Transition State Theory based Thermally Activated Breakdown in Fiber Bundles: Exact Solutions and Asymptotics for the Lifetime Distribution, Average and Variance

S. Hiemer[1*], P. Moretti[1,2], S. Zapperi[1,2,3], M. Zaiser[1]

[1] Institute of Materials Simulation, Department of Materials Science Science and Engineering, Friedrich-Alexander-University Erlangen-Nuremberg, Dr.-Mack-Str. 77, 90762 Fürth, Germany, Stefan.Hiemer@fau.de

[2] Center for Complexity and Biosystems, Department of Physics, University of Milan, via Celoria 16, 20133 Milan, Italy,

[3] CNR - Consiglio Nazionale delle Ricerche,Istituto di Chimica della Materia Condensata e di Tecnologie per l'Energia,Via R. Cozzi 53, 20125 Milan, Italy

Fiber bundles serve are the easiest model used to describe the statistical aspects of failure and fracture. For the special case of thermally activated failure in creep a model based on stationary Gaussian thermal noise in the form of additional force fluctuations has been introduced by Guarino for the equal load-sharing force fiber bundle [1]. Roux provided the exact solution for the average lifetime and the asymptotics of average and variance in the limit of many fibers and low temperature for a homogeneous fiber bundle [2]. However the assumption of a Boltzmann like distribution has been analytically difficult to handle and bears little empirical basis.

A new fiber bundle model based on transition state theory is established [3]. The failure rate of individual fibers is given by an Arrhenius relationship with an energy barrier linearly lowered by the applied force. Thermally activated fiber failure is assumed follow the usual Poisson process. for an arbitrary number of fibers the lifetime distribution, average and variance can be solved exactly. The asymptotic limit for many fibers reveals a constant average lifetime and the variance decreasing inversely proportional to the number of fibers. The exact and asymptotic expression agree perfectly with simulations. The low temperature limit by Roux shows the same with respect to the number of fibers, but a different relationship with regards to applied force and temperature is found [2]. For heterogeneous fiber bundles, the lifetime distribution is shown to be a high dimensional integral over a phase type distribution with no elegant closed form expression. For fiber strengths distributed according to uniform an exponential distributions, simulations show the lifetime average and variance to behave identically in the asymptotic limit of many fibers as bundles of the homogeneous fiber bundle. The lifetime does have a strong dependence on the details of the fiber threshold distribution. Preliminary results with regards to the asymptotic avalanche distribution will be presented which suggest a power law scaling of exponent 1.5 as has been derived by Hemmer for the quasistatic case [4].

References

[1] Guarino, A and Scorretti, R and Ciliberto, S, Material failure time and the fiber bundle model with thermal noise, arXiv preprint cond-mat/9908329 (1999).

[2] S. Roux, Thermally activated breakdown in the fiber-bundle model, Physical Review E 62 5 6164 (2000) APS

[3] H. Eyring, The activated complex in chemical reactions, The Journal of Chemical Physics 3 2 107–115 (1935) American Institute of Physics

[4] P. C. Hemmer, A. Hansen, The distribution of simultaneous fiber failures in fiber bundles, (1992)