Stimulated Simulation Methods for Accelerated Fatigue Characterizations In Heterogeneous Materials

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Abstract

Reifsnider and Case (2002)[i] have recently discussed a methodology for combining the effects of multiple physical phenomena (like fatigue and creep) to estimate long-term performance metrics (like remaining strength and life) in the presence of changes in material states and stress states. This methodology was originally conceived to enable the application of composites to high-performance aircraft, including the F-16 in the 1980's, with the help of several industrial partners. The most common operative form of that methodology is a simulation code (called MRLife) which combines data from physical measurables with rate equations and kinetic models of material state changes to simulate, in real time, the performance of composite materials and systems. Halverson[ii] has taken the methodology one step further and has shown that one can improve the predictions of performance for a specific component by using at least one of the physical measurables to "stimulate" the simulation in real time, to make a greatly improved prediction of future performance for <u>that specific</u> component. That "stimulated simulation" is the subject of the present paper. In particular, the authors will discuss the use of stimulated simulation to accelerate the characterization of the fatigue response of heterogeneous materials such as specialized composites (including functional composites used in fuel cells). Examples of the accelerating effects of stimulation will be presented. The integration of statistical considerations in the method will also be discussed.

The core of this approach is the use of physical measurements that are related to long-term performance. The plan can be applied in a statistical context, but the method is based on the modeling of the physical processes that are at the heart of the performance desired and changes in that performance with time and history of use. The method of accelerating testing is sketched below.

The method is based on a measurable performance metric, such as strength, or power in the case of a fuel cell, which we can also calculate based on the physical, chemical, thermal, and mechanical state of the materials in a given engineering component, and the applied conditions which specify the external variables such as temperature and mechanical loading. For a given level of applied conditions, a given cell operates within performance requirements for a specific time, or 'life.' For Level 01 in Fig. 1, for example, the life would the time, t01, the time required to reduce the performance down to the (constant) level of applied conditions (expressed in terms of the metric). For constant Level 02 conditions, t3 would be the life. If conditions are not constant, then the metric defines equivalent degradation.

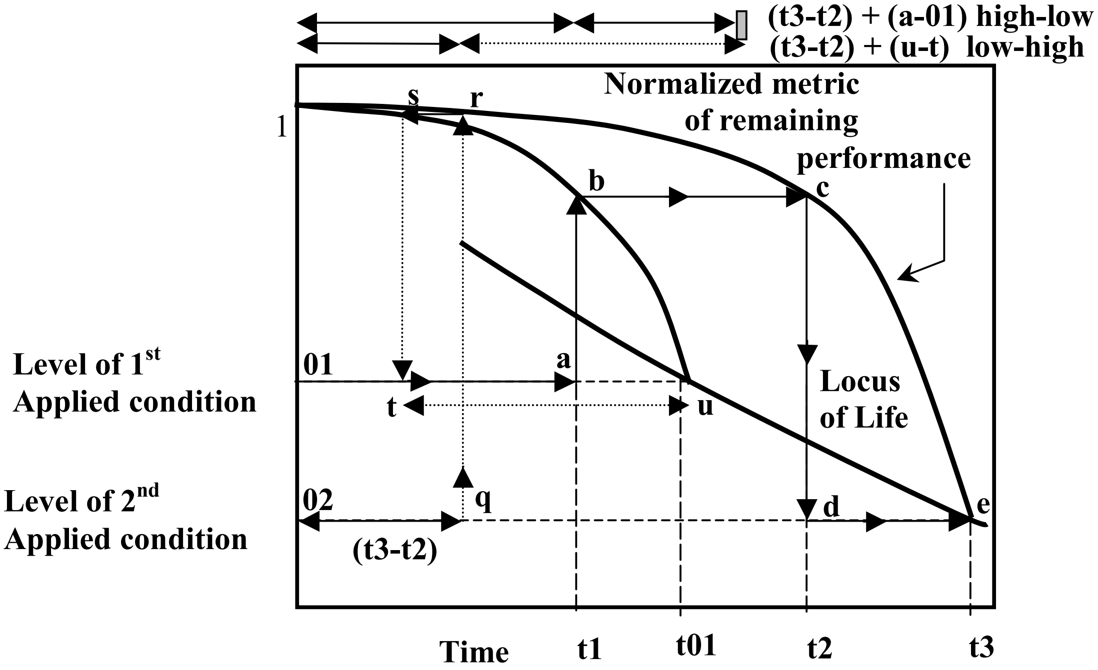

Figure 1 Schematic of accelerated testing concept.

If we stop Level 01 at t1, and change to applied Level 02, then the line (abcd) defines the equivalent time at Level 02 (same degradation) as t2, from which degradation continues at that new level. Then the remaining life is (t3-t2). If we reversed the order of the applied conditions, and apply Level 02 first for a time of (t3-t2), then ask what the life is left if we go to the higher level, Level 01, the line (qrstu) gives the answer. But unless the metric degradation lines are straight, the high-low sequence has a different life than the low-high sequence – high-low has a shorter life in this case as the comparison at the top of Fig. 1 shows. This is an easy way to test the validity of the metric in the laboratory (c.f. Reifsnider and Case, 2002). However, if we can predict the different life for these two sets of applied conditions, we can, by definition, "accelerate testing" by using observed data for short life conditions to predict long-term behavior, for that failure mode (only). This methodology will be discussed in the paper.

For fuel cells, candidate variables for use in accelerating testing include temperature, relative humidity, and external power load. Global measurables that may be followed to indicate the rates of degradation (once the mechanisms are identified) include H_2 crossover rate and fluoride concentration in collected water, as well as open cell voltage and the voltage-current curve. Accelerated fatigue testing of fiber-reinforced composite components will also be discussed, with examples of data compared to predictions.

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[i] Reifsnider, K.L. and Case, S.W., (2002), Damage Tolerance and Durabiliy of Material Systems," John Wiley & Sons, New York

[ii] Halverson, H. (1996), "Improving Fatigue Life Predictions: Theory and Experiment on Unidirectional and Cross-ply Polymer Matrix Composites," M.S. Thesis, Department of Engineering Science and Mechanics, College of Engineering , Virginia Polytechnic Institute and State University