Uncertainty Prediction Output of a Finite Element Model (FEM) Using Surrogate Modelling Approach

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ABSTRACT

Additive Manufacturing (AM) is a manufacturing approach that can build a three-dimensional object from a computer-aided design model by adding material layer by layer. This method has gained popularity due to its capability to manufacture a product with complex geometries. However, uncertainties exist in its structure as it involves the material properties and geometry parts. A computational approach via Finite Element Method (FEM) is an alternative to overcome these uncertainties. Due to its high computational effort and time consumption, the Machine Learning approach via Surrogate Modelling is another method to produce the output of the simulation results. Surrogate Modelling can generate output with an R^2 value of 0.98 intervals when compared with the FEM results. The results demonstrate the potential of Surrogate Modelling to run FEM output via sufficient training data input.

Keywords: Additive Manufacturing (AM), Finite Element Method (FEM), Surrogate Modelling, Machine Learning, Uncertainty Analysis

INTRODUCTION

Additive manufacturing (AM) is a revolutionary technology for manufacturing products without too much material waste compared to traditional manufacturing methods. This AM technology is gaining popularity among giant industrial players because of its ability to manufacture complex parts from computer-aided design (CAD) to end-user parts. Moreover, AM uses less energy regarding tooling and workers (Seharing et al. 2020). However, one major factor which halted the widespread implementation of AM is the variability and uncertainties in product quality. These uncertainties exist due to the porosity, geometric factors, and residual strength (Mahadevan et al. 2021).

Researchers have conducted corrective measures such as by performing physical experimental procedures. Nonetheless, this approach has created excessive material waste after each experiment. Thus, another method is by computational technique, such as by applying the Finite Element Method (FEM). As AM is a complicated procedure that involves multi-physics criteria, this FEM approach demands too much computational effort, cost, and simulation time. The advancement of Artificial Intelligence (AI) technology has led to the implementation of a surrogate model as another alternative method to emulate a computational simulation. This method is lighter and accelerates simulations (Huzni et al. 2022).

In this work, a surrogate model is applied to predict the outcome of a FEM simulation output. An aluminium plate is modelled as the FEM study case, as indicated in Figure 1. Force, F, is applied on the top edge of the model. Due to the symmetrical effect, a quarter of the plate is modelled. Table 1 shows the uncertainty parameters involved in the FEM simulation. In these parameters, a range of values is implemented. The simulation output focuses on the arc of the FEM model.

Fig. 1 Plate model with boundary conditions

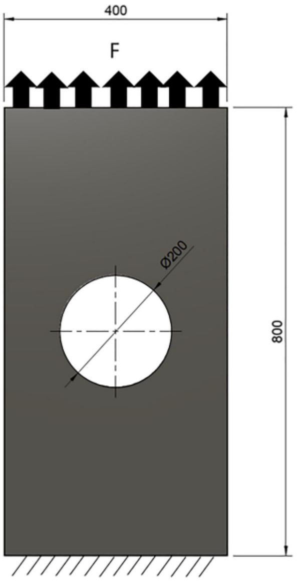

Table 1. Uncertainty parameters of FEM model

Uncertainty parameters
Young's Modulus, *E*
Poisson ratio, *v*
Force, *F*

RESULTS AND DISCUSSION

Figures 1 and 2 show the FEM prediction output of the surrogate model for Von-Mises stress and displacement of the FEM model. The prediction output is for the maximum force value of 6500 N and minimum force value of 6100 N that are applied to the FEM model. Both figures show that the predicted curves are almost superposed with the FEM output curve and follow the same trend. This indicates that the error between the FEM-generated output and the surrogate prediction has a very minimum error gap. Thus, the surrogate model can predict a FEM output with less error only with sufficient input data training (Asteris et al. 2021).

Tables 2 and 3 represent the error generated by the surrogate model prediction output when compared with the FEM output for the Von-Mises stress and displacement parameter. Four simulations are performed, each showing an error of less than 1%. The total average error value for each simulation is also less than 1%, which indicates the reliability of the surrogate model in predicting FEM output.

Fig. 2 Von-Mises Stress Output

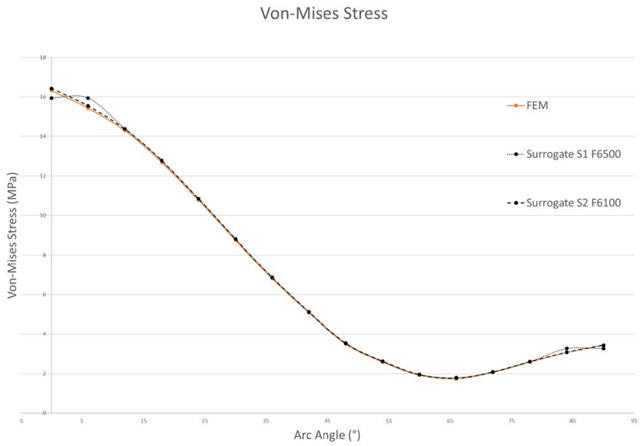

Fig. 3 Displacement Output

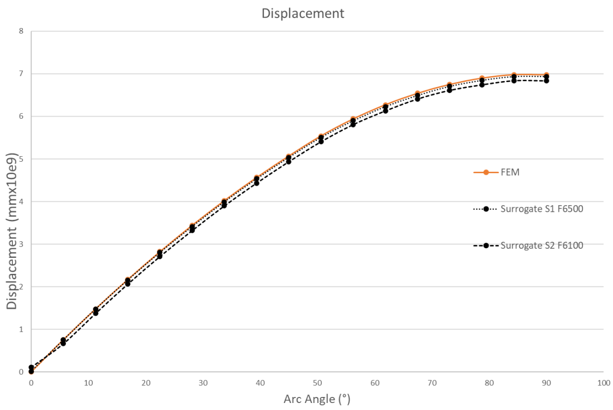

Table 2. Generated error output for Von-Mises

Surrogate model	***1***	***2***	***3***	***4***	***Average, ∑***
Regression error, R^2	0.9998	0.9988	0.9990	0.9996	**0.9993**

Table 3. Generated error output for displacement

Surrogate model	***1***	***2***	***3***	***4***	***Average, ∑***
Regression error, R^2	0.9857	0.9989	0.9990	0.9988	**0.9956**

CONCLUSION

Based on the results obtained, the surrogate model with sufficient training from input data can produce FEM output prediction with an error generated approximately less than 1%. This AI method helps to reduce FEM computational effort and time, especially when involving a complex model such as AM model.

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