Dynamic Laser Welding Behavior of Wrought and Additive Manufactured Stainless Steels

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1. Motivation

- Little information is available on the weldability of additive manufactured (AM) material.
- Concerns include complex thermal history, residual stresses, microstructure, composition and texturing differences as compared to wrought material

2. Background

- Variables that affect laser coupling efficiency:
  - Surface condition, power, travel speed, laser focus
- Variables that affect absorptance:
  - Power, travel speed, phase (i.e. solid vs liquid)
- AM builds have larger concentrations of oxygen than wrought products.
  - Oxygen is a surface active element and can affect the surface tension.

3. Objectives & Approach

- Objectives: understand what AM variables affect the coupling efficiency or welding behavior.
  - Surface Condition, Residual Stress, Compositional Differences
- Approach: use an integrating sphere and high speed video to determine the coupling efficiency and welding behavior.
  - Spot Weld: 1070 nm Yb-fiber laser, sharp focus, 10 ms pulse.
  - Collect surface profile

$$P_{abs} = P_{in} - P_{spec} - P_{diff}$$

$$\eta_{coupling} = \frac{P_{abs}}{P_o}$$

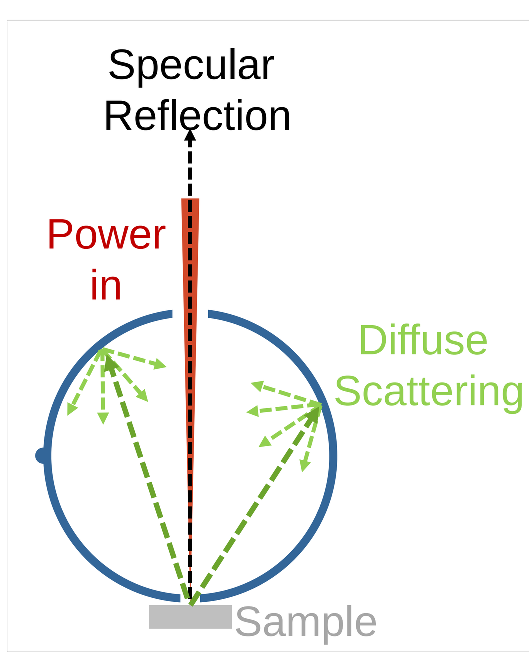

Figure 1. Schematic of integrating sphere.

Table 1. Experiment Variables

Material	Phase	Condition	Surface (µm)
Wrought 17-4	Martensitic	As-Received	Ra = 7.6
Wrought 304L	Austenite	As-Received	Ra = 7.1
AM 304L	Austenite	1. As-Built 2. As-Built 3. Heat Treat	1. Ra = 30.5 2. Ra = 7. 5 3. Ra = 7.8

4. Results & Discussion

Coupling Efficiency:

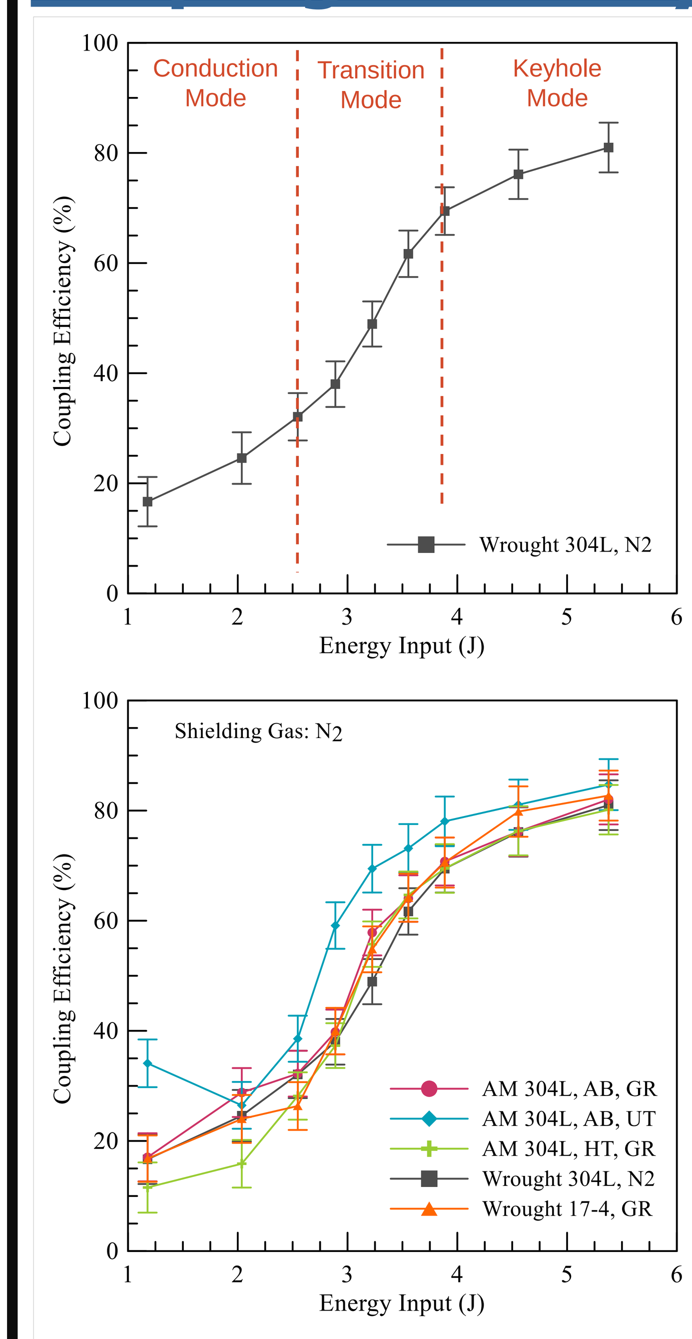

Fig. 2: Coupling efficiency as a function of input energy.

- Determines the transition from conduction to keyhole mode:
  - Transition ~ 2.5 – 3.8 J
- Variables that have little to no effect on the coupling efficiency:
  - Phase (FCC and BCC)
  - Composition
  - Residual stress
- Effect of Surface Condition:
  - Rough surface: transition to keyhole occurs at lower energies.
  - Transition ~ 2.3 – 3.3 J
  - Rough surface helps to produce multiple reflections to increase the coupling efficiency.

Weld Oscillations:

- During 10 ms pulse:
  - Oscillations alternate between mode a. and b.
  - Most dominant oscillation modes.
- Oscillations can change the absorptance behavior:
  - Pool shape may dictate the scattering light behavior.
- Weld Profile:
  - AM has larger magnitude of concavity and slightly smaller weld width than wrought 304L.
  - Suggesting a difference in surface tension.

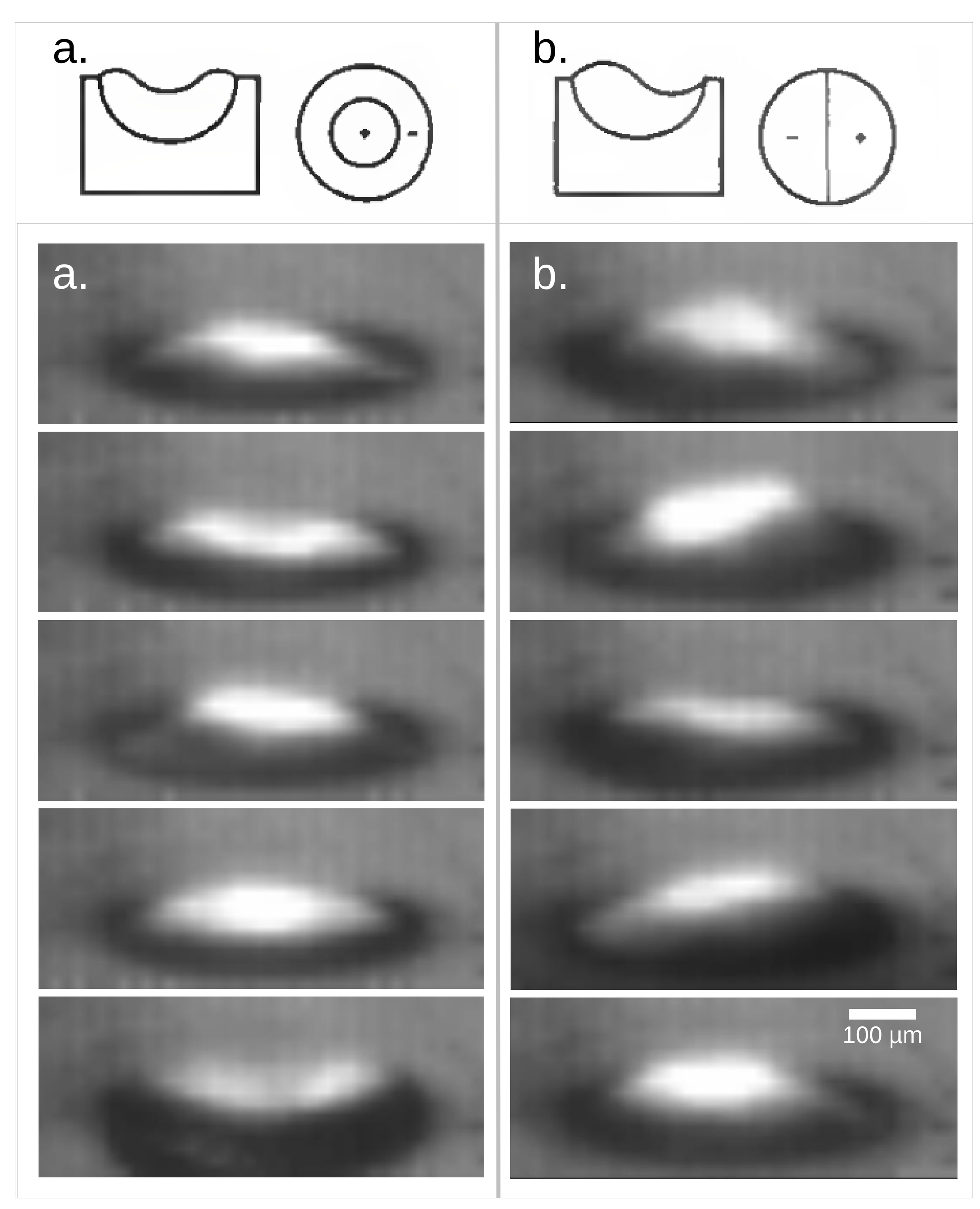

Fig. 3: High speed video of a 10 ms spot weld on 316L taken at 5400 frames per second.

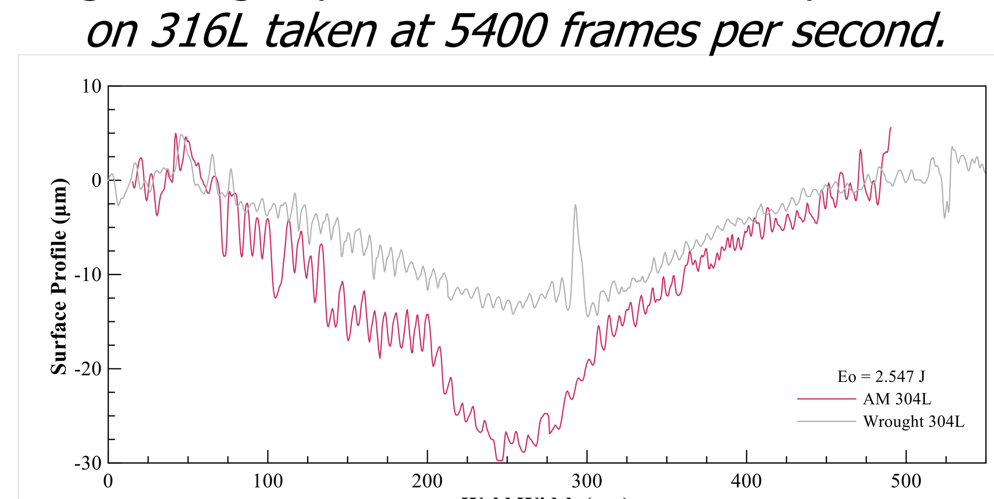

Fig. 4: Spot weld surface profile of wrought and AM 304L made

Dynamic Absorptance:

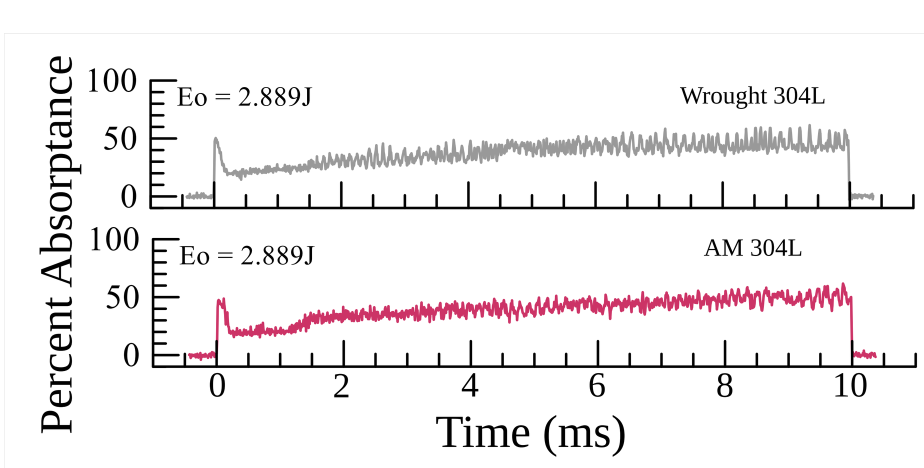

Fig. 5: Absorptance of wrought and AM 304L as a function of time.

- Oscillations:
  - High frequency oscillations observed only in the transition region.
  - High freq. oscillations can be from the weld pool oscillations.

5. Conclusions

- Coupling Efficiency:
  - Surface roughness changes the transition from conduction mode to keyhole mode.
  - Phase, composition, and residual stress have little to no effect on the coupling efficiency.
- Weld Oscillations:
  - The weld pool alternates between mode a and mode b
  - Oscillations can affect the scattering behavior and therefore the absorptance behavior.
  - The AM weld width is narrower than the wrought width and the concave surface profile is deeper than the wrought.
- Dynamic Absorptance:
  - High frequency oscillations are only observed in the transition regions.

6. Future Work

- Characterize weld oscillations and correlate the high speed video with the dynamic absorptance oscillations.
- Characterize fluid flow of melt pool.

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