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Laser beam melting of functionally graded materials with application-adapted tailoring of magnetic and mechanical performance

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ABSTRACT

The processing of functionally graded materials (FGMs) using laser beam melting (LBM) is a promising technique for increasing the efficiency of conventional machine components, especially for e-mobility. Therefore, the aim of the current study is to prove the manufacturability of tailored mechanical and magnetic properties in a rotor for an electric motor. For this purpose, the design of additively manufactured rotors with application-adapted tailoring of the properties in the same component using FGM was proposed. The first step was to investigate whether the FGM of the components, i.e. soft-magnetic steel for the rotor core and high-strength steel for the rotor shaft ends, are suitable for machining by LBM. Subsequently, multi-material samples of the two investigated steel types with their different arrangement were processed by LBM. Furthermore, post-processing heat treatments and their effects on the microstructure and resulting magnetic properties as well as the mechanical performance of mono- and multi-material samples were analyzed. The combination of LBM and an additional post heat treatment enables both the formation of a good adhesive bond between the two alloys and the desired tailoring of the properties in the FGMs investigated.

1. Introduction

Especially as a rapid prototyping method, laser beam melting (LBM) is gaining increasing importance as a small-batch production process for complex parts in the medical, oil, automotive, and aerospace industries [1–5]. Although LBM is a time-consuming process with low productivity and expensive material costs, both of which result in high part costs, it has numerous advantages over conventional technologies such as casting, forming, and subtractive processing. These advantages include freedom in part complexity, tool-less manufacturing, low material waste, and a high degree of process digitalization that allows the production of complex high-end components with extended functionality in small series [3,6–8].

Due to its layered approach, LBM is a suitable production technique for processing functionally graded materials (FGM). By varying the material chemistry [9–11], the microstructure [12–14], or the component structure/porosity [8,15,16], the local properties within a given part, i.e. mechanical, magnetic, thermal, corrosion, weight properties,

etc., can be strongly modified. This allows the design of application-specific products that are difficult to realize with conventional processing techniques [17]. Lower thermal gradients due to a preheated building platform or chamber [18], relatively small melt pool sizes, and the numerical simulation of suitable gradient paths [19] allow to avoid the formation of brittle phases and large segregations and thus improve the mechanical strength and ductility of joints between dissimilar materials.

Electric machinery is one of the application areas where the advantages of LBM can be used to create components with superior properties, an example being rotors for permanent magnet synchronous machines (PMSM). Here, the design of rotors with three-dimensional freedom makes it possible to integrate complex cooling channel systems and reduce the overall weight, both of which contribute to improving the efficiency of electric motors [16,20–22].

So far, LBM rotors have been manufactured as bulk bodies made of a mono-material. The implementation of the FGM concept could therefore help to increase their efficiency. A design of the rotor core as a bulk body

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