9. TOWARD DEVELOPING SURROGATE MODEL INTEGRATING MULTI-PHYSICS, MULTI-CRITERIA MODELS FOR ADDITIVE MANUFACTURING TECHNOLOGIES

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ABSTRACT

Additive Manufacturing (AM) is intensifying the digitalization of the manufacturing and generating disruptive changes and the paradigm shift in the industry. To boost the productivity in AM, the improvement in parts qualification is required. Qualifying the parts implies the capability to ensure constant and repeatable part properties meeting the engineering design requirements. It implies to certify not only the structure, properties and global performance of a part but also its manufacturing process. Modelling and simulation techniques can target them separately, but linking models describing those characteristics is quite challenging since they have the different level of details and sometimes different purposes. Presenting those models in the form of causal graph will enable us to combine models with different level of details. The current research utilizes functional analysis and dimensional analysis to present the models in the form of the causal graph between associated parameters. The DACM Framework integrating fundamental required methods and theories is briefly explained in this article. The current research will then aim at developing a surrogate model capable of integrating the different models such as microstructure models, layer by layer melting/solidification and part models. The final comprehensive model can simulate to AM system to fulfill multi-criteria performances.

INTRODUCTION

Integration of Additive Manufacturing into the existing manufacturing technologies and boost the productivity in AM requires a reliable part qualification. Therefore, a deep understanding of different AM processes, their capabilities, and limitations, their associated multi-physics, can guide the manufacturing sector to be able to certify the additively manufactured parts. To provide the required knowledge for each process with less amount of time and expense, the modelling and simulation play a significant role. Despite the existing modelling challenges such as the multiphysics nature of processes, the current models and simulations offer the relatively higher maturity, due to the advancement of information technology and computational science. Each model is developed with different purposes, different level of detail, and different constraint. Even though developing mature models are crucial, those models usually often cannot be reused by switching from machine to machine or from process to process. Furthermore, different models with different purposes and level of detail can be seen as the separate islands that are not integrated toward a worthwhile multi-criteria model. So the research question rises up here is 'how to link different models with different purposes and details, for having a holistic multi-criteria model in AM?'. Toward this end, Witherell et al. from National Institute of Standard and Technology (NIST) proposed to use a metamodeling approach and develop the ontology for supporting the model reusability [1]. To tackle this research question, we believe that presenting the models in the form of the causal graph will enable us to combine models with different level of details and different purposes. Different models such as microstructure models, layer by layer melting/solidification and part models for each AM process can be integrated into a surrogate model. So the fundamental goal of the research is to use the network-based approach to present a causal model that can be simulated. In order to achieve this aim, we are applying Dimensional Analysis Conceptual Modelling (DACM) Framework on different additive manufacturing technologies such as Direct Energy Deposition (DED) [2], Fused Deposition Modelling (FDM) and Cold Metal Transfer (CMT). The fundamental pillars of DACM Framework are briefly explained in the methodology section.

METHODOLOGY

Dimensional Analysis Conceptual Modelling (DACM) Framework is a powerful modelling methodology, initially developed for specifying, discovering, validating and analyzing system behavior [3]. The methods and theories integrated into the framework are articulated around fundamental pillars such as functional modeling, dimensional analysis, Bond graph organs, causal rules and colored hypergraph. Figure 1 illustrates the step by step modelling procedure using DACM Framework. After clarifying the model objective and defining system borders, the modeling starts with functional modeling of an existing system or a system to be designed. Presenting proper functional architecture is mostly important because a reliable modeling or simulation highly depends on upon a solid knowledge of the sequence of functions taking place in the system under investigation. Then the functional model of the system will be mapped to the Bond Graph representation of the system. This mapping is done for each function based on the vocabulary mapping presented by Hirtz et al. [4]. The Bond graph is a type of domain independent graphical representation of a system. The Bond graph is composed of limited 'elements' which are linked together by the 'bonds' [5]. The idea of mapping the functional model to the bond graph is first because of being able to multi-domain and multi-physics model, and second for the reason of using causality rules in the theory. In the next step, the influencing variables of the system are assigned to the latest bond graph representation. Based on the causality rules and assigned variable, we are able to present a special neural network, in which the variables are connected to each other based on their causality. So at the end of step 6 (See Figure 1) the models are presenting in the form of the causal graphs to describe the physical phenomenon of the model. This causal graph is then transferred to the colored hypergraph.

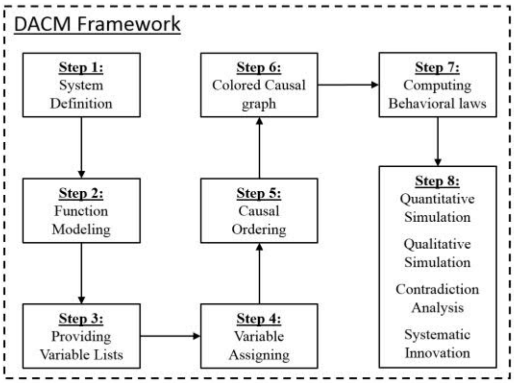

Figure 1 Modelling steps of DACM Framework

Afterward, based on the casual graph and the unit of each of variables, we are able to compute the behavioral laws of the system under investigation using dimensional analysis. Dimensional Analysis has been developed to deduce the mathematical relation between variables from the fundamental dimensions of variable (Mass, Length, Time, etc.) [6]. The eager readers are invited to find more detail information about the DACM framework in the article published by Eric Coatanéa et al. [7]. The models in the form of causal graph adding to their behavioral laws can be combined to each other. Then can be used for different kind of purposes such as quantitative simulation, contradiction analysis, qualitative simulations or as a systematic approach toward innovation.

CONCLUSION AND PERSPECTIVE

In this paper, the fundamental objectives of the current research and general description of the methodology were briefly explained. We are aiming at developing the method for presenting surrogate model capable of integrating the models with different purposes and level of detail that can be simulated. Having this kind of model will help us to increase the predictability and reliability of AM to boost the productivity of this emerging technology. One of our future research will be dedicated to the in-situ enrichment the network based model using the sensor on the additive manufacturing device and consequently act online on the parameter setting in order to reach the desired performance.

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