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Modeling corrosion-fatigue in bcc metals with unified mechanics theory

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Introduction

Corrosion-fatigue interaction is a common degradation problem in all metal engineering structures. The unified mechanics theory (UMT) was used to develop a model to predict the fatigue life of pre-corroded steel samples with the bcc crystal structure. The model was also verified experimentally. For verification purposes, A656-grade steel samples were immersed in a 5 wt.% sodium chloride (NaCl) solution at a pH of 7. Electrochemical measurements were made with a potentiostat to monitor corrosion. Then, ultrasonic vibration fatigue tests were conducted on these corroded samples at 20 kHz frequency. Unified Mechanics Theory is an ab initio unification of the laws of Newton and the 2nd law of thermodynamics as formulated by Boltzmann-Planck. Because entropy is included in the differential equation, no empirical curve fitting degradation/dissipation/aging function or potential is needed. However, the thermodynamic fundamental equation must be analytically derived from physical chemistry without test data to calculate the entropy rate. The thermodynamic fundamental equation of a material formulates all the atomic mechanisms the material utilizes to respond to external energy; these are entropy generation mechanisms during the corrosion and ultrasonic vibrations for this corrosion-fatigue case. The cumulative entropy generation was then used to calculate the Thermodynamic State Index (TSI), which starts at zero and asymptotically approaches one at failure. TSI is a linearly independent axis in addition to the Newtonian space-time axes coordinate system. Therefore, derivatives of displacement with respect to entropy are non-zero in UMT, unlike Newtonian continuum mechanics. The proposed model results agree well with the experimental measurements, thus proving that the UMT-based model can accurately predict the very high cycle fatigue life of previously corroded samples without relying on empirical curve fitting models.

Laws of the Unified Mechanics Theory (UMT)

Second Law of UMT: The initial impulse of an object will degrade according to the second law of thermodynamics and the thermodynamic fundamental equation of the material along the TSI axis.[1]

$$(1 - \Phi)F\,dt = m\,dv \tag{1}$$

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Third Law of UMT: The initial reaction of a body in response to an action will change over time in the composition according to the second law of thermodynamics and the thermodynamic fundamental equation of the material as stiffness degrades, displacement increases over time, [1]

$$F_{12} = F_{21} = \frac{d\left(\frac{1}{2}(k_{21}(1-\Phi)\, u_{21}^2\right)}{du_{21}} \tag{2}$$

where Φ The Thermodynamic State Index (TSI) is the normalized form of Boltzmann-Planck's second law of thermodynamics.

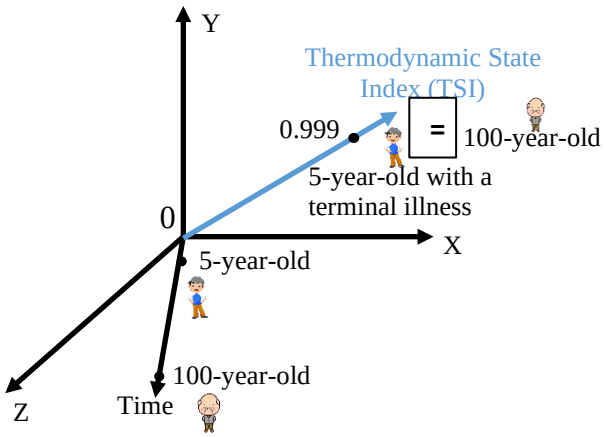

Figure 1: Coordinate System in Unified Mechanics Theory

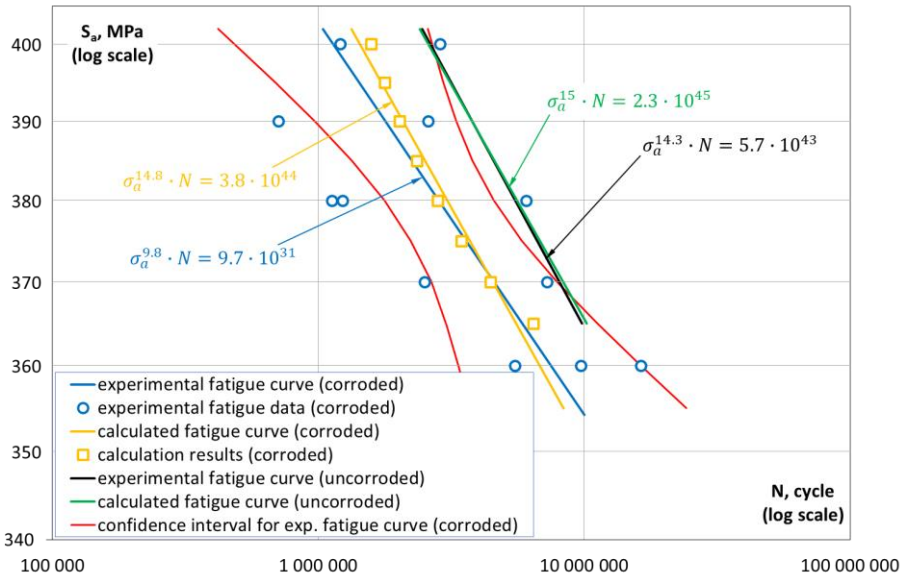

Figure 2. Comparing Experimental Data with Simulations

References

[1] Cemal Basaran, Introduction to Unified Mechanics Theory with Applications, second edition, Springer, 2023

[2] Hsiao Wei Lee, Hamidreza Fakhri, Ravi Ranade, Cemal Basaran, Halina Egner, Adam Lipski, Michał Piotrowski, Stanisław Mroziński, Modeling fatigue of pre-corroded body-centered cubic metals with unified mechanics theory, Materials & Design, Volume 224, 2022, 111383,

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