코팅의 건조 공정 중 공기의 유량이 코팅 층의 스트레스 발달에 미치는 영향

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Effect of gas flow on the stress development in the coating process

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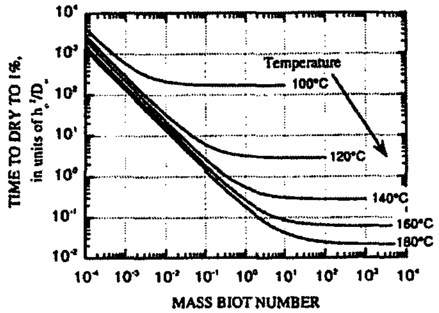
Introduction

Liquid coating is necessarily followed by solidification through the drying process. Drying process is the longest part in the coating process and dominates equipment space and coating productivity. Raising temperature and airflow enhances drying rate and can make higher process speed possible (Fig.1) [1]. However, product quality may be degraded by defects that are usually accompanied due to severe drying condition. One of the main reasons that cause defects such as peeling, cracking, curling and stretched pattern is stress in the coating layer. During and after solidification, coating layer shrinks due to solvent evaporation. Constrained shrinkage due to adhesion to a rigid substrate results in stress development [2]. In order to accomplish defect-free coating with fast drying, an important goal is to understand airflow effects on the coating stress. This study concentrates on the airflow rate and ignores air temperature effects assuming constant air temperature, room temperature. Stress is measured with in-situ cantilever deflection measurement technique [3].



$$Bi_m = \frac{\text{external mass transfer}}{\text{internal mass transfer}} = \frac{k_g h_0 \rho_{g0}}{D_0 \rho_0}$$

k_g:mass transfer coefficient
h_0:Initial thickness
ρ_{g0}:Conc. Of pure solvent vapor
D_0:Ref.diffusion coefficient
ρ_0:Ref. conc. Assume constant

Fig.1. Effect of airflow and temperature on the drying of PS/toluene coating [1].

Experimental

Coating material used in this study is 15% Polystyrene (Mw 280,000, Aldrich co.) toluene solution and 15% Polystyrene / MEK solution. These solutions were stirred for more than 24hours in order to make sure that they are completely dissolved.

Coating stress is measured by stress measurement apparatus in Francis group that measures deflection of cantilever substrate. Once coated by blade coating of draw down method on the Silicon substrate, coating is moved into the drying chamber with controlled environment such as relative humidity, airflow and temperature. Stress is measured by detecting deflection of cantilever induced by in-plane internal stress built up in the coating as it dries [3]. Images of the dried coating surfaces were taken with an optical microscope.

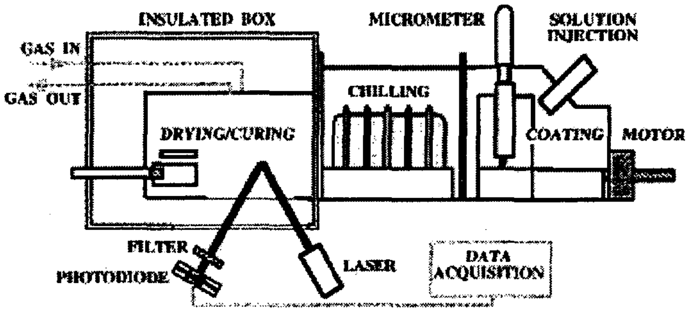


Figure 2. Coating stress measurement apparatus [3]

Results and discussion

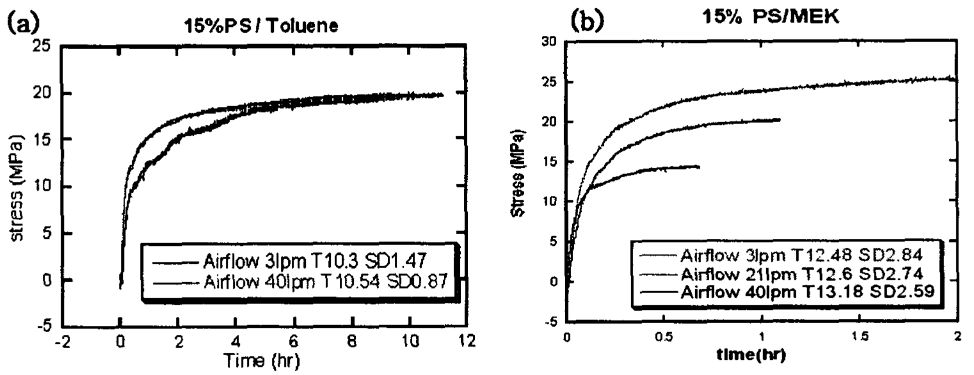


Figure 3. Stress build up of same thickness film during drying with diverse airflow rate of (a) PS/toluene coating and (b) PS/MEK coating.

Figure 3. is the result of in-situ stress development of PS coating during drying. Figure 3(a) proves that stress is independent of the coating thickness when using toluene as a solvent. Drying time of thin coating is shorter than thick coating and its stress develops earlier than thick one. But final stress value comes to same as stress reaches steady state. On the other hand, PS / MEK coating stress decreases with increasing airflow according to Figure 3(b). Possible reason that stress decrease with increasing airflow rate can be explained by residual solvent in the coating layer trapped by skinning in the coating surface.

Coating surface changes with changing airflow rate is also fascinating phenomena even if the mechanism is not well understood. According to Figure 4, coating surface for both two coatings gets rough in the same coating thickness as airflow increases and coating surface gets rough in the same airflow as dry film gets thick. One of possible mechanisms of rough surface is spatial modulus gradient caused by spatial solvent concentration gradient due to severe drying condition. When the topside of coating layer shrinks to stress free state as solvent evaporates, each space of the surface has different solvent concentration due to fast drying hence higher solvent concentration place in the surface doesn't shrink by tensile stress originated from the frustrated shrinkage on the bottom side during drying [4]. The other possible cause is solvent swelling due to the skinning, premature solidifying surface owing to fast dry [5].

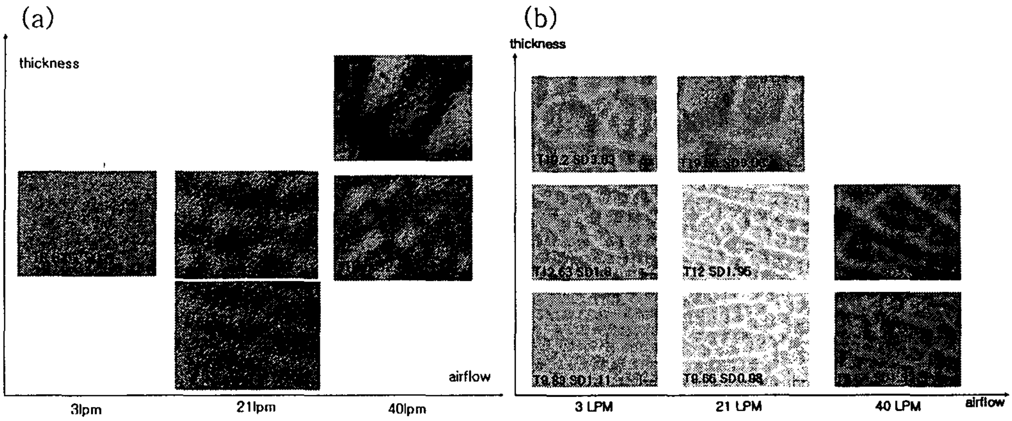


Figure 4. Surface image of (a) PS/Toluene film and (b) PS/MEK film taken by microscope

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