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Additive Manufacturing of hard magnetic materials via Cold Spray Additive Manufacturing

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Abstract

The Additive Manufacturing of hard magnetic materials, used in applications such as electrical drives, is achieved by exploiting the special characteristics of the Cold Spray Additive Manufacturing (CSAM) technology. This work aims to develop processing parameters for the Additive Manufacturing of magnets made of a neodymium-iron-boron-alloy (NdFeB). In order to enable the manufacturability using CSAM, a pure aluminium binder with a mass fraction of $w_{Al;a}$ = 25 wt. % and $w_{Al;b}$ = 10 wt. % was added to two different NdFeB powders with the particle size distributions of $D_{50;NdFeB;a}$ = 5 µm and $D_{50;NdFeB;b}$ = 22 µm. For this study, the gas pressure p_g was varied between 4 MPa ≤ p_g ≤ 6 MPa and the resulting remanence B_r and coercivity H_{cj} were analysed. A material combination and parameter set for the Additive Manufacturing of magnetic material via CSAM with a magnetic remanence of B_r = 414 mT and an intrinsic coercivity of H_{cj} = 854 kA/m was derived.

Additive Manufacturing, Cold Spray, Electrical Drives, Magnets

1. Introduction

Electrical drives play a pivotal role in steering various industries and the transportation sector away from combustion engines and fossil fuels in order to meet stricter environmental regulations. As a key part for rotors of electrical drives, magnets are responsible for 53 % of the total costs [1]. This is in part caused by the current manufacturing technologies, such as sintering, with a low shape complexity, expensive tooling and the need for assembly processes [2]. Additive Manufacturing technologies, such as CSAM enable the direct manufacturing of complex shapes onto rotors without tooling, thus increasing flexibility [3, 4]. Lamarre and Bernier [5] showed, that CSAM can be used to produce magnets with good comparable magnetic properties at various fixed processing parameters. As a key process parameter for achieving layer binding, the influence of gas pressure p_g on the magnetic properties of remanence B_r and coercivity H_{cj} has yet to be investigated.

2. Experimental procedures

In order to investigate the effects of the gas pressure p_g on remanence B_r and coercivity H_{cj}, cubic samples measuring 5 mm x 5 mm x 5 mm were manufactured using an Impact Spray System 6/10 EvoCSII from Impact Inovations GmbH, Rattenkirchen, Germany. Magnetic charging and measurement were carried out with a pulsed current generator in an axial coil by M-Pulse, Berlin, Germany.

3. Powder material

Four powder mixtures were prepared and tested. The particle size distribution D_{50} of the individual powders was examined with a Camsizer X2 from Microtrac Retsch GmbH, Haan, Germany. Figure 1 shows the fractions p_3 and the cumulative distribution Q_3 of the processed powder. Magnequench MQP 14-12 Isotoropic NdFeB Powders from Magnequench International INC., Singapur with a particle size distribution of $D_{50;NdFeB;a}$ = 5 µm and $D_{50;NdFeB;b}$ = 22 µm were mixed with 99.7 % pure aluminium powder from Toyal-Europe, Guyancourt, France with a particle size distribution of $D_{50;Al}$ = 30 µm in a mass fraction $w_{Al;a}$ = 25 wt. % and $w_{Al;b}$ = 10 wt. %.

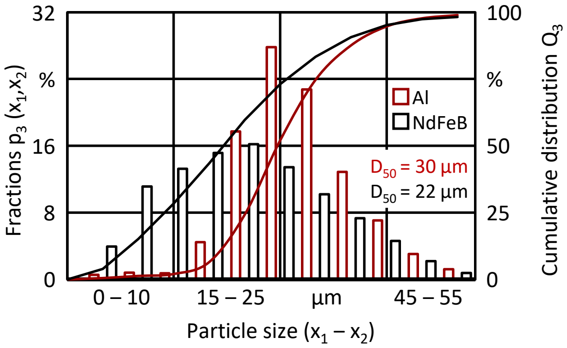

Figure 1: Particle size distribution of Al and NdFeB powder

3.1 *Processing parameters*

For this investigation, the gas pressure p_g was varied while the gas temperature θ_g, nozzle distance l_{gun}, spray angle α and travel speed v_{gun} were kept constant. Table 1 shows an overview of the processing parameters.

Table 1. Processing parameters

Parameter		**Value**
Gas pressure	p_g	40 MPa – 60 MPa
Gas temperature	θ_g	500 °C
Nozzle distance	l_{gun}	30 mm
Spray angle	α	90 °
Travel speed	v_{gun}	500 mm/s

4. Experimental results

The properties remanence B_r and coercivity H_{cJ} are key indicators to evaluate the performance of magnets. Figure 2 shows the remanence B_r and coercivity H_{cJ} of the manufactured cubic samples for different material combinations and varying gas pressures p_g. Firstly, it was established that a test specimen can be produced for each combination of material and gas pressure p_g. Due to material constraints, only one sample per parameter combination was produced. Therefore, the determined values could not be checked statistically and variation of parameters was limited. Looking at the influences of material and gas pressure p_g, it can be determined, that choosing the right magnetic material and mass fraction w_{Al} is more important than choosing the right gas pressure p_g when optimizing magnetic properties. Specifically focusing on particle size distribution $D_{50;NdFeB}$, for an identical mass fraction w_{Al}, the measured data shows that a particle size distribution $D_{50;NdFeB;b} = 22\ \mu m$ yields a better remanence B_r compared to $D_{50,NdFeB;a} = 5\ \mu m$. On the other hand, coercivity H_{cJ} is improved when choosing larger particle size distribution $D_{50;NdFeB}$. The highest combined values of remanence $B_r = 414$ mT with a high coercivity of $H_{cJ} = 741$ kA/m was achieved with a mass fraction $w_{Al,b} = 10\ \%$ and a particle size distribution $D_{50,NdFeB;b} = 22\ \mu m$ at a gas pressure $p_g = 5$ MPa.

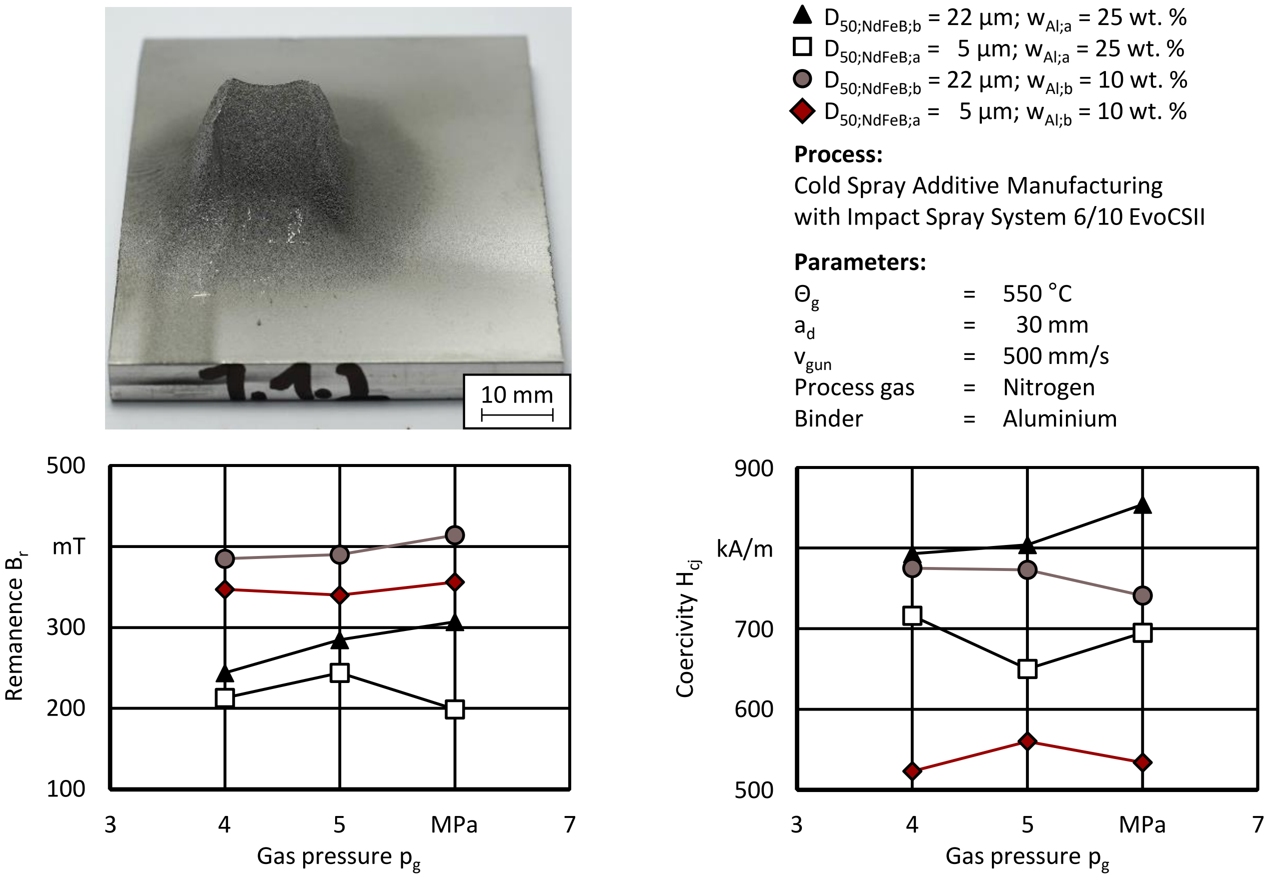

Figure 2: Remanence B_r and coercivity H_{cJ} in dependency of the gas pressure p_g with respect to particle size distribution D_{50} and mass fraction w_{Al}

5. Conclusion and outlook

This paper shows, that it is possible to manufacture magnets using CSAM. It can be concluded, that a bigger particle size distribution $D_{50;NdFeB}$ and a lower mass fraction of aluminium w_{Al} lead to a better remanence B_r. It was also shown, that a higher coercivity H_{cj} is achieved when using a smaller mass fraction of aluminium w_{Al}. The influence of the gas pressure p_g was negligible when compared to the influence of the magnetic material. The best achieved remanence $B_r = 414$ mT and coercivity $H_{cj} = 854$ kA/m translate to a relative remanence $B_{r;rel} = 50\ \%$ and a relative coercivity $H_{cj;rel} = 91\ \%$ when compared to a conventionally sintered magnet, made from the same powder material. Especially an improvement of the relative remanence up to $B_R > 90\ \%$ would enable the wide adaption of the process for manufacturing electrical drives. However, due to the freedom of design and tool-free manufacturing of complex shapes, Cold Spray offers a promising solution for manufacturing permanent magnets.

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