Flow Imaging & Instabilities Study of Multilayer Slide Coating

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Coating or the deposition of a thin film onto a solid surface is a unit operation used not only to embellish or protect a material surface but also to manufacture many high technology products such photographic films, printed circuits, photovoltaic cells, batteries, drug release patches and many others [1, 2]. In all of these new applications, the coating is required in a multilayer form with 4, 5 or more layers being coated simultaneously using slide or slot coating as illustrated in Figure 1. The thickness of the individual layers is one specification which is critical to the working of the product and typically these layers will be in the range 5-100 microns wet. The second specification is the speed at which the coating is applied; it dictates the economics of the manufacturing process and must be sufficiently high, typically more than 10m/min. Under these conditions of coating thin and fast and in a multilayer mode, instabilities (waves in the machine and transverse directions) arise on the top surface of the multi-layered film and at the interface between the individual layers. These instabilities spoil the performance of the final product and must thus be avoided.

There are much theoretical studies of the stability of single and multilayer films flowing down an incline starting from the early analytical work [3] to the more recent CFD study [4]. The experimental work is however limited to broad observations on the effect of the thickness of the individual layers and their viscosities. The broad conclusion recommended in the case of a 3 layers film is that stability is improved when the viscosity of the layers is increased from bottom to top and when a thin layer is used on the bottom and a thick layer in the middle.

In this paper we report detailed flow conditions on flow rate, slide angle, viscosity and surface tension leading to the onset of these instabilities on a 3-layer slide die, designed purposefully with a flow visualisation set-up for capturing images of the flow and associated instabilities. The die dimensions are 150mm wide and 140mm long (excluding the radius before the die lip) with 3 slots 7mm thick (including the chamfer). The slide die was made from stainless steel to the highest industrial specifications and fitted with sapphire glass windows on each side along the whole path of the slide as shown in Figures 1 and 2. A Microtron EoSens MC1362 high speed camera was used to capture a reduced image of 1056 x 406 pixels giving a frame rate up to 1283s^{-1} and shutter speed of 773µs. This was used together with an Edmund Optics 0.5XTML 63074 telecentric lens giving an image resolution of 35pixels/mm. To provide illumination a VOOI intralux dc – 1100 light source was connected to an Island Optical Systems Coaxial Telecentic TL – T1X300D lens by a fibre optic cable, with the lens being located opposite. This enabled the capture of the flow streams as they emerged from the slot and combined to produce the final film. Further zooming enables the resolution of vortices forming immediately on exit from the slot and waves on the interfaces and free surface. Figure 3 gives a typical view obtained when 2 layers form. Such views are also compared with predicted profiles obtained from CFD analysis. In the presentation we shall review previous work in the field, describe our experimental apparatus and method, the results of our observations and how they compare with prior work and propose a coating window that demarcate stable operation.

References

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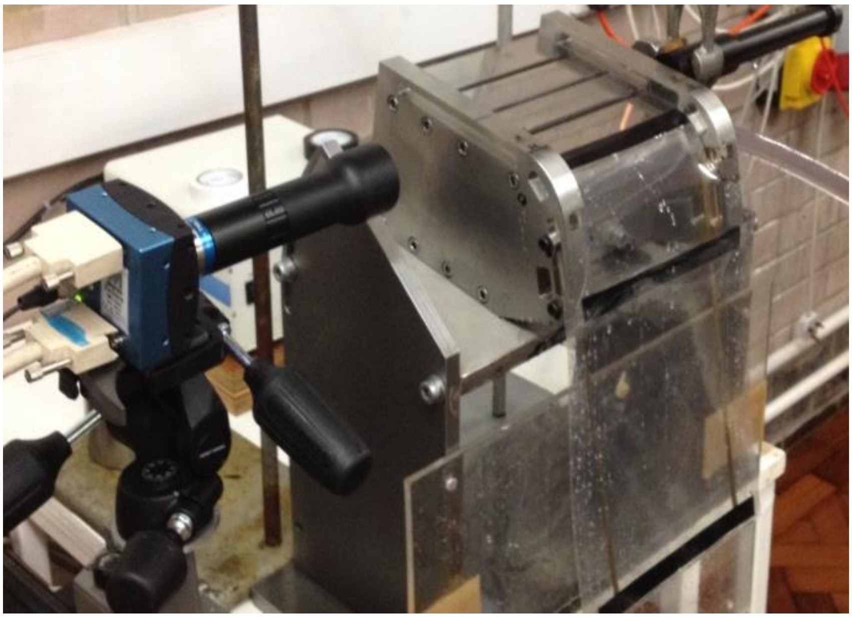

Fig.1: 3-layers slide die adapted here for flow visualisation.

Fig.2: A view through the sapphire glass onto the slide with the slot exits being visible.

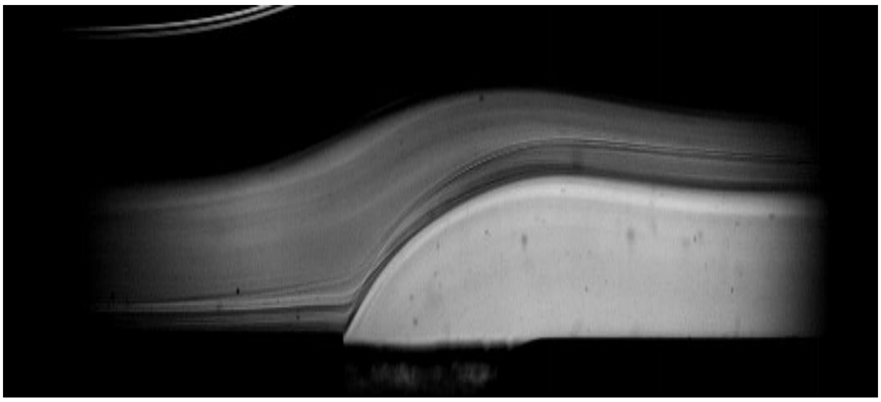

Fig. 1: Image of a 2-layer film forming on the die slide at incline angle of 23°.