Viscoelastic Effects in Multilayer Polymer Extrusion

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Abstract: The effect of viscoelasticity on multilayer polymer extrusion is discussed. In these coextrusion processes prede-
termined patterns are created with a remarkable breadth of complexity even in geometrically simple dies via
estric rearrangements caused by the second-normal stress differences. A computational method is offered,
based on the mapping method, which quantitatively describes the flow-induced patterns. Besides that the
results are esthetically beautiful, they are also relevant for practice, since process and die design optimization
is now possible. Not only to minimize interface distortion, but potentially also to deliberately create new process-
es and products based on this flow-induced patterning of polymers.

Zusammenfassung: Der Einfluss der Viskoelastizität auf die Mehrschichtextrusion bei Polymeren wird diskutiert. Bei diesen Koex-
trusionsprozessen werden vorher bestimmte Muster mit einer bemerkenswerten Komplexitätsvielfalt erzeugt,
sogar in geometrisch einfachen Düsen mit Hilfe elastischer Umlagerungen, die durch die zweite Normalspan-
nungsdifferenz erzeugt werden. Eine numerische Methode, die auf der Abbildungsmethode basiert, wird dar-
gestellt, die die strömungsinduzierten Muster quantitativ beschreibt. Die Resultate sind nicht nur ästhetisch
schön, sondern auch für die Praxis relevant, da die Optimierung des Prozess- und Düsensdesigns nun möglich ist –
nie nur um die Verzerrung der Grenzfläche zu minimieren, sondern um möglichst neues Produkte und Produkte zu schaffen, die auf der strömungsinduzierten Musterbildung bei Polymeren basieren.

Résumé: L’effet de la viscoélasticité sur l’extrusion de polymères multicouches est discuté. Dans ces procédés de co-extru-
sion, des empreintes prédéterminées sont créées qui possèdent une gamme remarquablement étendue de com-
plexité et ceci même pour des filières à géométrie simple. Ces empreintes sont associées à des réarrangements
élastiques causés par la seconde différence de contraintes normales. Une méthode de calcul numérique est pro-
posée, basée sur la méthode de cartographie qui décrit quantitativement les empreintes induites par l’écoule-
ment. En plus de l’obtention de résultats esthétiquement magnifiques, ceux-ci sont pertinents pour ce qui concer-
ne la pratique, puisque l’optimisation des procédés ainsi que des conceptions des filières est maintenant possible.
Non seulement est-il possible de minimiser les distorsions d’interface, mais aussi de nouveaux procédés et pro-
duits peuvent être potentiellement créés de manière délibérée grâce à cette technique d’empreintes de poly-
mères induites par l’écoulement.

Key words: extrusion, rheology, secondary flow, normal stresses, pattern formation

1 INTRODUCTION

Multilayer coextrusion is a process in which polymers are extruded and joined together in a feedblock or a die with the purpose of forming a single structure with multiple layers. The attraction of coextrusion is both economic and technical as it is a single-step process. Starting with two or more polymer materials, that are simultaneously extruded and shaped in a single die, a multilayer sheet or film can be formed. Coextrusion avoids the costs and complexities of conventional multistep lamination and coating processes, where individual plies must be made separately, and then primed, coated, and laminated. Moreover, coextrusion readily makes it possible to manufacture products with layers thinner than can be made and handled as an individual ply. Consequently, only the necessary thickness of a high performance polymer is used to meet a particular specification of the product. In fact, coextrusion has been used commercially to manufacture unique films consisting of hundreds of layers with individual layer thicknesses less than 100
Numerical simulations comparing layer rearrangement as a function of distance traveled down a square channel. The viscoelasticity was changed by changing the non-linear parameter in the one mode Giesekus model from 0 to 0.8 with steps of 0.2.

The mapping method was used to determine interface locations for coextruded polystyrene structures as they flow through square and rectangular channels. Excellent agreement between the experimental and numerical results was obtained. These results show the power of the mapping technique in determining interface deformation in monolithic coextruded structures. Moreover, the simulation results suggest that the technique can be used to determine the second-normal stress difference under realistic flow rates. Clearly, the flow-induced patterning method which was demonstrated here would be more useful if part of the polymer is provided with additional functionality, such as electrical conductivity to be used for LED or capacitor applications. Other possibilities include a controlled level of viscoelasticity can indeed be determined based on the amount of layer deformation caused by second-normal stress difference driven flows. These results indicate that the technique can be used to determine the second-normal stress difference under realistic flow rates by applying the technique in an inverse way. It is suggested by these results that (for this flow rate) a channel length of 50 < L/D < 100 should be chosen to differentiate the level of viscoelasticity. Via an iterative numerical and experimental approach, these flows could even help to design improved constitutive equations that can quantitatively predict second normal stresses over a broad range of deformation rates. Note that the secondary flow-induced deformations are (sensitive) integrals of the velocity field over time, rather than (non-sensitive) differentials, which are stresses.

5 CONCLUSIONS

The mapping method was used to determine interface locations for coextruded polystyrene structures as they flow through square and rectangular channels. Excellent agreement between the experimental and numerical results was obtained. These results show the power of the mapping technique in determining interface deformation in monolithic coextruded structures. Moreover, the simulation results suggest that the technique can be used to determine the second-normal stress difference under realistic flow rates.

Clearly, the flow-induced patterning method which was demonstrated here would be more useful if part of the polymer is provided with additional functionality, such as electrical conductivity to be used for LED or capacitor applications. Other possibilities include a controlled difference in the refractive indices of the different structures to control optical properties.

REFERENCES


