

Supplementary Material

The Effect of Rotationality on Nonlinear Shear Flow of Polymer Melts and Solutions

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Relaxation Spectra of Polystyrene Melts at Reference Temperature 130°C

Table SI.1

Lin180	
g_i [Pa]	τ_i [s]
3.466e+007	6.887e-004
8.279e+005	1.702e-002
3.066e+005	1.039e-001
1.170e+005	6.335e-001
5.708e+004	3.965e+000
5.303e+004	2.166e+001
6.254e+004	1.117e+002
7.992e+004	5.882e+002
6.976e+003	1.805e+003

Table SI.2

Lin180/20		Lin180/30		Lin180/90	
g_i [Pa]	τ_i [s]	g_i [Pa]	τ_i [s]	g_i [MPa]	τ_i [s]
2.169e+007	8.576e-004	1.587e+007	1.542e-003	1.988e+001	1.410e-003
5.979e+005	2.543e-002	5.603e+005	3.467e-002	6.388e-001	3.156e-002
2.169e+005	1.795e-001	2.021e+005	2.358e-001	2.301e-001	1.992e-001
8.983e+004	9.429e-001	9.572e+004	1.555e+000	9.365e-002	1.206e+000
5.551e+004	5.901e+000	5.893e+004	7.902e+000	6.454e-002	7.033e+000
5.433e+004	4.029e+001	4.321e+004	4.550e+001	6.309e-002	3.628e+001
4.501e+004	2.199e+002	4.177e+004	2.265e+002	7.245e-002	1.630e+002
3.475e+004	6.308e+002	3.498e+004	8.308e+002	4.077e-002	6.081e+002
4.310e+001	9.491e+003	2.015e+003	1.961e+003	7.761e-004	2.824e+003

Table SI.3

Star 20		Star 30		Star 90	
g_i [Pa]	τ_i [s]	g_i [Pa]	τ_i [s]	g_i [MPa]	τ_i [s]
3.494e+007	7.820e-004	4.645e+007	6.498e-004	2.306e+007	1.208e-003
7.607e+005	1.768e-002	1.037e+006	2.270e-002	6.878e+005	2.856e-002
3.324e+005	9.056e-002	2.140e+005	2.762e-001	2.109e+005	1.954e-001
1.099e+005	5.333e-001	6.653e+004	2.698e+000	8.720e+004	9.979e-001
6.925e+004	2.343e+000	5.055e+004	2.218e+001	4.993e+004	5.642e+000
5.204e+004	1.349e+001	5.011e+004	1.453e+002	5.059e+004	3.322e+001
5.153e+004	7.335e+001	3.507e+004	8.284e+002	5.273e+004	1.621e+002
3.843e+004	3.029e+002	1.312e+004	3.381e+003	4.785e+004	6.302e+002
3.538e+004	1.171e+003			3.342e+004	2.642e+003
2.583e+003	3.929e+003			5.682e+003	8.380e+003

Relaxation Spectra of Poly(propylene carbonate) Melts at Temperature 70°C

Table SI.3

PPC69k		PPC111k		PPC158k	
g _i [Pa]	τ _i [s]	g _i [Pa]	τ _i [s]	g _i [MPa]	τ _i [s]
3.156e+008	7.503e-006	3.108e+007	1.351e-004	2.464e+008	1.460e-005
5.242e+006	1.165e-004	9.950e+005	2.903e-003	1.733e+006	1.823e-003
8.424e+005	3.725e-003	3.485e+005	1.707e-002	3.665e+005	2.907e-002
1.671e+006	6.352e-004	1.449e+005	8.646e-002	1.427e+005	3.840e-001
3.485e+005	2.607e-002	1.041e+005	4.130e-001	1.474e+005	3.502e+000
2.192e+005	1.609e-001	1.078e+005	1.756e+000	1.870e+005	2.647e+001
2.170e+005	7.927e-001	1.291e+005	6.951e+000	2.204e+005	1.815e+002
2.363e+005	3.619e+000	1.649e+005	2.929e+001	1.646e+005	9.560e+002
1.930e+005	1.482e+001	1.787e+005	1.143e+002	2.258e+004	4.884e+003
8.224e+004	6.184e+001	8.728e+004	4.170e+002	4.134e+002	8.913e+004
8.460e+003	3.122e+002	1.148e+004	1.658e+003		
9.116e+001	9.855e+003	2.364e+002	1.920e+004		

The Persistence-of-Straining Tensor and Rotationality

Thompson and Souza Mendez (Thompson and Souza Mendes 2005a, Thompson and Souza Mendes 2005b) following earlier work of Astarita (Astarita 1979) defined a persistence-of-straining tensor $\mathbf{P}$,

$$\mathbf{P} \equiv \mathbf{D} \bar{\mathbf{W}} - \bar{\mathbf{W}} \mathbf{D} \quad (1)$$

$\mathbf{D}$ is the rate of deformation tensor,

$$\mathbf{D} = \frac{1}{2}(\boldsymbol{\kappa} + \boldsymbol{\kappa}^T) \quad (2)$$

and $\bar{\mathbf{W}}$ the relative rate of rotation tensor,

$$\bar{\mathbf{W}} = \frac{1}{2}(\boldsymbol{\kappa} - \boldsymbol{\kappa}^T) - \boldsymbol{\Omega} = \mathbf{W} - \boldsymbol{\Omega} \quad (3)$$

$\boldsymbol{\Omega}$ is the tensor that gives the rate of rotation of the eigenvectors of $\mathbf{D}$,

$$\dot{e}_i = \boldsymbol{\Omega} e_i = \boldsymbol{\omega} \otimes e_i, \quad i = 1, 2, 3 \quad (4)$$

where e_i is any of the three eigenvectors of $\mathbf{D}$, $\boldsymbol{\omega}$ is the angular velocity of these eigenvectors, and the dot indicates the (material) time derivative.

When $\mathbf{P} = 0$, the flow is extensional corresponding to total persistence of straining. The intensity of $\mathbf{P}$ is then a local measure of how far from maximum is the persistence of straining in a given flow. Thompson and Souza Mendez (Thompson and Souza Mendes 2005a, Thompson and Souza Mendes 2005b) define this intensity as

$$P = \sqrt{\frac{1}{2} \mathbf{P} : \mathbf{P}} \quad (5)$$

From Eq. (5) follows that $P=0$ for extensional flow, $P=\mathbf{D}:\mathbf{D}$ for shear flow, and $P>>\mathbf{D}:\mathbf{D}$ for flows which approach the limit of rigid body motion (Thompson and Souza Mendes 2005a, Thompson and Souza Mendes 2005b). Depending on the value of P , a frame-indifferent dimensionless measure of flow type can be constructed,

$$r(P) = 1 \text{ for } P = 0 \quad (6)$$

$$r(P) = 1 - \frac{P}{\mathbf{D}:\mathbf{D}} \text{ for } P \leq \mathbf{D}:\mathbf{D} \text{ and } \mathbf{D}:\mathbf{D} > 0 \quad (7)$$

$$r(P) = 0 \text{ for } P \geq \mathbf{D}:\mathbf{D} \text{ and } \mathbf{D}:\mathbf{D} > 0 \quad (8)$$

Thus, $r(P)$ can be considered as a measure of “flow strength” (Tanner and Huilgol 1975), which decreases with increasing “rotationality” from $r=1$ (irrotational or extensional flow,

also called “strong” flow) to $r=0$ for shear flow (“marginally weak” flow) and flows approaching the limit of rigid body motion (“weak” flows). Narimissa et al. (2020) considered “no flow”, i.e. $P = 0$ and simultaneously $\mathbf{D} : \mathbf{D} = 0$, as irrotational and assign a value of $r=1$.

References

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