# Predicting Fatigue Life Using Energy-Based Damage Measures

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This study evaluates energy-based fatigue damage measures - specifically the energy accumulation graph and the unified mechanics theory (UMT) thermodynamic approach - for predicting low-cycle fatigue life in steels exhibiting cyclic softening. The energy accumulation graph characterizes fatigue behavior by relating cumulative plastic strain energy to the number of cycles to failure in a double-logarithmic scale, obtained by summing the plastic strain energy dissipated in successive hysteresis loops (Fig. 1). This representation extends the classical Palmgren-Miner concept by using experimentally measured cumulative energy rather than assuming a constant per-cycle damage fraction. Lines parallel to the main curve denote equal damage levels and enable fatigue-life prediction under variable loading by comparing accumulated energy with the critical failure threshold. As an energy-based metric, it provides a more physically grounded description of degradation than stress- or strain-based methods and captures microstructure-dependent effects, including anisotropy.

The UMT approach further enhances fatigue prediction by integrating energy, entropy, and thermodynamic state variables, offering a more robust description of degradation than empirical models and improving differentiation between sample orientations. Experimental verification demonstrates that these energy-based methodologies improve the accuracy of fatigue-life calculations, particularly for anisotropic materials or components produced using advanced manufacturing, by enabling service load histories to be transformed into incremental plastic energy contributions and summed to a critical failure value.

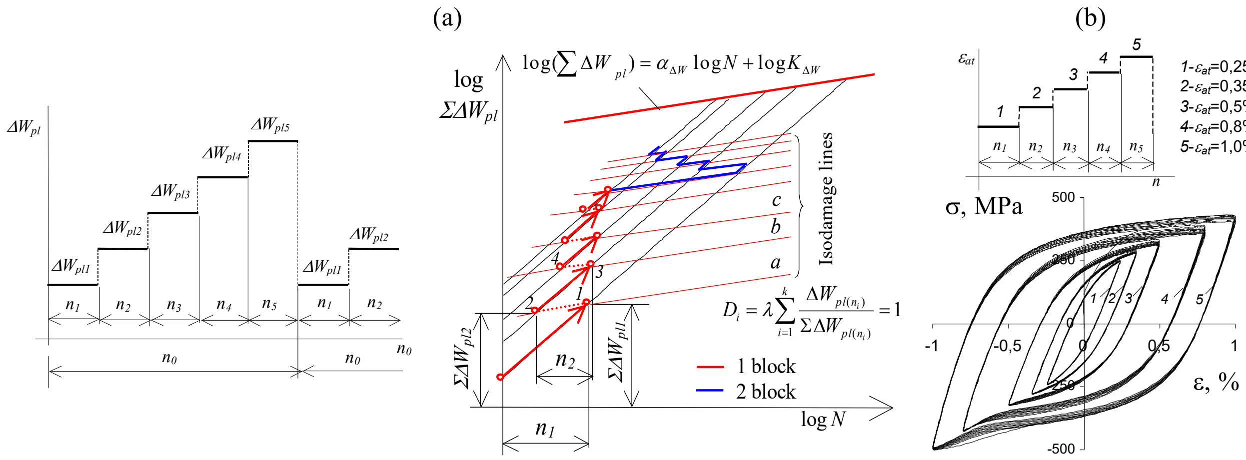


Figure 1. (a) Summing up damage using a cumulative chart; (b) Hysteresis loops in a single load block (last block before sample fracture) [1].

[1] A. Mroziński, M. Piotrowski, W. Egner, H. Egner, *Materials* **19**(2), 352, 2026. https://doi.org/10.3390/ma19020352