1. Uncertainty Quantification of Material Models for Process Simulation

Abstract: In composite process simulation, the ability to accurately capture changes in material behavior, such as degree of cure/crystallinity, viscosity, modulus and thermal expansion during the process is of great importance for making accurate predictions about the outcome of the process. Material behavior is commonly described by a mathematical equation whose parameters have been determined by fitting the equation to experimental data. This paper demonstrates the use of contemporary statistical methods to fit both parametric and nonparametric material models, how to quantify and reduce prediction error and uncertainty and how to avoid overfitting. Methods highlighted include: least-squares regression, Gaussian process regression, empirical Bayes and k-fold cross-validation. By quantifying prediction error and uncertainty, the value of data quantity and experimental design can be quantified, which is very useful when designing test matrices for material characterization.

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2. Building Future Factories: A Smart Robotic Assembly Platform Using Virtual Commissioning, Data Analytics, and Accelerated Computing

Abstract: Modern manufacturing platforms are defined by the quest for increased automation throughout the production cycle. This continuing pressure towards automation dictates that emergent technologies are leveraged towards this goal. Unfortunately, this increasing automation brings additional complexity and production issues. To address these challenges, this paper discusses the methods developed and deployed by our team (USC neXt) to employ (1) large-scale simulation, (2) system health monitoring sensors, and (3) advanced computational technologies to establish a life-like digital manufacturing platform and to capture, represent, predict, and control the dynamics of a live manufacturing cell. A machine learning based Digital Engine will be used to dynamically control and schedule operations in the live manufacturing cell, based on simulation results and real time data. Sensors, such as load cells, accelerometers, robot monitors, and thermal cameras will connect to digital twin systems, collecting and sharing accurate real-time plant descriptions between stakeholders. By creating our future factory using an Industrial Internet of Things (IIoT) platform, we will present data-driven science and engineering solutions to our industrial partners, accelerating the Smart Manufacturing Innovation. Future work will focus on applying the proposed methodology on more diverse manufacturing tasks and material flow, including collaborative assembly jobs, visual inspection, and continuous movement tasks.

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3. Applications of Machine Learning for Process Modeling of Composites

**Abstract:** Science-based simulation tools such as Finite Element (FE) models are widely used in engineering applications including process modeling of composites. There are inherent limitations associated with these models including trade-off between fidelity and cost, inability to tackle uncertainties such as unknown manufacturing boundary conditions, and difficulties with inverse modeling and optimization of multi-dimensional problems. With the rise of Machine Learning (ML) and data-driven modeling, many branches of science and engineering are exploring the applications of these methods with varying degrees of success. Here we explore current applications of ML in process simulation of composites. With several case studies, it is demonstrated how some of the limitations of traditional science-based models can be addressed using a combined FE-ML approach in the new paradigm of Theory-Guided Machine Learning (TGML). Specifically, case studies are presented for thermo-chemical analysis of composites processing, where surrogate Neural Networks (NN) are developed for near real-time modeling of the manufacturing process.

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4. Thermal Analysis of Historical Autoclave Data Using Science-Based Data Analytics Methods

**Abstract:** In typical aerospace composites manufacturing practice, autoclave thermal data is used for verifying the compliance of parts to specifications while rarely being used to turn the raw data into actionable items to drive tooling, equipment and specification improvements that could result in increasing production efficiencies and reducing composites manufacturing risk. Currently, any historical data analysis that is performed on such data sets is often manual, inefficient and analyst dependent. Consequently, improvements to production, such as the optimization of existing autoclave loads, the optimal introduction of new parts and the systematic management of process upsets, are not routinely performed.

Nine years of historic data from a production autoclave was investigated by composites manufacturing process simulation experts in order to extract actionable information. Thermal data from 4075 autoclave runs, totaling 75,130 individual parts with well over 200,000 thermocouples, was parsed into a NoSQL database and analyzed from a standard workstation PC. The local heat transfer coefficient for 24,373 parts were calculated from nearly 50,000 thermocouple traces using a lumped capacitance approach. The heat transfer coefficients showed a normally distributed response of 65.3±25.3 W/m² K. Almost all the heat transfer coefficient data fell between 0 and 200 W/m² K.

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