Effect of Humidity on the Surface Deformation

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1. Introduction

For optical films, the goal is to produce uniform and thin films at fast speeds. However, reaching this goal is challenging due to process limitations and defects. In this research, we focus on "blushing." Blushing, shown in **Figure 1,** occurs when moisture in the air near the coating surface diffuses into the coating to induce phase separation or condenses as dewdrops on the coating surface due to the evaporative cooling. In either case, the final coating microstructure is marked by surface distortion or deformation that scatters light and degrades coating performance. In this research, experimental drying and visualization studies on model polymer / solvent systems are combined with theoretical predictions in order to better understand the effect of relative humidity on blushing.

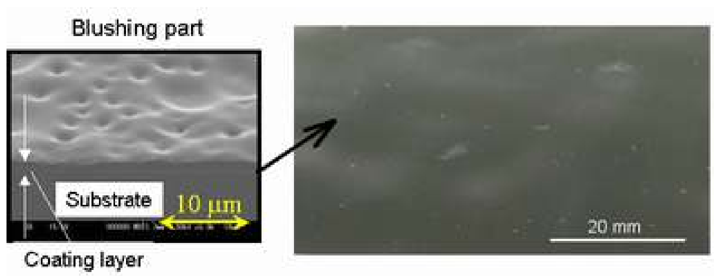

Figure 1 Coated film with blushing defect

2. Observation Experiment

2.1 Coating conditions

[1] Unpublished. ISCST shall not be responsible for statements or opinions contained in papers or printed in its publications.

Three coating solutions were used: polystyrene (PS)/ toluene (TOL), PS/ methyl ethyl ketone (MEK) and polymethylmethacrylate (PMMA) / MEK. **Table 1** shows the physical properties of solvents and molecular weights of the polymers. TOL is a hydrophobic solvent and MEK is a hydrophilic solvent. Coating solution (5 wt%) is applied on PET film substrate to make a coating, which has a wet thickness about 20 μm (dry thickness 1 μm).

Table 1 Physical properties of polymers and solvents

Polymer	Molecular weight
PS	5000 g/mol
PMMA	25000 g/mol

Solvent	Vapor Pressure	Solubility of Water
MEK	75.6 mmHg	12 % W/W
TOL	23.2 mmHg	0.303 % W/W

2.2 Wind tunnel apparatus

Figure 2 shows wind tunnel apparatus. Air with controlled temperature and humidity is generated with the air blower (Apiste: PAU-300S) and the airflow rate is controlled by adjusting the power of two fans. The coated sample is set in the observation section and its surface is observed by high-speed camera during drying.

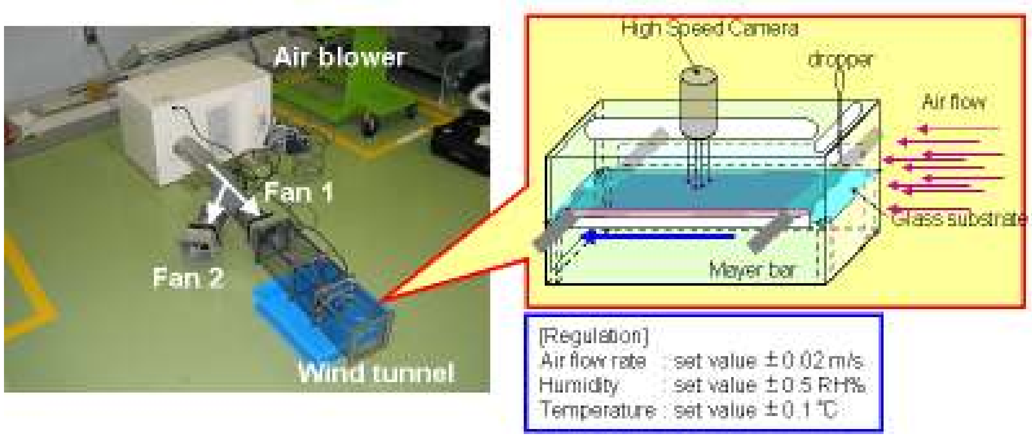

Figure 2 Wind tunnel apparatus

2.3 Visualization of film surface change during drying

Figure 3 shows the film surface change during drying in each system. In case of toluene solutions, blushing occurred due to water condensation. In contrast, blushing formed due to water dissolution into the coating and phase separation in case of MEK solutions. In addition, we found that the surface deformations were different between PS/MEK and PMMA/MEK systems even though the solvent was same.

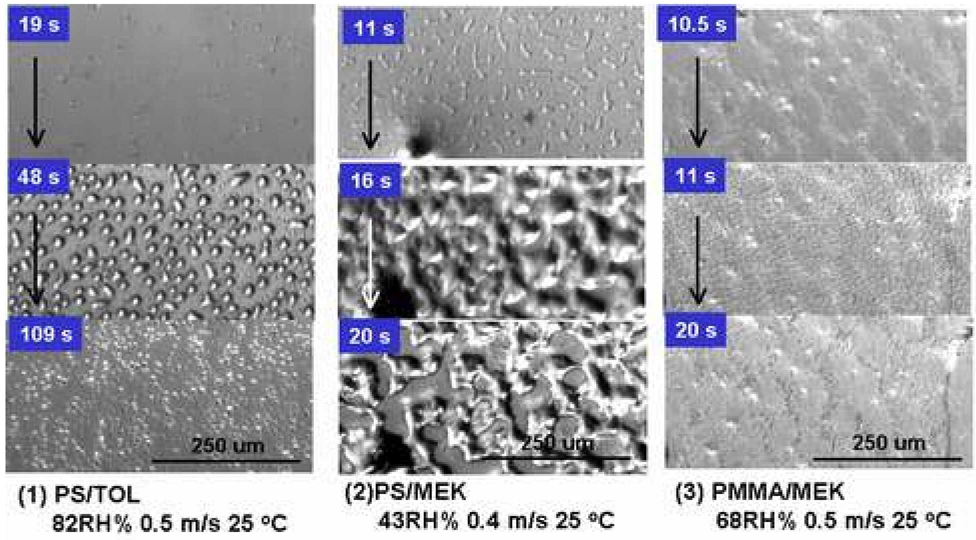

Figure 3 Surface deformations in each system

2.4 Dissolution behavior of water droplet

In order to better understand the coated surface deformation, a larger droplet (1 mm) of the coating solutions was observed. **Figure 4** shows the results. For PS/MEK system (left), the droplet was surrounded by a cloud right after dropping and they spread and coalesced with each other. We believe the cloud is fine water (or water rich phase) droplets. On the other hand, for PMMA/MEK system (right), the droplet dissolved in the solution slowly and the cloud did not appear.

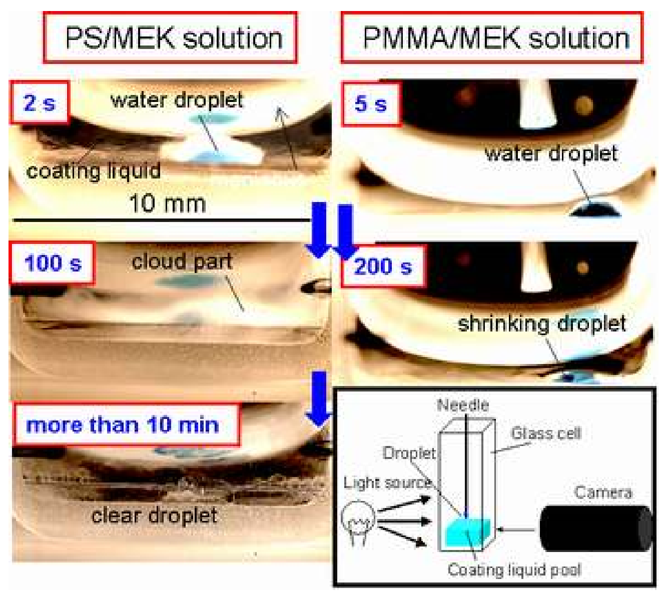

Figure 4 Water dissolution behaviors in each solution (left: PS/MEK, right: PMMA/MEK)

2.5 The phase diagrams of the ternary system (polymer-MEK-H_2O)

The phase diagrams for the ternary system (polymer-MEK-H_2O) shown in **figure 5** were constructed and we compared each diagram. According to this comparison, the clear region (one phase region) of

PS/MEK system is smaller than that of PMMA/MEK system, which means that dissolved water changes in fine droplets of water in PS/MEK system easer.

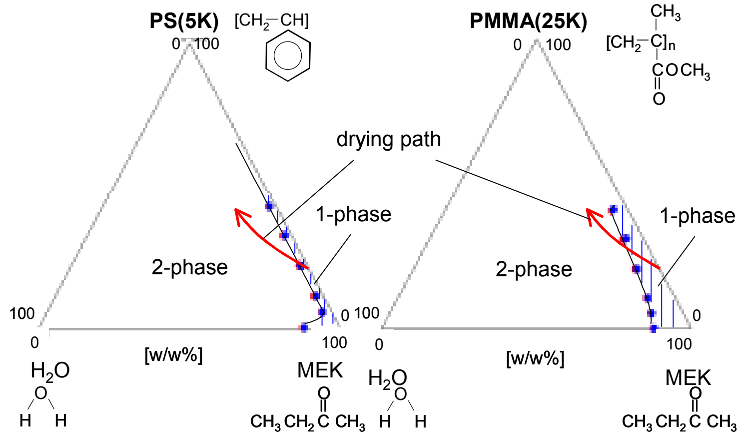

Figure 5 Phase diagrams of ternary systems (Polymer-H_2O-MEK)

3. Prediction for Blushing Occurrence

For theoretical predictions of blushing occurrence, the ternary polymer/H_2O/MEK diagrams were constructed and a drying model was developed to predict solvent composition and temperature as a function of time. Blushing is assumed to occur when the drying path enters the two-phase region. Water absorption rate into coating film was estimated experimentally. By comparing the theoretical prediction and the experimental result in PMMA/MEK system shown in **figure 6**, we can approximately predict blushing occurrence.

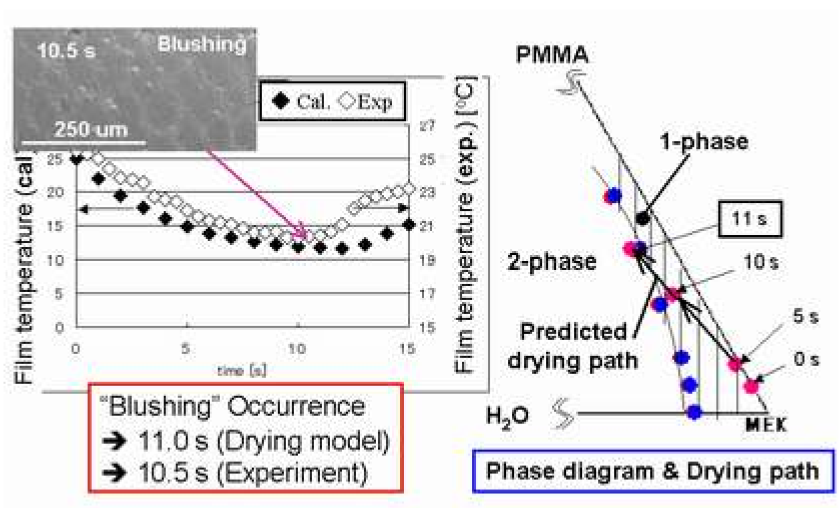

Figure 6 Comparison between the calculation and the experiment result (PMMA/MEK system; 68RH%, 0.5 m/s, 25 °C)

4. Conclusion

In order to investigate the coating deformation under the humidity air, the surface was observed in-situ and we found that the key issues of blushing were solubility of water in solvent and the type of polymer. In addition, it was possible to approximately predict blushing using a drying model.