing will cause the measured location of the split point to be less than the calculated valve, because some material is taken up in these small raised sections. The computer simulation will predict the average of this 3D geometry. This is consistent with our experiments where the simulation overpredicted the location of the split point.

The combined model was created primarily for the purpose of evaluating the validity of the velocity profile used in the split side model. Another reason was to gain experience for future use in simulating a deformable top roller. Deformable top rollers made of rubber or similar materials are commonly used in the industry to avoid damage that can occur if two steel rollers touch each other. This makes it possible to use smaller gaps; use less material and cut down on ribbing. Fluent is currently working on adding a deformable boundary condition that will make it possible to simulate a deformable roller and this will greatly increase the value of the analysis.

About 80 spectral elements were used in the combined inlet-outlet model. This was not enough to completely refine the model, which would have required about 150 elements in total. The combined model required much more time to set up and run. 100 iterations takes several hours on an IBM R/S 6000 Model 370. The combined model used a uniform velocity inlet boundary condition that is based on the fact that the roller is moving at a constant speed. The power law viscosity function is the same used in the split side model. The rolling bank on the inlet side showed two recirculating areas in the simulation. Fluent also provided us with several subroutines that we used to plot out shear rates and viscosity of the coating material. This provided us with information for selecting equipment that we now use to measure material properties of our fluids.

Overall, the project was a success and we felt that the correlation was very good considering the circumstances. What was most important was that the trend line of the simulation precisely matched the physical measurements. As a result, we now know that we can trust simulation for use in validating release coating materials. Our intent is to further refine our methods and make fluid flow modeling a tool for evaluating new release coatings. We expect cost savings because we can evaluate the performance of many materials on the computer, and select certain ones for further testing.