ACCELERATED APPROACHES FOR LIFE-TIME PREDICTION OF COMPOSITES UNDER STATIC LOADS

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Abstract

Composite materials in structural applications with several decades under static loads unfortunately tend to changings in the material performance over the material lifetime. In the current work, novel methods for the determination of long term strength properties of unidirectional glass fiber reinforced thermoset composites with different fiber orientations are investigated and discussed. Classic creep rupture tests with a constant static loading situation are quite simple tests with low requirements to the test equipment, however, need non-economic testing times. Accelerated approaches, especially the stress rate accelerated creep rupture test and the stepped isostress method offer potentials to reduce testing times in an acceptable prediction quality. Although the suitability of each approach could not be confirmed for all investigated laminate structures. Nevertheless, the developed stress rate accelerated creep rupture test can certainly be regarded as a trendsetting testing procedure in the development of time efficient test methods for the prediction of material life time under static loads.

1. Introduction

In structural applications, composite materials are used in different loading situations over years. Pressurized composite gas cylinders for the storage of hydrogen or natural gas for green mobility concepts or weight loaded composite reinforced concrete with thermal insulating properties in the civil industry are affected by long term static loads. Unfortunately, the mechanical material performance changes by viscoelastic creep, damage accumulation and environmental material degradation effects over the whole lifetime [1–3]. For a safe and reliable use in application the ultimate failure strength over several decades of lifetime must be known. Standard testing methods with high prediction accuracy usually lead to extraordinary long testing times. So accelerated determination concepts and test procedures combined with truthfully prediction approaches are essential [4,5].

2. Experimental

2.1. Materials

For the experimental investigation of the applicability of different accelerated test methods, unidirectional glass fiber reinforced thermoset composites with different fiber orientations are manufactured and tested. Therefore twelve dry layers of an unidirectional glass fiber fabric by Lange+Ritter GmbH (Germany), with a square weight of 220 g/m², were stacked as described in Table 1 and impregnated with an epoxy resin system (EPIKOTE™ Resin MGS™ LR160 and EPIKURE™ Curing Agent MGS LH160, HEXION, USA). The use of a composite press by WICKERT Maschinenbau GmbH (Germany) with a limited piston stroke, a vacuum chamber and a heated plate tool to cure the impregnated fiber stack at a curing temperature of 80 °C within a curing time of 200 min leads to laminate plates with uniform laminate thickness of 2 mm.

Table 1. Laminate designation and stacking sequences for the investigated laminates.

Laminate designation	Stacking sequence	Total number of layers
UD 0 °	$[0]_{12}$	12
± 45 °	$[+45\|-45\|+45\|-45\|+45\|-45]_s$	12
UD 90 °	$[90]_{12}$	12

2.2. Mechanical short term characterization

To get a first overview of the mechanical performance of the manufactured laminates with different fiber orientations, standardized tensile tests according to the test standard ISO 527 were carried out. For the following long term tests the applied stress levels σ were chosen in relation to the quasi static strength σ_b (ISO 527) for each laminate. The normalized stress levels σ_N can be calculated according to equation 1.

$$\sigma_N = \frac{\sigma}{\sigma_b} \tag{1}$$

2.3. Mechanical long term characterization

For the prediction of the material lifetime under static loading conditions two approaches for accelerated material testing were investigated and compared to the results of classic creep rupture tests. One of these approaches is a new concept developed by the authors based on modified creep rupture tests. This concept - the stress rate accelerated creep rupture test (SRCR) – uses a defined initial stress level σ_{ini} at the beginning of the loading process followed by a loading segment at a defined stress rate instead of the static load segment of classic creep rupture tests. A variation of the stress rate in several single tests leads to stress rate dependent rupture strengths with related rupture times, which allows the extrapolation to a failure time at a stress rate of zero, comparable to a static loading situation of a classic creep rupture test at the initial stress level. The schematic loading curves of this procedure are illustrated in Figure 1. This new procedure executed at different initial stress levels allows a significant acceleration of creep rupture tests and predicting long term material performance within a few testing days.

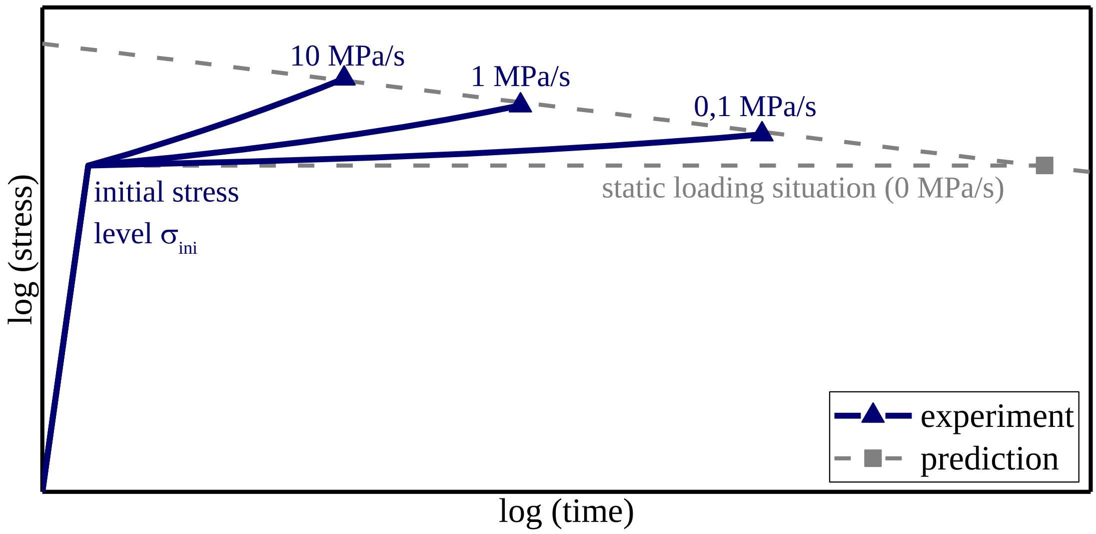

Figure 1. Schematic illustration of the SRCR stress curves.

The second investigated approach is the stepped isostress method, called SSM, where the test specimen is loaded stepwise in successive increasing isostress loading sequences up to the ultimate fracture of the specimen (Figure 2). The recorded creep deformation allows the determination of the failure time at the starting stress level by shifting the obtained creep sequences to higher time ranges. This is based on the fundamental, that long static loading times at a lower load level lead to a material creep response, which is similar to the creep response at higher static load levels [6–9].

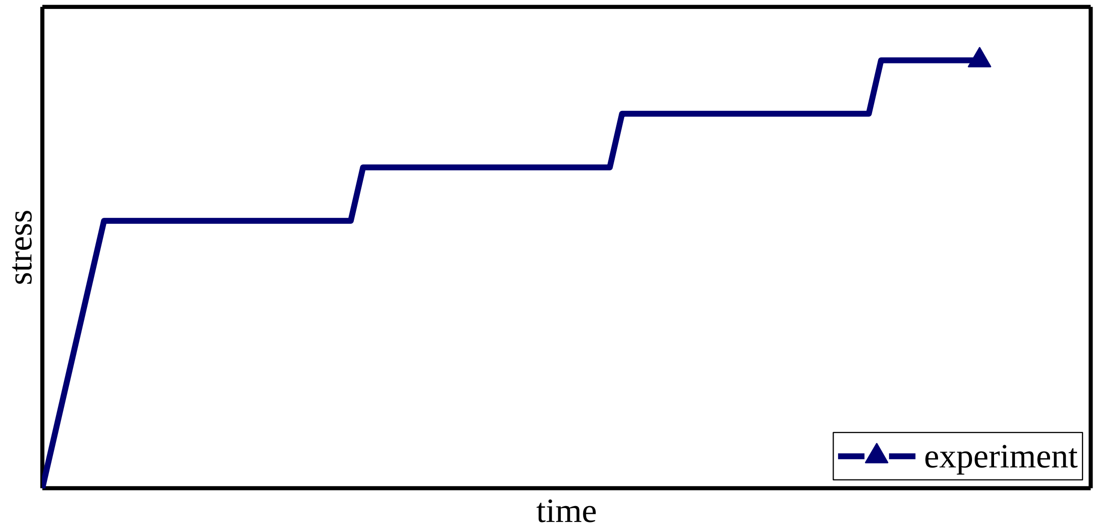

Figure 2. Schematic illustration of the SSM stress curve.

3. Results and discussion

Table 2 shows the results of short term tensile test of the investigated laminates with a wide range of the material strength between 57 MPa and 941 MPa resulting from the different fiber orientations.

Table 2. Tensile stiffness E_t, strength σ_b and elongation at break ε_b of the investigated laminates.

Laminate	E_t (GPa)	σ_b (MPa)	ε_b (%)
UD 0 °	42,1	941	2,4
± 45 °	12,6	138	10,2
UD 90 °	13,4	57	1,3

Based on the material strength of each laminate, classic creep rupture tests at several normalized stress levels were carried out for the investigated laminates. The test results are illustrated in Figure 3 and show a quite similar material behavior along the time with a significantly higher normalized stress level for the laminate ± 45 °. Obviously, the alternating laminate structure tends to lower defect propagation and failure susceptibility under a static load situation compared to unidirectional reinforced laminates.

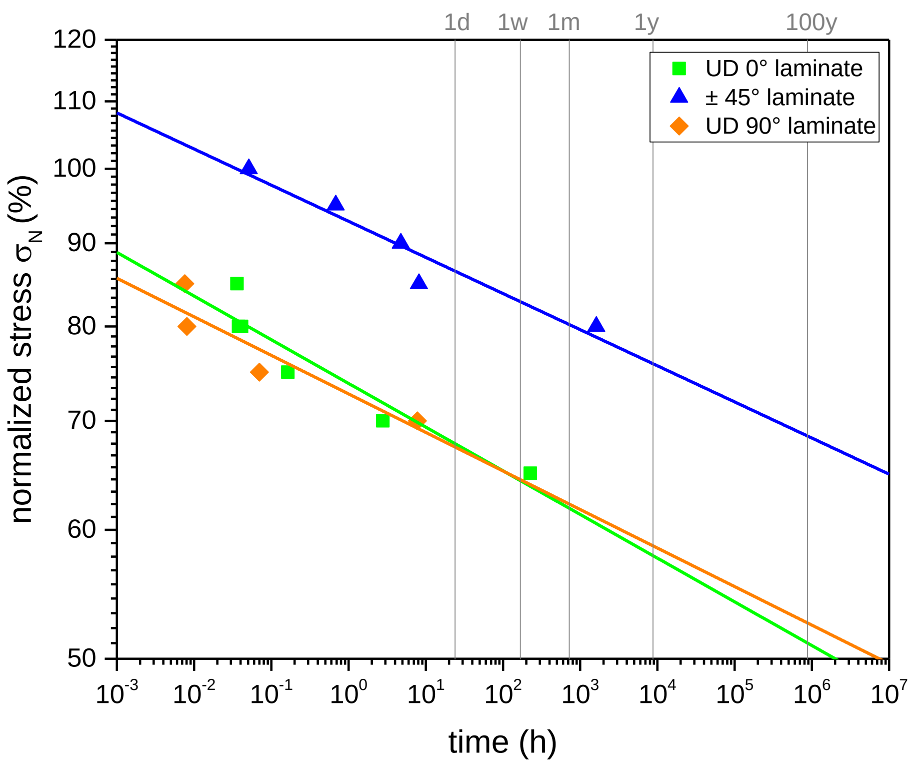

Figure 3. Creep rupture results for the investigated laminates.

The results of the accelerated approaches to investigate the creep rupture behavior are diagrammed in Figure 4. With the unidirectional reinforced laminates (UD 0° and UD 90°) both accelerating measuring methods lead to results whit a higher creep rupture strength at the same failure time, which is an indication that the acceleration of the test procedures cannot optimally reproduce the time dependent material degradation processes under static load. However, the absolute deviation is less than 10% normalized stress over the whole illustrated time range at a considerable reduction of testing time. For the laminate ± 45 ° the results of the SRCR show a similar long term material performance compared to the classic creep rupture tests. On the other hand the carried out tests based on the SSM fail earlier, especially at lower normalized stress levels, which is associated with a significant reduction of the elongation at break.

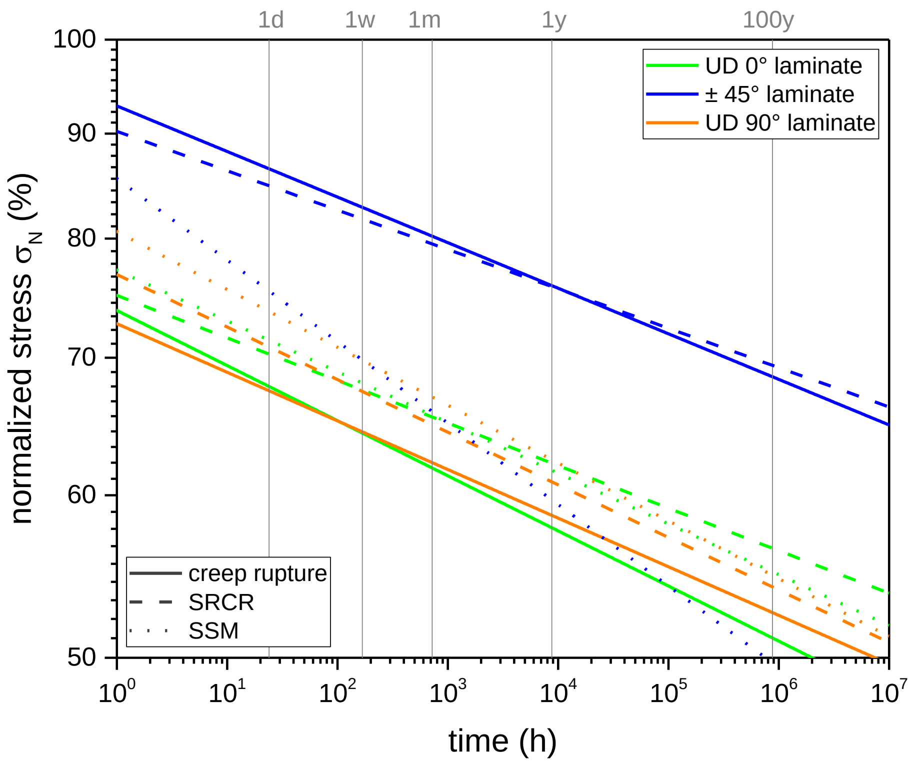

Figure 4. Results of the creep rupture tests (solid line), the SRCR (dashed line) and the SSM (dotted line) for the investigated laminates.

4. Conclusion and Outlook

The results of this investigation offers possibilities to reduce testing time and to accelerate testing procedures of classic creep rupture tests to predict the material lifetime of composite materials under static load with certain strengths and weaknesses. The summarized results of the accelerated testing approaches demonstrate, that the suitability of the investigated approaches are dependent on the fiber orientation of the investigated composite materials and still some work is necessary to identify the reason why. Nevertheless, due to the enormous time saving potential the applicability and limitations of these test procedures is worth to be studied in more detail. Based on the presented results for composite materials, the use of the SRCR is recommended. Another possible prediction method to reduce the experimental testing times are fatigue tests with increasing R-ratio (min load/max load) whose suitability is also under investigation.

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