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# Microstructure and Magnetic Properties of Magnetic Material Fabricated by Selective Laser Melting

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**Abstract**

Selective Laser Melting (SLM) is a powder-based additive manufacturing which is capable of producing parts layer-by-layer from a 3D CAD model. The aim of this study is to adopt the selective laser melting technique to magnetic material fabrication. [1]For the SLM process to be practical in industrial use, highly specific mechanical properties of the final product must be achieved. The integrity of the manufactured components depend strongly on each single laser-melted track and every single layer, as well as the strength of the connections between them. In this study, effects of the processing parameters, such as the space distance of surface morphology is analyzed. Our hypothesis is that when a magnetic product is made by the selective laser melting techniques instead of traditional techniques, the finished component will have more precise and effective properties. This study analyzed the magnitudes of magnetic properties in comparison with different parameters in the SLM process and compiled a completed product to investigate the efficiency in contrast with products made with existing manufacturing processes.

*Keywords:* Selective Laser Melting; Magnetic material

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## 1. Introduction

This research is focused on metallic material production and the microstructure of sintered material. In order to strive for uniformity in metal microstructures, conventional sintering uses a novel technique called “rapid warming inhibit sintering” which significantly improves the density of the sintered metal. Not until 3D printing can be used in printing soft magnetic materials, affect both traditional external sintering and the more advanced internal sintering

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strongly to the microstructure and properties of metal material. Selective laser sintering (Selective Laser Sintering; SLS) [2,3] and Selective Laser Melting (Selective Laser Melting; SLM) [4] are both revolutionary sintering technology. In this experiment, the samples were manufactured by EOSINT M280 machine, which is an additive manufacturing machine.

Unlike conventional heating or microwave heating, both sintered integrally in macroscopic pattern after materials were modeled. The SLS and FDM techniques don't have uniformly heating issues because material molding and sintering are performed simultaneously, the whole sintered macroscopic models turn out to be sintered single microscopic patterns between powder and powder. It can be expected that the microstructure uniformity will be significantly improved and the material will also have more protruding features. Permeability of the soft magnetic material is affected by many factors, such as magnetic particle composition, particle shape, size, packing density, this project will use Selective Laser Melting(SLM) technique.The laser power and scanning speed were used as variables.

The layer thickness and laser spot diameter are set to be 30 µm and 0.07mm while other SLS parameters remained constant.Samples were manufactured in the nitrogen environment, and the ratio of oxygen content in the chamber is controlled.The technique that oxygen is used to control insulation coating in chamber has replaced hot pressing sintering process to improve the porosity of soft magnetic materials. This also significantly increases the permeability of the soft magnetic composite material the level of complexity of the desired object can be. These objects can be applied to more applications and replace iron-silicon based alloy.Rapid prototyping is currently a promising method to produce soft magnetic material workpieces with complex 3D modeling. The main idea is to use iron powder, which has an average particle size less than 30µm, as a base material combined with SLM technique.

## 2. Experiment

### 2.1. Powder

Soft magnetic material powder, [FeSiCr] alloy powder, was used as a primary ingredient. It was produced using gas atomization of hot melting and provided by the manufacturing company HIMAG. The chemical composition of [FeSiCr] alloy powder is as shown in Table 1.

Table 1. Chemical composition of FeSiCr.

| | |
|---|---|
| Si (Wt%) | 3.5 |
| Cr (Wt%) | 4.5 |
| C (ppm) | <150 |
| O (ppm) | <3100 |
| S (ppm) | <50 |

### 2.2. Soft magnetic materials

Soft magnetic materials are low coercivity magnetic materials and are susceptible to external magnetic field. Its main features are: high permeability, low coercivity, high saturation of flux density, low power consumption and high magnetic stability. Currently the application of soft magnetic material for different requirements and characteristics of the magnetic material can be divided into different categories, Fe-Si, Fe-Ni-based, ferrite-based amorphous material. The history of soft magnetic materials have developed for nearly a hundred years, pivotal to many related technologies like power electronics which in turn stimulated social progress.

The most representative materials in this category are silicon steel, ferrite, permalloy, amorphous metals and nano-crystalline metals. In 2000, the output value of global soft metal alloy deposits is 15.1 billion US dollars, accounting for 72% of the total value of the soft magnetic materials; soft ferrite production value is 1.5 billion, accounting for about 7% of the total value of the soft magnetic materials. In present day applications, soft magnetic materials can be found in a wide range of important products such as industrial automation equipments, electronic instruments, communication equipments, electrical computers and peripherals, etc. It is a group of some of the most common metal deposits on earth which in turn makes it a widely used material.

### *2.3. Selective Laser Melting (SLM)*

The process which includes the laser device, metal materials powder and infrared laser beam on the machining plane, are shown in Fig. 1. The platform is covered with a thin layer (sub-millimeter thick) of uniformly spread powder as a raw material. The laser beam then scans the raw material two dimensionally with certain speed and energy under the precise control of a computer, stimulating the sublevel orbitals of the material.

The scanned powder is thusly sintered into explicit positions on the same layer while the unscanned areas remains in powder form. The machine proceeds to scan the upper layers after the initial layer, building up the finalized product . [5]The building-platform lowers by the preset layer thickness, then the leveling roller will pave powder on the platform and ready to start a new scan. This process will repeat over and over again until the desired number of layers are scanned. The finalized product, after manually removing the excess powder and other appropriate post-processing such as grinding and drying, will be ready to use. [6]

During the research the SLM in ITRI used as a machine has YB-fibre with a wavelength of 1070 nm and a maximum output power of 400 and 1000 W. The laser power and hatch distance were used as variables. Other SLS parameters remained constant: the layer thickness of 30 μm and the laser spot diameter of 0.07mm.

Samples were manufactured in the Nitrogen atmosphere and the use of the gas content in the body cavity control Oxidation Insulation coating in physical metallurgy aspect.

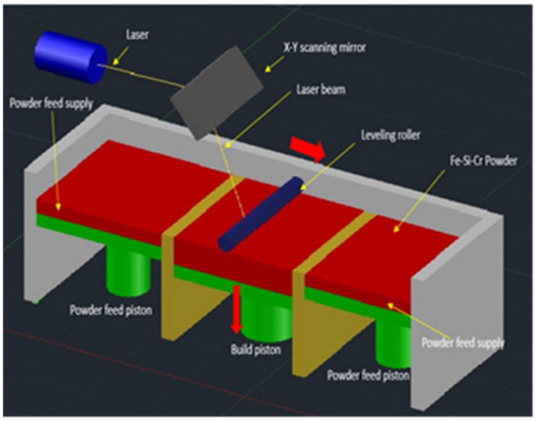

Fig. 1. (Selective Laser Melting；SLM) Architecture.

### *2.4. Analytical Instruments*

Particle-size distribution was determined by using the laser diffraction method on the LA-960 Laser Particle Size Analyzer with definition of 20 nm. The surface morphology and particle microstructure studies were conducted by using the FE-SEM 7000F scanning electron microscope (SEM). It works at 4-100x zoom with an accelerating voltage of 200 V to 30 kV. X-Ray diffractograms (XRD) of the samples were produced by using the Bruker D8 Advance diffractometer at the Cu Kα (λ = 1.5418 Å) radiation. Preliminary phase-shift analysis was conducted by using the MDIJade Plus Eva program diffractometer software.

The porosity was measured by using the metallographic method. The samples were embedded into plastic, burnished and polished.

Panoramic shots were taken by using the Leica NIKON LV100 light optical microscope at the 50-1000x zoom. The sample used for observation of micro-structure was grinded and polished with equipment provided by MTH Hrazdil, S.r.o. Company and was etched by Nital.

The sample used for observation of Superconducting Quantum Interference Device Vibrating Sample Magnetometer measurement with equipment, SQUID VSM Company.

## 3. Equations

### 3.1. Materials

We learned Selective Laser Sintering Shop powder as the main key, we use 400 mesh sieve to produce an average particle size of 30µm or less, which is suitable for dusting. Laser sintering power is 140 ~ 190W, scanning speed is 650 ~ 1550 mm / s, and the highest laser peak is 100mm / s.
The SEM images of the FeSiCr alloy powder, as shown in Fig.2, indicates that the particle shape is almost spherical.

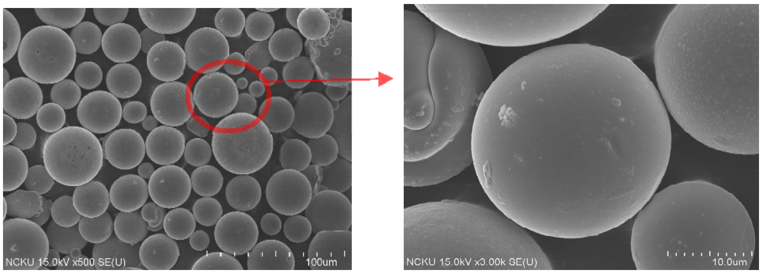

Fig. 2. The granulated spherical powder.

All particle size are less than 100 µm and the average size is 33.78 µm, as shown in Table 2.

Table 2. Particle size distribution measurements for the initial powder.

| | |
|---|---|
| D10 (µm) | 10.20 |
| D50 (µm) | 28.32 |
| D90 (µm) | 66.25 |

The powder particle is almost spherical and mean size is 33.78 µm, also with a sufficient flow rate, as shown in Table 3.

Table 3. Results of the alloy powder flow rate assessment.

| Powder under examination | Mass fraction in relation to the initial fraction (%) | Flow rate(s/50g) |
|---|---|---|
| Initial | 100 | 12.5 |
| <38µm | 75 | 12.7 |
| >38µm | 25 | 12.7 |

As can be seen from Table 3, the mass fraction of the powder with >38 µm particles accounts for 25% of the initial powder, whereas most particles are less than 38 µm in size.

This data correlates well with the particle-size distribution of the initial powder assessment.
In this work, the measurement of the phase composition (XRD-analysis) Fig.3. of the initial FeSiCr super alloy powder was carried out.[7]

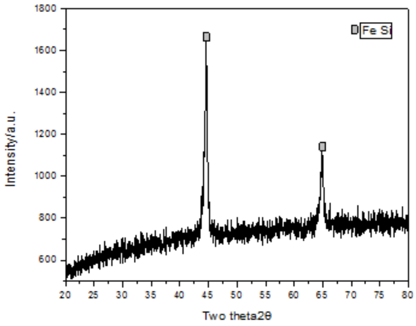

Fig. 3. XRD image of the particles of the 66FV <200M super alloy powder produced using gas atomization of the hot melt Fe Si Angle 45 and 65 2θ.

### 3.2. Processing

The schematic diagram for SLM process is shown in Fig. 4. The powders were delivered through a powder feeding apparatus, after that were rolled by a moving roller, thus a smooth powder layer can be obtained. When building multi-layers samples, the powders could be melted via the laser scanning system controlled by a CAD mode.

The laser power and scanning speed were used as variables. The layer thickness and laser spot diameter are set to be 30 µm and 0.07mm while other SLS parameters remained constant.Samples were manufactured in the nitrogen environment, and the ratio of oxygen content in the chamber is controlled.Laser Power: 140 ~ 190W Scanning speed: 650 ~ 1550mm / s. After SLM sintering tests, the optimum forming parameters are 170W, 950 mm/s, respectively, for FeSiCr alloy powder. SLM technique will compare with the traditional process .[8]

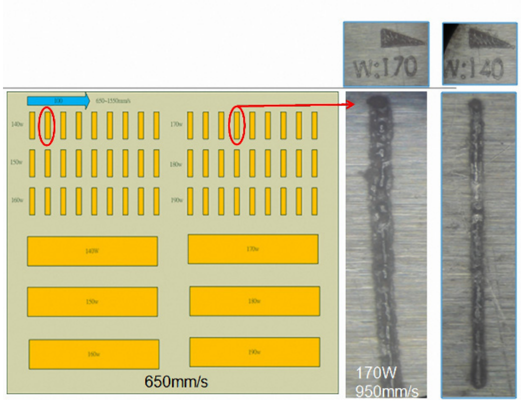

Fig. 4. Adjust power speed test and test conditionsPower: 140 ~ 190W Scan speed: 650 ~ 1550mm / s.

After parameters testing, using the parameters to form a metal block material, and control the ratio of oxygen content in the chamber.[9]

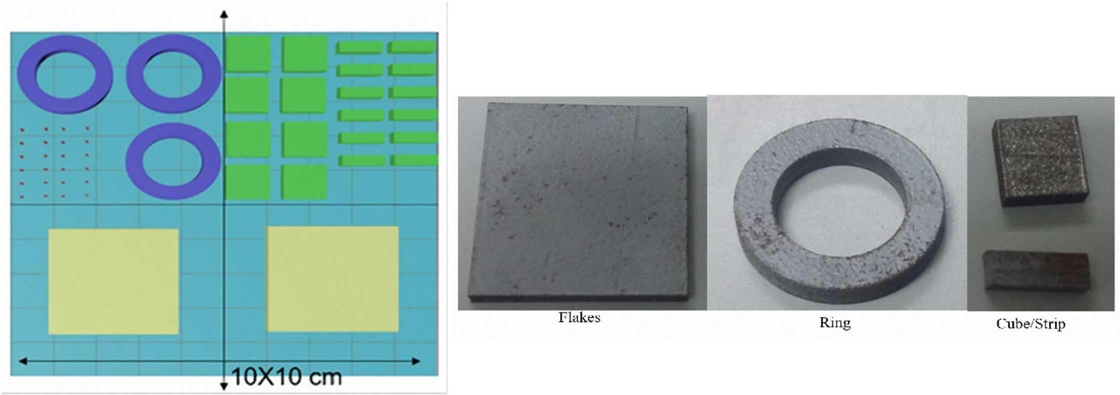

Fig. 5. (a) is a 3D CAD schematic diagram; (b) is the products made by SLM technique.

Ring core outer diameter is 21mm, inner diameter is 14mm, and height is 6mm, as shown in Fig.5. 50CS1300 is traditional silicon steel. M-H Curve and XRD analysis were used to observe the properties of ring and steel, as shown in Fig.6. the oxygen content of the element is 5%, as shown in Fig.7

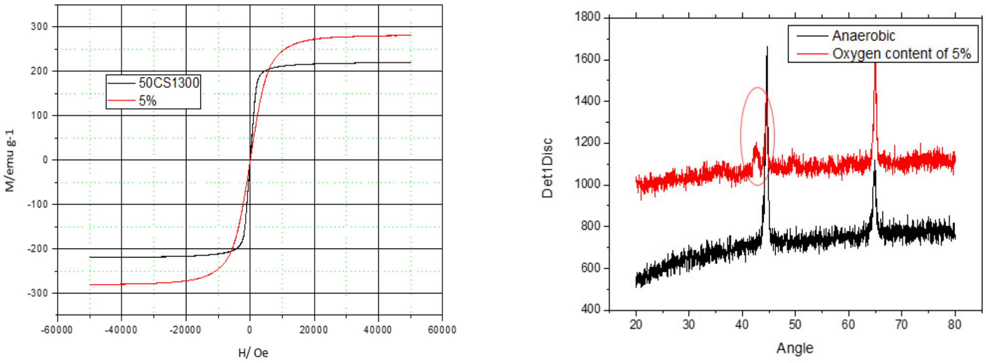

Fig. 6. M-H Curve&XRD.

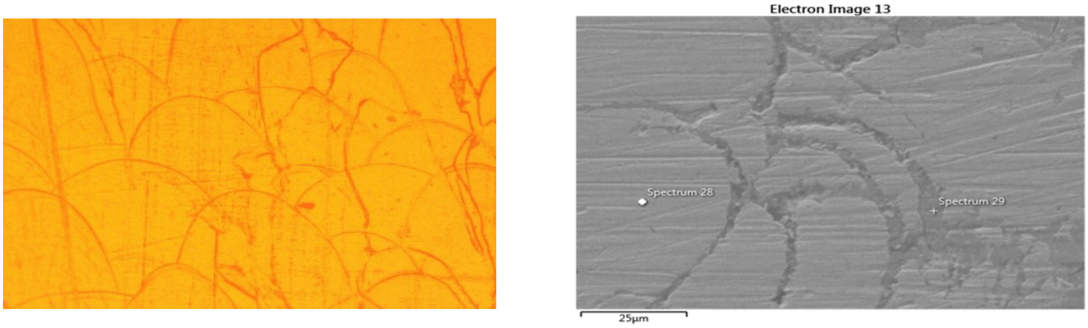

Fig.7. Micro-section images of the FeSiCr alloy powder with oxide layers.

## Conclusion

A detailed experiment has been performed to study the molecular structural and behavior of the FeSiCr alloy powder before and after going through SLM processing and here are the conclusions:

1. The initial FeSiCr alloy powder that we used is almost spherical, with an average particle size of 33.78µm.
2. Efficiency has been found to be maximized when laser power and scanning speed are 170 W, 950 mm/s, respectively.
3. The ratio of oxygen content in the chamber should be kept at 5% for best results.
4. M-H curve shows that the magnetic property of the sintered ring is better than 50CS1300 (traditional silicon steel).

## References

Yadroitsev, Smurov, Surface Morphology in Selective Laser Melting of Metal Powders. In: Sciencedirect Physics procedia, Vol.12(2011), p.264-270.

Tolosa I, Garciandia F, Zubiri F, Zapirain F, Esnaola A (2010) Study ofmechanical properties of AISI 316 stainless steel processed by"selective laser melting", following different manufacturing strate-gies. Int J Adv Manuf Technol 51(5–8):639–647.

Zhang WX, Shi YS, Liu B, Xu L, Jiang W (2009) Consecutive sub-sector scan mode with adjustable scan lengths for selective lasermelting technology. Int J Adv Manuf Technol 41(7–8):706–713.

Paul Jacobs "Rapid Prototyping & ManufacturingFundamentals of StereoLithography" Society of Manufacturing Engineers, 1992, U.S.A.

Bourell, D.L., Marcus, H.L., Barlow,J.W. and Beaman,J.J.,"Selective laser sintering of metals and ceramics",International Journal of Powder Metallurgy, Vol.28, No.4,1992, pp.369-81.

Chua C. K., Leong K. F. and Lim C. S., "Rapid Prototyping: Principles and Applications", WorldScientific, 2003.

Li Guowu, Leong K. F. and Shi Nicheng., "X-ray diffraction investigation of native Si-Fe alloy minerals from Luobusha, Tibet", Frontiers of Earth Science , February 2007, Volume 1, Issue 1, pp 21-25.

Li RD, Shi YS, Liu JH, Yao HS, Zhang WX (2009) Effects ofprocessing parameters on the temperature field of selective lasermelting metal powder. Powder Metall Met Ceram 48(3–4):186–195.

Ruidi Li & Jinhui Liu & Yusheng Shi & Li Wang &Wei Jiang Balling behavior of stainless steel and nickel powder during selective laser melting process Manuf Technol 2012) 59:1025–1035.