REVEALING THE CORRELATION BETWEEN STRAIN-INDUCED CRYSTALLIZATION AND LOCAL STRAIN FIELD AROUND THE CRACK-TIP OF NATURAL RUBBER

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ABSTRACT

Natural rubber (NR)[1] exhibits strain-induced crystallization (SIC) which is an important feature setting NR apart from other elastomer types. SIC serves as a self-strengthening mechanism, significantly improving the mechanical strength and fracture toughness of the rubber[2]. Specifically, the crystallization that occurs near the crack-tip increases crack-growth resistance which ultimately determines the lifespan of the elastomers[3]. Indeed, several studies[4-7] revealed the occurrence of SIC near the crack-tip of NR using micro-beam wide-angle X-ray scattering (μ-WAXS). In general, the area near the crack-tip has an inhomogeneous strain distribution as characterized by digital image correlation (DIC) technique[8,9]. However, the correlation between the SIC and strain field near the crack-tip has yet to be fully explored and comprehended[1-3].

In this study, we investigate the correlations between the degree and orientation of SIC, and the local strain field around the crack-tip in NR using a combination of μ-WAXS and μ-DIC techniques. We characterize the boundary of the SIC region and the spatial distributions of the crystallinity index and the c-axis of the SIC crystals. By relating the 2D strain field, we elucidate the strain criteria for the occurrence of SIC, and the relationship between the c-axis of SIC crystals and the principal axis of strain tensor.

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REFERENCES

1. Huneau, B. Strain-Induced Crystallization of Natural Rubber: A Review of X-Ray Diffraction Investigations. *Rubber Chem. Technol.*, ***84*** **(3)**, 425–452., 2011. https://doi.org/10.5254/1.3601131.

2. Persson, B. N. J.; Albohr, O.; Heinrich, G.; Ueba, H. Crack Propagation in Rubber-like Materials. *J. Phys. Condens. Matter*, ***17*** **(44)**. 2005. https://doi.org/10.1088/0953-8984/17/44/R01.

3. Creton, C.; Ciccotti, M. Fracture and Adhesion of Soft Materials: A Review. *Reports Prog. Phys.*, ***79*** **(4)**,

046601., 2016**.** https://doi.org/10.1088/0034-4885/79/4/046601.

4. Trabelsi, S.; Albouy, P. A.; Rault, J. Stress-Induced Crystallization around a Crack Tip in Natural Rubber. *Macromolecules*, ***35*** **(27)**, 10054–10061., 2002. https://doi.org/10.1021/ma021106c.

5. Brüning, K.; Schneider, K.; Roth, S. V.; Heinrich, G. Strain-Induced Crystallization around a Crack Tip in Natural Rubber under Dynamic Load. *Polym. (United Kingdom)*, ***54*** **(22)**, 6200–6205., 2013. https://doi.org/10.1016/j.polymer.2013.08.045.

6. Rublon, P.; Huneau, B.; Verron, E.; Saintier, N.; Beurrot, S.; Leygue, A.; Mocuta, C.; Thiaudière, D.; Berghezan, D. Multiaxial Deformation and Strain-Induced Crystallization around a Fatigue Crack in Natural Rubber. *Eng. Fract. Mech.*, ***123***, 59–69., 2014. https://doi.org/10.1016/j.engfracmech.2014.04.003.

7. Demassieux, Q.; Berghezan, D.; Creton, C. Microfocused Beam SAXS and WAXS Mapping at the Crack Tip and Fatigue Crack Propagation in Natural Rubber. *Adv. Polym. Sci.*, ***286***, 467–491., 2021**.** https://doi.org/10.1007/12_2020_79.

8. Osumi, R.; Yasui, T.; Tanaka, R.; Mai, T.-T.; Takagi, H.; Shimizu, N.; Tsunoda, K.; Sakurai, S.; Urayama, K. Impact of Strain-Induced Crystallization on Fast Crack Growth in Stretched Cis -1,4-Polyisoprene Rubber . *ACS Macro Lett.,* ***11*** **(6)**, 747–752., 2022. https://doi.org/10.1021/acsmacrolett.2c00241.

9. Schreier, H.; Orteu, J.-J.; Sutton, M. A. *Image Correlation for Shape, Motion and Deformation Measurements*; Springer US: Boston, MA, Vol. **54**, 2009. https://doi.org/10.1007/978-0-387-78747-3.