SHAPE MEMORY PERFORMANCE OF EPOXY RESIN-BASED COMPOSITES

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Abstract

One-way shape memory (SM) epoxy resin (SMEP) based systems and composites have been produced and characterized. Incorporation of different reinforcements along with their positioning were used to improve the recovery stress of the corresponding systems. Attempt was made to provide SMEPs with additional functionalities, such as self-healing.

1. Introduction

Shape memory polymers (SMPs) and composites thereof are emerging smart materials in different applications. SMPs may adopt one (dual-shape), two (triple-shape) or several (multi-shape) stable temporary shapes and recover their permanent or previous temporary ones (in multi-shape) upon the action of an external stimulus. The external stimulus is usually the temperature (set by direct or indirect ways). The "switching" or transformation temperature (T_{trans}), enabling the material to return to its permanent shape, is linked with the glass transition (T_g) in case of thermosets. The permanent shape is guaranteed by a chemical network and its sites are also termed net points. The temporary shape is set by mechanical deformation above T_{trans} and it is fixed by cooling below T_{trans} whereby maintaining the mechanical load. However, the deformation temperature may be below T_g of the corresponding polymer, as well. During setting the temporary shape, the segments between the crosslinks adapt to the external load via conformational rearrangements. The strain energy, stored by this way, is released when the material is unloaded and heated above its T_g via which the permanent shape is restored. All what is disclosed above is related to one-way (1W) SMPs. This means that the external stimulus activates only the change from the temporary to the permanent shape (dual-shape) or from one temporary to the other one (multi-shape version). The shape memory (SM) properties are typically quantified by the shape fixity (R_f) and shape recovery ratios (R_r). R_f means the extent of fixing of the externally applied deformation in the temporary shape. Its value is 100% when the applied deformation, introduced above T_{trans}, is fully kept below T_{trans} in the temporary shape. The deformation modes cover tension, compression, bending and torsion. R_r is the percentage of the recovery of the original shape when the material heated above T_{trans} subsequently. R_r=100% when the original shape of the material is fully restored. SM properties are often determined in cyclic (one or more) thermomechanical tests performed under stress- or strain-controlled conditions. Figure 1 displays the course of a SM thermomechanical test. Beside R_f and R_r, further SM characteristics, such as the temperature interval of recovery, recovery rate and recovery force, can be measured.

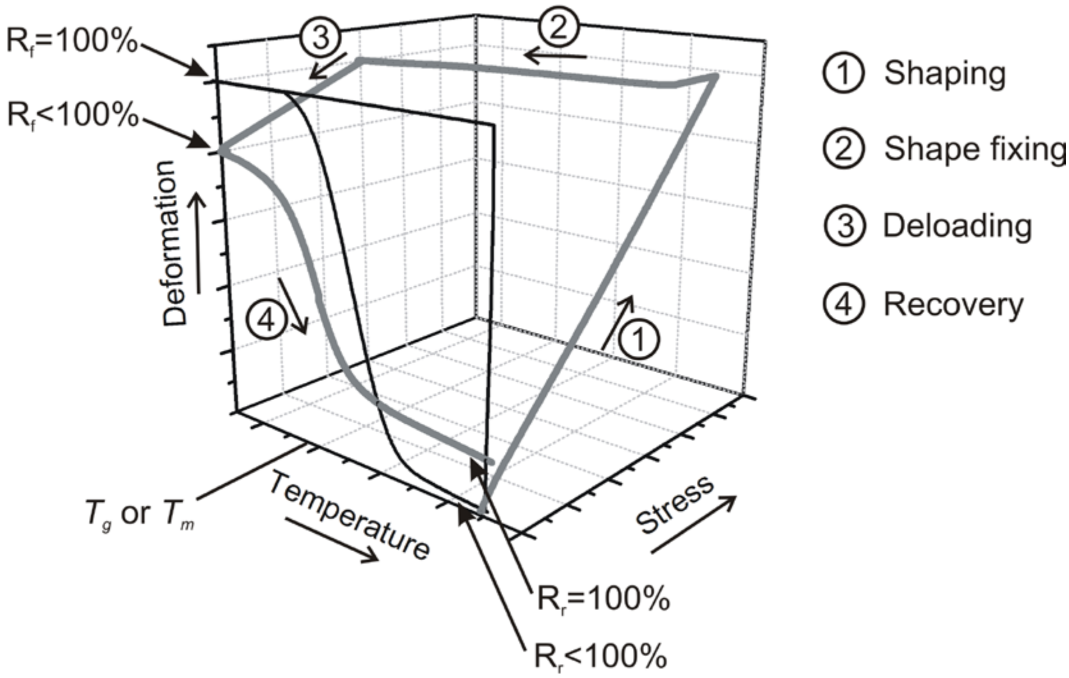

Figure 1. Single SM cycles of a 1W-SM polymer (black) and its composite (grey), schematically.

2. Fabric-reinforced SM epoxy (EP) composites

Four glass fiber (GF) fabric layers were infiltrated by EP yielding a composite with rather high reinforcement content (38 vol.%). It was found that with increasing GF fabric content R_f decreased opposed to the recovery stress that was enhanced by one order of magnitude (ca. 40 MPa). Parallel to that the critical bending strain, not causing observable damage, was highly reduced compared to neat EP (from >6% to 1%) [1]. In a follow-up study Fejős and Karger-Kocsis [2] studied the SM properties of carbon fiber (CF) fabric reinforced composites in bending. The CF layers were either on the tensile or on the compression side of the specimens during unconstrained and constrained tests. Again, the critical bending strain for SM testing was highly reduced by the reinforcement. The temperature and stress developments as a function of time are depicted in Figure 2 for the EP and EP/CF composites with CF layers positioned on the top (compression side) and bottom (tensile side), respectively. One can notice, that the stress values needed for deformation and measured during recovery agree well with each other. This implies good R_f and R_r data which were >93%, in fact. For the shape fixing required stress of the specimen containing CF layers on the top (under compression) was, however, much higher than the recovered one. This suggests the onset of microbuckling associated with an increment in the elastically stored energy. A substantial part of this is released, however, before passing the T_g of the EP matrix – see the courses of apparent stress and temperature in the related time interval in Figure 2.

Following the actual research trend, attempt was made to produce SMEP composites from fully renewable resources. To produce a "biocomposite" epoxidized linseed oil, cured by anhydride, was selected as matrix, and flax fabrics (nonwoven mat, twill-weave and quasi-unidirectional fabric) served for reinforcement [3]. Recall that natural fibers may be a favored reinforcement for SMEP because its presence imparts the deformability of the corresponding composite in lesser extent than traditional reinforcing fibers. The flax fiber content (< 58 wt.%) was varied through the number of fabric layers, their surface weight and fineness of the flax fibers. The R_f and R_r data of this epoxidized linseed oil based EP were 92 and 25%, respectively. The very low R_r substantiates that the recovery performance is controlled by the crosslink density, which was much lower in this "bioresin" than in typical "petro-based" EPs. R_f was reduced and R_r improved by the flax reinforcement, though they remained still moderately low [3]. This study also revealed that the fabric type and its architecture with respect to the loading direction have a strong impact on the SM properties.

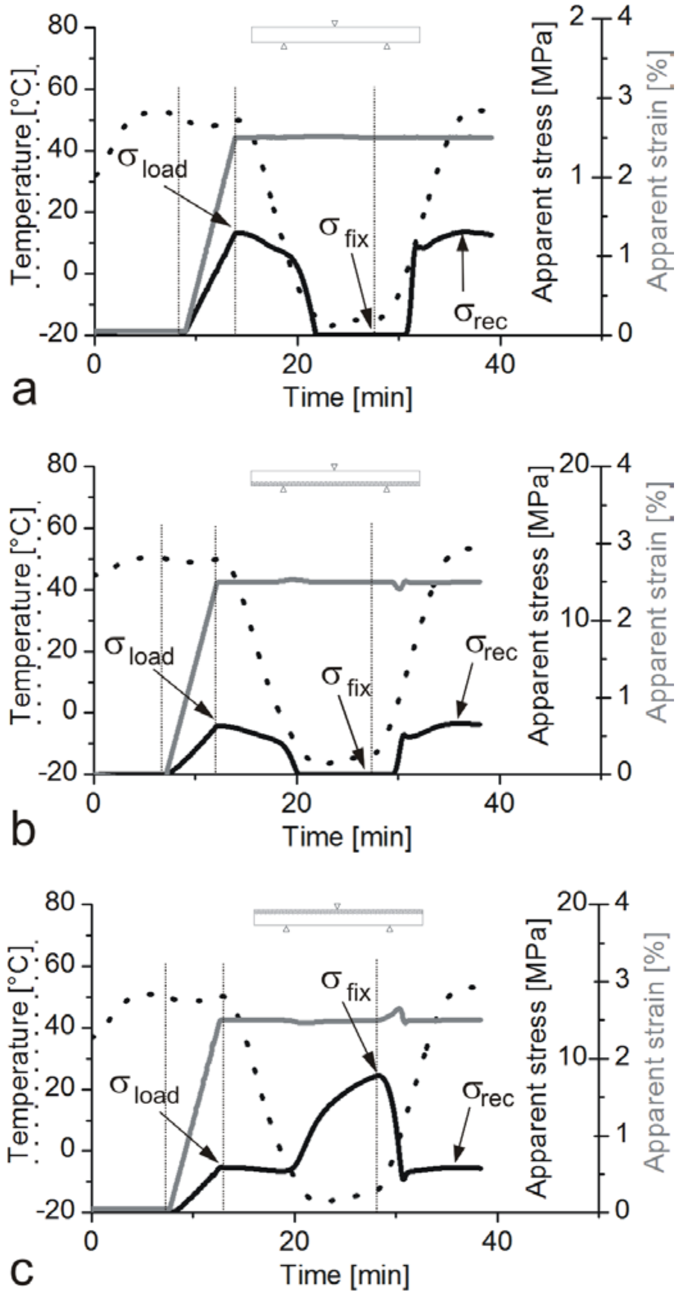

Figure 2. Shaping and recovery cycles of the neat EP and its asymmetrically positioned CF-fabric (2 layers) reinforced composites in bending (based on Ref. [2]).

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