Modelling of an epoxy matrix based on the shear transformation zone framework

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Bottom-up multi-scale modeling approaches of composites involve a first scale-transition from the constituents at the microscopic scale to the behavior of the yarn and the ply at the mesoscopic scale. In this contribution, finite element (FE) simulations carried out on representative volume elements (RVE) of a unidirectional composite (UD), based on a random generation algorithm, are confronted to experimental results obtained from transverse compression tests on thick UD cubic specimens. The results highlight the inability of a classical constitutive model identified and validated at the macroscale (see [1]) to accurately predict both the time of failure and the non-linearity of the stress-strain response. While a correction of the hardening law using the ratio between the insitu hardness, obtained through nanoindentation in resin pockets, and the bulk hardness can lead to satisfactory predictions of the UD mechanical response. However, digital image correlation (DIC) analyzes performed at the microscopic scale using in-situ compression tests in a scanning electron microscope (SEM) emphasize the differences between the local strain field and the strain field calculated in FEA using the same fiber distribution as in the DIC analyzes.

As a matter of fact, seeking an alternative to classical constitutive models considering the macroscopic behavior to be valid in every region of FE models, at the scale of the fibers, a material model based on the framework of the shear transformation zones (STZ) is presented. The STZ framework has been widely used in the field of metallic glasses in which plasticity and failure is governed by the shearing of nanoscopic volume elements which propagate under the form of large shear bands. The STZ framework accounts for the activation of zones, represented as a group of finite elements, which are sheared at each activation. The rate of STZ activation is based on a Eyring type of equation. The STZ model is adapted to the particular case of glassy polymers whose plastic behavior has been shown to be the consequence of the propagation of micro-shear bands which can propagate. The STZ model is first shown to be able to adequately predict the visco-plastic mechanical behavior of the RTM6 epoxy resin (non-linearity upon unloading, rate-reversal phenomenon, recovery,…), widely used as a matrix in CFRP, and to account for its temperature, strain rate and pressure dependence. Interestingly, the hardening law of the material is never provided a priori, enabling the mechanical response to change with respect to the loading conditions or the confinement of the resin. While this kind of model cannot be directly used in macroscopic models, because of the size of the STZs, it is shown to be a promising tool to be used at the micro-scale and, thus, to account for the differences between the matrix behavior at the scale of the fibers and at the macro-scale.

References

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