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EXTENDED SUMMARY

The shape of the extrudate of polymers and polymer melts is very much like the wavy shapes one sees in core-annular flows of heavy oils in water. These flows are lubricated by the water and can be said to give rise to slip. A wave on the oil must steepen at its front and flatten at its rear because the pressure is larger in the front and lower in the back. Photographs of the ubiquitous asymmetric waves which are shown as a cartoon in figure 1 can be found in many places; for example, Feng, Huang, Joseph [1995].

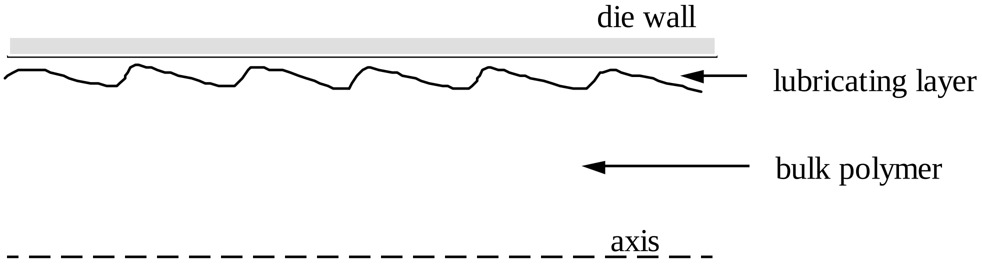

Figure 1. A cartoon of the proposed wave shape (enlarged) in the interface between the bulk polymer and the thin lubricating layer in a die.

The high and low pressures which are generated in the water as a wave on the oil pushes forward are much more intense when the gap is small; in a slipper bearing the pressure maximum is proportional to the reciprocal of the square of gap size. In journal bearings the low pressure on the back side are severe enough to produce cavitation even under rather mild conditions. The slipper bearing model underestimates the severity of the pressure changes, which inevitably produce steep waves in the front instead of the back of the slipper. Direct numerical simulation (Bai, Kelkar and Joseph [1996]) shows that enormously high pressures develop at a stagnation point on the front face of the steep wave. The wave length shrinks when the gap size is reduced, leading to “sharkskin” as a rigorous consequence of the direct simulation.

It is widely agreed that many polymer melts and solutions slip along the walls of capillary tubes. The word "slip" is rather general and is subject to different interpretations all of which would appear to imply lubrication by different mechanisms. If a polymer melt or solution slips at a wall, it must slip on something. Even solids in dry friction are lubricated nearly everywhere by a thin fluid or air layer. Slip may arise as a failure of adhesion in which the bond between two materials, the polymer and the wall, is broken and the substance between on which slipping takes place must give rise to lubrication, as in core-annular flow. The substance between sticks to the extrudate and to the wall. A substance between is also required by cohesive fracture in which bits of the fractured polymers remain on the wall. Another idea is that a thin layer of polymer softens as a consequence of instability associated with a non-monotone stress-strain relationship in the constitutive equation. This also gives rise to a lubricating layer of less viscous material at the wall on which the polymer may slip. It is of interest to inquire what is the substance between and what are the dynamic effects of the lubricating layer.

Assuming, for the moment, the presence of a lubricating layer and a dynamic effect similar to the one which steepens wave fronts in core-annular flows, exacerbated by the surpassingly small gaps for slipping polymers, we expect that every wavy extrudate will have a steep wave front and a flatter rear. This idea seems to work well in all of the cases in which the direction of flow could be ascertained from photographs or the associated text. In fact, researchers in this subject do not say much about the direction of flow, and they do not look at the asymmetry of the wave as a window for understanding. We were able to know the direction of the extrudate only in the cases in which the die exit is shown. In all these cases the steep part of the wave advances. We do not know which way the extrudate is going when the die exit is not shown; the authors don’t say. We guess that the direction of motion in all cases is such that the steep side advances, as in figure 1. Schallamach waves, which are universally present in experiments on friction and abrasion of rubber, have the steep part in front and they look just like melt fracture.

The relation between wall slip and extrudate distortion is not clear. Loss of adhesion may not occur uniformly but at different spots as in Schallamach’s [1971] “waves of detachment”; this could lead to the messy extrudates seen in photographs. A more organized loss of adhesion occurs as "stick-slip"; the slipping occurs on a lubricating layer and when the lubricated part comes out of the die it spurts. Even in the messy cases, the steep part of the wave appears to advance.

The dynamics which give rise to the steep wave fronts in the extrudates is not well understood but may share features like those that produce the same type of shock-like waves on heavy oil in water in which the steep part of the wave advances. Perhaps the asymmetric form of waves on extrudates in slipping flow are as universal as they are in core-annular flow.

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