Perner's Contacts ***17****(2), 2022*
DOI: 10.46585/pc.2022.2.2366

ANALYSING THE PRE-DEFORMATION IN CASE OF SELECTIVE LASER MELTING PROCESS

Tamás Markovits[1,*], László Ferenc Varga[1], Ármin Fendrik[2]

Abstract *In Selective Laser Melting technology, the deformation of a metal model depends on many parameters. A complex model geometry needs simulation software to compensate for it. In this research work, the different types of model geometries, materials (316L, Ti64) and pre-deformation processes were analysed in a Selective Laser Melting dedicated simulation software and the real model. The result shows the geometrical difference between the standard and the pre-deformed models and the simulated results and printed parts. Due to the result, the necessity of pre-deformation, the right choice of simulation parameters and the simulation process become more understandable and predictable in SLM technology. Of the two raw materials, in the case of titanium, higher internal stresses are generated during printing, so knowing what the deformations are is even more important than in the case of steel. An important result of the research is that it clearly demonstrates where and to what extent deformation occurs in the case of post-printing operations, thus the desired geometry can better meet the requirements.*

Keywords *additive, SLM, metal, deformation, 316L, Ti6Al4V*

1 INTRODUCTION

The process of selective laser melting (SLM) is spreading in the industry due to its ability to produce unique and more complex geometries in a small series that can only be produced using fewer times or more costly (Bhrigu, A. et al., 2014, Amanda, S. W. et al., 2014). The selective laser melting is similar to a multitrack and a multilayer micro-welding process where the internal stresses and deformations form in welding tracks. These deformations and internal stresses affect the dimensional accuracy and, in some cases, may prevent the printing process (T. Mukherjee et al., 2017, H. S. Park et al., 2017). Simulation methods and software for studying deformation and internal stresses are not yet sufficiently accurate and are still being validated (Mostafa Y., et al., 2020, Bilal, A., et al., 2018).

The current research investigated the pre-deformation capabilities of steel and titanium components printed with SLM technology. Two of the pre-deformation procedures have been investigated. This was compared with the previously nondeformed model. The tests were carried out on simple, well-measurable

[1] Department of Automotive Technologies, Faculty of Transportation and Vehicle Engineering, Budapest University of Technology and Economics, 3. Műegyetem rkp, 1111, Budapest, Hungary
[2] MouldTech Systems Ltd., 7. Fuvar street, 8900 Zalaegerszeg, Hungary
*Corresponding author: markovits.tamas@kjk.bme.hu, Tel. +36-1-436-3468, 3. Műegyetem rkp, 1111, Budapest, Hungary

geometries so that the complexity of the model and the difficulties of measurability did not affect the underlying phenomenon we wanted to explore.

2 EXPERIMENTS

The experiments were performed with an EOS M100 SLM printing apparatus having a cylindrical working space with a diameter of 100 mm. High purity (4.6) argon gas was used for printing. The building platform was a disc shape with a 100 mm diameter and 15 mm high. The standard EOS 316L and Ti6Al4V alloy powders were used as the base material. In the case of the technology, the default EOS parameter sets were used for 20 micrometer build layer thickness, so no changes were made to the basic technology. We chose a simple cuboid model geometry because of the well-known deformation behaviour and good measurability. The cuboids have 28 x 8 mm dimensions, and the thickness was varied to 1 or 3 mm. A 4 mm high block type support was used between the models and the platform with a 0.6 mm hatching distance. Before printing, the expected deformation was determined by Simufact Additive software. Two method types were applied for pre deform the models. The first was the inverse type when the expected deformation of the model is multiplied by the -1 value. The other method was the iteration type when the software calculates the pre-deformed shape by iterating until the distortion values are less than the given value. Six different setups were used depending on the model thickness (1 or 3 mm) and the type of pre-deformation (none, inverse, iteration). Every setup was repeated three times on one platform. After printing, the models were cut in a plain, with a 1 mm cutting gap in the middle of the 4 mm support. In the next step, we removed the remaining support by milling from the model, ensuring that the deformation was not affected by the machining. Using a Mitutoyo Quick Vision optical coordinate measuring machine, the workpiece geometry was measured by measuring the vertical z-directional coordinates at specific points.

3 RESULTS AND DISCUSSION

3.1 Effects of process steps on deformation

A photo of the printed piece is shown in Fig. 1. In the photograph taken after the successful printing, traces of small deformation can be observed on the upper surface, which result from the process building up layer by layer.

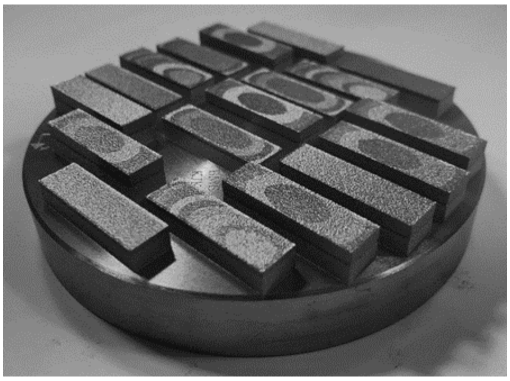

Fig. 1 *photo of printed models on the build platform (316L)*

The effect of the printing and each post-process step are shown in Fig. 2. Here the compensated height values are illustrated according to the points measured in the direction of the longitudinal axis of the cuboids after the various process steps mentioned above.

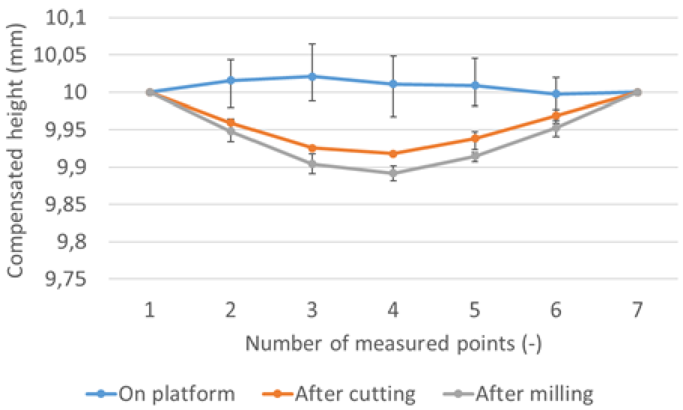

Fig. 2 *Effects of process step on the deformation (316L)*

From the interpretation of the compensated height, points 1 and 7 give the measurement baseline. Measurements show a concave shape relative to the theoretical flat shape. The maximum deviation from the plane is 0.02 mm. The curve depicting the condition after being cut off from the platform shows that significant deformation occurs due to being cut off from the platform. The maximum deformation value is 0.8 mm. Measurements from the model after removing the remaining support indicate that the model has been further deformed after removing the stiffening block support grid, resulting in a final deformation of the finished model that is greater than 0.1 mm relative to the theoretical plane surface.

In other setups, the deformations were similar, so in summary, the most significant change in deformation occurs when the models with remaining support are removed from the platform, which shows the high effect of the platform on the realisation of deformation. It can also be stated, and this was the case for the other setups, that removing the remaining support from the model allows further deformation of the workpiece, but it is just 10-20 % of the total deformation.

3.2 Effects of pre-deformation methods on deformation

Examining the effect of the pre-deformation type on the deformation, we can see the results on the platform in Fig 3. and after milling in Fig. 4. for the 316L steel.

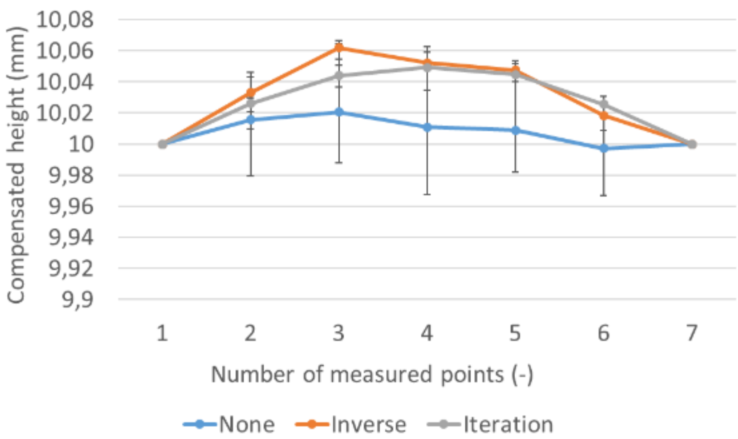

Fig. 3 *Effects of pre-deformation types on the deformation on the build platform (316L)*

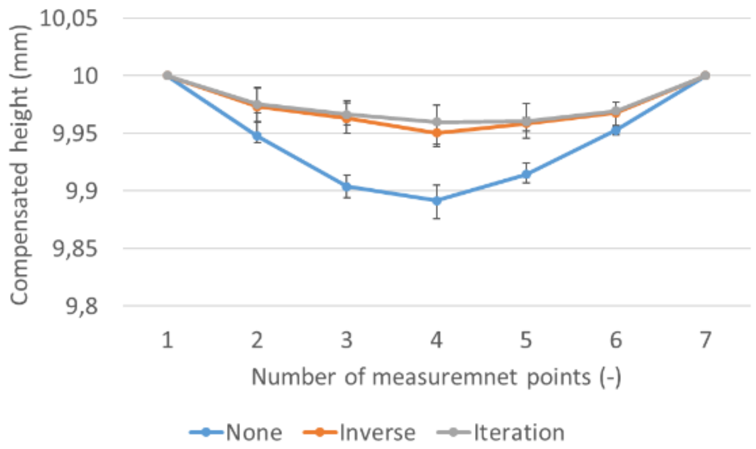

Fig. 4 *Effects of pre-deformation types on the deformation after milling (316L)*

It can be seen in the diagram that the model without pre-deformation deviates from the theoretical plane by less than 0.02 mm in concave form, while the inverse or iteration type pre-deformations increase this value by three times higher until 0.05-0.06 mm. The pre-deformation increases the initial deformation. There is no significant difference between the two types of pre-deformation values. There are minor differences in the shape, but they increase concavity, which is later reduced by internal stresses. The figure shows that the final deformation is a convex form in every case and the largest when the model is without pre-deformation (0.1 mm). In contrast, the half deformation occurred in the pre-deformed cases, and it was lower than 0.05 mm. It can be seen that as a result of the pre-deformation, the deformation of the finished model can be reduced. A larger pre-deformation would further reduce the final deformation in this particular case. With this simple geometry, the resulting deformation does not differ between the two pre-deformation methods, but it should be noted that the iteration method requires more time in the simulation software, so this should be taken into account for later use in more complex geometries.

3.3 Effects of base material on deformation

In Fig 5. and 6. the impact of the base material is illustrated. The curves connected to the 316L steel are completed with the values of titan alloy. The compensated height shows that the Titan material has almost the same shape when the models are on the platform. The pre-deformed shape has a higher concavity in the case of titan alloy, and the differences are higher in the case of inverse type pre-deformation methods, taking into account that the titan has higher inner stress during the SLM process.

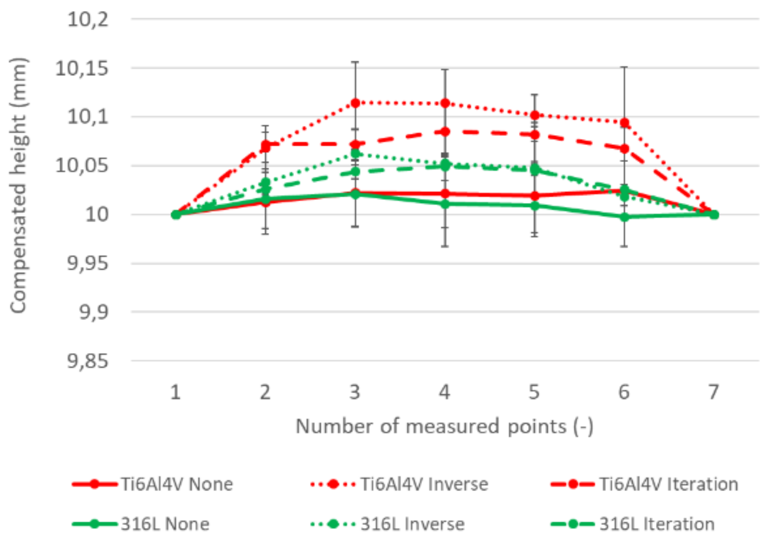

Fig. 5 *Effect of the base material on deformation on the build platform*

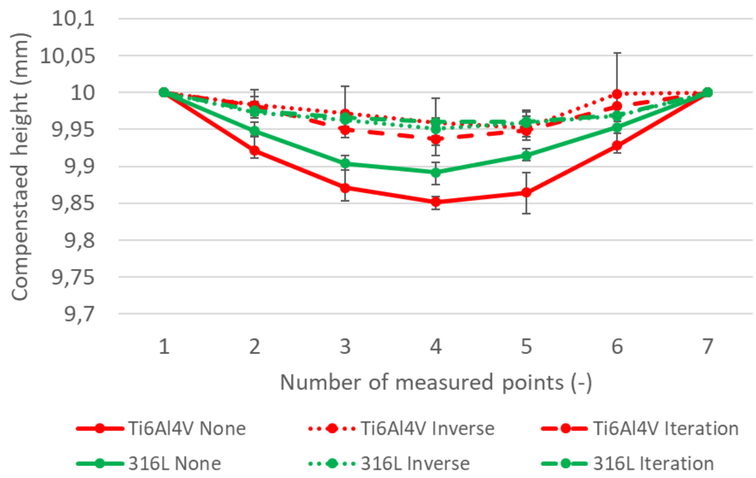

Fig. 6 *Effect of the base material on deformation after milling*

Without pre-deformation, the convexity of titan is higher than the steel model, although the initial deformation on the platform was almost the same. This is due to the fixturing effect of the support and the building platform together.

In the case of pre-deformation, the application of the Inverse method caused less final distortion from the theoretical was comparing the Iteration method. The difference in the case of titan alloy comes out better.

4 CONCLUSIONS

Investigating cuboid geometries and measuring the characteristic deformation without heat treatments, the following can be concluded:

- The cutting post-process step is the dominant effect from the viewpoint of the final deformation of the models. The 80 % of the final deformation comes from the cutting step, and the remaining 20 % comes from the removal of remaining support,
- The pre-deformation method causes higher deformation on the platform and can effectively reduce the final deformation of printed parts,
- The two investigated pre-deformation methods (Inverse and Iteration) did not show high differences in the deformation values in the case of steel, but the Inverse method reduces better the final deformation in case of titan alloy, and it is less time consuming,
- The higher inner stress of titan alloy (Ti6Al4V) causes higher final deformation than 316L steel material without pre-deformation, but it can reduce to the level of steel without heat treatment applying the pre-deformation methods,

Acknowledgements

The project is funded by the National Research, Development and Innovation (NKFIH) Fund. Project titles: "Development of multi-purpose fixed-wing drone based on innovative solutions and the creation of necessary competencies". The application ID number: 2019-1.1.1-PIACI-KFI-2019-00139. The authors want to express their thanks for the financial support.

References

Bhrigu, A., Michael, K., Konstantin Yu. N., Michael S. **2014**. Fabrication and Characterization of High Strength Al-Cu alloys Processed Using Laser Beam Melting in Metal Powder Bed, Physics Procedia, 56, pp. 135 – 146.

Amanda, S. W., Donald, W. B., Mukul K., Gilbert, F. G., Wayne, E. K. **2014**. An Experimental Investigation into Additive Manufacturing- Induced Residual Stresses in 316L Stainless Steel, METALLURGICAL AND MATERIALS TRANSACTIONS A, 6260—VOLUME 45A,

T., Mukherjee, W., Zhang, T., DebRoy **2017.** An improved prediction of residual stresses and distortion in additive manufacturing, Computational Materials Science, 126, pp. 360–372

H. S., Park, N. H., Tran, D. S., Nguyen **2017.** Development of a predictive system for SLM product quality, IOP Conf. Series: Materials Science and Engineering, 227, 012090

Mostafa Y., M.A., Elbestawi, S.C., Veldhuis and S., Nangle-Smith **2020.** Influence of thermal properties on residual stresses in SLM of aerospace alloys, Rapid Prototyping Journal, 26/1, pp. 213–222

Bilal, A., Sjoerd O., V., Michael E., F., Hua, G. **2018.** Residual stress evaluation in selective-laser-melting additively manufactured titanium (Ti-6Al-4V) and Inconel 718 using the contour method and numerical simulation, Additive Manufacturing, 22, pp. 571–582