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# Meltpool Temperature Measurement and Monitoring during Wire-DED via Optical Thermal Devices

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## Abstract

The advent of additive manufacturing (AM) has reduced manufacturing costs, increased design flexibility, and fostered new component design development. Among additive manufacturing (AM) methods, Directed Energy Deposition (DED) excels in producing large-scale components with moderate to high geometric complexity and deposition rates. The main obstacle preventing the broader use of these technologies, particularly for expensive, high-precision parts, remains the difficulty in achieving consistent quality and repeatable results. Monitoring and closed-loop control of the meltpool cooling rate and shape is a significant approach to overcome this formidable challenge. A limited number of studies have explored the cooling rate of DED methods. However, the high-frequency melt pool cooling rate, which is crucial for controlling and predicting mechanical properties and microstructure, remains unexplored. In this research, we propose a framework for monitoring the meltpool cooling rate using optical techniques, enabling closed-loop control of printed part properties. The proposed approach is independent of material emissivity variations and remains effective across different temperature ranges.

The framework was tested on a wire-arc additive manufacturing (WAAM) system utilizing a cold metal transfer (CMT) cycle as a case study. This cycle minimizes heat input, mitigating heat accumulation issues. The proposed method employs an optical thermal device to measure the cooling rate, with results compared to alternative techniques. Specifically, an Optris 2M ratio pyrometer, operating at 1000 Hz, was mounted 300 mm from the meltpool region on the torch. During the process, as the heat source moves at the desired speed, the pyrometer records the molten metal temperature at 1 ms intervals, enabling continuous monitoring of temperature changes and precise cooling rate calculations. The resulting temperature gradient provides insights into growth rates, solidification modes, and microstructural evolution. Given the complexity of the CMT cycle, this method enables detailed cooling rate analysis for different cycle stages. The collected data, when combined with location data and other sensor inputs, facilitates the development of a digital twin of the printed part. Additionally, this dataset can be utilized to train neural networks in predictive modeling and heat simulation applications. As a proof of concept, multiple parts were printed using ER70-S6 along different toolpaths. Their microstructure and mechanical properties were analyzed in relation to the meltpool cooling rate, demonstrating the effectiveness of the proposed framework.