HUMAN-IN-THE-LOOP MACHINE LEARNING WITH GPTIPS: APPLICATION TO CREEP CONSTITUTIVE MODELING

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ABSTRACT

The objective of this study is to develop a framework for the creation and development of human-explainable mathematical models by applying symbolic regression (SR) techniques and the Human-In-The-Loop (HITL) Machine Learning (ML) method. We seek to demonstrate the capabilities of the HITL ML method by obtaining a constitutive model capable of describing and predicting the creep behavior of different classes of steels across several isotherms and stress levels. Explainable, constitutive models of creep have been developed either empirically or derived by performing a rigorous physics-based analysis of the mechanics of materials. Such approaches have been challenging and time-consuming; the limited availability of data, as well as the increasing complexity and introduction of more variables—such as processing, microstructure, and chemical composition—have made it harder to discover the underlying relationships between the variables. Previous ML approaches have proved useful. However, good predictions have mainly involved the creation of hidden ("black-box") models, for their complexity is such that they are not human-interpretable. In this study, we use the GPTIPS (Genetic Programming Toolbox for the Identification of Physical Systems; a MATLAB toolbox) software to leverage its SR capabilities and illustrate the effectiveness of the HITL ML method by creating predictive, human-explainable stress-rupture models. Based on few creep data for an austenitic stainless steel (< 60 data points), we obtain a high-predictive-performance model and apply it to a set of three additional high-chromium steels (9, 12, and 21 wt% Cr). The model's performance exhibits good fit and low error ($R^2 \leq 95.5\%$, NMSE ≥ 0.004 for log-scale approximations). The authors foresee that inclusion of more data and variables to train the model would positively contribute to the development of constitutive models. The importance of this work lies on the established framework, capable of supporting the development of human-explainable models by applying both the high throughput capabilities of machines and the knowledge/expertise of human researchers.