

Supplementary Information

Numerical Investigation of Die Swell Behavior in EPDM Rubber Extrusion: Effects of Compound Formulation and Processing Conditions

S1. Low-Temperature Control Experiments at 20 rpm

To provide boundary evidence on thermal sensitivity, low-temperature control experiments were conducted at 20 rpm for all three compounds. The barrel set-point was reduced by approximately 5°C relative to the normal condition.

Table 1: Low-temperature control results at 20 rpm. Correction factors: $f_t = 0.065$, $f_c = 0.035$; $B_{\text{corr}} = B_{\text{exp}}/[(1 - f_t)(1 - f_c)]$; $\Delta P_{\text{die}} = P_3 - P_7$; $T_{\text{max}} = \max(T_1, T_6, T_8, T_{10}, T_{11}, T_{14}, T_{15})$.

Compound	B_{exp} (normal)	B_{exp} (low)	ΔB_{exp} (%)	B_{corr} (normal)	B_{corr} (low)	ΔB_{corr} (%)	ΔP_{die} (normal)	ΔP_{die} (low)	$\Delta \Delta P$ (%)	T_{max} (normal)	T_{max} (low)	ΔT_{max} (°C)
EPDM-60	1.0363	1.0338	-0.24	1.1485	1.1458	-0.24	2.09	2.30	+10.0	81	76	-5
EPDM-70	1.0130	1.0150	+0.20	1.1227	1.1249	+0.20	2.58	2.23	-13.6	81	76	-5
EPDM-80	1.0083	1.0119	+0.36	1.1175	1.1215	+0.36	2.98	3.63	+21.8	84	79	-5

Interpretation. At 20 rpm, low-temperature controls show small swell changes (within $\pm 0.36\%$) and a consistent 5°C decrease in T_{max} . The pressure-drop response remains compound-dependent. EPDM-60 and EPDM-80 show higher ΔP_{die} under lower temperature, whereas EPDM-70 shows a lower value. This pattern indicates interaction between temperature, viscosity, and compound-specific flow resistance. Because this control set is sparse (single-speed comparison), it provides directional boundary evidence only and is not used to support standalone mechanistic conclusions in the main text.

S2. Inlet Boundary Conditions for Low-Temperature Cases

Table 2: Inlet boundary conditions for the three low-temperature simulation cases.

Compound / Condition	T_{inlet} (K)	Q (m ³ /s)
EPDM-60 / 20 rpm (low T)	345.15	1.18×10^{-6}
EPDM-70 / 20 rpm (low T)	346.15	1.24×10^{-6}
EPDM-80 / 20 rpm (low T)	351.15	8.03×10^{-7}

S3. DMA Isothermal Frequency-Sweep Summary at 80, 100, and 120 °C

To support the Arrhenius cross-validation discussion in Section 2.2.1 and the wall-to-core thermal-gradient analysis in Section 3.9 of the main text, isothermal frequency sweeps were collected on EPDM-60/70/80 at three temperatures (80, 100, 120 °C) using a TA Instruments

Q800 (TA Instruments, New Castle, DE, USA) in dual-cantilever bending at 0.1% strain amplitude. The first normal stress difference $N_1(\omega)$ at each angular frequency $\omega = \dot{\gamma}$ is inferred from the Laun rule:

$$N_1(\omega) = 2 G'(\omega) \left[1 + \left(\frac{G''}{G'} \right)^2 \right]^{0.7}.$$

Table 3 reports the band-averaged moduli, loss tangent, and $\overline{N_1}$ over the measured 0.01–100 Hz window (21 logarithmically spaced points per isotherm). The full point-by-point dataset is archived in the accompanying file `polymers-4238061-S3_DMA_data.csv`.

Table 3: Band-averaged DMA storage modulus, loss modulus, loss tangent, and Laun-rule-inferred first normal stress difference $\overline{N_1}$ for EPDM-60/70/80 at 80, 100, and 120 °C. Bands are arithmetic means over the full measured frequency range (0.01–100 Hz, 21 logarithmically spaced points per isotherm). The $\overline{N_1}$ ratio between adjacent isotherms supports the Arrhenius cross-validation in Section 2.2.1 of the main text and bounds the wall-to-core thermal-gradient impact on the FMM-corrected swell discussed in Section 3.9.

Compound	T (°C)	$\overline{G'}$ (Pa)	$\overline{G''}$ (Pa)	$\overline{\tan \delta}$	$\overline{N_1}$ (Pa)	n points
EPDM-60	80	9.78×10^4	1.77×10^5	2.066	5.47×10^5	21
	100	1.14×10^5	1.71×10^5	1.418	5.23×10^5	21
	120	6.60×10^4	8.45×10^4	1.173	2.61×10^5	21
EPDM-70	80	9.95×10^4	1.80×10^5	2.039	5.53×10^5	21
	100	1.17×10^5	1.77×10^5	1.436	5.42×10^5	21
	120	6.72×10^4	8.69×10^4	1.180	2.68×10^5	21
EPDM-80	80	1.02×10^5	1.82×10^5	2.035	5.62×10^5	21
	100	1.21×10^5	1.80×10^5	1.415	5.51×10^5	21
	120	6.91×10^4	9.06×10^4	1.181	2.79×10^5	21

Interpretation. The $\overline{N_1}$ values at 80 and 100 °C provide the empirical basis for the linear-scaling estimate of the wall-to-core thermal-gradient impact on the FMM-corrected swell discussed in Section 3.9 of the main text. Across the three compounds, the band-averaged $\overline{N_1}$ values at fixed temperature differ by less than 3% at 80 °C, less than 6% at 100 °C, and less than 7% at 120 °C, consistent with the compound-resolved N_1 spread reported in Section 3.9. The full per-frequency dataset (189 rows: 3 compounds $\times$ 3 temperatures $\times$ 21 frequency points) is archived as `polymers-4238061-S3_DMA_data.csv`.