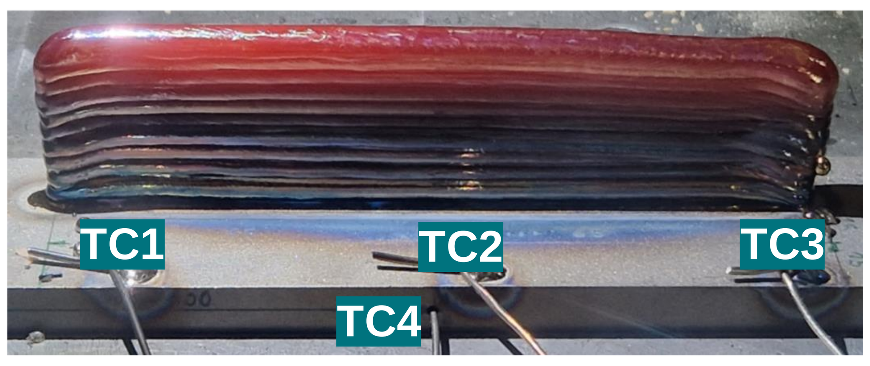
Parameter Study for the Numerical Analysis of the Wire Arc Additive Manufacturing Process

Motivation

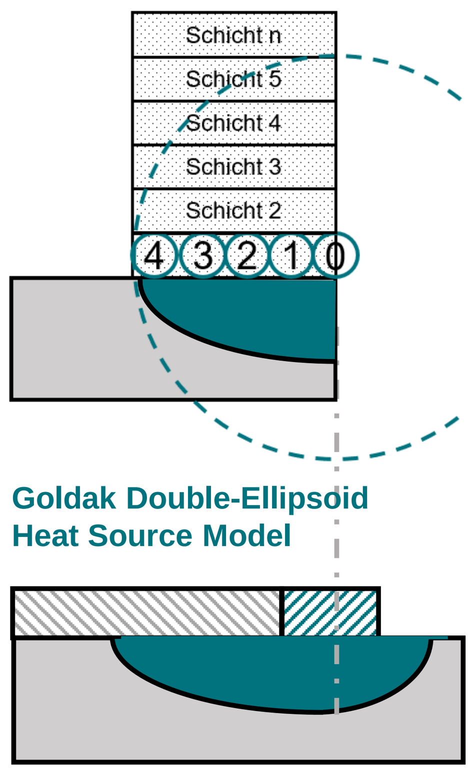
Wire Arc Additive Manufacturing (WAAM) is primarily used to produce large, complex components from titanium and nickel-based alloys. The greatest potential of this process lies in the selective creation of structures, whereby subsequent mechanical processing can be eliminated or greatly reduced. Arc welding energy sources achieve 40 to 100 times the melting rate of powder bed processes, but at the same time induce much higher temperature gradients, which cause residual stresses and distortion. Further, the welding process is dependent on many parameters, which makes it difficult to manufacture as close as possible to the final geometry. A reliable prediction using Finite Element Analysis (FEA) is therefore unavoidable. However, many process parameters are currently assumed, which makes this detailed parameter study necessary to obtain sufficient process knowledge.

Reference Experiment



A numerical simulation was conducted on an 8 mm wide Ti-6Al-4V weld bead built onto a 10 mm thick substrate plate to achieve a 50 mm high wall with 32 stacked layers. The plasma welding device operated within a process chamber filled with argon to shield the atmosphere. Four thermocouples (TC 1-4) recorded temperature data, with TC4 specially positioned inside the substrate for effective comparison due to its shielded position.

Numerical Modelling



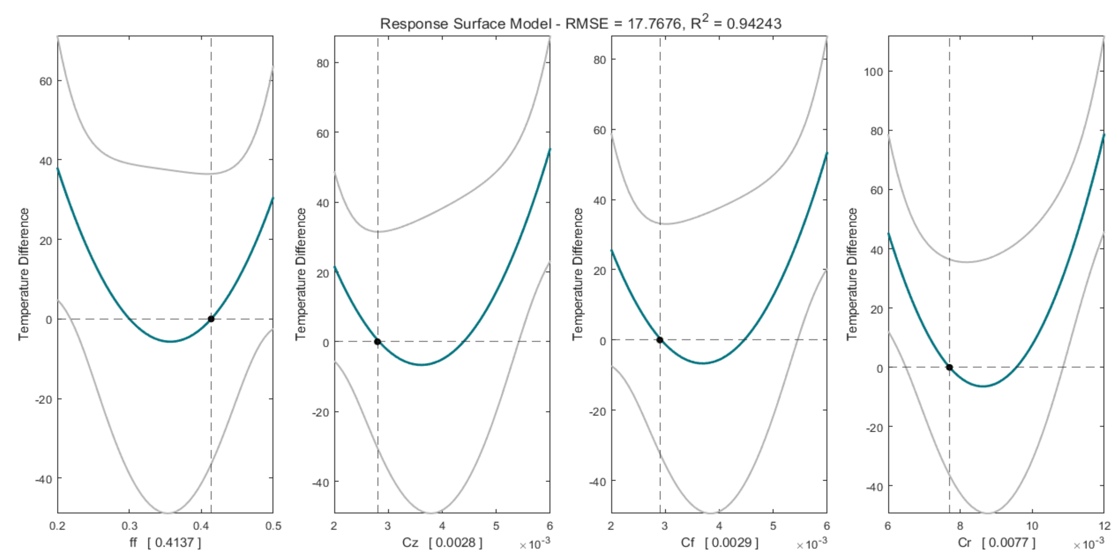
The in-situ measurement of weld seams is very complex, thus a rectangular approximation of individual layers is chosen due to its practicality. Using the measured welding power and feed rate, a difference factor adjusts energy input in the simulation to match the real energy per volume unit. Additionally, a strategy that activates elements with a cuboid volume centered on the heat source is applied.

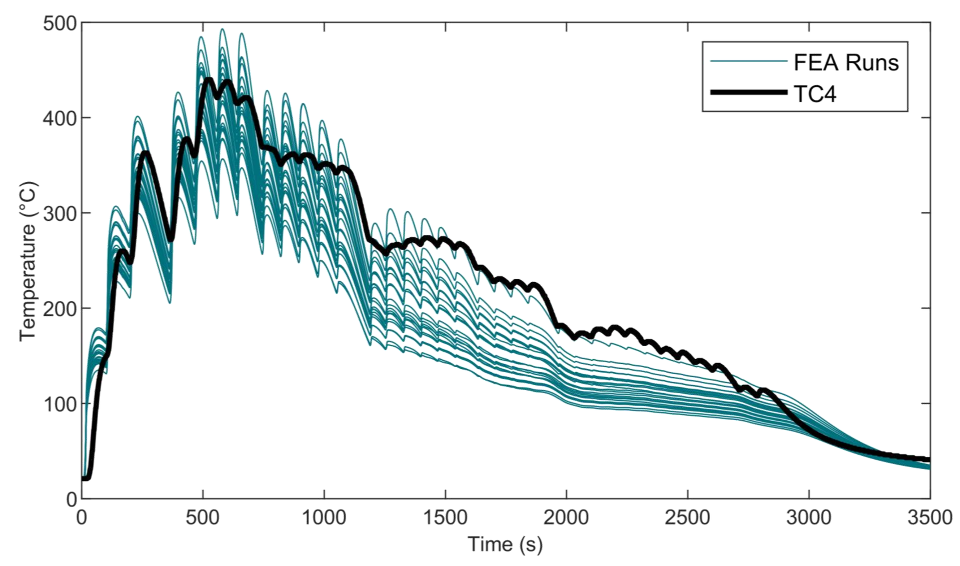
Parameter Study

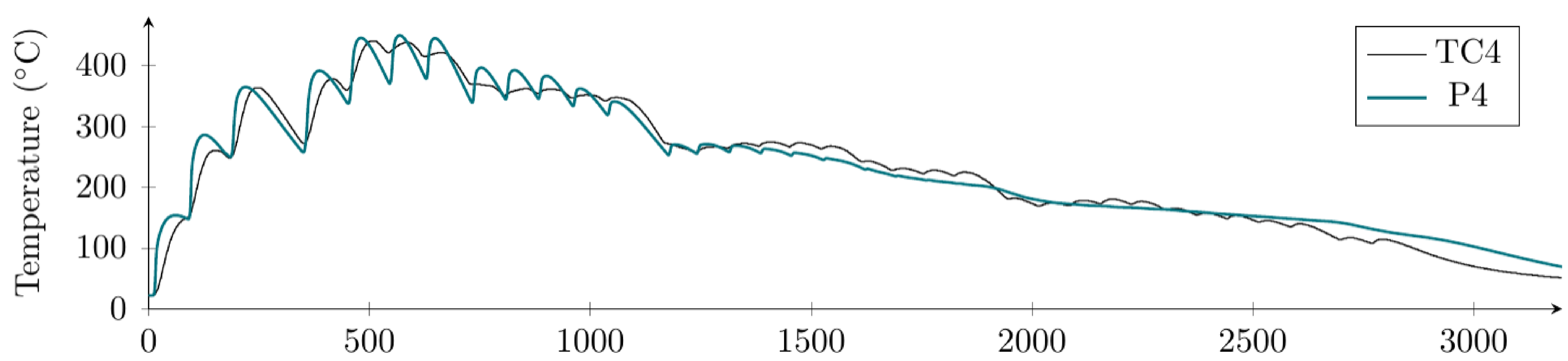
The FE simulation employs DEFORM 12.1 with a new AM module. To activate melting elements accurately, four dummy heat sources with volumetric parameters are utilized, preserving energy input on the main heat source. TET10 and HEX8 elements, which are used in a mixed mesh structure, optimize efficiency in the weld seam area. Considering conduction, convection, and radiation on all surfaces, the model is refined by comparing TC4 data with simulation values. Optimization, using a Circumscribed Central Composite (CCC) Design of Experiments (DoE), yields a response surface model within a 95 % confidence interval for each step. Filtering data around the mean value minimizes fitting errors in the assembly to a time series data set, which proposes optimal parameter choices for any chosen time. This process, applied to three different parameter sets, yields an $R^2 > 92\,\%$ and RMSE < 30 K, resulting in a close approximation of the real temperature curve in the normalized FE model, proving the concept.

Summary & Outlook

The parameter study revealed the potential for a statistical approximation of optimal process parameters. However, the database requires improvement and targeted raw data acquisition can enhance results and areas of narrow parameter variation. Further investigation is needed, particularly in contact conditions, to understand thermal energy distribution based on contact pressure. The complex and dynamic behavior of variables suggests a potential for continuous improvement through machine learning, aiming for a digital shadow adapted to reality through in-situ measurements.







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Research Topics

Wire Arc Additive Manufacturing

Finite-Element Analysis

Digital Transformation

Measurement of Arc Welding