Chemistry of fatigue

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Fatigue has been studied exhaustively in materials of many types, including metals, ceramics, and polymers. Recent advances in hydrogels have opened a new opportunity to study fatigue—through chemistry.

A hydrogel is an aggregate of water and a three-dimensional polymer network. Whereas hydrogels constitute most tissues of animals and plants, synthetic hydrogels are relatively new materials. Initial successes were contact lenses in the 1960s and superabsorbent diapers in the 1980s. Recent decades have seen intense development for medical applications, such as drug delivery and tissue regeneration.

Hydrogels are often brittle, like jello and tofu. The situation has been changed fundamentally in the recent decade or so. It has been discovered that hydrogels of many chemical compositions can achieve high toughness, some being as tough as natural rubber [1,2]. The discovery has stimulated efforts to seek new applications of hydrogels. Examples include artificial muscles [3] and tough tissue adhesives [4].

Tough hydrogels derive their high toughness through dissipation, and dissipation often causes fatigue. This talk describes how hydrogels of different chemistries respond to cyclic loads [5-8]. Emphasis will be placed on experiments and models that link fatigue to chemistry. It is hoped that researchers worldwide will report the fatigue behavior of their own hydrogels under development for load-bearing applications, and will soon discover fatigue-resistant hydrogels.

References

[1] Gong, J.P., Katsuyma, Y., Kurokawa, T., Osada, Y., "Double-network hydrogels with extremely high mechanical strength," Advanced Materials 15, 1155-1158 (2003).

[2] Sun, JY., Zhao, X.H., IIIeperuma, W.R.K., Chauhuri, O., Oh K.H., Mooney, D.J., Vlassak, J.J., Suo, Z.G., "Highly stretchable and tough hydrogels," Nature 489, 133-136 (2012).

[3] Keplinger, C, Sun, J,Y., Foo, C.C., Rothemund, P., Whitesides, G.M., Suo Z.G., "Stretchable, transparent, ionic conductors," Science 341, 984-987 (2013).

[4] Li, J.Y., Celiz, A.D., Yang, J.W., Yang, Q.S., Wamala, I., Whyte, W., Seo, B.R., Vasilyev, N.V., Vlassak, J.J., Suo, Z.G., Mooney D.J., "Tough adhesives for diverse wet surfaces," Science 357, 378-381 (2017).

[5] Tang, J.D., Li, J.Y, Vlassak, J.J., Suo, Z.G., "Fatigue fracture of hydrogels," Extreme Mechanics Letters 10: 24–31 (2017).

[6] Bai, R.B., Yang, Q., Tang, J., Morelle, X.P., Vlassak, J.J., Suo Z.G., "Fatigue fracture of tough hydrogels," Extreme Mechanics Letters 15, 91-96 (2017).

[7] Zhang, W.L., Liu, X., Wang, J.K., Tang, J.D., Hu, J., Lu, T.Q., Suo, Z.G.,"Fatigue of double-network hydrogels," Engineering Fracture Mechanics. https://doi.org/10.1016/j.engfracmech.2017.10.018

[8] Bai, R.B., Yang, J.W., Morelle, X., Yang, C.H., Suo, Z.G., "Fatigue fracture of self-recovery hydrogels." In preparation.