# ME – PhD Thesis defence

## Towards metal additive manufacturing using alternate powders

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### ABSTRACT

Metal powders are predominantly produced using processes derived from atomization, which, apart from being highly energy intensive, are also inflexible and very material specific. These limitations are particularly acute when viewed in the context of additive manufacturing (AM), especially with the use of high-performance structural alloys, refractories, and emerging materials such as high entropy alloys.This work explores an alternative method for making metal powders for AM applications using mechanical deformation and is presented in two parts.

In the first part, we develop an abrasion-based process for making powders in plain carbon and stainless steel. The curious occurrence of perfectly sphere-shaped particles in a grinding configuration is studied in detail as a potential source of spherical powders. A new hypothesis is forwarded for their formation based on theoretical four-body heat partition calculations and coupled infrared thermography measurements. The particles are postulated to form via heating at the abrasive-substrate contact zone, followed by exothermic oxidation leading to melting, and finally rapid solidification to ambient temperature. Given the difficulty in directly assessing these phenomena using in situ techniques, each step of the formation process is analyzed using a combination of physical models and postmortem characterization (XRD, HRTEM and EDS). The result is a comprehensive analytical framework to predict when and how perfectly spherical particles may be obtained via abrasion.

Building on these fundamental studies, a protocol was then developed for collecting and evaluating the produced powders for use in AM applications. This was done in three steps. Firstly, bulk powder flowability was evaluated post and prior to size segregation via sieving. Secondly, the elimination of surface oxide layers was undertaken using a novel reduction kinetics analysis under a hydrogen atmosphere. Finally, energetics calculations of the entire process were used to quantify its potential use vis-à-vis atomization-derived powders. Based on these post-process investigations, a stand-alone tool was developed for producing powders at scale using commercial CNC machines.

In the second part of this work, we explore the use of these powders, both as unaided feedstock for AM and as potential blending candidates with other commercial powders. For this purpose, we designed and developed an open architecture directed energy deposition (DED) based AM system. Unlike existing DED systems, the powder handling module of the developed system is customized to handle non-standard metal powders. To demonstrate the capabilities of this system, extensive benchmarking tests were first performed, and an 'operating map' was determined for its use with a given metal powder.

Using this DED system, the powders produced in the first part of the work were used for making standard test geometries. Corresponding microstructural, elemental, and mechanical evaluations were carried out to analyze the properties of the final printed parts and were found to be comparable to those obtained with commercial powders. In summary, this work demonstrates a plausible alternative route for making metal powders specifically for metal AM applications.

### ABOUT THE SPEAKER

Harish is a PhD candidate in the Department of Mechanical Engineering, IISc Bangalore. He works with Prof. Koushik Viswanathan at the laboratory for advanced manufacturing & finishing processes (LAMFiP). He obtained his MTech from the Indian Institute of Space Science and Technology (IIST), Thiruvananthapuram, in 2018. His broad research interests include metal additive manufacturing, solidification & phase transformations, and mechanics of materials.