# Additive manufacturing of soft ferromagnetic Fe6.5%Si annular cores: process parameters and magnetic properties

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**Introduction:** Additive manufacturing (AM) has been a rapid growth in recent decades. The parts produced by AM are first designed in a CAD program, conveniently stratified and then constructed, layer by layer, by a continuous material addition process. Many different kinds of technical approaches are used by AM machines (binder jetting, extrusion, laser melting ). In the context of metallic parts production by AM processes, one of the most widely used is the Laser Beam Melting (LBM). In this process, thin layers of powder are selectively irradiated and melted by a laser source. AM LBM has been largely investigated for processing a range of metallic materials and improving their mechanical properties. However, in the case of ferromagnetic materials, the potential of this technology is marginally explored[1-2]. The goal of the present work is to show the impact of the process parameters on the magnetic properties of ferromagnetic (Fe6.5%Si) parts.

**Experimental methods:**

A series of annular cores were manufactured by AM LBM (external diameter $d_e = 25$ mm, internal diameter $d_i = 35$ mm and height $h_c = 6{,}2$). The raw material employed was high-silicon steel powder with approximately 6.5% wt Si (commercially acquired –HL POWDERS), the LBM machine used was a Realizer SLM-250. The magnetic properties of the Fe-Si alloy under quasi-static conditions were determined using the hysteresigraph method described in IEC standards (AFNOR IEC 60404, 2004)[3] . A parametric study was performed by varying the LBM parameters : laser power $q$, laser beam diameter $r_b$, hatch-spacing $h$, layer thickness $l$ and laser scanning speed $v$. 25 samples were manufactured using a combination of these parameters. For each sample, a measure of density was realized. Then a microstructural study was performed by optical microscopy and Electron Back Scatter Diffraction (EBSD).

**Results:** In a first step, the micro-structural study was used to identify the links between mechanical output variables (density, grain size) and the input parameters. This was possible by the use of a normalized energy [4] expressed as,

$$E_0^* = \frac{Aq}{(2r_b lv)(\rho c_p (T_m - T_0))}$$

where $A$ is the surface absorptivity (0.3 and 0.8), $\rho$ is the material density, $c_p$ is the specific heat, $T_m$ the melting point of the raw material and $T_0$ the initial temperature of the powder bed. Thus, a maximum density point was identified, which, in our case,

corresponds to a density of ≈98.5%.
A second step was carried out to identify the influence of the normalized energy over magnetic properties. This study was focused on the annular parts with high densities $\geq 90\%$ (six samples).
It was found that the normalized laser energy plays a major role on the final grain size and magnetic properties. For a higher injected energy, the average grain size increases and leads to a decrease of the coercivity $H_c$ but also in an increase of the maximum and remanent induction ($B_{max}$, $B_r$).

**References:**

[1] D. Goll, D. Schuller, G. Martinek, T. Kunert,. Additive manufacturing of soft magnetic materials and components. Additive Manufacturing, 27 :428-439, 2019
[2] Garibaldi, M., Ashcroft, I., Simonelli, M (2016). Metallurgy of high-silicon steel parts produced using Selective Laser Melting. Acta Materialia, 110, 207-216
[3] NORME INTERNATIONALE CEI IEC INTERNATIONAL STANDARD 60404-1-1 2004
[4] Thomas, M., Baxter, G. J., & Todd, I. (2016). Normalised model-based processing diagrams for additive layer manufacture of engineering alloys. Acta Materialia, 108, 26-35.