International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 10 Issue 3, May-Jun 2026 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Mechanical Joining of Materials with the Support of Simulation Tools

Jan Varga, Lubos Kascak

Department of Technology, Materials and Computer-Aided Technologies,
Technical University of Kosice, Kosice, Slovakia

ABSTRACT

Currently, additive manufacturing is increasingly used in the production of simple-shaped parts, but its technology also contributes to the production of complex-shaped parts for various industries. Simulation tools that can predict possible errors and provide comprehensive information about the behavior of materials in the additive manufacturing process of metals currently enable the prevention of errors in the manufacturing process. This article deals with the application of the Simufact Additive 2024.2 simulation program for predicting errors in parts, known as press, dies, in the metal additive manufacturing process. Simulating the printing process in the Simufact Additive simulation program made it possible to predict possible deformations and errors that could occur in the production of press dies.

KEYWORDS: *metal additive process, support geometry, volume fraction*

How to cite this paper: Jan Varga | Lubos Kascak "Mechanical Joining of Materials with the Support of Simulation Tools" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-10 | Issue-3, June 2026, pp.476-480, URL: www.ijtsrd.com/papers/ijtsrd133270.pdf

IJTSRD133270

I. INTRODUCTION

Currently, methods of mechanically joining sheet metal and other parts are widely used, involving the use of additional elements in the form of various screws, nuts, rivets, pins, etc. The joining of materials using mechanical joining methods can be achieved by plastic deformation or by pressure at the contact interface of the parts and their mutual interlocking, whereby the process is carried out by applying heat from an external source or by adding another medium (e.g., in the form of an adhesive layer). As a result, the joint is created by joining the parts in the form of thin sheets through controlled plastic deformation, ensuring the correct creation of pressure and form-fit in the form of interlocking between the joined materials [1].

In terms of predicting errors in the joining process, simulation tools prove to be effective, ultimately enabling the resolution of design problems and the analysis of material behavior in the forming process or plastic injection molding. Another group of simulation programs consists of simulation tools specific to the field of metal additive manufacturing. These are simulation tools applied in the production of parts, focused on the process of applying molten polymer layer by layer. We also encounter simulation tools in which metal powder is sintered and applied layer by layer - the process of powder bed fusion.

One of the specific advantages of this metal additive manufacturing is the production of parts regardless of their geometry. The metal additive manufacturing process offers several advantages over conventional manufacturing technologies such as machining. The synergy achieved in metal additive manufacturing, where the material in powder form and the geometry of the product is created simultaneously, also requires the design of the part to be linked to knowledge of the process. Since the entire manufacturing process, properties, and factors involved in additive metal manufacturing are closely related and connected, it is necessary to understand their impact on the production of the part. One way to achieve this is by applying simulation tools.

It is important to remember that the process of additive manufacturing by applying molten plastic layer by layer is completely different in nature from metal printing. The complexity of the geometry encountered in the manufacture of metal parts represents the highest degree of difficulty in terms of the size of the elements and their structure [2,3]. The purpose of using simulation tools is therefore not only to understand the processes that take place during production, but also to prevent undesirable effects. By using them, we can obtain a relatively accurate idea of part deformations, residual stresses, and other errors even before the actual part production phase, i.e., the printing process takes place. Among other things, they can provide data on material behavior at the voxel level displayed in three-dimensional volume. This fact has an impact not only on the possibilities of part production, but also on the design, optimization, and control of the proposed materials. Ultimately, this is a costly process compared to conventional technologies, where the goal in this case is to achieve part production with minimal errors [4].

One of the simulation tools that enables virtual simulation and optimization of factors such as parameter and material settings, removal of direction and support, and creation of a support structure is Simufact Additive software. It is a simulation tool focused on predicting and solving failures throughout the entire process of printing, heat treatment, cutting, and HIP (hot isostatic pressing process) before sending the part to the machine [5].

Simufact Additive software works with its own deformation values (ε∗) used to calculate and predict residual stress and partial distortion. It also works with voxel elements, whereby a smaller voxel size means a longer calculation time. The application of simulation tools and the ability to compare the effects of parameter changes or the use of different materials is more advantageous in terms of time and economics. Simulation tools work with FEA methods designed to evaluate shape deformation and residual stresses in printed parts. Various scalable approaches are available within the analysis (Fig. 1) designed only for the laser powder bed fusion (L-PBF) process.

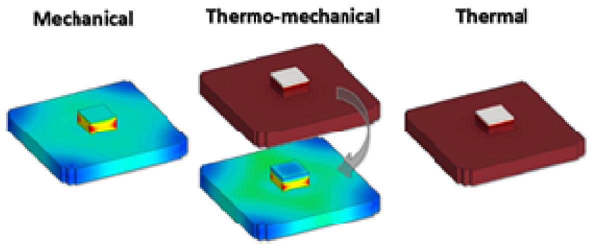


Fig 1. Simulation options in the Simufact Additive simulation program [1]

Mechanical analysis allows for quick, strict mechanical analysis. The main input data required is the actual deformation. Thermomechanical analysis enables a combined thermomechanical analysis. With this approach, the temperature, deformations, and stresses in the component, support structure, and foundation plate due to the energy supplied by the laser can be obtained. Thermal analysis enables quick and strict thermal analysis. This approach considers the temperature field in the component, supporting structures, and base plate.

Due to the large number of simulation tools designed for metal additive manufacturing, Simufact Additive was used for the experiment, which, with its powerful and scalable software solution, is suitable for simulating metal-based additive manufacturing processes [5]. A major advantage of these simulation tools used for the additive manufacturing process is not only the wide range of input parameters that can be entered, but also the ability to control stress states and part geometry. Finally, it also allows for microstructure control based on the volume of the component, using process maps. The aim of the paper was to predict errors that could occur in the production process of a part – a press die – using the Simufact Additive 2024.2 simulation program, which offers a wide range of options for analyzing the additive manufacturing process of metals.

II. Methodology of research

AlSi10Mg aluminum alloy powder was used for the experiment, which has several advantages for use not only in the aerospace industry, but also in the automotive industry. First, a die-shaped sample was imported in STL format into the Simufact Additive 2024.2 simulation environment, where its orientation was determined. A total of five samples – dies – were used for the simulation. After defining the orientation for the construction of the molds, the support geometry was selected, as shown in Fig. 2.

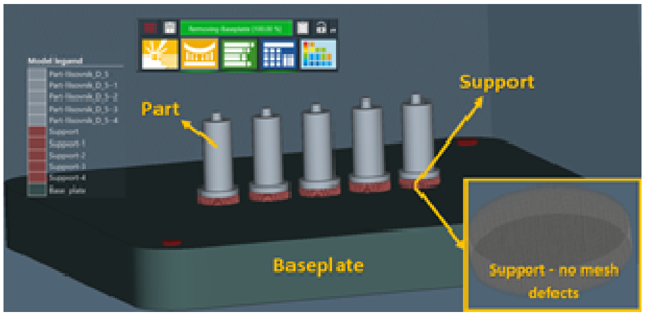
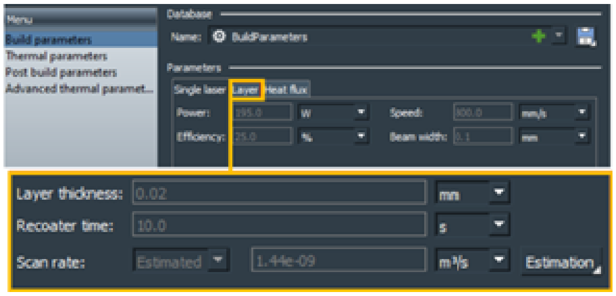


Fig 2. Display of 5 press dies with defined support geometry

The following parameters were selected for the mechanical analysis of the laser powder melting process: laser power 195 W, build layer height 20 µm, as shown in Fig. 3. The selection of these parameters made it possible to predict future errors in the process that could occur during the production of 5 press dies. The most common problems we recognize in the metal additive manufacturing process are deformations, cracks, and residual stresses, which could affect the mechanical properties of the manufactured parts as well as their functional properties in the final production.



Name: BuildParameters

Power: 195.0 W

Efficiency: 25.0 %

Speed: 800.0 mm/s

Beam width: 0.1 mm

Layer thickness: 0.02 mm

Recoater time: 10.0 s

Scan rate: Estimated 1.44e-09 m³/s

Fig 3. Display of laser input parameters and layer thickness

When selecting the support material, we based our decision on the simplicity of the shape of the samples (press dies). For this reason, a cylindrical geometry was chosen, a closer view of which is shown in Fig. 4.

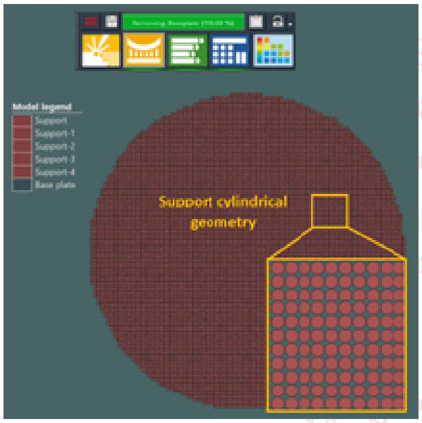


Fig 4. Display of cylindrical geometry designed for support creation

For the final implementation of the simulation, the size of the element (voxel) was defined, the purpose of which was to define the value of the grid in 3D space. This element size also allows for a more detailed analysis of the deformation states that will occur during the process. It is important to note that the size of the selected element also affects the volume fraction of the part. Therefore, for the purposes of simulation analysis, we chose an element value of 0.8 mm for all X, Y, and Z directions. The value of 0.8 mm was chosen in terms of the simple geometry of the part as well as the speed of calculation.

After running the analysis and processing the simulation, the volume fraction was displayed for a total of 5 test samples, the value of which describes how much of the voxel element is filled with geometry. The display of the volume fraction in the production of 5 press dies in the simulation area is shown in Fig. 5. Within this volume fraction, 49.763 voxel elements, 73.304 node points, and a total of 34 layers were obtained for the part construction process.

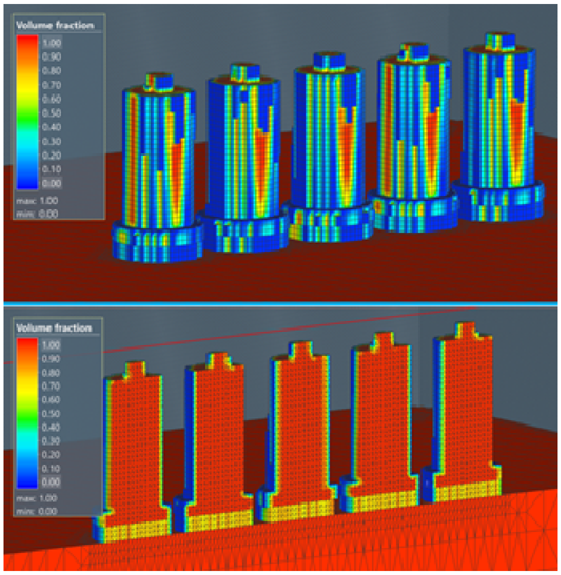
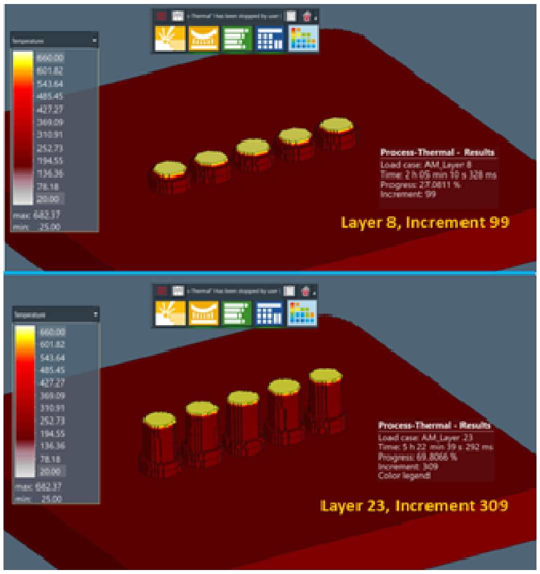


Fig 5. Display of the volume fraction inside the press dies

To assess the quality of the volume mesh in the part, the quality of the mesh was verified in a cross-section, where, as can be seen in the figure, the interior of the part was red, which resulted in a volume fraction of 1. This result qualifies the mesh as being of sufficient quality, so it was not necessary to adjust the size of the element. If we had achieved a blue color inside the part, it would have been necessary to consider changing the size of the voxel element.

For the final calculation and simulation, a solver called Iterative Sparse was selected, which makes it possible to obtain results in the form of shape deviations, relative density, total displacement, elastic and plastic strain, and others. Fig. 6 shows an example of the gradual temperature transfer in the simulation process with respect to a specific layer. The highest temperature during the construction of the component was 682.37 °C.



Load case: AM_Layer 8
Time: 2 h 05 min 10 s 328 ms
Progress: 27.0811 %
Increment: 99

Load case: AM_Layer 23
Time: 5 h 22 min 39 s 292 ms
Progress: 69.8066 %
Increment: 309
Color legend

Fig 6. Display of heat transfer in individual layers during the production of press dies

Another important parameter for the manufacturing process is the equivalent stress parameter, which includes the complex stress state, the value of which makes it possible to determine the extent to which the material is stressed against the yield strength Re. The simulation (Fig. 7) showed the lowest and highest values of this parameter, namely max: 264.086 MPa and min: 28.31 MPa, which, considering the mechanical properties of the material, is a satisfactory maximum value achieved in the simulation. In the case of an exceeding value, it would be necessary to subsequently adjust the geometry of the supports, because of which these stresses would be transferred from the component to the supports. In our case, however, the use of cylindrical support geometry can be considered sufficient.

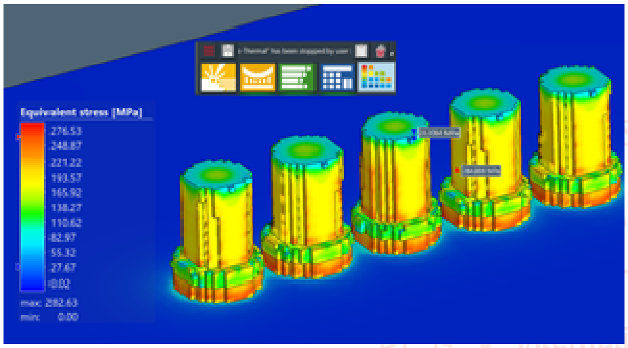


Fig 7. Display of the results of the equivalent stress of the press dies

Another parameter that is key to understanding the current strength of the material at each moment and point in the process is the flow stress parameter, which is shown in Fig. 8. Compared to the equivalent stress parameter, it also tells us how much the material can still withstand at a given moment before it begins to deform permanently. In our case, the simulation showed a maximum value of 280.88 MPa and a minimum value of 148.466 MPa. When comparing the results obtained with Equivalent Stress, where the maximum value was 264.086 MPa, and the results obtained with Flow Stress, where the highest value was 280.88 MPa, it can be concluded that the material is elastic, i.e., it will return to its original shape after release.

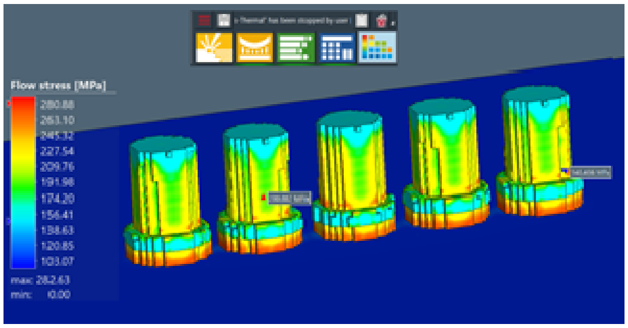


Fig. 8 Display of deformation stress of press dies

The additive metal printing process is closely related to the distortion factor, which cannot be avoided in the manufacturing process. This is the result of heating a small amount of material to its melting point on an otherwise cooler layer. It is not possible to eliminate it completely, but the Simufact Additive 2024.2 simulation program has options to mitigate this geometry compensation. This involves changing the geometry of the part with the possibility of predicting distortion (Fig. 9) that will occur during the manufacturing process so that the part is deformed into the desired final shape. In other words, the Simufact Additive software takes the final distortion into account in its simulation calculations and predefines the compensation so that the most accurate dimensions are achieved during printing and the part itself is not deformed.

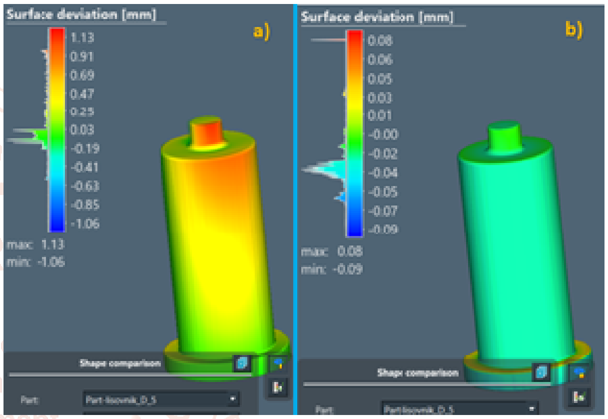


Fig. 9 Display of press die deviations a) before compensation b) after compensation

III. Results and discussion

The results showing the gradual temperature transfer in the simulation process with respect to a specific layer show the highest temperature reached during the construction of press dies, 682.37 °C. Within these results, no hot spots, i.e., places that cannot cool down fast enough, were displayed. These are areas that would be displayed in the core of the press in the form of red spots. The simulations showed the core as a solidified layer. The results in the form of equivalent stress showed that there will be no permanent deformation of the material or its fracture, as the value obtained is below the yield strength Re.

In terms of material strength prediction, the Flow Stress parameter was used to determine that the material must exceed 280.88 MPa for permanent deformation to occur. Compared to the Equivalent Stress results, where the maximum value was 264.086 MPa, it can be concluded that the material behaves elastically, i.e., it returns to its original shape after release. Within the final distortion without compensation, the maximum deviation reached a value of 1.13 mm and the minimum deviation without compensation had a value of -1.06 mm. To be able to produce samples with the required accuracy and geometry later, the compensation for the given geometry was calculated, where, after analyzing the final distortion with compensation, the maximum deviation reached a value of 0.08 mm and the minimum deviation with compensation had a value of -0.09 mm.

IV. Conclusion

Based on the results achieved by defining the input parameters in the simulation process, no defects or errors were found that would be critical for the die production process.

Acknowledgment

Author is grateful for the support of experimental works by project VEGA 1/0330/24.

References

[1] B. N. TURNER, R. STRONG, S. GOLD, "A review of melt extrusion additive manufacturing processes," Process design and modelling. Prototyping Journal., vol. 20(3), pp. 192 – 204, 2014.

[2] T. NGO, D. KASHANI, A. Imbalzano, et al., "A review of materials, methods, applications and challenges," Composites Part B: Engineering, vol. 143, pp. 172-196, 2018.

[3] Ľ. KAŠČÁK, J. VARGA, et al., "Numerical and experimental studies on clinch-bonded hybrid joining of steel sheet DX53D+Z," Acta Metallurgica Slovaca, vol. 28(4), pp. 219 – 223, 2022.

[4] D.D. GU, W. MEINERS, R. POPRAWE, "Laser additive manufacturing of metallic components: materials, processes and mechanism," International Materials Reviews, vol. 57(3), pp. 133 – 164, 2012.

[5] B. MUELLER, "Additive Manufacturing Technologies – Rapid Prototyping to Direct Digital Manufacturing," Assembly Automation, vol. 32(2), pp. 1 – 10, 2012.