Timescales in the case of unstable fragments ($\gamma \rightarrow \infty$)

By rewriting Eq. (14) in terms of the two length scales, i.e., the entanglement length $L_e$ and the initial average length $\langle L \rangle$, we obtain

$$\sigma(t) = L_e \exp \left( -R^2 - t/\tau_1 \right) + \langle L \rangle \text{erfc} \left( R + t/\tau_2 \right) \exp \left( (t/\tau_2)^2 \right)$$

(1)

where $R = \sqrt{\frac{\pi}{2}} \frac{L_e}{\langle L \rangle}$, $\tau_1 = \frac{1}{\alpha L_e}$, and $\tau_2 = \frac{\sqrt{\pi} R}{\langle L \rangle}$. This expression gives two different timescales $\tau_1$ and $\tau_2$ indicating that in the regime where $L_e < \langle L \rangle < L_d$, stress initially decays as $\frac{1}{\langle L \rangle}$ (see inset of Fig. 4 in the main text) and then relaxes as $\frac{1}{L_e}$.

Length-independent stress relaxation for finite $\gamma$

Figure S1 shows the stress relaxation for two different initial average length $\langle L \rangle$ in the regime where $L_e < L_d < \langle L \rangle$ (regime II in Fig. 2a and b in the main text). As expected, the stress relaxation is length-independent in this regime. The deviation of the curve corresponding to the smaller length is due to numerical errors. Likewise, by plotting stress relaxation curves for two different $\langle L \rangle$ in the regime where $L_d < L_e < \langle L \rangle$ (regime III in Fig. 2a and b in the main text), which is shown in Fig. S2, we clearly see a length-independent relaxation.

![FIG. S1. Stress relaxation for two different $\langle L \rangle$ as shown in the legend in the regime where $L_e < L_d < \langle L \rangle$ for $L_e = 20$ and $L_d = 150.$](image-url)
FIG. S2. Stress relaxation for two different $\langle L \rangle$ as shown in the legend in the regime where $L_d < L_e < \langle L \rangle$ for $L_e = 150$ and $L_d = 20$. 