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Additive Manufacturing: A Renaissance for Powder Metallurgy Research

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Additive manufacturing is an umbrella term that encompasses the various methods of producing bulk material and three dimensional parts by adding one layer of materials at a time. The best known of these processes, Fused Deposition Modelling (FDM) which involves 3D printing with thermoplastic filament, has reached commercial status for the consumer. Affordable 3D printers that can connect to desktop PC's have turned anyone with a few thousand dollars and some CAD software into a "rapid prototyper." While the technology has been around for decades, the recent mainstream acceptance of additive manufacturing has pushed the additive manufacturing methodology to the forefront of advanced manufacturing. It has long been known in the Ceramic and Powder Metallurgical community that that ability to tailor the microstructure of a material can be controlled trough the proper selection of precursor powders, particle sizing, sintering methods and attention to process parameters like atmosphere, mechanical pressure and temperature. In many ways, ceramics and powder metallurgy are the root technologies of all solid state additive manufacturing processes. With the technology of affordable and industrial scalable printing combined with material deposition and fusion methods, powder metallurgy is poised for a renaissance.Why a "renaissance?" The dark ages that preceded the Italian Renaissance were marked by centuries of reliance on proven methods, and lacked innovation. Certainly the timeframe is compressed, but for decades powder metallurgy as an industrial fabrication process has benefited from relatively few leaps of innovation. Limited to traditional powder compaction and densification methods, applications of powder metallurgy were limited by part geometry and design loading conditions, and the sequential nature of compaction, densification/sintering and finishing. With the advent of additive manufacturing in the last decade, the fusion process is coincident with the powder layup, eliminating the need for separate compaction and sintering. Heat sources such as lasers and electron beams provide the energy for fusion by sintering or melting in an extremely localized fashion. The resulting capabilities and diminishing scale of the operations is forcing process developers to revisit the fundamental science of sintering, fusion, and evolving microstructure. Scientific studies of the process parameters of powder metallurgy have been given a new mandate, where the limitations of traditional powder metallurgy have been lifted, and innovation can flourish. In short; a possible renaissance.Production successes have been achieved in many powder systems using various methods of additive manufacturing. Selective Metal Laser Sintering (SMLS) has seen great success in the production of medical implants, and other similar high-cost, low-volume products. While these successes are encouraging, they do not readily scale up to high volume industrial processes, and will remain relegated to specialty manufacturers without advances in processing. These advances must come as improvements in cost and efficiency. By its very nature, solid state sintering is a diffusion limited process and therefore particle fusion acts as a rate limited step in realization of strong, fully dense parts. Reducing sintering times can be a function of the energy supplied by the system, or the choice or precursor powders. The application of energy intended to drive the fusion process is one of the earliest material processing technologies developed by man. Traditional methods of ceramics were carried over into the powder metallurgy industry decades ago, as was the mindset that radiant or conductive heat is the best way to deliver that energy. Lasers and electron beams present a myriad of possibilities for the application of energy in extremely dense and precise means. The resulting material response is the rise in temperature that inspires atomic mobility either in the form of diffusion of localized melting. Both can be potent fusing mechanisms, but may cause unwanted effect such as oxidation or reactions in an uncontrolled atmosphere, or microstructural changes within the powders themselves. Technologies like cold gas dynamic spray (aka "cold-spray")that utilize kinetic energy as a large fraction of the overall energy input, may bridge the gap by using high velocity particle deposition to inspire partial fusion or, at the very least, particle compaction into the layup process, obviating or minimizing the need for a rate limiting, heat-driven sintering process. In addition, contact modes involving localized delivery of high energy electric fields, like the ones in spark plasma sintering, may provide further avenues of development. By exploring energy input beyond in multiple forms, and combinations, processes could work around the physical limitations of diffusion.The selection of alloy systems and development of specialized powders presents a great avenue for development of the additive manufacturing industry in powder metallurgy. Much like the development of liquid phase sintering, capitalizing on reacting or phase-transforming precursors to hasten or shortcut the diffusion process can drastically reduce cycle times. Relying on faster kinetic processes can be achieved in many ways. Specialty powders are currently being produced with multiple discrete coatings, highly specialized morphologies, nano-scaled grains structure, etc. Some of these innovative precursor systems are yielding phenomenal success in specific applications of cold sprayed technologies. One drawback to an industry driven approach to process development is the proprietary sequestering of game changing technologies. There must be encouragement within the scientific community to take up the mantle for powder metallurgical research in the additive manufacturing field.

Federal research funding can be elusive, especially when the proposed research doesn0t fall into the category of currently hot research topics. When the term "manufacturing" lives in the title of a proposal, there is often an assumption that the research must possess a high technical readiness level rating. Unfortunately much of the research that will push the envelope for additive manufacturing in the P/M industry falls under the auspices of basic science. As members of the scientific research community, we must seek ways to link these basic science discoveries to advances in the additive manufacturing process. Only through a prudent scientific approach of understanding the mechanisms of fusion, diffusion and densification among the game changing parameters of energy beams, high velocity impact, and reacting systems all at nano scales, can we bring about this renaissance in powder metallurgy.

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