IRES Projects: In-Depth

Smart sensors for surface defect detection: Fast segmentation and localization of defects

Background: Recent advancements in additive manufacturing (AM) and other technologies are transforming the manufacturing practices to allow the fabrication of custom components with complex geometries (with improving precisions and finish). This is not feasible with conventional technologies. The market for AM technologies is set to grow beyond $50 billion by 2025 with expanding industrial applications. However, defects, such as pores, undiffused powder, geometric distortions, surface cracks, and non-equilibrium microstructures (Fig. 1), significantly deteriorate the mechanical performance and overall functionally integrity of the components. The current imaging systems need to be improved for fast and reliable detection of these defects.

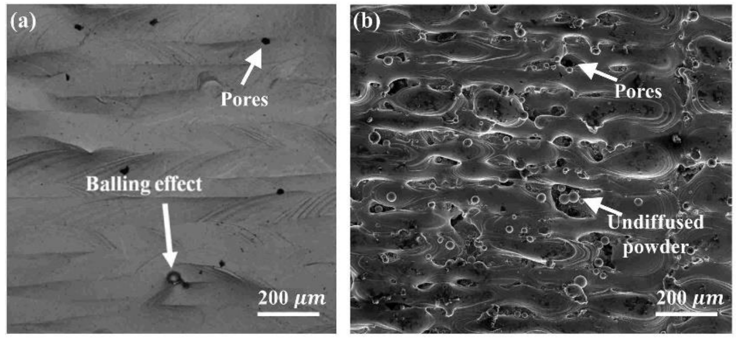

Fig. 1. Micrograph images showing the defects including pores, balling effect, and undiffused powder

Research Objective: This project will investigate novel real-time imaging strategies that are fundamentally non-supervisory, i.e., uses the information from the images themselves to locate the defects.

Research Plan: An REU student will team with a graduate student and an assistant professor at AMIT to leverage the imaging capabilities of a novel instrument from STIL for fast defect localization. STIL's patented Chromatic Confocal sensing technology is one of the very few non-contact techniques for 3D metrology recommended by the ISO 25178 standard. The proposed tasks are: (1) customizing the PI's fully unsupervised learning approach with theoretical guarantees [37] for images from the STIL instrument, (2) addressing the background removal methods for image enhancement, and (3) applying the model on specified benchmark images as well as those provided by the industry partners and extracting performance benchmarks. The challenge here is different from typical image sensing in that we need to learn without the use of labels so that the defect identification may be faster, customized, and granular. The following research questions will be addressed in this context: (1) How to represent the highly textured images as random field and graphs, and how to estimate the parameters of the resulting graph representation? and (2) How to characterize different types of backgrounds, and how do these representations affect the performance fundamentally? The proposed work would lead to a software prototype of the intelligent imaging approach, becoming essential for realizing smart manufacturing systems.

Student Outcomes: The students will gain hands-on experience with the instrumentation and operation of machine tools, as well as the implementation of image processing methods and data interpretation. The research work spurred from the IRES efforts will be communicated to manufacturing journals.

Rapid casting process: XCT characterization of sand mold permeability

Background: Rapid casting project addresses a novel approach (Fig. 5) for casting magnesium and aluminum alloys. Although magnesium and aluminum alloys offer tremendous advantages for the aerospace industry's next-generation structures, their chemical properties pose a significant challenge to the foundry processes used to create critical components of engine blocks and turbines. The novel approach is based on low-pressure casting process coupled with 3D printing of sand molds. The technical and scientific consortium is composed of Airbus, Eurocopter, Danielson, Fonderie de Midi, Transvalor, and ESI to develop the aerospace industry in South France. This R&D project is also supported by PEGASE cluster, INOVSYS' regional platform Henri-Fabre Technocenter, and the EU with an investment of over €3M.

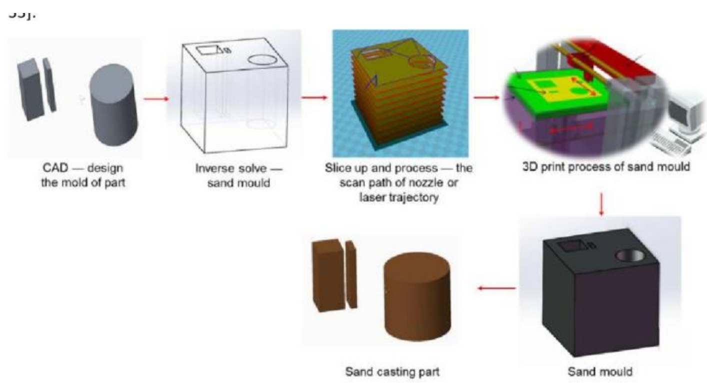

Fig. 2. Overview of the rapid casting process

Research Objective: This project will study the effects of 3-D sand printer settings on the strength and permeability of the resulting molds using x-ray computerized tomography characterization.

Research Plan: An REU student will team with a recent Ph.D. and assistant professor at AMIT to conduct an experimental study of printing cylindrical and bar-shaped test specimens to perform, respectively, traditional permeability and bending strength measurements. Experiments will be designed to measure the progressive effect of binder evaporation on the particular structure of the sand mold, and X-Ray CT scans on select specimens at different times and temperatures to see the resin binder bridge and measure the porosity and permeability through the 3D reconstructed mesh. Recent advances in image analytics and percolation network theory provide a new approach to characterize XCT images. The characterizations can lead to (1) optimal setting of the 3D sand printer machines to provide desired final geometry, strength, and permeability, and (2) computational design of the rapid casting process to minimize experiments to create optimal casting parameters for different geometries and materials.

Student Outcomes: The students will gain hands-on experience with instruments, 3D sand printers, XCT analysis, and data interpretation. The research results from these efforts will be communicated to manufacturing journals.

Smart, sustainable machining of natural fiber polymer (NFRP) composites: Acoustic emission analysis of process variations

Background: Natural fiber reinforced polymer (NFRP) composites are low-cost, light weight, biodegradable, and strong natural fibers that are dispersed in a matrix polymer. Despite these advantages, there isn't sufficient understanding about their mechanical properties and mechanic failure modes. Hence, acoustic emissions (AE) are useful in understanding NFRP's mechanical behavior as they occur as a result of internal structure damages caused by crack formations, aging and external forces. AE testing can provide real-time monitoring of the stress waves generated during mechanical tests on NFRP composites. Analysis of acoustic emission data is important to use AE as a predictive tool to find information about the mechanical properties of the composites as they strongly influence their industrial applications.

Research Objective: The project will investigate advanced characterization and machine learning methods to understand the process of material removal in these biocomposites, and design the composite structures to enhance the industrial quality and productivity assurance.

Research Plan: An REU student will team with a recent Ph.D. and assistant professor at AMIT to conduct an experimental study of the NFRP machining process. Experiments will be conducted to enable in-situ direct observation of the material removal and surface modification under various process conditions. The data and image streams from these experiments will be used to predict quality and productivity outcomes, based on employing advanced deep learning methods. In particular, bi-directional recurrent deep learning methods will be employed, along with explainable AI techniques to impart the capability to detect incipient defects, and develop suitable composite structure design strategies.

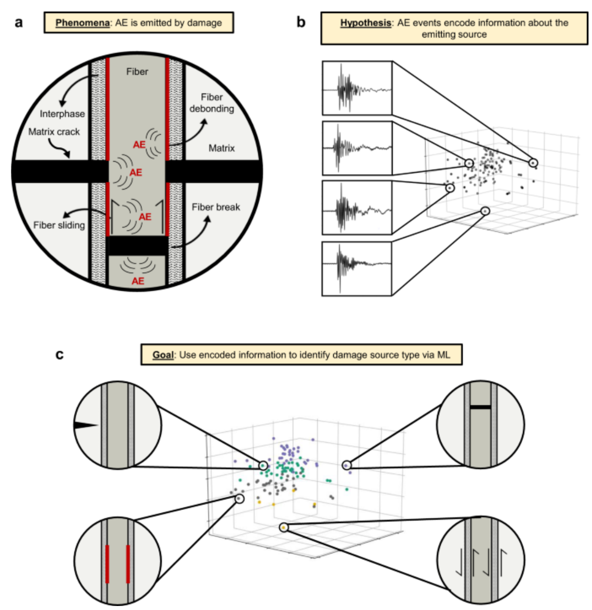

Fig. 3. Damage mechanism identification in composites via machine learning and acoustic emission

Student Outcomes: The students will gain hands-on experience with instruments, manufacturing process platforms, advanced machine learning/AI techniques, and data interpretation. The research results from these efforts will be communicated to manufacturing and data science related journals.

<u>Smart Additive Manufacturing: Development and characterization of functionality graded microstructures in powder-bed AM</u>

Background: Additive manufacturing (AM) is an advanced technology with the capability to produce high-performance components with complex structures and unique characteristics to meet the demands of high-end industries in aerospace, nuclear and space. Powder-bed fusion is an additive manufacturing process that builds each layer of a 3D CAD model by melting then solidifying metal powder via laser. The laser is then fed another layer of powder to create the next layer of the 3D design. Despite the many advantages to AM, there is a challenge to combine material selection, structural design, process control and functionality within an encompassing AM process. A key step to

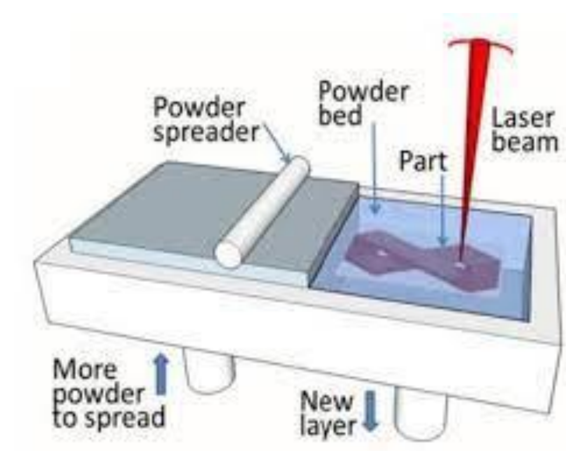

Fig. 4. Schematic of Powder Bed Fusion Additive Manufacturing Process

solving this problem is understanding formation and effect of microstructures in AM components. All in all, microstructures play a significant role in the mechanical properties and structural integrity of an AM component, therefore, bridging the gap between microstructural complexity and design functionality of an AM component is crucial to the integration of additive manufacturing into industry.

Research Objective: This project aims to establish physical relations between the different parameters of the SLM manufacturing process and the mechanical properties of FGMs samples

Research Plan: During this study, we will realize a series of functionally graded materials via selective laser melting (SLM) technique. The FGMs samples will be printed with different energy density and diverse layer thickness. The mechanical properties of elaborated FGM samples will be revealed via a tensile test and Digital Image Correlation (DIC) technique will be used to provide strain measurement. The study should allow establishing a relation between the different parameters of the SLM manufacturing process and the mechanical properties of FGMs samples.

Student Outcomes: The students will gain hands-on experience with in-situ and ex-situ imaging and characterization instruments, SLM 3D printing process, XCT analysis, and data interpretation. The research results from these efforts will be communicated to manufacturing journals.

Fig. 5. ENSAM at Aix en Provence

Facilities, Equipment and Other Resources

ENSAM Campus

Texas A&M Engineering (TEES/TAMU) signed a memorandum of agreement with the Arts et Metiers ParisTech/ENSAM Campus of Aix-en-Provence, France, to establish a joint TEES-TAMU/ENSAM Centre in Material Science and Manufacturing in Aix en Provence. As part of this nascent relationship a study abroad programs for undergraduates have been successfully conducted for the summers of 2018 and 2019. An REU program for one undergraduate student was also successfully completed in Smart Additive Manufacturing for Functionally Graded Materials. The logistics and cost model, including the cost reduction offered by the ENSAM leadership, as well as various social and co-curricular activities, would be available to the proposed IRES-Site program.

ENSAM and Available Facilities

Located near the historic heart of Aix-en-Provence, the campus has a strong territorial anchorage on two strategic industrial sectors: aeronautics and nuclear and renewable energies. Close relations have been established with leading players, such as Airbus Helicopters and the SAFE competitiveness cluster, for aeronautics, and CEA Cadarache, and the Capenergie competitiveness cluster, for energies. The research activities are based on two laboratories of the institution: LSIS-INSM (Laboratory of Information Science and Systems – Digital Engineering of Mechanical Systems) and MSMP (Laboratory of Mechanics, Surface, Materials, and Processes). They contribute to innovations in several areas: the design of production systems, digital engineering, tribology, and surface treatment, and foundry. Also, the campus has a technological platform: Inovsys, dedicated to product design and prototypes. The proposed IRES-Site will leverage the fast casting platform and advanced measurement resources available at MSMP Laboratory.

Henri-Fabre Technocenter

The PI and the international mentor have been collaborating for the past couple of years on topics closely aligned with the proposed IRES-Site. They have access to the world-class industry beds at the Henri-Fabre Technocenter, located near the ENSAM campus. The testbeds at the Technocenter will be leveraged to conduct immersive lab sessions for the proposed IRES-Site. Additionally, the Technocneter brings together several industry partners and technical experts to work with the academe on fundamental R&D challenges. The technical experts from these partner companies would provide special lectures to educate students about the latest and emerging thrusts and challenges in advanced manufacturing.

Fig. 6. Sensor-integrated smart machine tool to be employed for IRES efforts

Henri Fabre Technocentre and Available Facilities

Spread over an area of 150 hectares organized for industrial performance, the vision of the Technocenter is to allow the emergence of a world reference center around the key areas: Mechanics, Materials, and Processes of the future. The Henri-Fabre Technocentre is an unprecedented public-private project enabling partners to synergize their expertise, resources, skills, and projects, and to structure a network with all those involved in innovation and research. The Technocenter around mechanics, materials, and industrial processes. The Technocentre is a place of pooling resources, research, and innovation at the service of industry, especially Small and Medium Enterprises. It is a place of exchanges and technological transfers between sectors subject to similar requirements (innovation, security, sustainability, and productivity) and a place for training and sharing of high-level knowledge. It’s a virtuous circle, based on sharing, to boost innovation and develop market opportunities.