Case study: **Effee Induction AS**

Simufact products help through-process simulation and numerical analysis for robust additive manufacturing of advanced components

Directed energy deposition (DED) process simulation for WAAM processing of complex components.

Based on an interview with: Dr. Amin S. Azar – Head of additive manufacturing at Effee-Induction AS.

Overview

When you come up with a brilliant business idea, it is necessary to find the right tools to help you succeed.

Production of metallic materials for various industries with stringent regulatory practices requires proof and documentation that the procedure complies with standards and safety guidelines.

This becomes bolder for the cases where the component is meant for demanding environments and built with a novel material or process. The latter is among the greatest challenges in the industry since new materials may pose an immense setback as it will have to go through costly test campaigns before being permitted for operation. Therefore, there is a great demand for developing a predictable procedure that reduces the time-to-market.

We at Effee Induction AS have cracked the code by developing a ground-breaking AM technology that takes advantage of advanced robots and DED methods. In this process, numerical analysis of the entire DED process using Simufact Welding software is a great leap forward within our digital twin approach, in accordance with understanding the challenges, taking timely measures, and cultivating a vigorous contingency plan.

AM and challenges with fast-track developments

The additively manufactured components shall comply with a set of requirements. For instance, in case of building steel components, the materials shall contain a certain microstructure, hardness, residual stresses and homogeneity.

It means that the determined DED procedure shall all be addressed in a proper manner. The influential factors consist of process parameters, in-service temperature and pressure of the component, tolerances, thermodynamic and kinetic behavior of the materials, intermittent temperature ranges, tool path, timing, costs, and many more.

The circumstances change constantly from one geometry to another, and therefore, a totally new model shall be developed to study various factors. Effee Induction AS is using the Simufact Welding software to investigate the applicable boundary conditions for each single job in an expedited, yet trustworthy fashion.

"Simufact Welding software helps us to find relationship between the applied tool path and the cooling rate, phase transformation, residual stresses and other factors that can determine the quality of the delivered materials.

The software simulates the entire value-chain, from pre-heating, deposition, laser processing, induction heating and stress-relief heat treatment of the material on the same model and in the same software environment".

Practical use of Simufact in developing AM components

A case study by Effee Induction AS

Thermal cycles and heat spread

The primary goal of using the numerical approach is to simulate the recurrent thermal cycle in the material. This will allow us to manage the timings and fine-tuning the process parameters towards a more viable set of conditions for any given geometry.

In the following example, a cylindrical geometry with 8 supporting ribs was studied. The material is S355 steel, and the tool path consists of 25 layers to produce the presented geometry. The diameter of the cylinder is approximately 130 mm, and the height of the component is 50 mm.

Based to the simulation results in Figure 1, we could understand the effect of the layer number on the extent of the reheated zone in the deposited material, as well as the shape of the heated zone in the supporting ribs regions. It was observed that the ribs, especially on the higher layers are acting as heat sinks and introduce deformity in the thermal profile.

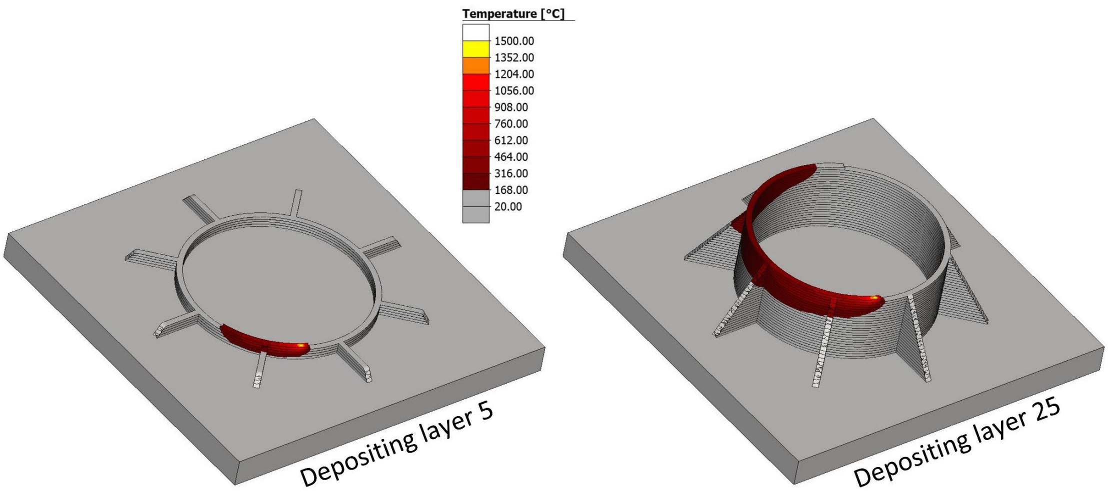

Figure 1: Temperature field comparison when the 5th layer and the 25th layer are being deposited.
Robot tool path developed by Terje Alfsen, Effee Induction AS.

Structural deformation

Parameters such as temperature dependent material flow property, temperature distribution, cooling rate and structural support are among the factors that influence the overall deformation of a material that is processed by DED.

Figure 2a shows the total displacement field on the deposited geometry after completion and cooling down to the room temperature. The maximum deviation can be observed between the supporting ribs, with the maximum deformation value of 0.2 mm. This is an acceptable value for the given conditions, showing that the selected tool path can be comfortably used to process the material with relatively high tolerances.

The displacement field suggests that the heat distribution in the supporting ribs regions plays a leading role in material deformation. Because of the relatively higher cooling rate in those regions after deposition, the material will resume its room temperature strength faster than the areas that take longer time to cool down.

Moreover, the ribs will structurally support the material in the connection regions and prevent deformation.

Figure 2b depicts the post-deposition reconstructed geometry from a 3D-scanning data, and comparison with the nominal CAD geometry. As it can be clearly seen, the maximum deviation is registered for the areas that are between the supporting ribs, agreeing with the predicted results in the simulation.

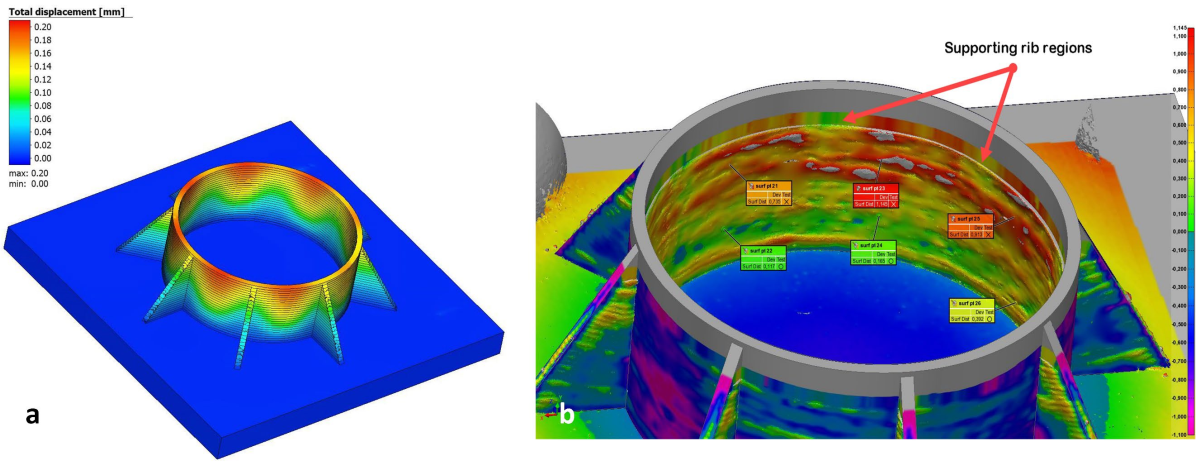

Figure 2: (a) Calculated displacement field, showing how the material is deformed under the given tool path and (b) comparison between the nominal CAD dimensions and the 3D-scanned geometry after deposition.
3D-scanning and comparison analysis performed by Danni Houmøller, Effee Induction AS.

Microstructural evolution and hardness

Simufact Welding can predict the microstructure of the component, based on the Continuous Cooling Transformation (CCT) and Time-Temperature-Transformation (TTT) data. The software can import such information from various validated databases.

The approach is based on the registered cooling rate between 800 °C to 500 °C, also known as $\Delta T_{8/5}$ in welding terminology, based on which, the microstructure evolution and hardness can be predicted.

Figure 3 shows the martensite volume fraction and the hardness prediction in the deposited geometry. The lower layers were deposited on a material with room temperature that causes faster cooling rate, and therefore higher martensite content prediction.

The connection region between the ribs and the cylinder body are also of higher cooling rate. This is primarily because of the tool path end points and the fact that the cylinder geometry acts as a heat sink. More interestingly, there are a few predicted martensitic spots on the body of cylinder.

Conclusion

After careful investigation, it was found that the spots are the end points in the tool path for the body of the cylinder. This finding suggests that the tool path should be investigated for the coincidence of these spots with the region where the ribs are connecting the cylinder body, to avoid excessive hardness and possibility for cracking or failure.

The predicted hardness is also in good agreement with the microstructure. The hardness field shows higher values where the hard phases such as martensite and bainite was predicted.

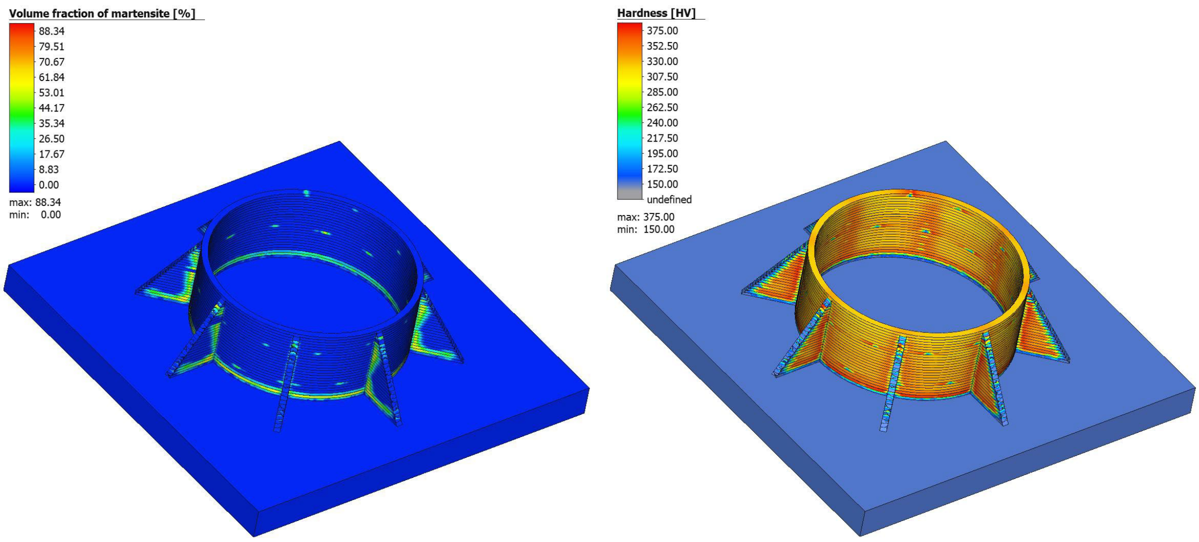

Figure 3: Martensite volume fraction and the estimated hardness profile, calculated based on the CCT data of the material.

Failure probability predicted using Simufact Welding

Simufact Welding provides the opportunity to explore the results through a “user-defined” field. Any combination of the results can be specified and mapped to improve our insight to the material and its performance.

Figure 4 shows a user-defined field to predict the failure probability in the deposited geometry. The field is defined based on a unique combination of results, including von Mises yield criterion, stress triaxiality and the microstructure. The susceptible regions that this approach has predicted are shown with higher probability in the depicted figure.

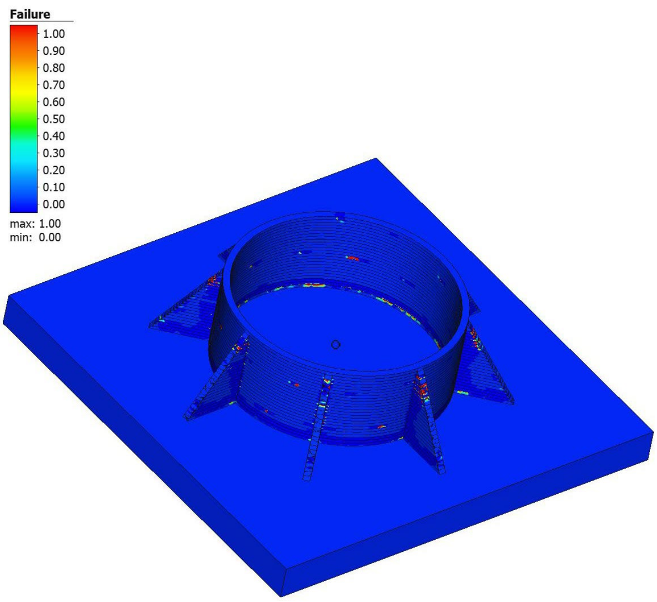

Figure 4: User-defined field of failure probability criterion, showing the vulnerable areas.
Analysis method developed by Pål Idar Ingebo, Effee Induction AS.

Experiments

The numerical investigation of the process enabled us to optimize for various parameters and fabricate the geometry right in the first attempt.

Figure 5 shows the images during and after processing. Figure 5a shows how the robot is depositing the material using the WAAM technology, and Figure 5b shows the as-deposited material. Figure 5c and 5d are showing a comparative image from the real deposition and the identical time in the numerical simulation.

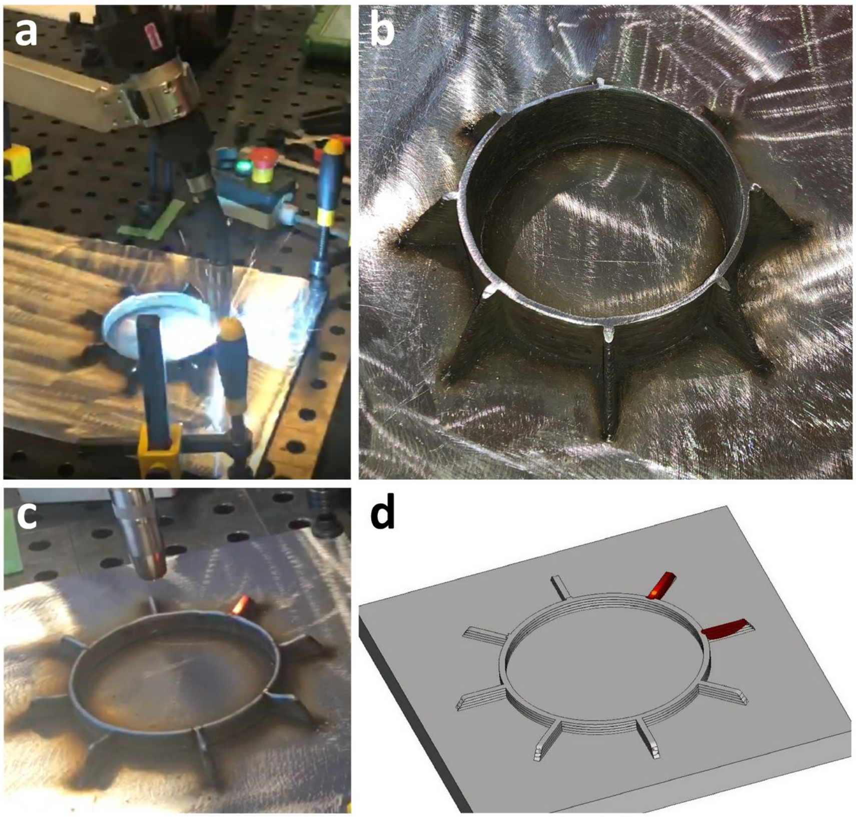

Figure 5: (a) WAAM deposition of the geometry, (b) the geometry after deposition, (c, d) a comparative image from the actual deposition and the numerical simulation results, showing the temperature field distribution.

Concluding remarks

DED processing of the materials comprises of various complex phenomena. For demanding applications such as energy and aerospace, there is no room for trial and error, and the process must be performed correctly in the first attempt.

Simufact Welding is a powerful tool that gives us the opportunity of studying the process wholistically prior to the experiments and rectify the possible sources of problems in advance, from tool path to post-DED processing. The software provides possibility for documenting the entire process and performing the cost analysis in addition to the deep scientific analyses.