Nanotechnology Project II

Project Summary

Architected materials are engineered materials with topological aspects that enhance their related physical and mechanical properties. Cellular metallic structures represent a new class of materials with significantly reduced density combined with superior mechanical and physical properties. Orthopedic implants are one of the widely known applications that benefits from utilizing cellular structures. With the current advances in 3D printing, additive manufacturing has facilitated the fabrication of complex cellular metallic parts with ultrahigh resolution. Accordingly, the proposed project represents 3-fold research fields: (a) Advanced Materials Design, (b) Advanced Manufacturing, and (c) Advanced Characterization. The graduate student will carry out the research work from their second semester after enrollment for 18 months.

Introduction

With the perceived ongoing advancements in fabrication techniques, the experienced obstacles and challenges for the manufacturing of geometrically complex architected materials are alleviated. Additive manufacturing (AM), also known as 3D printing, is a technology used to manufacture parts by printing them in a bottom-up approach/layer-by-layer fashion. With the current industrial expansion based on large investments in Egypt and the region, it is important to establish an informative highly-skilled generation of scientists and engineers who are capable of leading the latest technology of AM into the industrial sectors in Egypt and the region. AM should be one of the main in this respect. Combining the advantages of AM and advanced materials, an outstanding ultrahigh performance complicated products with pre-engineered designs can be manufactured with ultrahigh resolution. This opens up opportunities in a wide range of fields with orthopedic implants being one for which cellular structures can address the main issues associated with the bulk implants, such as the stress shielding effect.

Problem Statement

Cellular structures are widespread as a building block in nature such as in plants and animal tissues. Adaption of such structures into product design can be used to optimize and engineer the resulting properties, such as the specific strength, energy absorption, and heat transfer. In addition, cellular structures can also be important for biomedical implants. Orthopedic implants suffer from stress shielding effect, which reduces the lifetime of the implant and results in issues at the implant-bone interface. In this respect, structures with engineered porosity at the bone–implant interface can facilitate permanent bone ingrowth and provide secondary stability for cement-free cases. Metal-based Additive Manufacturing facilitated the design and manufacturing flexibility needed for fabricating engineered cellular structures. Capitalizing on the expertise and collaborative research between the research team at AUC and the research team at Birmingham University, will investigate the influence of cellular structures geometry and material (Ti and Stainless alloys) as a function of AM processing parameters on their respective relative density.

Background

Cellular materials can be classified into two categories: stochastic foams and lattice structures. Lattice structures are formed of repeatable unit-cells [1] composed of an interconnected network of struts. Relative density of a lattice structure is considered the most significant feature because it defines the fraction of solid material [3]. This property is key for the special physical properties a lattice structure possesses; such as low thermal conductivity, high energy absorption and specific strength [2,5]. These exceptional properties open up opportunities in a wide range of fields that could not be fulfilled by dense structures [3], with orthopedic implants being one of these fields [7]. Additive Manufacturing the 21st centuries state of the art technology enabled the fabrication of complex geometries and reduced the number of fabrication steps required by conventional methods [6]. Many studies extensively focused on investigating the influence of the processing parameters on the defect formation in dense structures [7-9]. However, for lattice structures, few studies focused on the influence of the SLM process parameters on the internal porosity and geometrical accuracy.

Significance
The proposed project represents 3-fold research fields: **(a)** advanced Materials Design, **(b)** Advanced Manufacturing and **(c)** Advanced Characterization. Cellular metallic structures represent a new class of materials, attracting attention due to their significantly reduced density and superior mechanical and physical properties. Accordingly, **design** and **manufacturing** of engineered cellular structural metals and alloys are hence classified as **multi-functional lightweight materials.** Cellular structures with controlled micron and nanoscale engineered porosity are not easily achieved using conventional manufacturing/fabrication techniques. With the emerging 3D printing, the use of **metal additive manufacturing** facilitates the fabrication of complex structures with ultrahigh resolution. Introducing our graduate students to one of the most recent advances in manufacturing technologies is vital for their preparation in introducing and developing these technologies locally, regionally and internationally.

Project Description
The objective is to introduce graduate students to the fabrication of **advanced engineered porous cellular structural materials** using **metal additive manufacturing** for the fabrication of orthopedic implants. The methodology entails the fabrication of engineered porous metallic implants with controlled, predefined pore size and distribution, and enhanced performance: **(1)** Design and manufacturing of cellular biocompatible structural materials with engineered porosities using metal additive manufacturing (AM), with the optimization of the AM processing parameters**; (2)** Investigate the influence of engineered cellular structural design on the mechanical properties, strut uniformity and durability for biomedical implants. The duration of the project is 18 months. The first 9 months will be used for the design and manufacturing of the cellular structures. The next 9 months will be used for characterization and assessment of the structures' properties and the finalization of the thesis document. The outcome will be the fabrication of a high performance porous metallic Ti or stainless steel alloy biocompatible cellular structure, with enhanced properties for biomedical implants.

The Advancement of Scientific Knowledge and Broader Impact
Combining the advantages of AM and advanced materials, facilitates the fabrication of outstanding ultrahigh performance complicated products with pre-engineered designs with ultrahigh resolution. Preparing generations of engineers and scientists equipped with the knowledge needed for interaction with the most recent advancements Worldwide will have a profound impact on society. This, in turn, will positively reflect on the national economy through domestic production serving various industry sectors, including the biomedical sector.

Biographical Sketches
Hanadi A. G. Salem is a professor of materials science in the Department of Mechanical Engineering. She is the founding director of the Nanotechnology Master's Program at AUC. She is a co-founder of the Egyptian National Nanotechnology Network (ENNN). She received her BSc and MSc degrees in materials science and engineering at AUC, and received her PhD from Texas A&M in 1997. Salem's research currently focuses on Powder and Wire feed additive

manufacturing using Selective Laser Manufacturing and Wire Arc Additive Manufacturing (WAAM). She is the first to introduce the state of the art WAAM process locally and regionally for the repair and remanufacturing of parts. Salem's also has vast expertise in the processing of bulk nanostructured materials (BNSM).

Leveraging Resources

Capitalizing on the prior expertise in the fields of advanced materials design including engineered cellular structures [10]. Salem's collaboration with Birmingham University, UK, renders the 3-fold proposed research project becomes feasible. The AUC Mechanical Engineering Department has the (a) softwares necessary for cellular structure design, (b) advanced mechanical testing, and (c) automated microstructural characterization microscopy. At the Youssef Jameel Sciences and Technology Research Center (YJSTRC) facilities such as state of the art electron microscopies and nano-characterization equipment are also available.

Deliverables

Deliverables include a master thesis deposited at the Digital Archive and Research (DAR) Repository of the American University in Cairo, publically accessible. In addition, the results of the research project will be disseminated through recognized venues in the field, such as international conferences and/or journals.

Professional Development and Mentoring Plan

The Co-PI will be committed to the close mentoring of the graduate student through thesis research supervision, in order to have them develop the required skills for successfully carrying out the research, in addition to mentoring, support and guidance for results dissemination at local and international venues of relevance.

References:

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