Fused-Filament Fabrication of Metal with a Markforged Metal X System

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Abstract

Now anyone can 3D print a metal part. No longer are specialized engineers needed for metal part fabrication. Hundreds of Markforged Metal X system users are taking designs from computer model to sintered part in as little as 2 days. Building upon mature fused filament fabrication technology, a metal FFF machine enables light weighting infill structures, non-machinable geometries like internal cavities, and complex features with automatically generated support structures. Similar to MIM, these printed green parts are readily solvent debound and then sintered in a furnace according to a schedule pre-optimized for each material. This paper discusses the capabilities and limitations of FFF metal additive manufacturing through an example use case, and reviews the material properties of printed 17-4PH.

Introduction

Metal three dimensional printing (3DP) technology has been commercialized for over 20 years - however it has only recently emerged as a viable method for mass production. Many metal additive manufacturing (AM) technologies such as selective laser melting, directed energy deposition, electron beam melting and binder jetting require costly equipment and setup. By combining the established process of Fused Filament Fabrication (FFF) of polymeric materials and well-known sintering and debind technology from the Metal Injection Molding (MIM) industry, new 3DP systems that utilize a FFF method of metal forming have lowered the barrier to entry. The transformation of manufacturing on the factory floor will hinge on two main factors – cost effective performance and ease of use.

Background

The 3DP filament material used in FFF is similar to MIM feedstock material and is composed of 3 major components: metal powder, backbone polymer and debindable (solvent, water, catalytic) component. The filament material is heated in a print head and extruded out a nozzle depositing material layer by layer to build up the desired part geometry. Once the part has been printed, it goes through a primary debinding process (solvent, water or catalytic) leaving behind a porous interconnected network structure that allows the remaining backbone polymers to be thermally debound in a secondary process either in a sintering furnace or a dedicated debind oven. The remaining powder metal material is then sintered together.

There are a number of sintering process parameters that play a role in the final sintered part properties. Part characteristics such as density, microstructure, and mechanical and chemical properties, depend both on the input materials and the process parameters: metal material composition, particle size and shape, sintering process temperature and hold time, and sintering atmosphere in the furnace. Companies providing full metal 3DP systems will optimize the machine and process for their material removing the need for specialized sintering expertise and simplify the user experience.

Like FFF printing of plastic materials, part geometries with an overhanging features greater than a threshold angle (which can vary based on materials) will require support structures for successful printing. With metal FFF, these support structures are not only necessary for printing but vital for successful part sintering as well. Since the support structure is made of the same metal material as the part, they will shrink at the same rate as the part minimizing geometric distortions such as slumping, warping and twisting that may otherwise occur during the thermal debind and sintering process. To prevent the printed support structures from sintering to the part itself, a separation or release layer is