Modelling the Discrete Cell Gravure Roll Coating Process: A New Perspective

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Gravure rolls, in particular ones etched with a discrete cellular patterning, have been used for many years in the manufacture of an array of coated substates, but unlike their rigid roll counterpart have remained remarkably stubborn with respect to the derivation of predictive models. This paper follows on from the authors's recent work [1] with respect to the modelling of tri-helical gravure roll coating, with the aim of elucidating the underlying physics involved in the discrete cell gravure process. The analysis is presented in two stages:

The practice to date has been for investigators to examine the problem at a cellular level and to consider the deformation of the coated substrate into the cells [2, 3]. In such cases the substrate is assumed to be flexible - that is, the stiffness provided by the finite thickness of the material is neglected. In the current cellular level analysis a two dimensional model is utilised, whereby the equations for Stokes flow (written in terms of the primitive variables, u, v and p) are coupled to those describing the deformation of the substrate, and solved numerically, using a finite element formulation, for a range of cell geometries, fluid properties and pickout ratios (i.e. the fraction of fluid released from a cell during the process). The latter was varied by adjusting the pressure difference between the inlet and outlet, ensuring that the entire range of physically possible pickouts was examined for each cell geometry considered. It is shown that, in contrast to previous work, the stiffness of the substrate plays an important role in the process and that the resulting substrate deformation on a cellular scale is minimal for all operating conditions but for the smallest roll-to-substrate gap formations, even for the thinnest substrates($25\mu m$) examined.

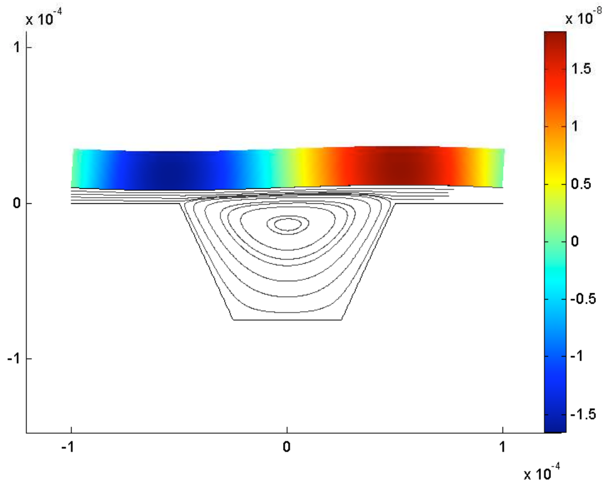

Figure 1: Predicted substrate deformation for a single cell, with the deformation magnified by a factor of 100 for viewing purposes. Surface colour corresponds to vertical deformation; streamlines are also shown. Pickout is 0.5 for a substrate speed of $3m/s$ (left to right) and a roll speed of $3m/s$ (right to left); fluid viscosity is $5 \times 10^{-2} Pas$, Youngs' modulus for the substrate is $0.4MPa$ and the Poisson's ratio is 0.33. All dimensions are in meters.

Using the insight provided by the above, the small level of web deformation experienced at the cellular scale is neglected in developing a refined model for predicting the overall coating 105
performance of the discrete cell gravure roll-coating process. This is achieved by permitting web deformation to occur but under the assumption that it is slowly changing from one cell to the next - consistent with the two different scales involved. This enables Stokes flow for different cells to be solved over a range of roll-to-substrate gaps. Using a flexible substrate approximation, a linear flux - pressure gradient relationship is determined which together with appropriate boundary conditions enables the entire process to be modelled, yielding the shape of the substrate, pressure profiles and pickout data. The results obtained are found to be qualitatively similar to those obtained experimentally by Kapur [4]; further experiments are currently being performed for additional comparison purposes.

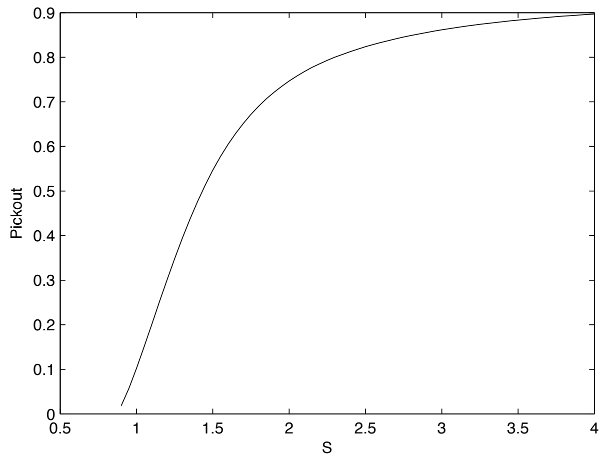

Figure 2: Illustration of pickout from a two-dimensional cell as a function of the substrate to roll speed ratio, S. Groove dimensions are: land width $= 0.5\times$ groove width; groove base $= 0.5 \times$ groove width; groove depth $= 0.5 \times$ groove width. Capillary number (based on the roll speed) $= 0.01$; web tension $(\frac{\text{force per meter}}{\text{viscosity}\times\text{roll speed}}) = 10000$; roll radius $= 1000\times$ groove width.

References

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