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VISCOPLASTIC STRAIN DEVELOPMENT IN STRESS CONTROLLED TENSILE LOADING: EFFECT OF TEMPERATURE

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ABSTRACT

The range of applications of epoxy matrix composites where they are exposed to elevated temperatures is increasing. It is well-known that polymers are not linear elastic materials and their response to loads is time and loading rate dependent. The main phenomena responsible for this type of behavior are viscoelasticity (VE) and viscoplasticity (VP). In order to develop multiscale predictive tools for simulations in nonlinear VE and VP formulation, adequate constitutive models have to be introduced and methodology suggested for determination of material functions in these models. Therefore, a good understanding of the effect of elevated temperature on long-term, time-dependent behavior and model development that is based on physically sound and consistent experimental methodology is of paramount significance.

The current investigation is aimed to VP model development. Zapa's integral representation of VP strain development [1] generalized by introducing a "viscoplasticity threshold" is used as a starting point

$$\varepsilon_{VP}(\sigma,t) = C_{VP}\left\{\int_0^{\frac{t}{t^*}}\left(\frac{\sigma(\tau)-\sigma_y}{\sigma^*}\right)^M d\tau\right\}^m \tag{1}$$

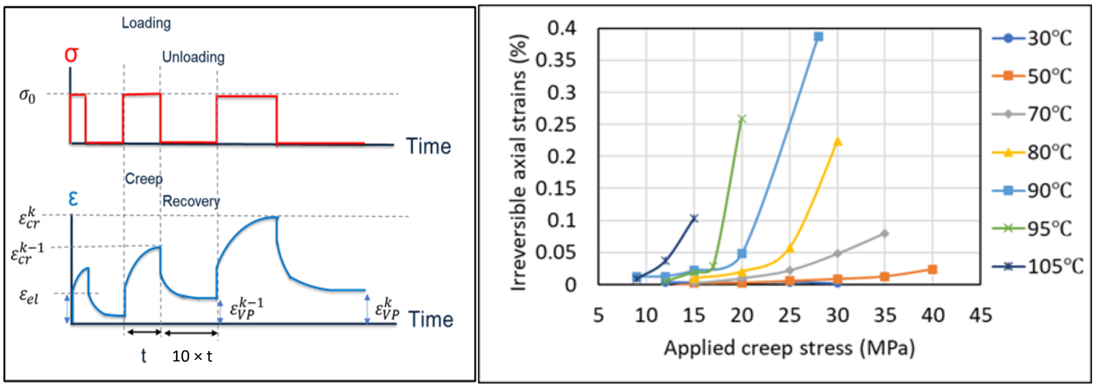
where C_{VP}, m and M are fitting parameters, t^* and σ^* are arbitrarily chosen normalization constants, σ_y is a stress threshold below which the VP strain development is negligible. The meaning of σ_y is similar to the "yield stress" in models for metals. The original formulation of the Zapa's model has been successfully used for short fiber composites and resins [2, 3]. In the used approach the VP strain data for a given temperature are fitted with (1) to find parameters C_{VP}, m and M . They are temperature dependent, and the aim is to identify the T-dependency and to describe it by empirical functions.
Therefore, the first step is a parametric study to determine VP strains under uniaxial loading at different temperatures starting from RT to up to 105 °C which is close to T_g of the used epoxy. Fully cured, annealed, and physically aged samples of Araldite® LY 5052/ Aradur® 5052 epoxy system were used.

Annealing removes all residual strains accumulated during manufacturing, and aging leads the polymer closer to thermodynamic equilibrium, ensuring very small aging state changes during long term tests at elevated temperatures.

Short-term tensile creep tests were performed on Instron 3366 universal testing machine utilizing the single specimen approach introduced in [2] and [3]. Creep and strain recovery tests at various times and stress levels under constant temperature were performed. Then, using a new specimen, the sequence of tests was repeated at a different temperature. During the whole sequence of test steps, the specimen was not removed from the machine to avoid introducing possible errors comparable in value with very small VP strains. Apparent elastic modulus in the strain region between 0.05 and 0.3% was measured prior to each creep stress test sequence using displacement rate of 2mm/min, unloading with the same rate, and then left to recover for 20 min.

For each creep test sequence (Figure 1 a), the specimen was loaded in a constant stress rate to pre-determined stress, held at this stress for a specific time interval, unloaded and left to recover the reversible strains before loaded again to the next creep time interval. Creep time intervals of 10, 20, 30 and 60 minutes were applied making up a total of 2 hours creep test at each stress level. A recovery time of 10 times the creep times was allowed. However, at higher temperatures and relatively high stresses, this time was increased to 15. All irreversible strains recorded by the extensometer after the end of recovery period were considered as VP strains. Creep stresses were selected to cover 30 to 90% of the ultimate tensile stress as determined by a separate tensile test.

Preliminary experimental results (Figure 1 b) show that the VP strains at temperatures below 70 °C and creep stresses up to 40 MPa are negligible (tensile strength for the epoxy system at RT is 44 MPa). This leads to two conclusions: a) below this temperature it is safe to assume pure viscoelasticity and stress-strain curves may be used to identify nonlinear VE model such as those suggested by Schapery [4]; b) there should be a threshold in equation (1).



(a) (b)

Figure 1: (a) Schematic for the creep sequence at a specific stress level. (b) Irreversible strain dependency on stress at different temperatures for a total of 2 hours creep time.

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