THERMO-MECHANICAL MODELING OF ACOUSTIC SOFTENING DURING ULTRASONIC CONSOLIDATION OF THIN ALUMINUM FOILS

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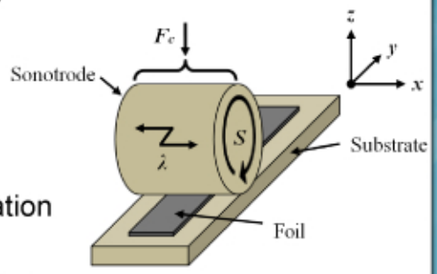
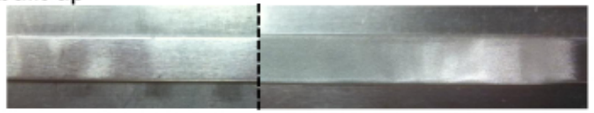
ULTRASONIC CONSOLIDATION (UC) BACKGROUND

- Ultrasonic Consolidation (UC) is a solid-state bonding process in which thin foils or tapes can be built-up layer by layer
- Process Components
  - Sonotrode
  - Foil
  - Substrate
- Weld Parameters
  - Sonotrode Oscillation Amplitude (λ)
  - Clamping Force (F_c)
  - Sonotrode Speed (S)



OBJECTIVE AND MOTIVATION

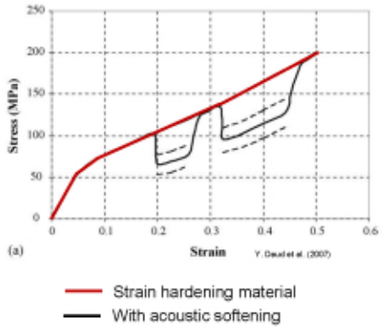
- Objective: Quantify the amount of acoustic softening that occurs during UC
- Acoustic softening is an important part of UC for the following reasons:
  - Acoustic softening increases plastic deformation, bringing materials into intimate contact and improving bond quality
  - Acoustic softening increases the geometry chance of metal foils during UC and influences tape spacing in large parts
  - Acoustic softening enables the sonotrode's knurl pattern to be filled in when multiple layers of foil are built up



Aluminum foil on a substrate — After UC processing, foil width expands and knurl pattern is imprinted on top of foil

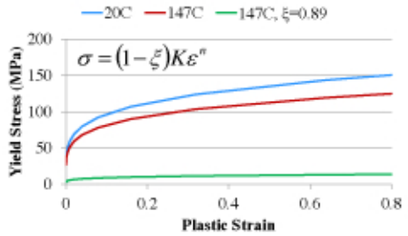
ACOUSTIC SOFTENING

- Reduction in the apparent static stress required to yield a material
- Two causes of acoustic softening:
  - Acoustic energy is absorbed at dislocations in the material, allowing it to yield more easily
  - Stress superposition
- Influenced by the frequency and amplitude of vibrations
- Yield stress is immediately reduced upon application of acoustic energy and is immediately restored upon removal of acoustic energy
- Efficient method to soften metals



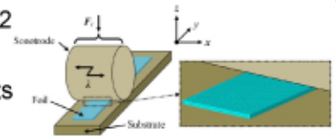
MATERIAL MODEL

- The material model accounts for the thermal and acoustic softening that occur during UC
- The strain hardening behavior of Al 1100-0 follows a power law model
- Model includes acoustic softening (ξ)

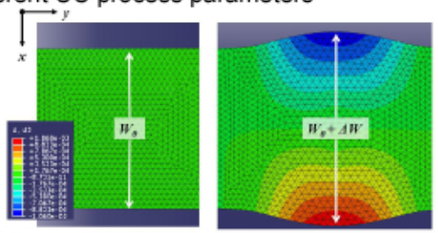


THERMO-MECHANICAL MODEL

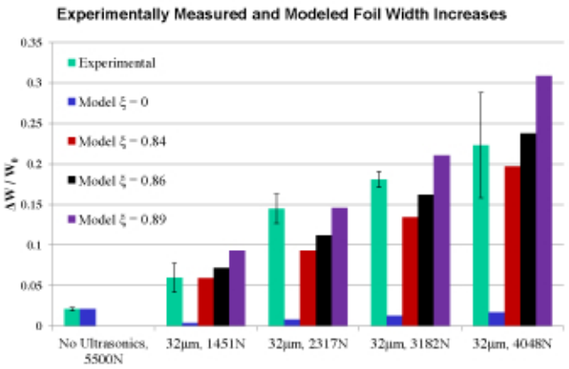
- Abaqus Explicit 6.9-2
- 10-node quadratic tetrahedron elements



- The value of acoustic softening (ξ) is iteratively solved by comparing experimentally measured foil width increase to model prediction under different UC process parameters



RESULTS



CONCLUSIONS

- Acoustic softening reduces the yield stress of the Al 1100-0 foils by approximately 86% under the investigated UC process parameters
- Thermal softening is an order of magnitude smaller than acoustic softening during UC
- This model can be used to quantify acoustic softening for a wide range of UC process parameters, foil materials and foil geometries

ACKNOWLEDGEMENTS

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