Digitalisation and Artificial Intelligence in Forging

Towards a hybrid FEM-Machine Learning solution for enhanced simulation of manufacturing processes

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- Mechanical engineer from Universidad Simon Bolivar, Venezuela in 2011
- Master & PhD. On computational mechanics and materials sciences at CEMEF (center for material forming) from PSL – MINES ParisTech (France)
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- Scientific Software developer at Transvalor since 2015 working on: electromagnetism, damage & fracture mechanics, numerical methods for parallel computing.
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Abstract

The current work introduces some of the research activities conducted by Transvalor S.A. in the integration of Machine Learning algorithms with traditional Finite elements simulation tools.

The first topic focuses on developing surrogate models to expedite the parametric response-surface exploration process. Although current technologies based on Finite Element Method (FEM) solvers offer robust, accurate, and reliable results, they can be computationally expensive. Novel approaches employing Machine Learning allow us to harness fast hardware, producing quicker models by learning from extensive datasets and capturing non-linearities to infer results in a fraction of the time. However, this comes at the expense of accuracy and the resources needed to train the model.

By combining the strengths of high-fidelity finite element analysis, which generates quality datasets, with the application of Graph Neural Networks architecture to capture the distribution of selected results on 3D shapes as a function of a few process parameters, a fast surrogate was constructed [1]. This innovative approach showcased the acceleration of parametric response surface analysis in a closed-die forging scenario, specifically for predicting wear damage on the surface of the dies. The surrogate model efficiently replicated wear damage at the conclusion of the specific forging process within milliseconds, achieving accuracies above 90% compared to the reference Finite Element Method (FEM) solution.

The second topic explores efforts in developing Digital Twins capable of reproducing full-field results through the use of Physics Informed Graph Neural Networks [2]. Such architectures aim to boost the run-time of numerical simulations by by-passing or partially replacing FEM solvers. Preliminary results on problems ranging from pure elastic deformation, elasto-plastic deformation or coupled electro-thermal application show good agreement between results from GNN and FEM, while accelerating computational time.

[1] Shivaditya, Meduri Venkata, et al. "Graph Neural Network-based Surrogate Models for Finite Element Analysis." 2022 21st International Symposium on Distributed Computing and Applications for Business Engineering and Science (DCABES). IEEE, 2022.

[2] Chenaud, Marien, José Alves, and Frédéric Magoulès. "Physics-Informed Graph Convolutional Networks: Towards a generalized framework for complex geometries." arXiv preprint arXiv:2310.14948 (2023).