Development of Grain Refinement Technologies using Compressive Loading and Advanced Pulse GTAW in Wire-Arc Direct Energy Deposition Ti-6Al-4V

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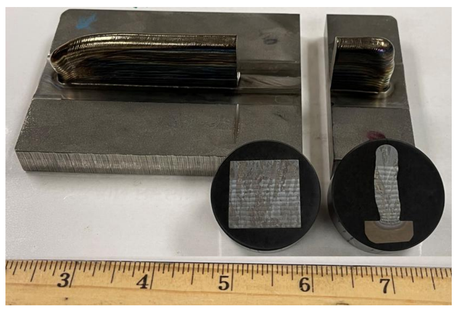
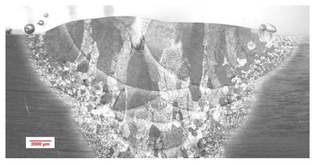
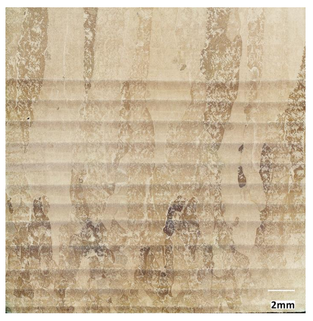
Background & Motivation

Fusion welding of titanium alloys results in large, columnar prior-β grains that exhibit a coarse texture. These microstructures result in loss of mechanical properties, namely strength, compared to wrought microstructures. This microstructural evolution is especially evident in components made using additive manufacturing (AM). Anisotropic properties are observed when AM is used, namely wire arc direct energy deposition (DED) also known as wire arc additive manufacturing (WAAM).

Considerable effort is spent developing methods to mitigate undesirable microstructures in titanium. Two possible approaches include the introduction of inter-pass deformation via peening or rolling and pulsed current during arc welding. Literature on pulsed arc welding of titanium exist in the 0 Hz - 100 Hz and 10 kHz - 100 kHz ranges, but discrepancies exist among results. Literature fails to study the 100Hz to 10kHz range. Publications evaluating interlayer deformation methods show promising results but lack consistent empirical relationships and differ in mechanistic explanations for how grain refinement occurs.







OBJECTIVE: Evaluate and develop methods of grain refinement in AM Ti-6Al-4V components

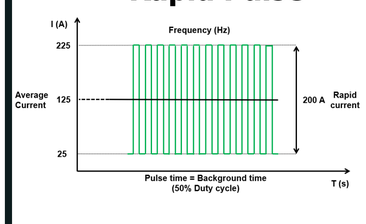
Experimental Methods

- Single pass width walls were deposited using 0.045″ Grade 5 Ti-6Al-4V wire and matching 1/2″ thick substrate
- The Rapid Pulse waveform was first evaluated by depositing 5 layers
- Subsequent Thermal Pulse and Thermal Rapid Pulse waveforms were evaluated by depositing 16 layers to reach a build height ≥ 1″
- Interlayer ultrasonic impact peening was studied in a build without pulsed current by depositing 16 layers to reach a build height ≥ 1″ with peening between every layer

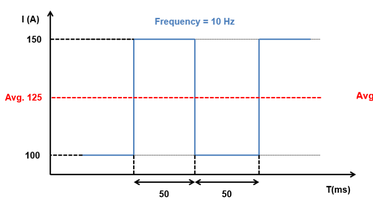
Welding Process Parameters	Value
Average Current (A)	125
Arc Voltage (V)	10
Weld Travel Speed (IPM)	6.5
Wire Feed Speed (IPM)	79.5

Peening Process Parameters	Value
Tool Frequency (Hz)	25700
Peening Travel Speed (IPM)	10
Tool Impact Energy (mJ)	~10-80

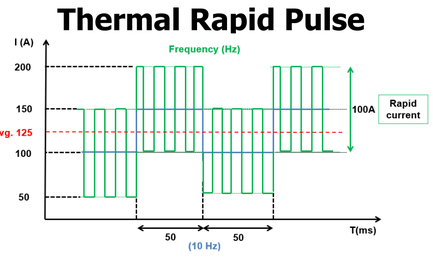
Rapid Pulse



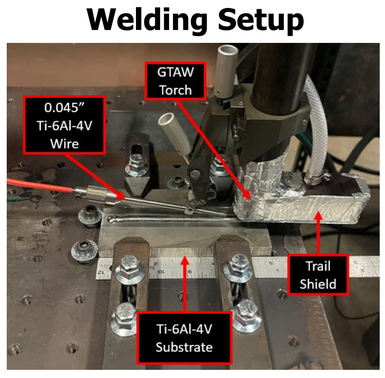
Thermal Pulse



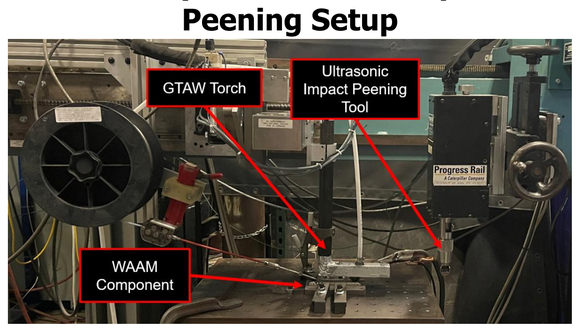
Thermal Rapid Pulse



Welding Setup



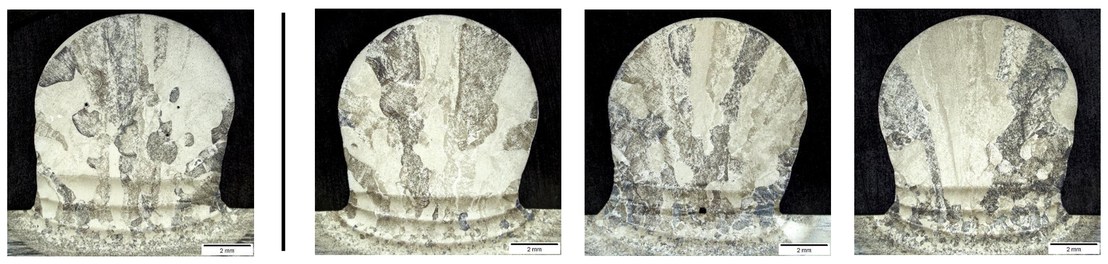
Interlayer Ultrasonic Impact Peening Setup



Results & Discussion

Rapid Pulse

No Pulsing | 500 Hz | 5 kHz | 10 kHz

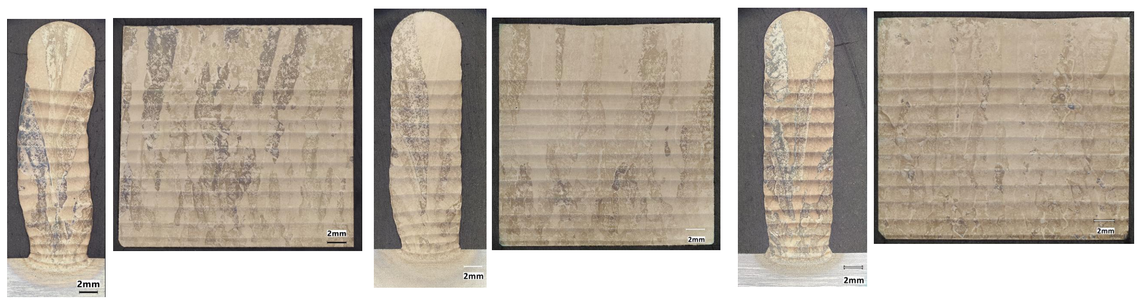


- The Rapid Pulse waveform tested at 500 Hz, 5kHz, and 10 kHz resulted in no significant prior-β grain refinement

Thermal Pulse and Thermal Rapid Pulse

No Pulsed Current | Thermal Pulse - 10 Hz

10 Hz + 500 Hz | 10 Hz + 5 kHz | 10 Hz + 10 kHz



- The Thermal Pulse tested at 10 Hz and Thermal Rapid Pulse waveform tested at 10 Hz + 500 Hz, 10 Hz + 5kHz, and 10 Hz + 10 kHz resulted in no significant prior-β grain refinement

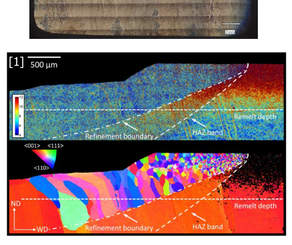
Interlayer Ultrasonic Impact Peening

No Interlayer Peening | Addition of Interlayer Peening

- Initial evaluation of interlayer ultrasonic peening shows noticeable prior-β grain refinement. Further characterization is necessary to quantify refinement and determine mechanisms.

Conclusions & Future Work

- Introduction of pulsed current GTAW had no observable effect on prior-β grain growth Ti-6Al-4V WAAM components
- Initial testing of interlayer deformation via ultrasonic peening show promising results of prior-β grain refinement
- Future work will evaluate additional parameters of ultrasonic peening conditions to build empirical relationships
- Future work will also evaluate the addition of interlayer deformation via compressive rolling
- Analysis of interlayer deformation methods aims to contribute to discussion of microstructural evolution and mechanisms at play



[1] J.R. Hönnige, A.E. Davis, A. Ho, J.R. Kennedy, L. Neto, P. Prangnell, S. Williams, The Effectiveness of Grain Refinement by Machine Hammer Peening in High Deposition Rate Wire-Arc AM Ti-6Al-4V, Metall. Mater. Trans. A 51 (2020)

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