SUBSTRATE SCRATCHES AND THEIR EFFECT ON AIR ENTRAINMENT IN CURTAIN COATING

J. Rousseau (* and **), Prof. H. Benkreira (*) and Dr. M. Cosgrove(**)

(*) School of Engineering, Design and Technology,
University of Bradford, Bradford, West Yorkshire, BD7 1DP, UK

(**) Organic Coated Product Department,
STC Corus RD&T, Rotherham, South Yorkshire, S60 3AR, UK

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Introduction:

In the coating industry, substrates often get scratched prior to entering the coating head and this affects the maximum speed at which air begins to be entrained, V_{ae} , i.e. the maximum speed at which they can be coated. Unlike roughness, scratches are essentially longitudinal groves which are not necessarily uniformly distributed across a web. They may also be intermittent in the machine direction. Clearly coating disguises scratches and it is thus desirable to understand the air entrainment phenomenon in this situation in order to maintain economical coating speed operation. This is precisely the industrial motivation behind this research. From an academic view point, the problem is also interesting as it addresses the issue of dynamic wetting and how substrate properties affect this situation. At the outset, one must state that no academic research reported in this subject was found. There has been much work reported on the effect of roughness [1-3] showing that roughness can increase or decrease the air entrainment speed depending on the viscosity. Roughness however is not a scratch as it is uniform and multidimensional, and according to Scriven [4], this topography enables "air to escape through the valleys between peaks in the surface". The research question posed here is : can we get a flow situation , using a scratched substrate that allows coating at higher speed than with a non-scratch substrate? Alternatively will a scratch always reduce the air entrainment speed? These are the issues addressed in this paper in relation to the coating method of curtain coating,. This research is more than likely applicable to any other coating situation.

Experimental work:

The experiments were performed on a laboratory multilayer slide curtain coater (width 150mm), designed to operate at speeds up to 10m/s in a continuous fashion (i.e. with a fresh substrate) or in a loop mode (i.e. with a substrate belt). In the loop mode, it is required to remove the coated film before subsequent coating could be undertaken. This is done by as series of scrapers that cause scratches. In the reel to reel mode, a fresh substrate is always coated as the top surface of the fresh substrate does not experience any contact with rollers. Coating experiments in the reel-reel mode with a engineered grove produced just before the curtain were also performed. These groves located in the center of the substrate were created by emery paper. The grove geometry, in these experiments, could be varied so as to simulate scratches with different depths and widths. In this program of work, the coating flow conditions, i.e. viscosity of the coating fluid, curtain height h and linear flow rate q, were varied. In addition and in order to address the concept of the maximum speed of wetting, experiments at different β angles of rotation of the die were performed as previously tested in other coating flows by Benkreira and Cohu [5-6]. The onset of air entrainment was determined by visual observation on a Perspex scraper with a black background illuminated with grazing light, a method similar to that used by Blake *et al.* [7-8]. A substrate sampling just before the scrapers for the grove experiments allows an examination of their profile with a Wyko profilometer (white light interferometer).

Results and Discussion:

The first experiments solely in loop configuration assess the accuracy of the measurements and their fit with Blake *et al.*'s normalized procedure [7]. As indicated by Figure 1, which displays the data with the scratched substrate, the fit is excellent and gives confidence in the measuring technique. The fit with the normalizing procedure (top left box in Figure 1) suggests that the hydrodynamic assist aspect of the flow is maintained albeit reduced by the presence of the scratches.

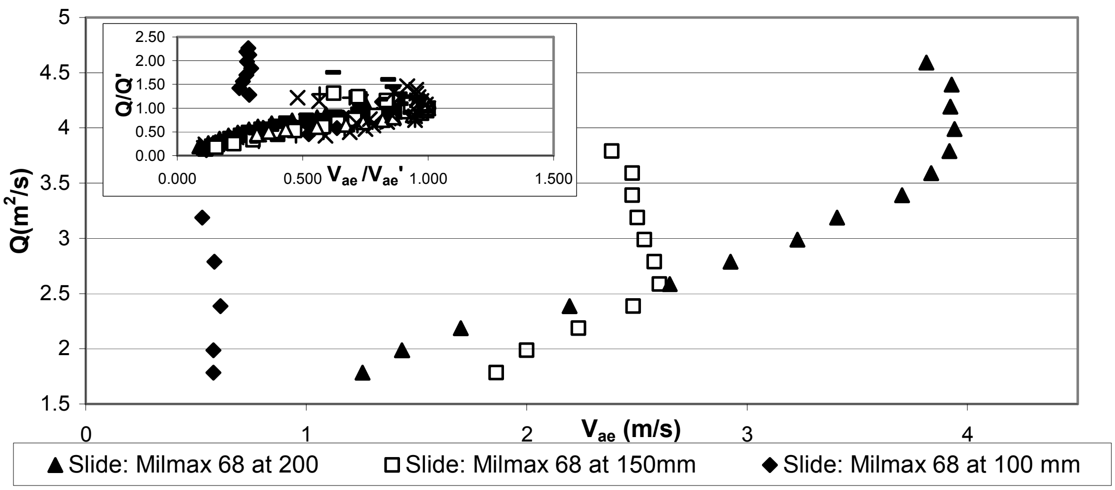

Figure 1: Air entrainment onset speed for 200mPa.s fluid on scratch PET substrate with slide curtain coating (Top left box : Master curve for Experiments for the various conditions studied)

The second set of experiments was aimed to compare air entrainment speeds in the loop mode and in the reel to reel both with unscratched substrate and engineered scratches. The results presented in Figure 2 and 3 clearly show that scratches reduce the air entrainment speed considerably at all flow rates. Figure 3 gives a comparison of the ratio of the maximum air entrainment speeds of the scratched / unscratched as a function of scratch depth. One can see that scratches as deep as 10-15 μm trigger air entrainment at less than 20% the air entrainment speed observed for a fresh substrate.

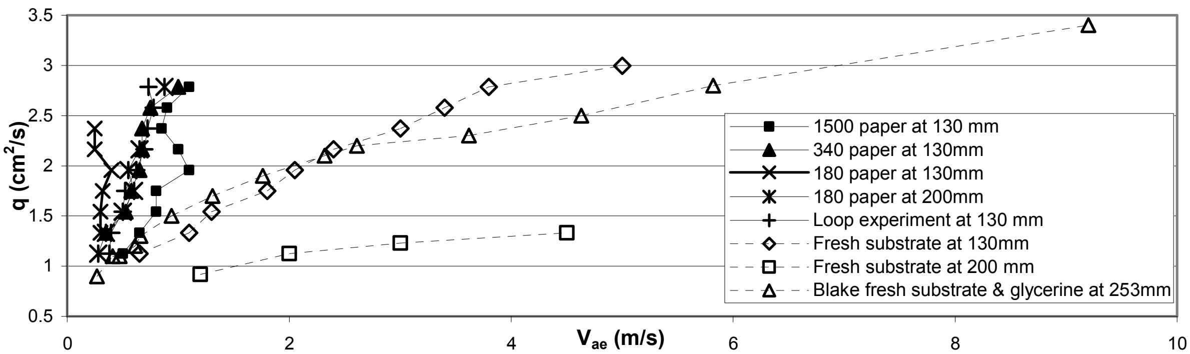

Figure 2 Comparison of air entrainment onset speeds for scratch and unscratched substrate for a 600 mPa.s oil

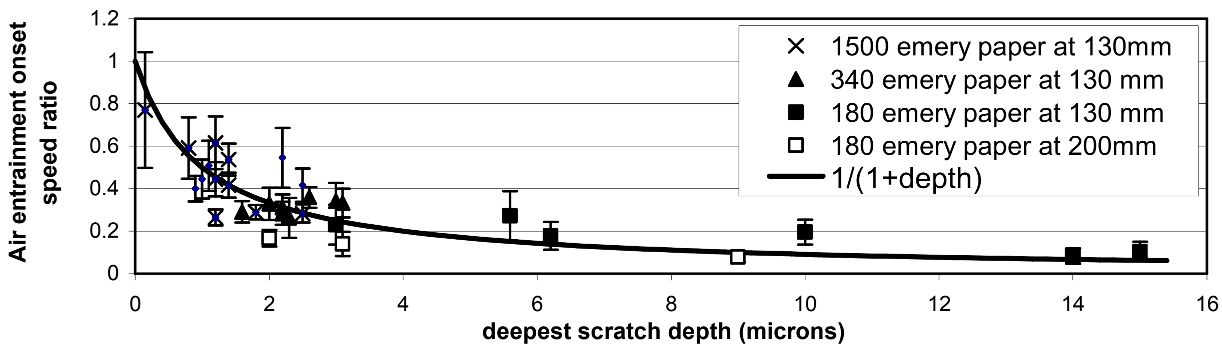

Figure 3: Air entrainment onset speed ratio ($V_{ae, scratch}/V_{ae, fresh substrate}$) for engineered scratches for a 600mPa.s oil

The next set of experiments aimed to test the data via the maximum speed of wetting as carried out by Benkreira and Cohu [5-6]. Figure 4 presents such data and shows that the fit is perfect with reel to reel (unscratched) whereas a deviation with the 1/cos β rule is observed with a scratch. As discussed below (see Figure 5), the fit is $1/(\cos\beta)^{0.5}$.

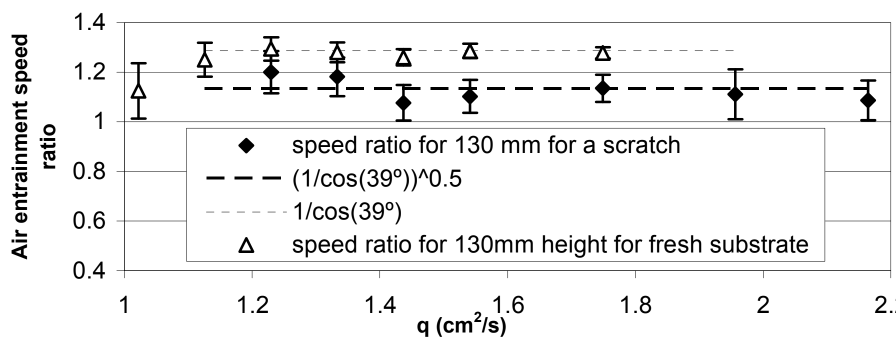

Figure. 4: Ratio of air entrainment speed at β angle ($V_{ae, 39°}/V_{ae, 0°}$) for scratched and unscratched substrate (reel to reel) Curtain height, 130 mm; Viscosity 600mPa.s.

Observing that the data for the scratched substrate deviate from the maximum speed of wetting rule, correlating the data following Clarke's approach [2] to curtain coating rough substrates was considered. In this approach, the computed maximum air entrainment speed is given as $S_{\max} = \left[\left(\frac{8\gamma}{3\pi\sqrt{2}(1+m)\eta_A} \right)^{2/3} \frac{R_z S_z P_L}{2\gamma} \right]^{3/5}$

This equation indicates a different mechanism as the roughness, R_Z, increases the air entrainment speed; whereas in our scratched substrate experiment, the reverse is observed. The skipping mechanism suggested by Clarke [2] can not operate as the scratches are longitudinal "valley" and never offer the liquid the opportunity to skip over a peak. One can only conclude that the reduction in the air entrainment speed is due to a diminished hydrodynamic assistance caused by the groove deploying a larger surface area in comparison with a smooth substrate thus reducing the pressure at the dynamic wetting line. Further research is in progress to explain the discrepancy with the maximum speed of wetting rule. When re-plotting the loop mode data along this principle, as in Figure 5 a fit with $1/(\cos.\beta)^{0.5}$ is confirmed. This figure relates to a loop mode experiment and not a reel to reel scratched substrate due to requirements of accuracy (repeat experiments) and substrate cost.

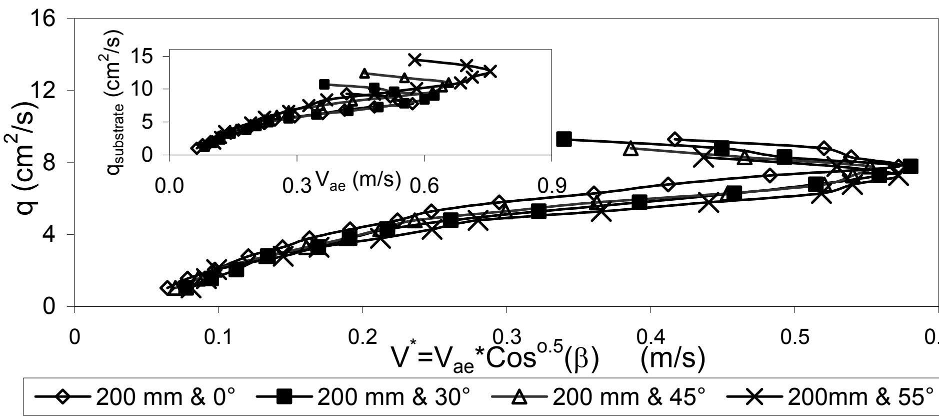

Figure. 5: Modified correlation for scratched substrate in loop configuration for a 600 mPa.s oil following the maximum speed of wetting approach of Cohu and Benkreira [5-6].

Conclusion:

This research reports original data on the effect of scratches on air entrainment speed. The data show that scratches cause the air entrainment speed to decrease significantly. Comparing the maximum air entrainment speed in curtain coating with scratched and unscratched substrates shows the ratio of speed to be less than 20% when the scratch depth is in the order of 10-15 microns. The accuracy of the experimental method was tested against the normalized method of Blake *et al*.[7] and it was found to be in good agreement. It is important here to distinguish between scratches and roughness, shown from earlier studies [2-3] to potentially increase V_{ae} depending of viscosity-roughness choice. Scratches are longitudinal valleys which we postulate decrease the hydrodynamic assistance because they deploy on a larger surface area. This work requires further data which is in progress in our laboratory.

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