The Interesting Influence of Nanosprings on the Viscoelasticity of Elastomeric Polymer Materials: Simulation and Experiment

Jun Liu, Yong-Lai Lu, Ming Tian, Fen Li, Jianxiang Shen, Yangyang Gao, and Liqun Zhang *
Supporting Information

The Interesting Adjusting of "Nanospring" on the Viscoelasticity of Elastomeric Polymer Materials: Simulation and Experiment

Jun Liu\textsuperscript{2}, Yong-Lai Lu\textsuperscript{1,2}, Ming Tian\textsuperscript{1,2}, Fen Li\textsuperscript{2}, Jianxiang Shen\textsuperscript{2}, Yangyang Gao\textsuperscript{2}, Liqun Zhang\textsuperscript{1,2}

\textsuperscript{2}Key Laboratory of Beijing City on Preparation and Processing of Novel Polymer Materials and \textsuperscript{1}State Key Laboratory of Organic-Inorganic Composites, Beijing University of Chemical Technology, Beijing 100029, People's Republic of China.

\textbf{Figure S1:} Before cross-linking (a) the decay of the end-to-end vector $<u(t)\cdot u(0)>$ of system I as a function of MD steps; after $1.5\times10^7$ MD steps of equilibration (b) the change of the potential energy of system I and II and (c) the variation of the mean square end-to-end distance $R_{eed}^2$ and radius of gyration $R_g^2$ of system I.
Figure S2: After cross-linking (a) the change of the potential energy and (b) the variation of the number density of beads for both systems I and II.
Figure S3: The TEM observation of carbon nanosprings, it is noted that in order for clear observation we have used carbon nanosprings with large diameter and aspect ratio.

Figure S4: The microscopic deformation of the carbon nanosprings in the elastomer matrix during the tension and recovery process.
Figure S5: For nanosprings filled cross-linked polymer system (system I) without interfacial coupling, comparison between tension-recovery curves in the x and y directions. For clarity the stress-strain in the z direction is not shown, but almost the same as those in the x and y directions. For better comparison, the pure system is as well added. The volume fraction of the nanosprings is $\phi = 14\%$ and the spring constant is $K^* = K / \varepsilon = 500$. 
Figure S6: For nanosprings filled cross-linked polymer system (system II) and for the spring constant $K^* = 500$, (a) comparison of tension-recovery curves in the x, y and z directions; (b) the change of the elastic energy during the tension and recovery process. The volume fraction of the nanosprings $\phi = 14\%$, and the dimensionless spring constant $K^* = K / \varepsilon$. 
Figure S7: For nanosprings filled cross-linked polymer system (system II) and for the spring constant $K^* = 0.05$, (a) comparison of the tension-recovery curves in the x, y and z directions. (b) the change of the elastic energy during the tension and recovery process. The volume fraction of the nanosprings $\phi = 14\%$, and the dimensionless spring constant $K^* = K / \varepsilon$. 