Additive Manufacturing of Soft and Hard Magnetic Materials Used in Electrical Machines

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ABSTRACT

Additive manufacturing (AM) techniques such as cold spray and fused filament fabrication allows for 3D build-up permitting fabrication of high complexity shapes and configurations. The fabrication of soft and hard magnetic materials using these techniques was investigated in the context of 3D electrical machines. The use of 3D finite element analysis (FEA) to develop new motor topologies based on the advantages offered by AM will be discussed. FEA was also used to orientate the material development by identifying the most critical properties. The hard magnetic properties (coercivity and remanence), soft magnetic properties (permeability and losses) of both types of materials fabricated by both AM processes will be presented.

INTRODUCTION

Additive manufacturing (AM) of metal parts was successfully used in various applications for the fabrication of complex shape mechanical parts. As AM techniques and processes are maturing, a new focus in research and development is devoted to functional materials where various physical properties of the materials need to be optimized for their utilization. Magnetic materials are one type of functional materials that has generated interest lately in the AM community. In the last five years, research and development efforts for the development of conventional magnets has been steadily increasing. The main motivation for this work is the potential benefits arising from the agility of AM processes both for the prototyping stage and for the realization of complex designs. Ultimately, additive manufacturing could offer significant advantages for the low volume production of customized parts while increasing the design flexibility for magnetic components in electrical machines.[1]

In most electrical machines applications, hard magnetic materials are used in combination with soft magnetic materials. When compared to AM of mechanical components, AM of magnetic materials presents additional difficulties and challenges. One of the most important challenges is probably that the high energy used tends to negatively affect the physical properties of the materials. For NdFeB, oxidation and phase transformation can adversely affect the performance of the magnet.[2-3] In the case of soft magnetic materials, the difficulty to incorporate insulation between powder particles in an AM process limits their utilization when low eddy-current losses are required.[4] In order to address these shortcomings, the research presented in this paper was focused on low-energy, solid-state AM processes that can offer the flexibility and design advantages of AM without modifying the functional properties of the soft and hard magnetic materials.

Another challenge often encountered in the development of new additive manufacturing processes and parts is the availability of high quality feedstock. In the case of the highest energy density magnets (i.e. NdFeB),[5] commercial powders are readily available since powder metallurgy (compaction, sintering and injection molding) is the traditional manufacturing route. Soft magnetic materials (such as electrical steel) are usually produced using a cold rolled strip process. Some high performance materials, such as high silicon FeSi and FeCo, are brittle and difficult to manufactured using rolling process. Powder injection