Characterization and Prediction of P420 Laser Cladding for Digital Twins

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Abstract

Modern manufacturing technologies such as Additive Manufacturing are a vital pillar of Industry 4.0 and Smart Manufacturing systems. One of the most promising AM techniques is Directed Energy Deposition (DED) which uses a thermal source to generate a melt pool on a substrate into which metal powder is injected. Laser Cladding (LC), a DED additive process, is widely used in machine parts repair and functional coating due to its advantages, such as the low heat input into the substrate. Compared to conventional welding, this results in less induced stress, lower dilution rate, small heat-affected zone, and good metallurgical bonding between the coating and the substrate. The LC technology is not as robust or standardized. The part quality, mechanical properties, and microstructure of Laser-Cladded parts are neither as commercially predictable nor controllable. This research aims to develop Deep Learning models that predict and classify the LC process for LC coating and single and interfering-bead samples. The ML models will detect faulty process input parameters and predict the quality. This detection and prediction take place in real time, which is vital in producing the additive process's data model component of a Digital Twin (DT). Digital imaging of a coaxial CMOS camera and melted pool temperature measurements using a LASCON LPC04 pyrometer are being used as in-situ sensory devices. A plethora of articles have limited their ML models to individual combinations of substrate and powder and focused on the three main process parameters (laser power, laser beam scanning speed, and Powder feeding rate). This research project expands the scope to include a different substrate and powder combinations, utilize additional parameters, and exploit different powder/substrate combinations. The Inputs

will be gathered and manipulated in a controlled environment to predict both good-quality and poor-quality LC. The process will take place by building geometries selected strategically to associate uncontrollable parameters, especially the temperature of the substrate, in the prediction model. The online optical images and the offline microscopic analysis of the sectioned bead are mapped together. In a later stage, the ML can potentially integrate into a control system and digital twin models.

Keywords
Additive Manufacturing; Laser Cladding; Prediction; Machine Learning; Melt Pool; Digital Twin.

Biographies
Malek Mousa is a Ph.D. student in the department of Industrial Engineering at the University of Windsor. He received his B.Sc. degree in Mechanical Engineering from Jordan University of Science and Technology, in 1997. He received his M.Sc. in Mechanical Engineering from Concordia University, in 2008. His current research areas include additive manufacturing, design for hybrid manufacturing, and cost engineering. Malek also has extensive experience working in the automotive industry in the product qualification field.

Dr. Hany Osman received the Ph.D. degree in Industrial Engineering from Concordia University, Montréal, QC, Canada. He is an Assistant Professor at the Systems Engineering Department, College of Computer Sciences and Engineering, King Fahd University of Petroleum and Minerals, KSA. His research interests include data mining, operations research, and operations management. Specifically, his research focuses on investigating problems related to production scheduling, inventory control, transfer line balancing, knowledge extraction from datasets and application of data mining in systems engineering. He has developed efficient algorithms by using mathematical programming, decomposition techniques, and nature-inspired metaheuristics.

Dr. Ahmed Azab, PEng, is Director of the Production & Operations Management Research Lab at the University of Windsor and Professor at the Department of Mechanical, Automotive, and Materials Engineering. He has been recipient and nominee for international and national research excellence awards. Dr. Azab's research has been sponsored by National and Provincial granting agencies, which include NSERC, CFI, OCE, MITACS, FEDEV, as well as direct research funds provided by the local industry. He is one of three faculty members to receive a $1M CFI-LOF/MEDI-ORF grant supporting research infrastructure. As for operating funds, He has earned to date in access of $0.6M. Dr. Azab has graduated to date three doctoral students who currently hold faculty positions at the University of Minnesota, Duluth, Cape Breton University, and the United Arab Emirates University. He also has supervised to date eight masters students, eight graduate interns, and three postdoctoral fellows, most of them now work in the industry or holding positions and finishing terminal degrees in research labs. He currently supervises ten graduate students (four of which are doctorate), and one postdoctoral fellow, and one research assistant. He is partnering with national as well as international research collaborators from various research labs and academic institutions in Europe, the Middle East, and USA. He serves as a reviewer for a number of reputable international journals and national granting agencies; he also sits on the editorial board for a few international journals.

Dr. Fazle Baki is Co-Director Director of the Production & Operations Management Research Lab at the University of Windsor. He joined the Odette School of Business in the year 2000. He is cross appointed with the Department of Industrial and Manufacturing Systems Engineering since 2003. He was involved with an industrial research project in Daimler Chrysler as a Summer Professor Intern in 2004 and 2005. Previously, he served the Institute of Business Administration, University Dhaka, Bangladesh from 1992 to 1993. His research interest is to carefully look into systems and processes and find some improvement opportunities with the development of new and improved algorithms. The improvement may be found in the requirement of resources such as capital assets, human resources, time requirement, etc. The improvement may also be found in the quality of service delivered. The systems and processes he look into are usually large and complicated as the optimization problems may often be classified as "NP-hard." Finding a good and efficient algorithm for such problems is generally difficult. However, a mathematically rigorous investigation into the variables, parameters, constraints and objectives may provide some models and algorithms, which are acceptable to the contemporary researchers and practitioners. The algorithms he develops are usually based on mixed integer linear programming, dynamic programming, goal programming, and metaheuristic methods. In the past, he published papers on manufacturing, scheduling and traveling salesman problem. Recently, he is working in the areas of inventory management and healthcare.