

A Parametric CFD Analysis of Preheating Duration and Molten Metal Temperature on Solidification in Aluminothermic Rail Welding

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Extended Abstract

The present work investigates how preheating time and molten metal temperature influence the thermal behaviour of aluminothermic rail welding, with a focus on the solidification stage. A simplified numerical model is developed using OpenFOAM®, based on the Finite Volume Method (FVM). The steel-slag multiphase system is handled via the Volume of Fluid (VoF) approach, whereas the solid-liquid phase change is captured using the enthalpy-porosity method on a fixed Eulerian mesh. The numerical framework has been extensively validated and detailed in prior work [1] and is applied to explore the coupled influence of thermal input and duration on the extent of solidification and thermal gradients within the weld region.

This study focuses on the THERMIT® SkV-ELITE L25 aluminothermic welding system, used for joining 60E1 rail track profile. The SkV (German: *Schnellschweißverfahren mit kurzer Vorwärmung*; English: *Rapid welding process with short preheating*) process is investigated, in which preheating is carried out using the Smartweld Jet system. The preheating stage is modelled through a back-calculated surface heat flux derived from experimental data corresponding to a standard cycle of 2.5 minutes of preheating followed by 30 seconds of tapping. This inverse heat-flux strategy has been commonly used in the literature [2-4], which enables realistic thermal conditions to be applied without the need for detailed simulations of combustion or gas-phase dynamics, thereby reducing computational complexity. However, the temperature distribution within the rail is obtained via a trial-and-error calibration, in which the surface heat flux profile is iteratively tuned in the numerical simulations to reproduce the experimentally observed temperature field.

The calibrated heat flux profile is subsequently applied to simulate a range of preheating durations from 1.5 to 6.5 minutes, each followed by 30-second tapping period. The mould filling stage is excluded under the assumption of instantaneous pouring, allowing the study to focus solely on preheating, solidification, and subsequent cooling. Moreover, the evolution of the fusion zone (FZ) and heat-affected zone (HAZ) at various molten metal temperatures, ranging from 2073 K to 2673 K, is investigated for each of the considered preheating times. Results demonstrate that, despite the simplifications, the model captures key thermal phenomena and provides an efficient tool for parametric studies and process optimisation in aluminothermic rail welding.

Looking ahead, the presented simplified numerical model lays the groundwork for continued model development and future coupling with microstructure evolution and thermo-mechanical simulations in OpenFOAM®. It represents an initial step towards developing a digital twin of the aluminothermic rail welding process.

Keywords: Aluminothermic welding, CFD, Multiphase, OpenFOAM®, Preheating, Rail joining, Solidification/melting

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