Simulation of Dynamic Thermal Fields Assisting DMLS Additive Manufacturing of Biocompatible Ti-Alloy

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1. Introduction

For the complex 3D biocompatible metallic parts, with high level of customization, used in medical prosthesis and implants Direct Metal Laser Sintering (DMLS) and Selective Laser Melting (SLM) are the most common Additive Manufacturing technologies used nowadays.

However, both technologies require costly post-processing operations of the 3D printed parts, and are facing quality and precision limitations.

A dynamic thermal field assisting a wider area of the powder bed fused with laser during DMLS metal powder printing could modify the heat flow distribution within the 3D printing process and during successive printed layers consolidation, with effects upon post-processing paths.

2. Theory

Although metal 3D printing (additive manufacturing) it is mostly a CNC manufacturing process based on Powder Bed Fusion physical processes (Direct Metal Laser Sintering –DMLS; Selective Laser Melting - SLM; Electron Beam Melting -EBM), it faces some limitations.

Excluding the cost and equipment related ones, remain the technical issues related to the material properties and to the powder bed fusion process itself [2]:

- frequent inconsistency and build failure (compared to traditional manufacturing methods);
- restricted material choice.
- significant and costly post-processing (support removal and hot isostatic pressing-HIP)
- macroscopic properties of AM parts not identical to traditionally manufactured parts.
- restricted build volumes and speed limits application to low volume production.

Readdressing the Powder Bed Fusion thermal process dynamics could improve the quality of DMLS printed parts and reduce the post-processing operations time and costs.

3. Use of Simulation Apps

COMSOL Multiphysics ® was used to analyze and describe in depth the thermal field distribution into the Ti-6Al-4V ELI spheroids powder bed during the laser sintering and the successive layer addition and heating for a usual DMLS process, as well for microwave assisted processes. One radiation source, respectively two radiation sources microwave oven were modelled and simulated with COMSOL Multiphysics® to assist DMLS of Ti6Al4V powder bed.

a new path of heat transfer within the powder bed Was designed and modelled using the results of material data analysis and the DMLS process characteristics. SolidWorks® models were exported through the LiveLink™ for SolidWorks® add-on in COMSOL Multiphysics® where heat transfer and phase transformation analyses were performed (fig.1,2).

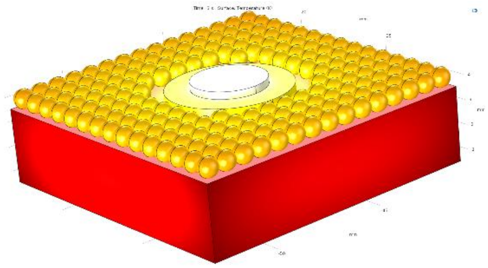


Figure 1. Laser fused powder bed (DMLS) Ti6Al4V powder volume model

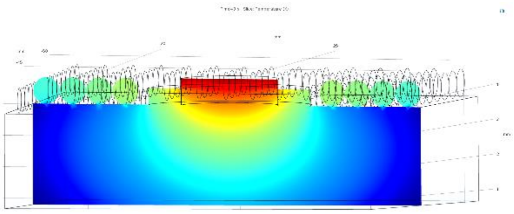


Figure 2. Laser fused powder bed (DMLS) Thermal effect during DMLS [1]

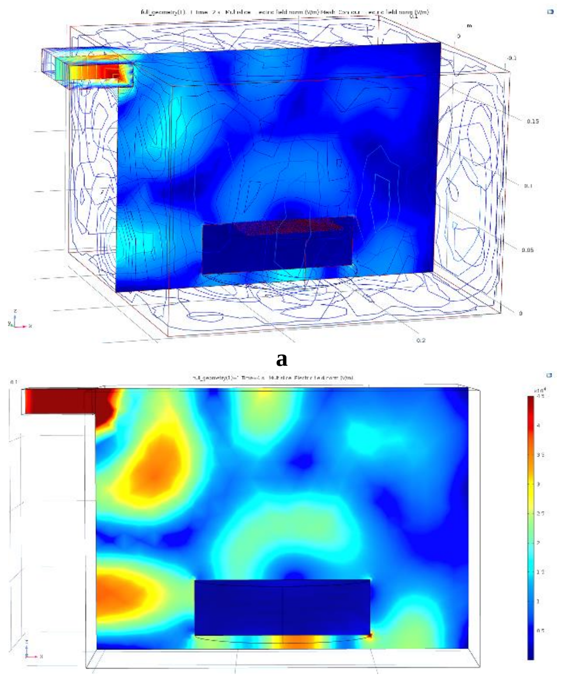
Complete powder bed geometry inside microwave oven was designed and modelled, and each phase of the process was properly described with the use of

3D/2D plot groups and line graph tools in COMSOL Multiphysics®.

In order to simulate accurate processing conditions, COMSOL Multiphysics® material data base was used and customized with new material (Ti-6Al-4V ELI, Grade 23)

4. Simulation Results

Rebuilding the powder bed unit volume with 3D/2D plot groups and line graph tools in COMSOL Multiphysics®, and placing it in one / two radiation source microwave oven generate relevant studies on Electromagnetic Field dynamics during DMLS.


a

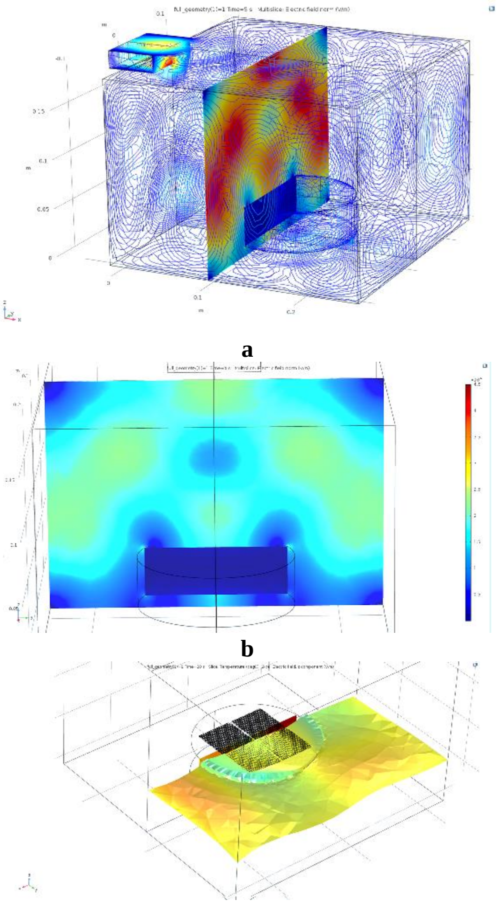
b

Figure 3. Electromagnetic Field distribution within one radiation source microwave oven containing Ti6Al4V powder volume unit: (a, b) longitudinal section (different moments)[2]

Within the powder bed, as well as in the inert gas (Ar) filling the oven under controlled processing pressure flow (PC), it was a periodical non-uniform intensity distribution that influenced heat distribution as well (fig.3-13).

One radiation source microwave oven (fig.3-6) assisting DMLS process precede the laser beam, pre-heating the powder bed, and improving the melting and fusion process.

However, a non-uniform distribution of the Electromagnetic Field intensity may affect the quality of the growing fused structure, beyond the envisaged few layers' depth (fig. 5-6).


a

b

c

Figure 4. Electromagnetic Field distribution within one radiation source microwave oven containing Ti6Al4V powder volume unit: (a, b) transversal section (different moments); (c) plane-section within powder bed volume

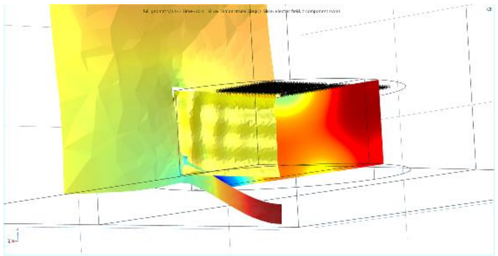


Figure 5. Electromagnetic Field distribution within Ti6Al4V powder bed (transversal section)

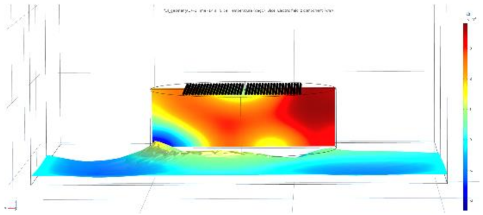
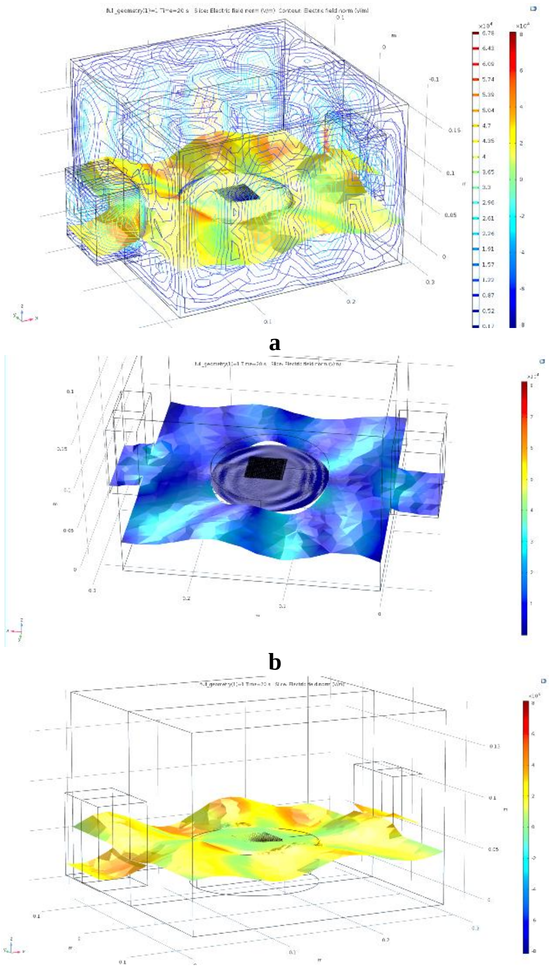


Figure 6. Electromagnetic Field distribution within Ti6Al4V powder bed (plane- section)


a

b

c

Figure 7. Electromagnetic Field distribution within two radiation source microwave oven containing Ti6Al4V powder volume unit: (a, b, c) plane-parallel section (different moments)

Corroborated thermal effects (laser, electromagnetic radiation, etc.), supplementary pressure (inert gas flow) and periodical Electromagnetic Field distribution become more predictable on two radiation source microwave oven (fig. 8, 9)

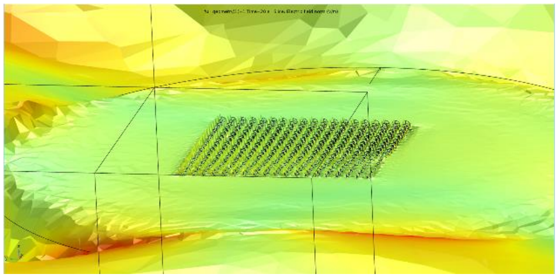


Figure 8. Thermal field on powder bed surface layers within the two radiation source microwave oven

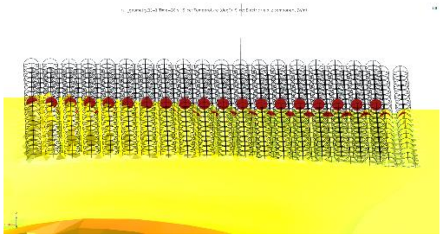


Figure 10. Electromagnetic thermal effect preceding the laser effect (beneath the powder bed surface layer)
- - two radiation source microwave oven--

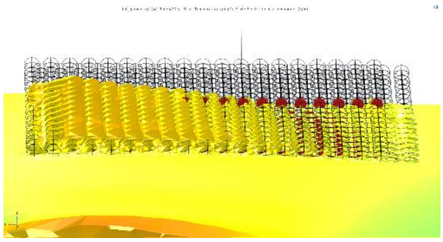


Figure 11. Electromagnetic thermal effect preceding the laser effect (emerging to the powder bed surface layer)
- - two radiation source microwave oven--

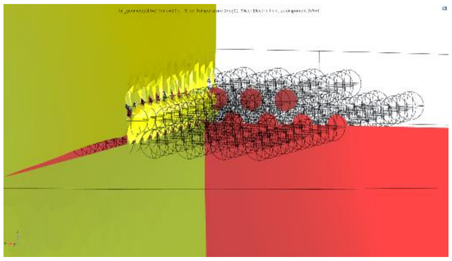


Figure 12. Thermal field on powder bed surface layers within the two radiation source microwave oven (fields superposition effect)

5. Conclusions

Biocompatible 3D printed parts made from metal powders have to answer very strict requirements related to the medical end-using area particularities. Meanwhile, they have to face design challenges to overcome the pitfalls related to shape sharpness and residual thermal stress resulting from 3D Additive Manufacturing itself.

The Dynamic thermal fields assisting DMLS process of biocompatible titanium parts could reduce or eliminate post-processing cost of the printed parts.

References

1. E. Lacatus, M.A.Sopronyi, G.C. Alecu, A. TudorA, Analysis of 3D Biocompatible Additive Structures Using COMSOL Multiphysics®, *Excerpt from the Proceedings of the 2014 COMSOL Conference in Cambridge*, (2014)
2. COMSOL Multiphysics ® models: Microwave Oven