Roll-to-roll coating of flexible materials: Focus on scale-up

By Charles A. Bishop, Ph.D., principal, CABConsulting, Ltd.

Editor's Note: *This report covers what the author believes highlights the two days of presentations at the recent ProFlex 2017 technical conference in Dresden, Germany. To see the full list of papers or to purchase access to the presentations, go to* https://www.fep.fraunhofer.de/en/events/pro-flex-2017.html *or email* events@fep.fraunhofer.de.

ProFlex 2017 was aimed not just at vacuum roll-to-roll (R2R) processing but was open to any R2R technology and from a variety of different points in the research, development and manufacturing of products.

This was highlighted in the first two papers, the first of which was presented by Prof. Dr. Jan Cremers, dean of the Dept. of Architecture and Design at HFT Stuttgart, which showed how woven fabric can be used in structures. What they refer to as fabric is a woven-fiber-reinforced sheet that has a polymer coating of materials, such as ETFE, PVC or PTFE. The materials are stable to sunlight and weather and so is the material of choice for lightweight complex curved surfaces. Modern architecture makes use of the material's light weight, including the lightweight supporting structure to make very large roofs or walls that have controlled light transparency. Many examples of different constructions were shown demonstrating the use of single-skin and multiple layers. The double-layer systems can be inflated to control the curvature and insulation. The bubbles of material can be large, such as 6.5 x 14 meters, and are strong enough to be walked over. These bubbles are not leak-tight, so the design has to include a continuous feed of gas that has to be dry to prevent problems of condensation within the bubbles.

Minimizing flexible-glass breakage

By contrast, the second paper was from Corning detailing the advantages and disadvantages of using thin, flexible rolls of glass. This included highlighting specific users of the firm's glass in the development of high-end electronic applications, such as flexible displays. While everyone is happy with the attributes of the glass, such as the hardness, high-temperature processing capacity, intrinsic barrier, smoothness and high transparency, the big concern still is the sensitivity of the glass to defects that can result in breaking the glass. Sue Lewis, the presenter, stated that Corning offers training and advice to users and system manufacturers to help them avoid situations where glass breaking is likely.

While the first two papers were at opposite ends of the manufacturing spectrum, they both described using material attributes to the full, and the paper that followed from DuPont Teijin Films continued the theme. The major part of this paper described how the polyester film has been developed specifically to meet the needs of the electronics industry. This is accomplished initially by managing the water and oligomer content and heat-stabilizing the film to minimize shrinkage, and then by the coextrusion of a peelable layer that can be removed immediately prior to deposition to give a peelable clean surface (PCS) to minimize any possible particulate contamination.

ALD barriers for electronics films

Key to a number of the advanced electronic flexible-film applications is the need for barrier to water vapor or oxygen or both. The glass substrate has intrinsic barrier properties, whereas the PET PCS enables coatings to be deposited onto a clean surface to give the best possible opportunity to deposit a dense, defect-free layer and so produce a high-quality barrier coating. This linked well to other papers that described the advantages of using spatial atomic layer deposition (ALD) systems to produce thin, high-barrier coatings.

The first of these papers from Fraunhofer IVV described its development coater, which uses a fixed spacer to define the drum-to-substrate gap to enable greater flexibility in gas flows to the process than using the gas-bearing approach. This gas-bearing approach was described in the second paper from Meyer Burger that is scaling-up the process and selling systems. They described the modeling work they have done to better understand the variables of the process and so enable successful scaling to wider web widths than the 600 mm currently used to produce high-barrier films. All of this work on ALD is specifically directed at the production of aluminum-oxide (AlOx) transparent barrier coatings. Although it is possible to deposit other coatings, it was pointed out that most other materials are much more expensive as the precursor materials themselves are more expensive. This is either because the manufacturing process is more expensive or the volumes are small, so they do not have economies of scale.

Advances in PECVD

The presentation from Fujifilm on plasma-enhanced, chemical-vapor deposition (PECVD) provided a good contrast to the ALD barrier films. PECVD has been available for many years but has always struggled for sufficient deposition rate. In this evolution

> "Legislation is already on its way within India to ban all multi-material laminate packaging next year."

of the process, a dielectric barrier-discharge system has been designed with a suitable power supply that has sufficient reactive control such that the plasma does not produce any filamentary arcs, and so does not require the use of helium to help stabilize the plasma. Coupled with using the process at atmospheric pressure, this helps reduce the cost of the coatings to make it competitive with alternative processes.

I found this work interesting as it referred to work done by Yasuda defining the "power parameter" more than 30 years ago as still being valid for the new process. Basically, the more power per unit atom is applied, the denser the final coating, albeit at a slower deposition rate. This can be addressed by using a graded coating through the thickness such that the initial layers are less dense but deposited quickly, while the final coating is deposited at a lower rate but is denser.

Surface treatment lends added value

Surface treatment in all forms is a necessary part of being able to produce value-added flexible products, and a group of papers addressed this. Taking the basic process, as used in holography, of making a customized, patterned, three-dimensional surface in a hard material and then pressing it into a softer surface and so replicating the mirror image of the surface – enables a whole variety of different surface attributes.

As the surface shapes and dimensions get more complex, it is easier if a polymer shim is used rather than a hard chromium shim. This also is more environmentally beneficial as all of the the nasty chemicals can be avoided, too. In addition, the polymer can be customized to be hydrophobic to aid release for the complex shapes. Effects that can be produced include shark skin, moth-eye, insect/moth color-shifting surfaces, gecko adhesion, the hydrophobic effect as in lotus leaves and, the opposite to this, the enhanced wicking effect. The shark-skin surface can reduce the drag on wind-turbine blades or airplane wings. The moth-eye is a way of modifying the surface to have an anti-reflecting improvement. Dr. Barbara Stadlober of the Joanneum Research Graz gave insight into how these biomimetic structures are now being produced R2R.

In many respects, an overlapping technology was the topic described in the paper that followed from the Leibniz-Institute about the production of filled, polymeric gravure cylinders. In this case, a polymer gravure roll was laser-patterned, with finer patterns being cut using UV lasers and the coarser ones by the longer wavelength IR lasers. As it is expected that chromium plating will become increasingly regulated or even banned, this would provide an easier, alternative route. Instead of having to send gravure cylinders away for processing, they could be processed in-house, saving time and money. The lifetime of these shims has been evaluated in the laboratory as equivalent to original chromium shims.

Lasers, layering for flexible electronics

The use of lasers in thin-film flexible electronics is increasing, from ablation of coatings to produce fine tracks to scribing of glass or coatings to the curing or sintering of printed metal pastes. The additive aspect of using lasers for sinter-printed metal inks for circuit tracks was explained by Dr. Marco Fritsch from Fraunhofer IKTS. Chris Reidel from 3D Micromag AG, a system manufacturer, also referred to that firm's ability to laser-weld, drill and engrave, as well as the sintering of printed inks with the metal inks being deposited by industrial inkjet printing. These industrial inkjet printheads are coarser than those used in research, but they do allow the ink to be recirculated such that the metal does not settle out, leading to print failures. The benefit of using lasers to sinter the inks is that the intensity and residence time can be controlled; short duration heating can sinter the metal and drive off any surfactants but does not have enough energy to overheat polymer substrates.

Conducting layers are critical to many flexible-electronics applications, so there is always great interest in these papers. The first presentation, from Dr. Henrick Hemmen of Condalign AS, described the use of dielectrophoresis of conducting particles in the polymer substrate to make the film conductive through the thickness of the film. Dielectrophoresis is when an electric field is applied across a film; then, the conducting filler particles attract in one direction and repel in other directions. If done when the polymer is still liquid, the particles move and align as conducting tracks through the polymer thickness. The polymer then can be cured, and this anisotropic conduction becomes fixed. The amount of filler needed to achieve this is well below the amount normally needed to achieve the percolation threshold. This process has been demonstrated as in R2R process. This same process also is being evaluated as a way of organizing a dispersion of an immiscible liquid in a polymer film, so when the columns of droplets are formed and the polymer cured, the columns can be dried so they form fine holes, and the film becomes porous. This could be a method of making controlled porosity membranes.

Filling in the cracks

Another paper showing a different way of producing conducting layers was presented by Alexey Dolbunov of FunNano USA. He described depositing an organic coating that is dried so it forms a "mud-crack" pattern as the coating dries and shrinks. This surface then is vacuum-coated with the desired metal. Next, the surface is washed so the organic layer is removed along with the metal

continued on page 28 ▶

VACUUM COATING ProFlex 2017

◀ continued from page 27

deposited on the organic layer. This leaves behind a network of conducting metal. This is not dissimilar to the random nature of silver nanowires forming a network of conducting material. The advantage being that where the nanowires cross the thickness is doubled, but with the in-filled cracks, the track height is uniform across the surface. This transparency is dependent on the track width and the density of the network, and this depends on the organic material and how it shrinks and cracks.

This has the potential to be a low-cost, transparent, conducting material, although it still requires vacuum deposition and most of the coated material is washed away. Consequently, it would be interesting to see detailed costing of the process. There also was the suggestion that the conductivity could be increased if, after the network is produced, the surface has carbon nanotubes applied. This too would add cost but could improve making contacts to the network. Against this approach is that the transparency would be reduced further. This technology is being included in a new product due to be launched this year in the US that is aimed at low-cost electrochromic strips that can be added to existing windows.

Cascade slot-die for uniform, multilayer coating

Moritz Graf zu Eulenburg from InovisCoat GmbH presented an interesting paper that described a process first developed in the photographic industry where a high number of layers needed to be deposited quickly – and in the dark. The process described was for a nine-layer cascade coater where the coating slots are all in a single sloping block so each layer is introduced over the previous layer as the liquid travels down the slope. At the end of the slope, all nine layers then are brought into contact with the substrate. All of the liquids are designed to be water-based, and adjacent layers must not interact to retain the lamella structure to the coating. Coatings can be in the range 0.30- to 20-gsm dry weight, which corresponds to 300-nm to 15-microns dry thickness and at speeds of 20 to 120 mpm. A video was shown of the process starting with the different layers being added sequentially and then the final product showing how uniform the coating can be applied. One issue mentioned: The oven used to dry the aqueous coatings was 240 meters long. The multilayer liquid needs to be dried carefully to prevent gas flows affecting the coating quality.

Klaus Crone of Coatema Coating Machinery GmbH described the firm's slot-die coating process to deliver intermittent coatings. There is difficulty in applying and stopping coating quickly and evenly as the leading and lagging edges show a considerable

> "This technology is…aimed at low-cost electrochromic strips that can be added to existing windows."

variation in thickness that needs to be managed. There are different ways of accomplishing this: 1) Sucking the ink back, 2) diverting the ink elsewhere or 3) inserting a diverter plate to coat onto instead of the original substrate. Diverting the ink path and pulling back the slot-die coating head at the same time were demonstrated via a video. A second method used a flexible, slot-lip that is piezo-controlled to change the slot-die volume as an alternative to sucking back the ink. This shows promise, but there is obviously still work to be done to improve the sharpness and coating-thickness uniformity.

Enlightening new OLED barriers

The final group of papers focused on OLEDs with one concentrating on the barrier needs of OLEDs, and a second on intermittent printing as a way to eliminate cutting R2R OLEDs down to size. The final two papers not only talked about OLEDs currently available but went on to highlight limitations of current offerings – i.e., manufacturing costs are too high. Moving to R2R is expected to deliver benefits in productivity and cost but not without difficulties. The complexity of the process, capital cost of the system and the ability to run the process with sufficiently high production efficiency are all hurdles yet to be addressed. The conclusion: "Hockey-stick" growth is expected but not this year.

Other papers dealt with the choice of power supply for magnetron sputtering; the use of a protected silver mirror for use in a solar-thermal conversion tube; the production of highly dense, AlOx-barrier films using plasma-enhanced, aluminum-evaporation R2R metallizers; and other value-added products from metallizers.

One final paper on flexible packaging by Prof. Dr. Achim Grefenstein of Constantia Flexibles Germany GmbH deserves mention. It highlighted the waste of food because of either insufficient packaging or poor choice of packaging and the need for improved use of resources and recycling. Included in his presentation was the need to move away from mixed-polymer types when making multilayer packaging and to instead use monopolymer types, thus easing recycling. This includes downgauging, as well as aiming to eliminate all volatiles in packaging while maintaining package performance. The talk included the observation that legislation is already on its way within India to ban all multi-material laminate packaging this year and the EU to ban or limit polymer packaging that can go to landfill. This could have a major impact on the use of many existing packaging structures.

ProFlex 2017 conference was one of the best I have attended with a broad mix of interesting papers. Dr. Nicolas Schiller and his team at Fraunhofer FEP are to be congratulated on putting together an excellent program that was well received by the 100-plus participants. ■

Dr. Charles A. Bishop holds a Bachelor's degree in Materials Engineering with a Diploma in Industrial Studies. His research led to developing a process for manufacturing titanium-based

> "[The ALD] development coater... uses a fixed spacer to define the drum-to-substrate gap to enable greater flexibility in gas flows to the process."

bone implants for tendon location. He went on to obtain a Master's degree and Ph.D. following further research into vacuum-deposition processes. Bishop has more than 35 years of experience in vacuum deposition, mainly onto flexible webs. He has published two books, writes the "Vacuum Verbiage" Q&A technical column for this publication and moderates the online "Vacuum Web Coating" Technical Channel. Bishop can be reached at +44-1509-502076, email: cabuk8@btinternet.com.