

Major trends in the elasto-visco-plastic behaviour of highly cross-linked epoxy resins

Nathan Klavzer¹, Jérémy Chevalier², Christian Breite³, Yentl Swolfs³, Christian Bailly⁴, Thomas Pardoën¹

¹ Institut of Mechanics, Materials and Civil engineering, UCLouvain, Louvain-la-Neuve, Belgium
E-mail: nathan.klavzer@uclouvain.be, thomas.pardoën@uclouvain.be

² Solvay S.A., Bruxelles, Belgium
E-mail: jeremy.chevalier@solvay.com

³ Department of Materials Engineering, KU Leuven, Leuven, Belgium
E-mail: christian.breite@kuleuven.be, yentl.swolfs@kuleuven.be

⁴ Institute of Condensed Matter and Nanosciences, UCLouvain, Louvain-la-Neuve, Belgium
E-mail: bailly.christian@uclouvain.be

Keywords: epoxies, mechanical properties, property correlation

Highly cross-linked thermosetting polymers, widely used as matrices for advanced polymer-based fibre-reinforced composites, have suffered from a lack of in-depth mechanical characterisation. The assumption is that their overall mechanical response is inherently similar to that of high glass transition temperature (T_g) amorphous thermoplastics, except for a lower ductility and a better creep resistance [1]. However, multi-scale test strategies have increasingly been used to improve the understanding of the deformation and failure of epoxies in order to feed computational models. The main motivation driving these studies is the recognition that a micro-scale level understanding of the deformation mechanisms of these materials is necessary to accurately predict the failure of the corresponding composites structures [2]. This is particularly important for loading conditions where plastic flow within the matrix is dominant such as overall shear or creep. However, these studies mostly limit themselves to the analysis of the elastic modulus and of the yield point, highlighting the remaining knowledge gap about the post-yield visco-plastic response of epoxies.

The purpose of this work is two-fold. First, in order to supplement the scarcity of accurate experimental data, we establish master trends for the entire stress-strain response of highly cross-linked epoxies, hence providing a basis for first-level modelling attempts. Additionally, we unravel trends within the stress-strain response that can be correlated to one or several physico-chemical or molecular structure parameters. For this purpose, a vast database of the elasto-visco-plastic properties resulting from tension and/or compression tests performed on seven different epoxy systems is gathered. Parameters such as rate sensitivity, softening, re-hardening and activation volumes are carefully extracted as it has been shown that they strongly affect the local fibre/matrix level stress development [3]. Among other trends, correlations between the yield and softening stresses and strains and the corresponding T_g and cross-linking densities are found for the tested resins. The re-hardening is mainly dictated by the cross-linking density, as expected.

References

- [1] Oleynik, E., "Plastic deformation and mobility in glassy polymers", *Progress in Colloid & Polymer Science*, 80, 140-150 (1989).
- [2] Chevalier, J., Camanho, P.P., Lani, F., Pardoën, T., "Multi-scale characterization and modelling of the transverse compression response of unidirectional carbon fiber reinforced epoxy", *Composite Structures*, 209, 160-176 (2019).
- [3] Breite, C., *Aligning fibre break models for composites with the observable micro-scale material behaviour*, KU Leuven, Leuven (2021)