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Stress Development in Nano-composite Silica Coating

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Particulate ceramic coatings are used in variety of applications [1-3] such as paints, ink-jet print media, abrasion resistant coatings and optical coatings. Particulate coatings are prepared by casting dispersions of ceramic particles in a liquid media onto a substrate and drying. However, cracking from drying induced stresses is frequently a problem [4]. Organic binders are added to prevent cracking. The binder provides strength to the particulate coating, but also changes the microstructure by filling in pore space. The binder also affects the stress that develops. For porous coatings in particular, understanding the effect of binder content on stress development, microstructure and mechanical properties is necessary to create crack free coatings.

The most common method to determine coating stress is to measure the curvature or deflection of a coated elastic substrate[5]. The stress in a coating deforms the underlying substrate, resulting in a curvature or deflection. Provided that conditions are chosen appropriately and the stress is uniform, the coating stress can be determined from the cantilever deflection (d), length of cantilever (L), the coating thickness (t_c), the substrate thickness (t_s), the substrate elastic modulus (E_s), and the substrate Poisson's ratio (ν_S)[6]:

$$\sigma = \frac{E_s t_s^3 d}{3 t_c L^2 (t_s + t_c)(1 - \nu_s)} \qquad (1)$$

In this research, the effect of binder on the mechanical properties, microstructure and stress of silica nanoparticle coatings is explored. The complete studies will be published elsewhere[7].

Nanocomposite coatings were fabricated from suspensions of polyvinyl alcohol (PVA) and nanosized silicon oxide particles (20 nm primary particle diameters within branched aggregates of 150 nm diameter). The suspensions were deposited as coatings onto silicon substrates and dried at room temperature. Direct visualization of these coatings revealed that a lateral drying front is present at low binder level (Figure 1), but this front is not present at high binder concentration (>75 wt %). In the derivation of Eq 1, pure bending of the cantilever beam is assumed and therefore the stress must be uniform. Therefore, only the final stresses after the drying can be found for coatings that have a lateral drying front. High PVA content coatings (PVA> 72 wt%) do not show the presence of lateral drying fronts. These coatings dry uniformly and the stress plot can be calculated from the deflection measurements taken during drying. Fig 2 shows the stress evolution curve for such coatings.

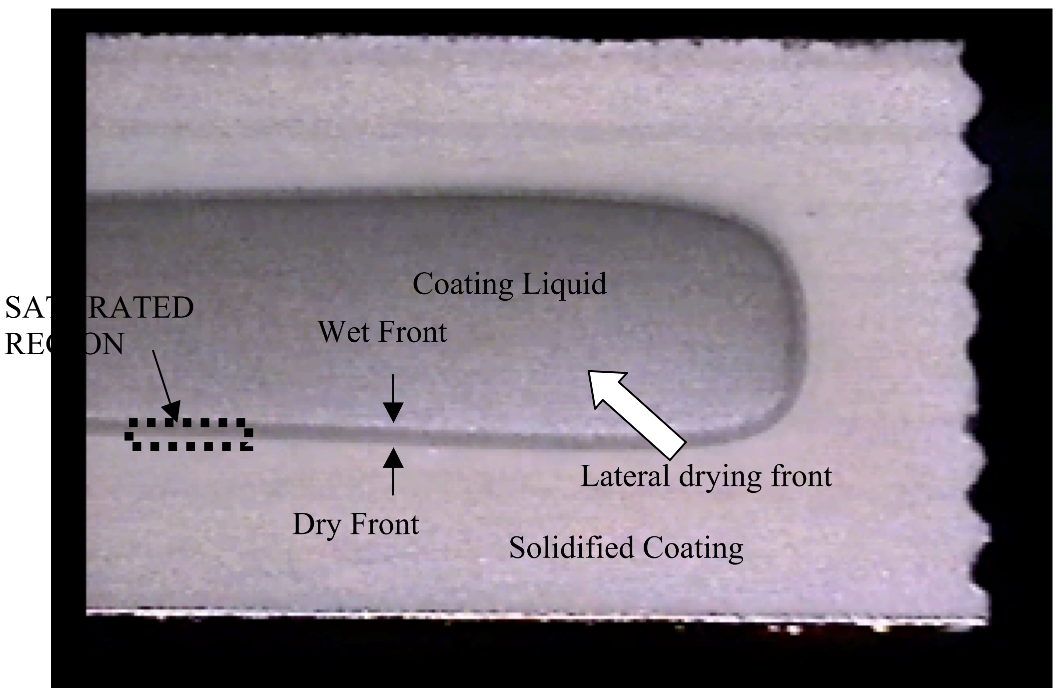

Figure 1: Image captured from a video camera during the drying of silica nanocomposite film with 30% PVA.

Measurements of final coating stresses over a broad range of coating compositions show that the stress goes through a maximum as PVA content increases. The highest final stress was found to be ~110 MPa at a PVA content of 60 wt%. The coating microstructure was characterized using scanning electron microscopy (SEM) and CryoSEM. Porosity measurement using nitrogen gas adsorption (micrometrics ASAP 2000) reveals that all the pores of the coatings were filled at 50 wt% PVA content. Nanoindentation results for nanocomposite coatings of varying composition show that the elastic modulus goes through maximum at 50 wt% PVA, near the maximum stress. More details will be provided elsewhere.

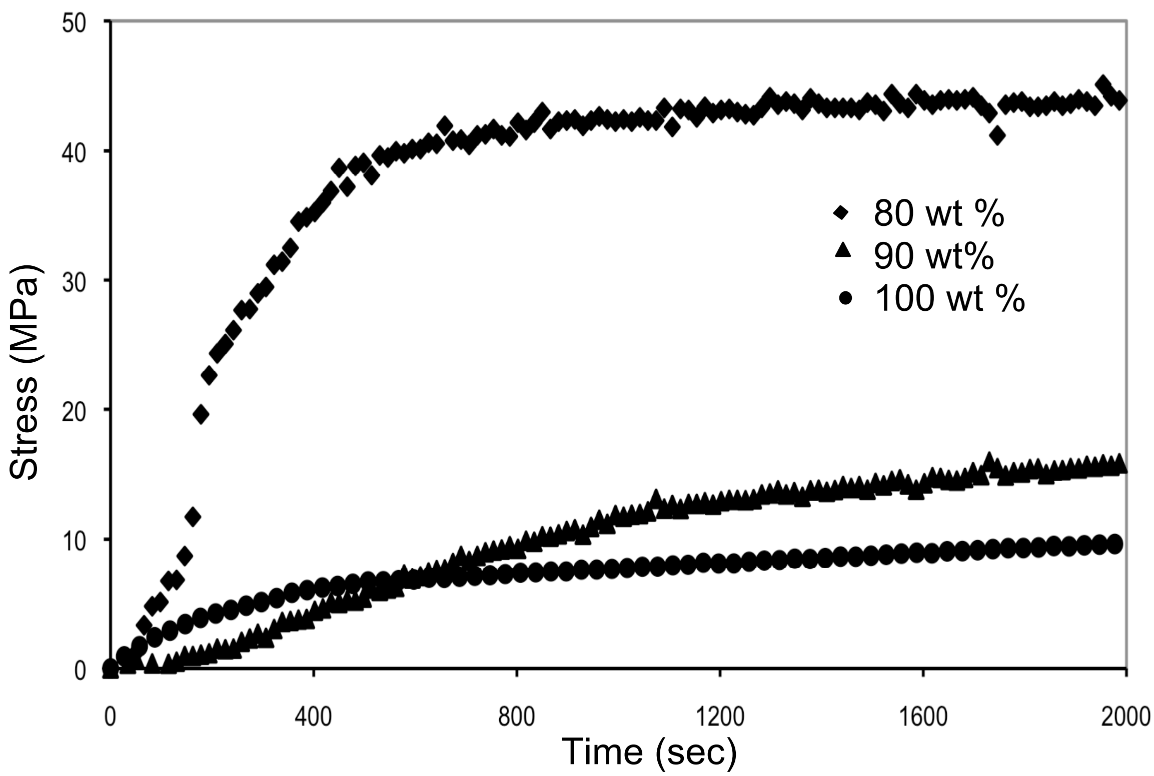

Figure 2 Stress development during drying of silica – PVA composite coatings with high PVA content (80, 90 and 100 wt% PVA)

References

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