Engineered Materials and Materials Design for Expedient Manufacturing

"Assessment and Improvement of the Metallurgical Bonding in Cold Sprayed Al6061 and Al2024"

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Abstract

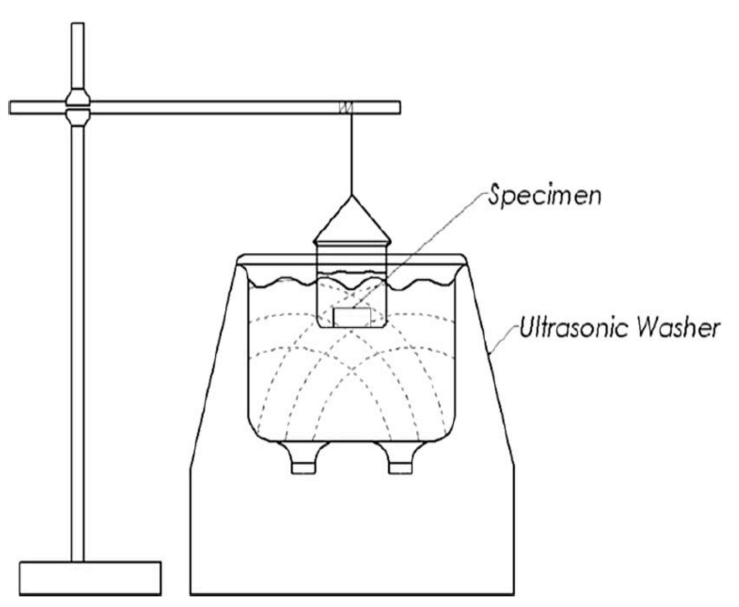
An ultrasonic washing test (UWT) is used as a tool to semi-quantitatively assess the strength of splat bonding in CS Al alloys. UWTs have determined that splats in CS Al6061 and CS Al2024 are not fully bonded metallurgically. Post-CS warm rolling and heat treatment provide an effective means for improving the splat bonding in CS Al alloys. Effectiveness of post-CS warm rolling and heat treatment in improving ductility is confirmed by tensile tests and TEM/STEM.

Method

1. Ultrasonic Washing Test (UWT)

Sample Preparation:

- Al2024 coating deposited on Al6061, He, 425 °C,1050 m/s (581 psi)
- Al6061 coating deposited on Al6061, He, 425 °C, 1075 m/s (508 psi)
- Al6061 coating deposited on Al6061, N_2, 425 °C, 721 m/s (721 psi)



- Polished sample cross section is ultrasonically washed in water (Fig. 1) to cause weakly bonded splats to come off. (Fig. 2)
- The areal percentage of the voids left is determined by image analysis.
- % retention (100% - % voids) represents the bonding strength.

Fig. 1: Schematic of UWT setup[1]

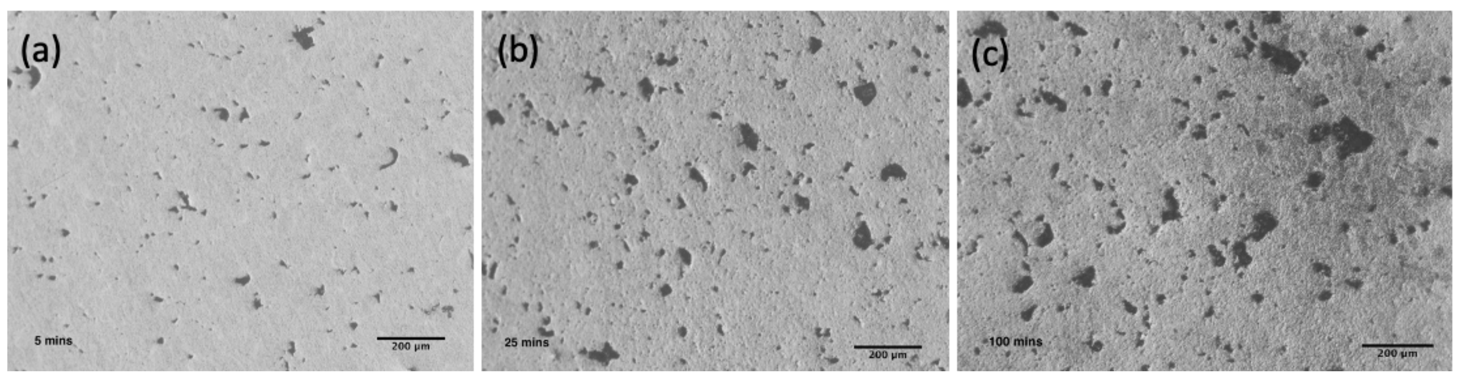


Fig. 2: Cross section of N_2-sprayed CS Al6061 subjected to ultrasonic washing at 80 W for (a) 5 mins, (b) 25 mins and (c) 100 mins.

2. Post-CS Rolling

- CS Al6061 and Al2024 removed from Al6061 substrate were rolled.
- CS Al2024 and Al6061 samples were rolled at 100 °C in 2 passes for 40 - 55% total thickness reductions.
- N_2-sprayed Al6061 sample cracked due to its insufficient splat bonding.

3. Tensile Tests

- ASTM standard and miniature tensile specimens (Fig. 3) were machined from as-sprayed and rolled CS Al2024 and Al6061 samples.
- Machined tensile specimens were heat treated to standard T6 temper.
- Heat treated tensile specimens were hand-polished and final thickness were measured.
- Room-temperature tensile tests were performed at initial strain rates of 0.00033 s^{-1} (standard) and 0.00046 s^{-1} (miniature).

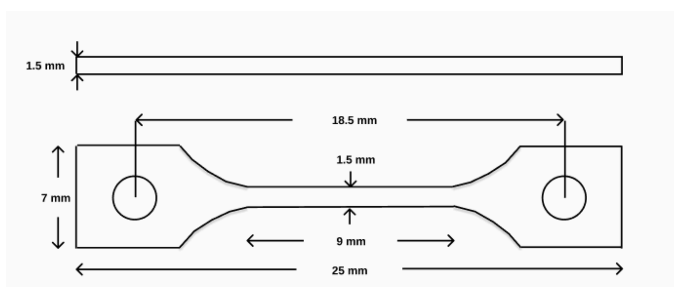


Fig. 3: Miniature tensile specimen

4. TEM/STEM

- 40% - rolled CS Al2024 and CS Al6061 were investigated.
- FEI Scios DualBeamTM was used for thin lamella samples fabrication by FIB milling.
- FEI Titan Themis 300 was used for S/TEM and energy-dispersive X-ray spectroscopy (EDS) - both at Kostas Research Institute of Northeastern University.

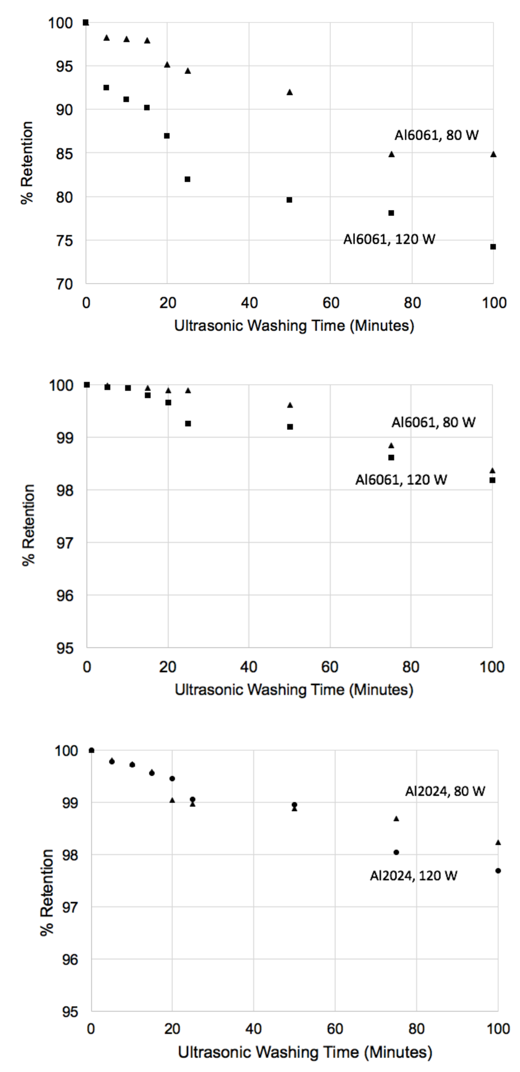
Reference

1. Y. Li, Y. Hamada, K. Otobe and T. Ando, J. Thermal Spray Technology, 2017, 26, 350-359

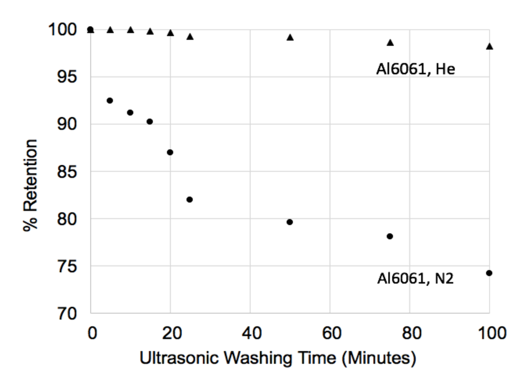
Results

1. Ultrasonic Washing Test (UWT)

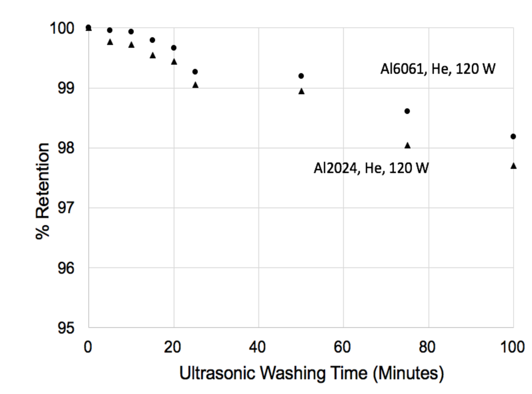
(a) Effect of Washing Power



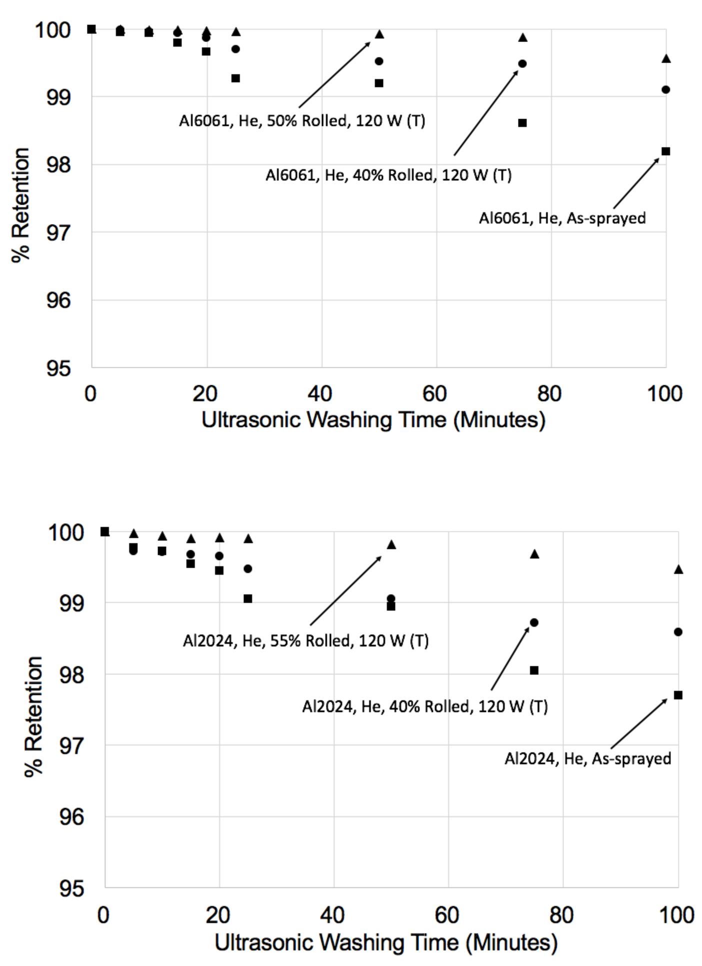
(b) Effect of Spraying Gas



(c) Effect of Powder Hardness

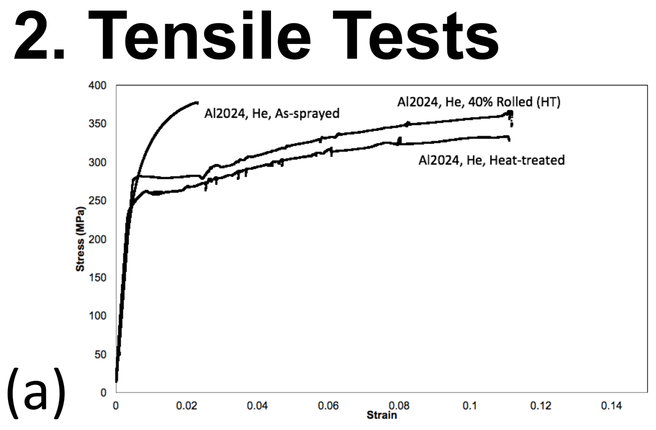


(d) Effect of Rolling at 100°C

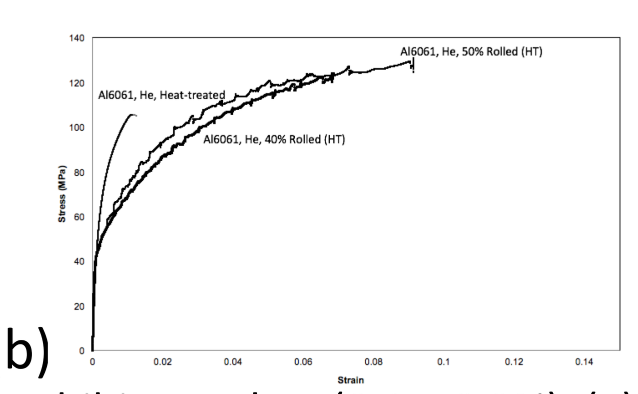


- The bonding of deposited splats may arise from both metallurgical and mechanical interlocking effects, with varying contributions of the two.
- % splat retention decreases with increasing UWT time, **(a) – (d)**, attesting to partial metallurgical bonding of deposited splats. *If splats were fully bonded, they would not come off during UWT.*
- Low rates of % retention reflect high degrees of metallurgical bonding, **(a) – (d).**
- % splat retention decreases with UWT power at higher rate for N_2-sprayed samples (Al6061 and Al2024) than for He-sprayed sample(Al6061), **(a)**. *He-spraying yields higher degrees of metallurgical bonding than N_2-spraying.*
- Softer powder (Al6061: HV85) gives deposited splats higher degrees of metallurgical bonding than harder powder (Al2024: HV142), **(c)**. *Low powder hardness promotes powder particle deformation upon impact, creating fresh metal surface required for metallurgical bonding*.
- Rolling increases % splat retention in both CS Al6061(He) and Al2024(He), **(d)**. See also 3. TEM/STEM-EDS.

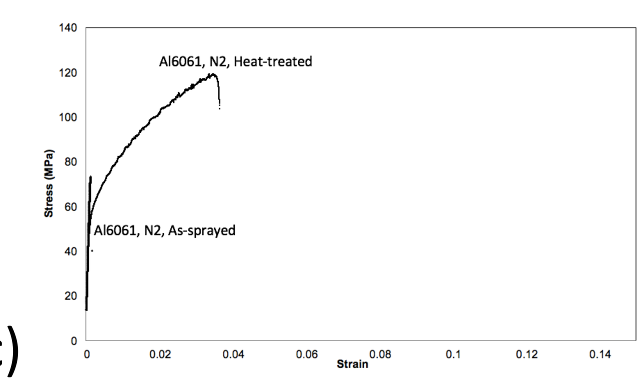
2. Tensile Tests



(a)



(b)

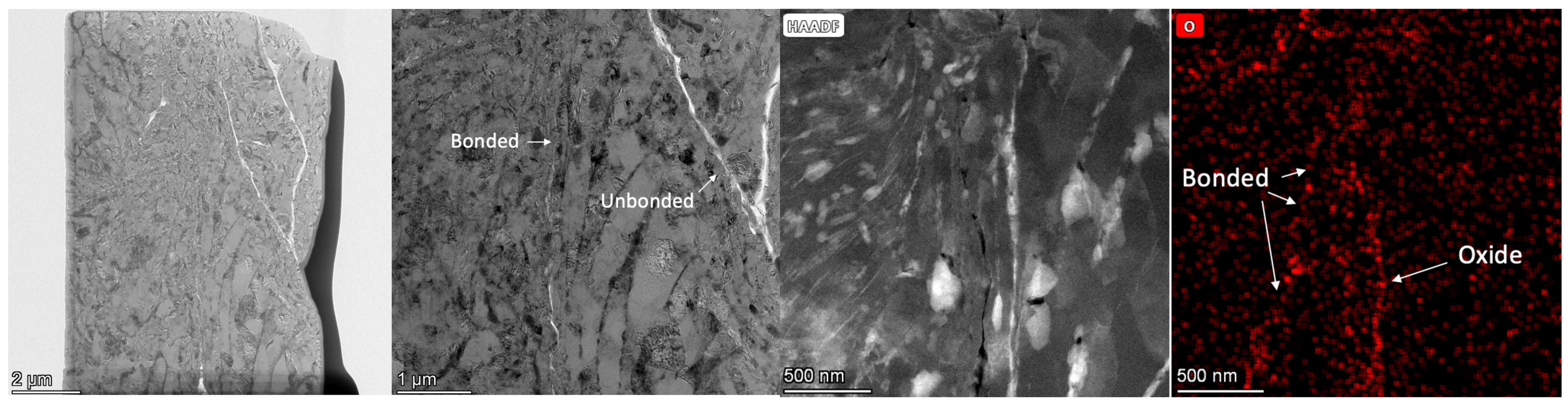


(c)

- As-sprayed Al6061(He) and Al2024(He) exhibit very low (0.1 – 0.2%), (a) and (b).
- T6 heat-treatment increased elongation to > 10% for He-sprayed Al2024, (a), and > 0.3% for N_2-sprayed Al6061, (c), but it had no significant effect for He-sprayed Al6061 (b).
- Rolling at 100 °C increased elongations to >10% for Al2024 and up to 9% for Al6061 in T6 temper.
- Increased ductility (elongation) reflects increased metallurgical bonding due to rolling and T6 treatment.

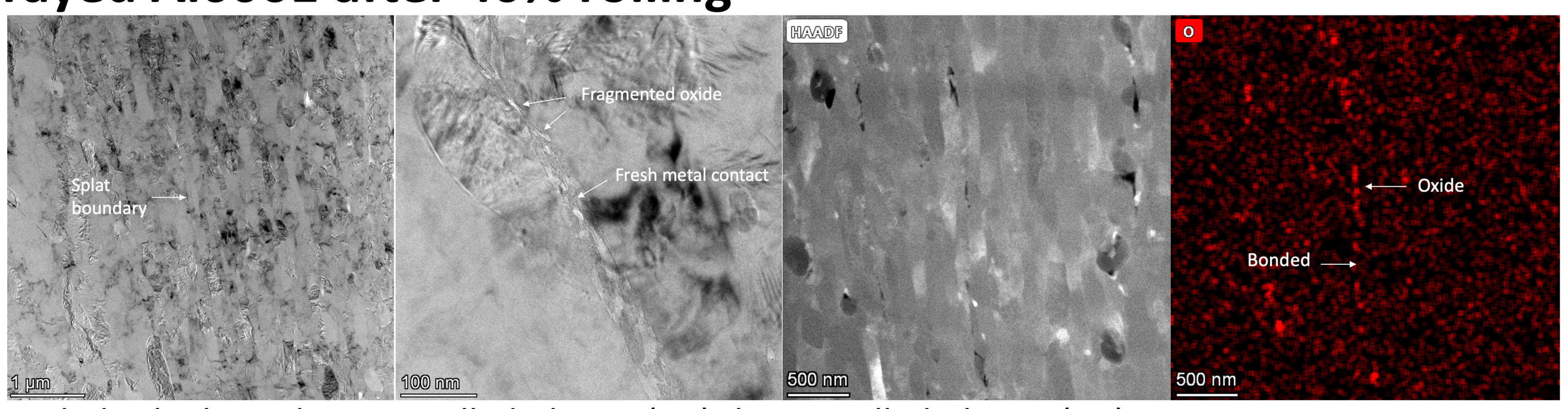
3. TEM/STEM-EDS

He-sprayed Al2024 after 40% rolling



- Mixture of bonded and unboned splat boundaries.
- Bonded splat boundaries exhibit fragmented oxide.

He-sprayed Al6061 after 40% rolling



- More bonded splat boundaries in rolled Al6061 (He) than in rolled Al2024 (He).
- Bonded splat boundaries exhibit fragmented oxide.