Mechanistic Modeling and Machine Learning for Humping Control in Wire Arc Additive Manufacturing

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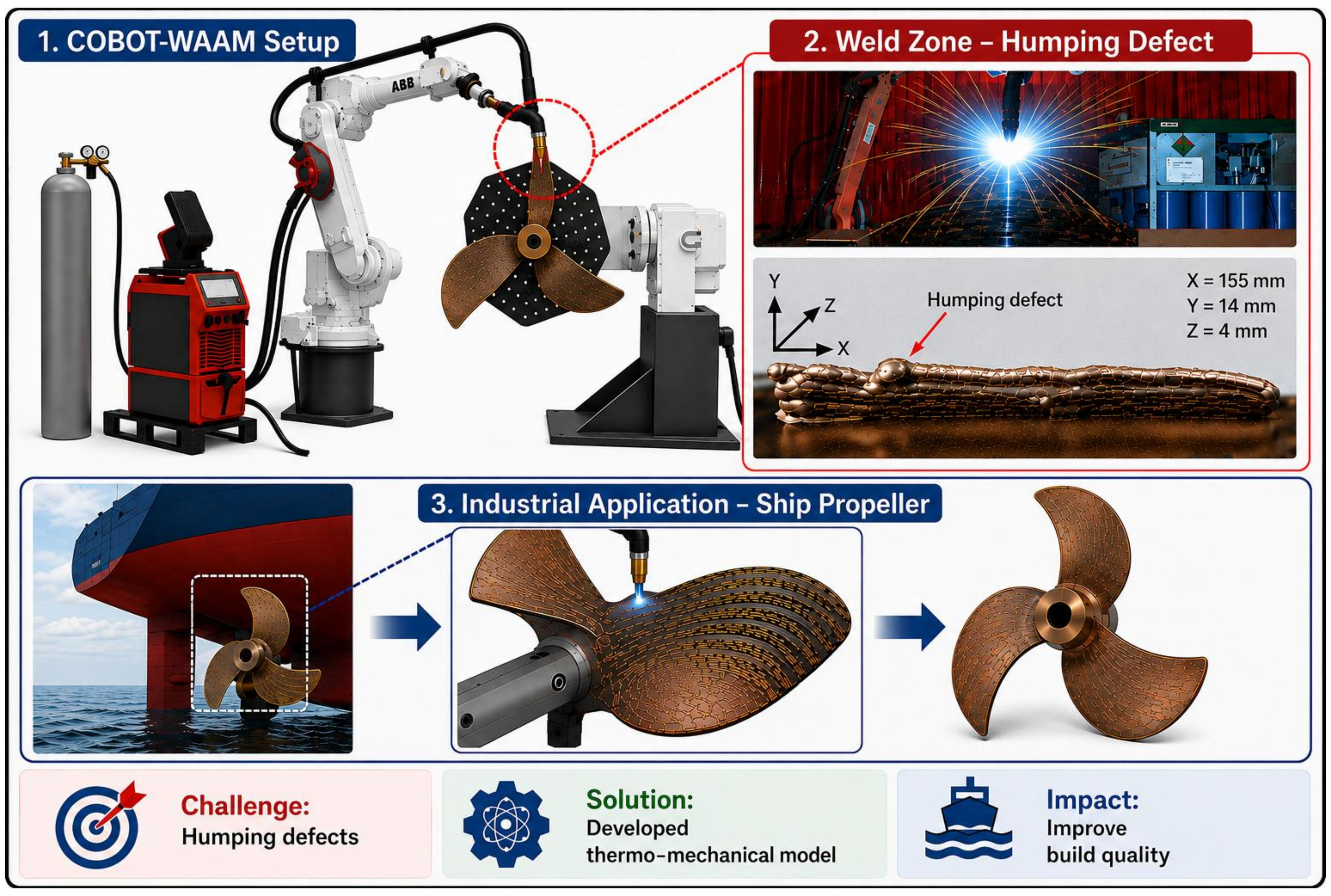

Figure 1: A schematic representation of the methodology used in this work. Subfigures taken from RAMLAB and Shah et al.

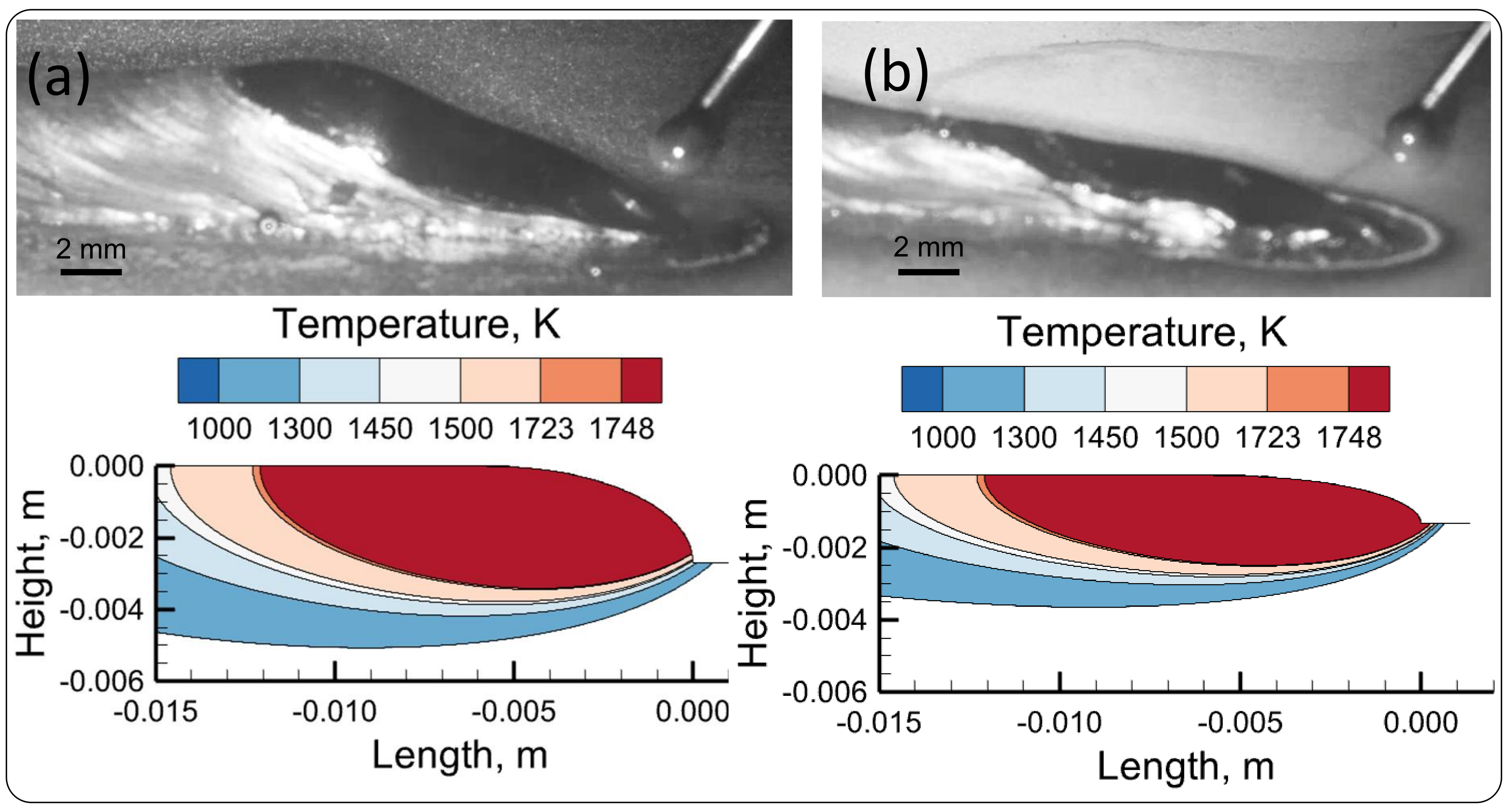

Figure 2: Experimental and computational molten pool dimensions at different scanning speeds. High-speed imaging of molten pool during wire arc deposition of ER308 using an in-house COBOT-WAAM setup: (a) 5mm/s and (b)10mm/s

Results

- Temperature distribution governs molten pool evolution and cooling behavior.
- Richardson number and pool aspect ratio distinguish stable and unstable bead.

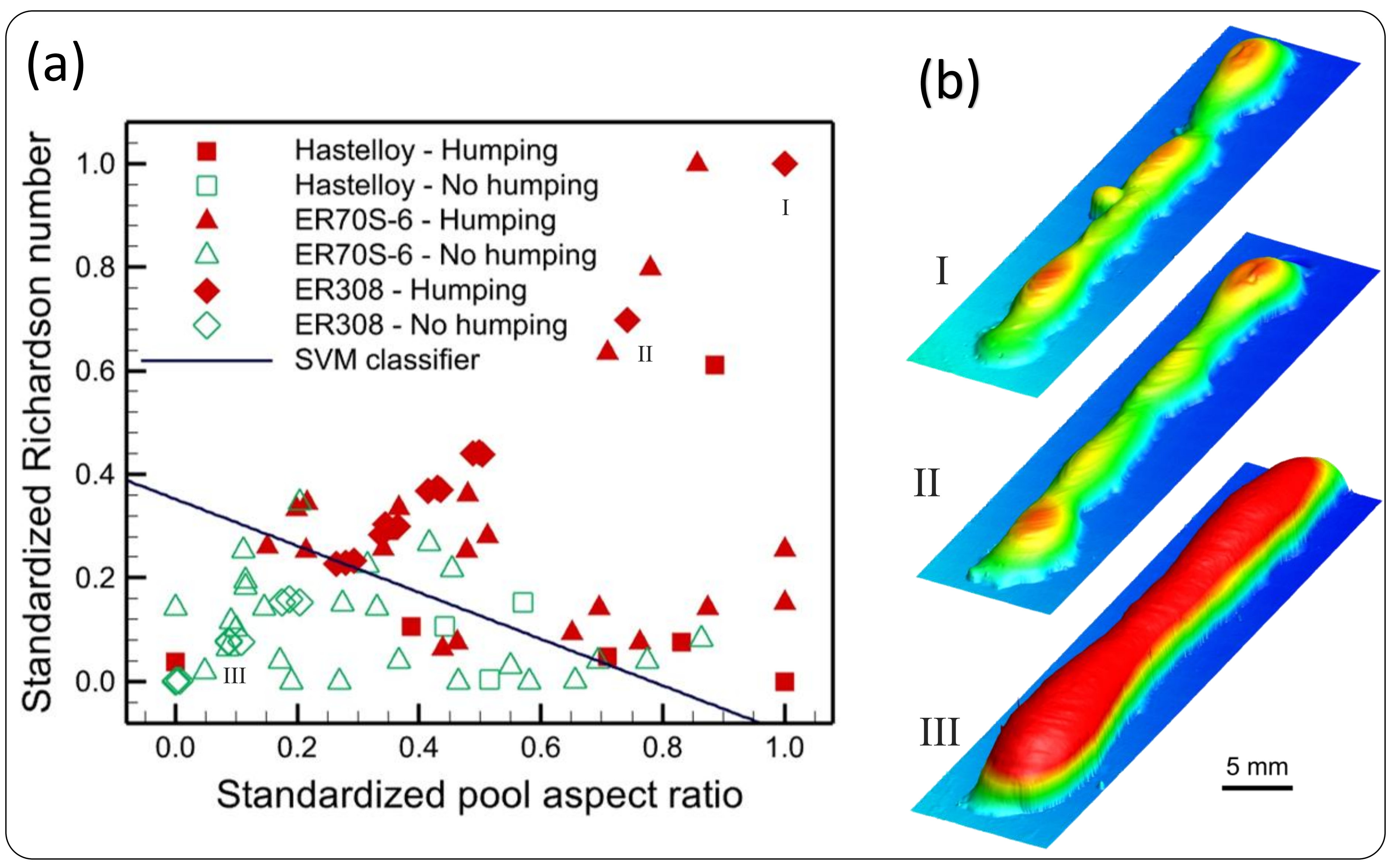

Figure 3: (a) SVM classification with experimental data for three different materials (Hastelloy X, ER70S-6, and ER308), (b) 3D confocal microscopy for the 3 deposited tracks with different travel speeds, which are identified in Figure (a)

Conclusions

- Thermophysical properties and processing conditions collectively govern thermal response, deformation, and molten-pool stability in WAAM.
- The framework connects material properties, process conditions, and deposition behavior, providing a physics-informed basis for consistent builds.

Problem Statement and Objective

- WAAM enables efficient fabrication of large metallic components through high deposition rates and low material waste.
- Thermophysical properties govern heat transfer and melt pool evolution, strongly influencing the deposition process.
- Unstable thermal and melt pool behavior can lead to defects such as humping, residual stress, and distortion.
- This work develops an integrated thermo-mechanical framework combining mechanistic modeling, experiments, and machine learning to understand and improve process stability.

Methods

- Developed a thermo-mechanical model to predict transient thermal fields, pool dimensions, residual stress, and distortion.
- Validated numerical predictions using high-speed imaging and confocal microscopy.
- Combined mechanistic modeling with Support Vector Machine (SVM) learning to classify humping and no-humping conditions.

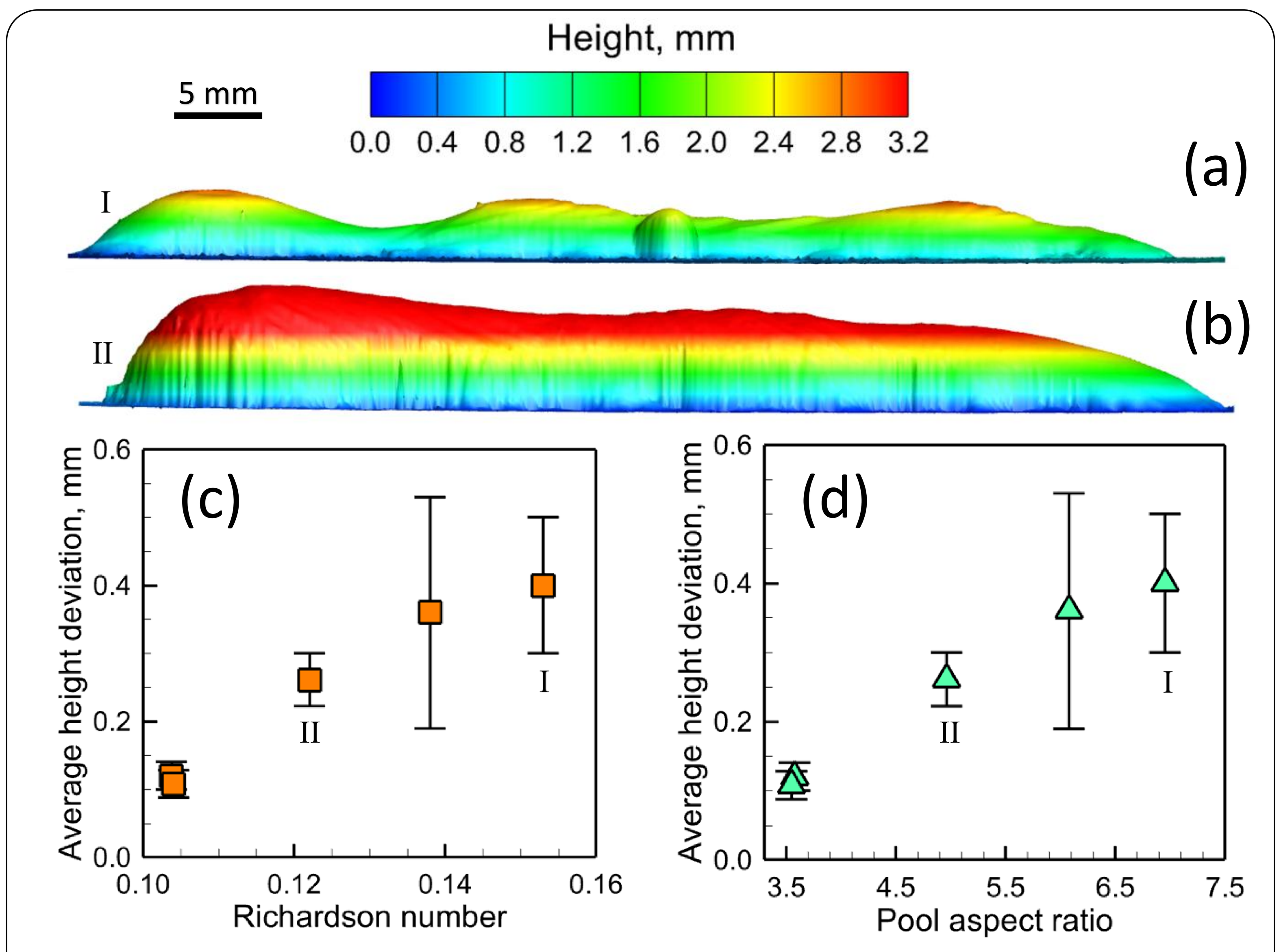

Figure 4: (a-b)Side view of the deposited tracks by using confocal microscopy for different travel speeds c) average height deviation vs Richardson number d) average height deviation vs pool aspect ratio for the four tracks of ER308 at different scanning speeds.

Discussion

- Molten pool stability is strongly governed by process conditions, with scanning speed playing a dominant role; higher speeds increase the Richardson number and pool aspect ratio, promoting humping and greater surface-height variation.
- Integrating mechanistic modeling with machine learning provides a physics-informed pathway to predict molten pool instability.

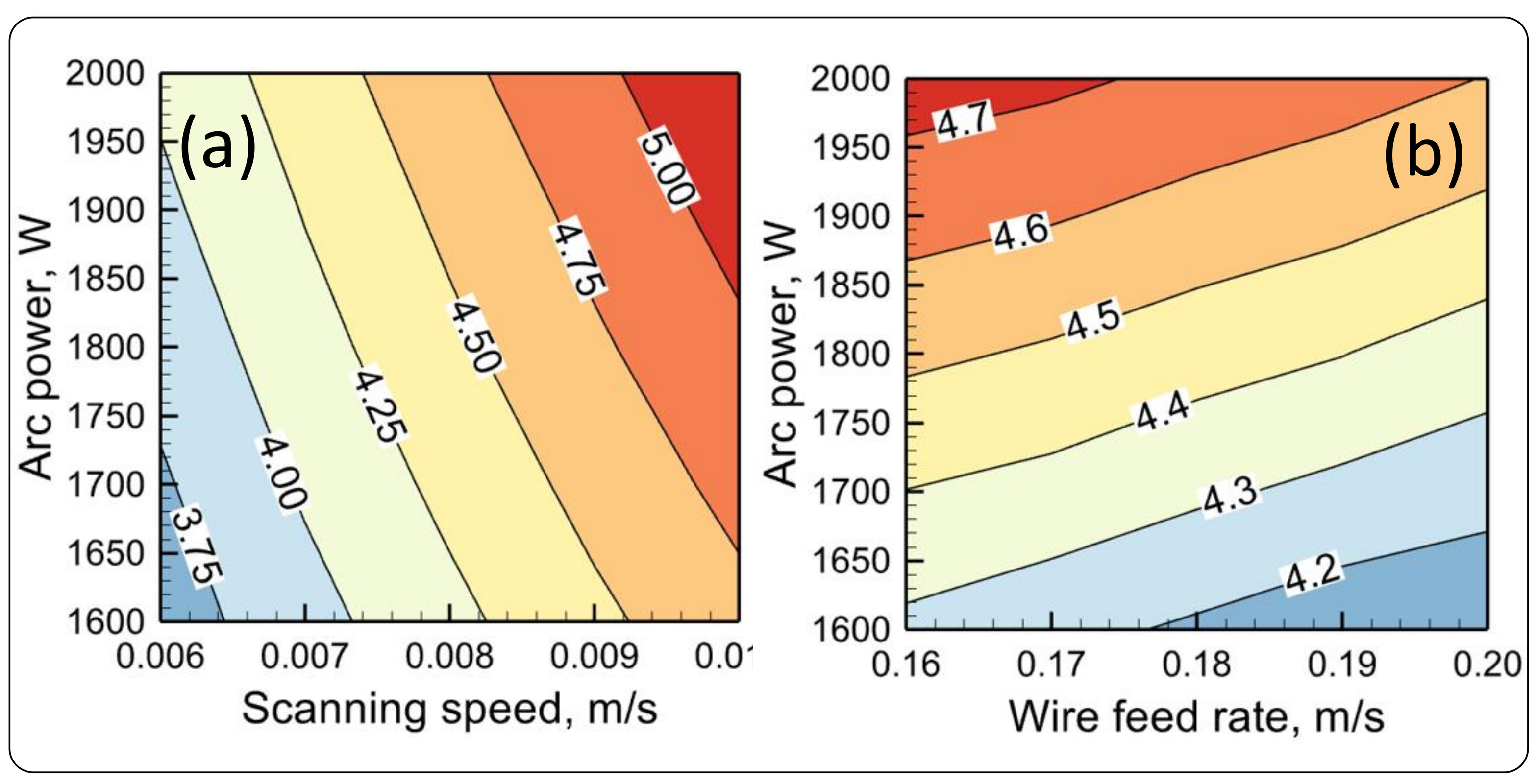

Figure 5: Pool aspect ratio process maps with (a) scanning speed and arc power and (b) wire feed rate and arc power

Acknowledgments

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