Analysis of the feasibility of the incremental manufacturing process by atomic diffusion method under laboratory conditions

Dominik Caus, Damian Piwowarski, Mikołaj Polak, Łukasz Ruba, Jacek Tarasiuk, Sebastian Wroński

AGH University of Krakow, Faculty of Physics and Applied Computer Science,
Władysława Reymonta 19, 30-059 Kraków

Abstract

In the last two decades, CAD (Computer Aided Design) and Additive Manufacturing (AM) technologies have revolutionized part design and production. AM, through layer-by-layer material addition, offers significant advantages. However, traditional metal AM processes often yield structural defects and residual stresses, limiting their utility. We explored A.D.A.M. (Atomic Diffusion Additive Manufacturing) by Markforged, a promising technique that combines metal and polymer extrusion, followed by sintering to achieve 99.7% finished product density. Our research aimed to reproduce A.D.A.M. in a lab setting using BASF 316L filament. We designed, 3D printed, annealed, sintered, and characterized samples with X-ray microtomography, SEM, and XRD. We compared these lab-produced samples to commercially available ones. Our findings revealed isotropic, stress-free samples with the desired crystallographic structure. While sintering optimization is needed, our results lay a solid foundation for future atomic diffusion research in lab environments and material analysis

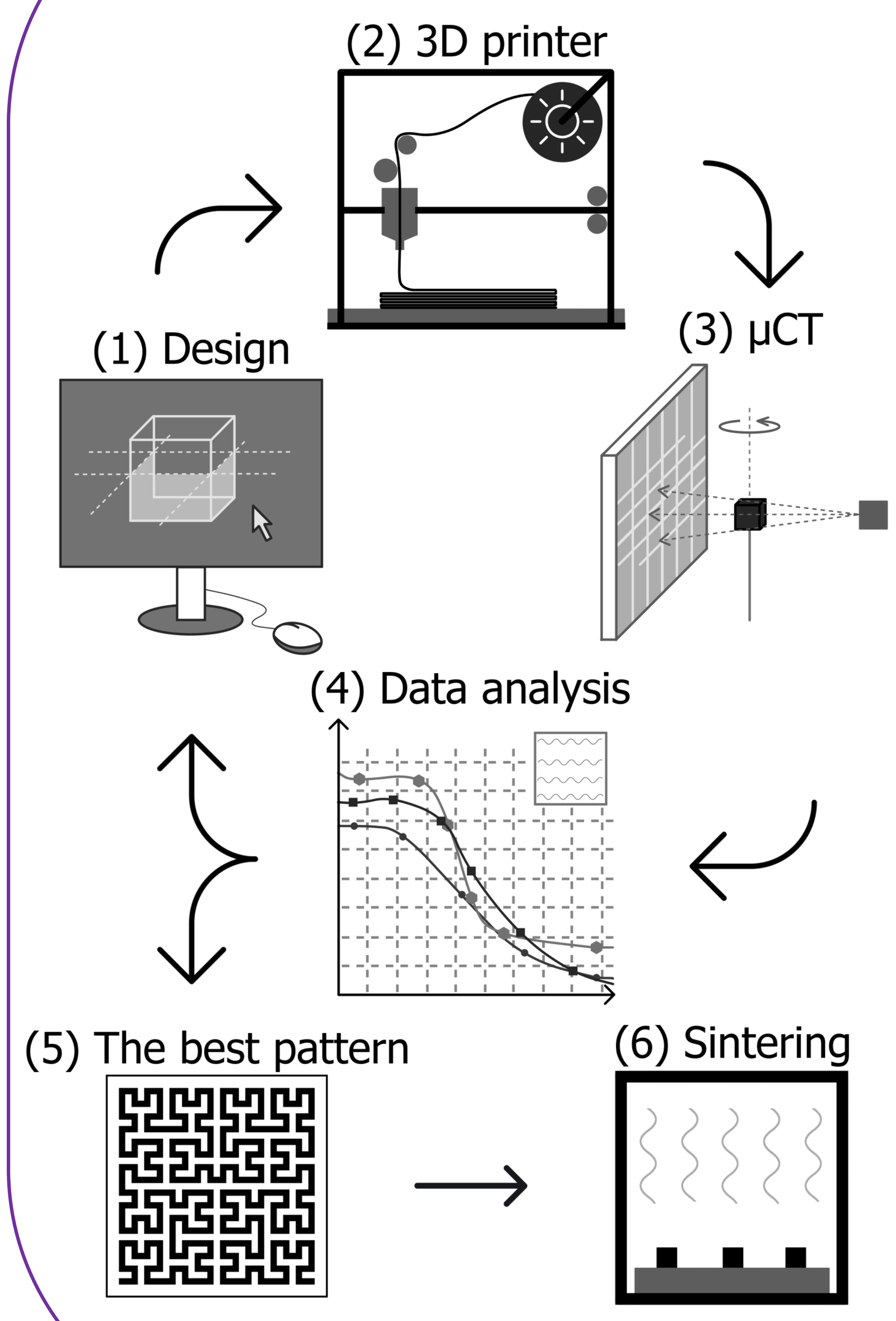
Introduction

There are many methods for manufacturing metal parts; among them, the machining method and the injection molding method are notable. Unfortunately, these methods come with many disadvantages that make them impractical to use in a laboratory setting. The use of the atomic diffusion method can potentially enable cost-effective production of necessary parts within laboratory, without a need to outsource the production to external companies. This project analyzed the possibility of transferring the atomic diffusion method to a laboratory environment, using BASF Ultrafuse 316L 1.75mm - a PLA filament infused with stainless-steel particles. Post-printed samples were heat-treated and were subsequently compared to samples provided by an industrial manufacturer to assess the feasibility of producing samples of similar quality in a laboratory setting.

Methods and instruments

- **3D printing – Prusa i3 Mk3**
- **SEM – Jeol JSM 6460LV**
- **Microtomography – GE nanotom S**
- **X-ray diffraction – PANanalytical X'pert**

Manufacturing process



(1) A cube was designed with a fill pattern to achieve 100% volume fill of the sample.

(2) The designed model was 3D printed at set head temperature, table temperature and print speed.

(3) The printed sample was measured with uCT.

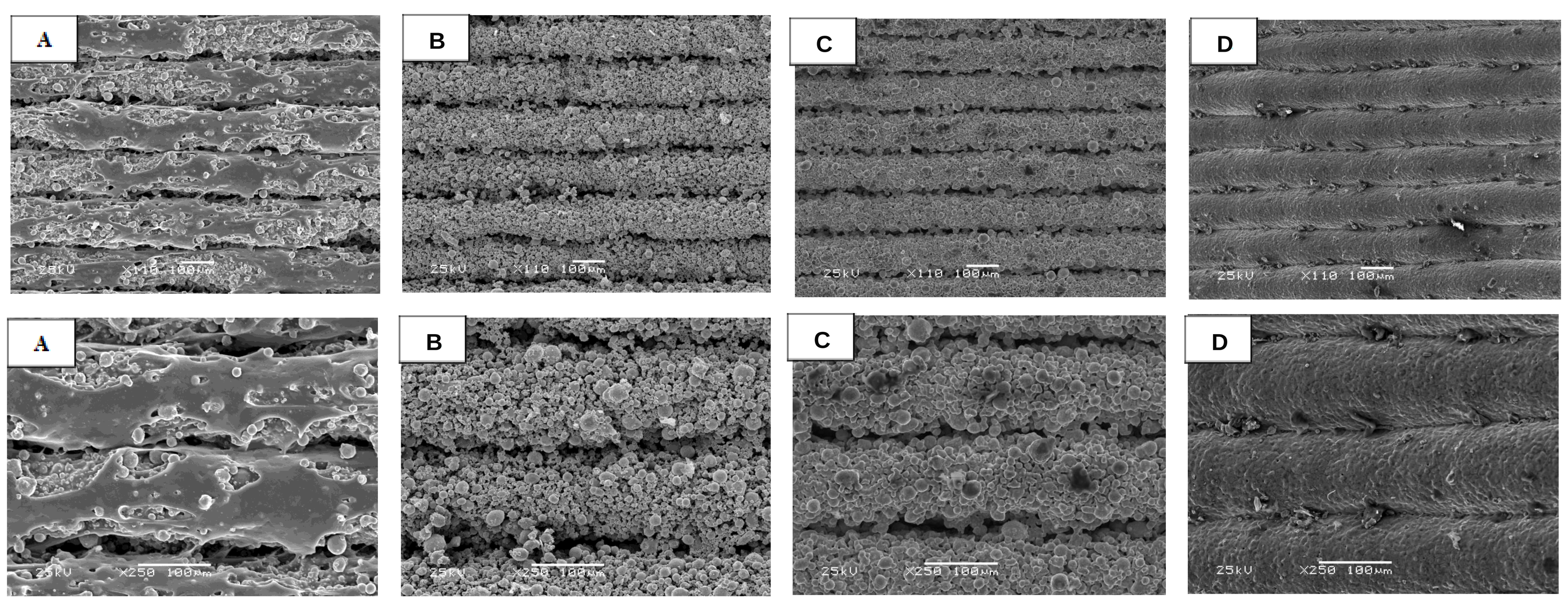
(4) The obtained data was analyzed to determine the porosity of the sample under the specified print parameters and selected infill pattern.

(4) -> (1) This process was repeated for all possible patterns that achived 100% volume fill of the cube.

(5) Based on the collected analysis, the optimal printing conditions were selected, and new cubes were subsequently printed.

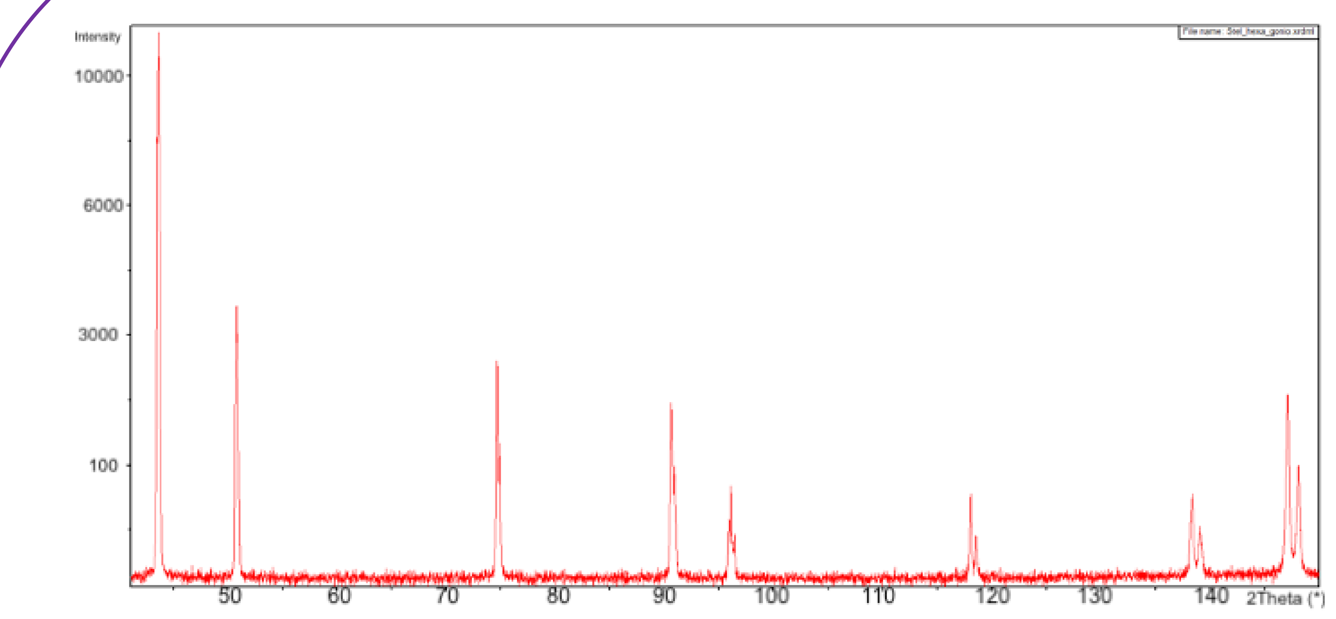
(6) The printed cubes were sintered in a chamotte furnace to evaporate the polymer and merge the steel microparticles together.

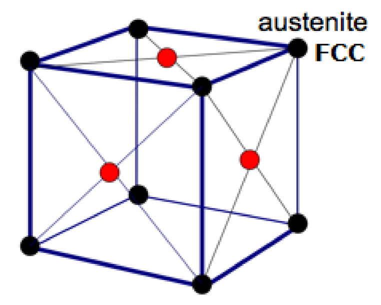
Results - SEM imaging



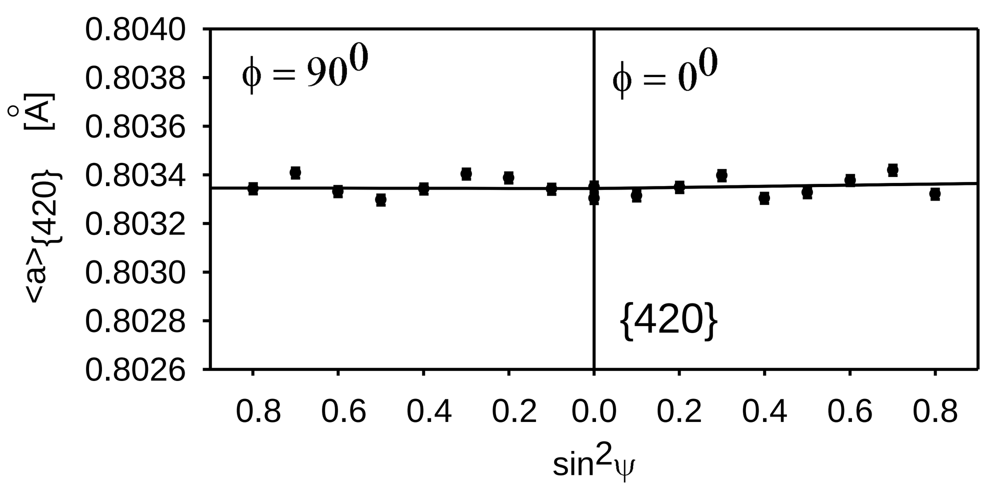
SEM images of the sample during different stages of the process (A) after printing (B) after high temperature treatment in the muffle furnace (C) after high temperature treatment in the tube furnace (D) manufacturer's sample.

Results



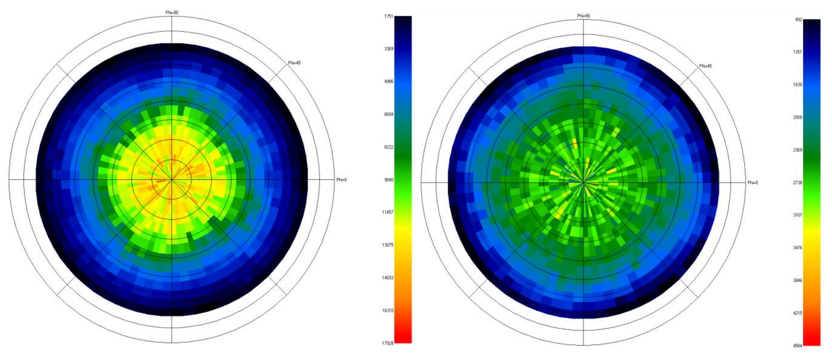


X-ray diffraction (XRD) studies revealed characteristic crystallographic structures for regular systems. This is a satisfactory result since austenite, the main component of stainless steel, occurs in the Fm$\bar{3}$m space group, forming an elementary cell with an FCC structure.



Measurement of the second-order stresses of the sample in two planes showed that the values of residual stresses are very small - even negligible. This means that the sample is not more prone to cracking or corrosion at any point compared to the whole.

The obtained polar figures for the tested samples indicate the absence of texture. This implies that the samples are homogeneous and isotropic, what distinguishes them from samples produced by other methods. The lack of texture could enhance the mechanical strength of the parts produced through A.D.A.M method, demonstrating the potential advantage over other methods of producing metal parts.



Conclusions

- **The material was found to be isotropic, exhibit no residual stress and has desired crystallographic structure (FCC).**
- **The binding of the material was not completely merged, due to insufficient sintering time.**
- **Results obtained are a strong foundation for research in the field of atomic diffustion method under laboratory conditions.**

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