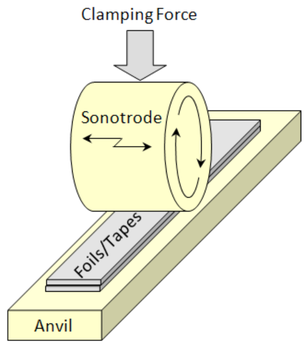
A COUPLED THERMAL-MECHANICAL MODEL OF ULTRASONIC CONSOLIDATION

G. S. Kelly, S. G. Advani, J. W. Gillespie, Jr. and T. A. Bogetti (ARL)

University of Delaware . Center for Composite Materials . Department of Mechanical Engineering

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
  - Foils / Tapes
  - Anvil / Substrate
- Weld Parameters
  - Sonotrode Oscillation Amplitude, λ
  - Clamping Force, F
  - Sonotrode Speed, S



MOTIVATION AND OBJECTIVES

- Selective reinforcement using metal matrix composite (MMC) tapes to create lightweight structures with a high stiffness
- UC can achieve bond strengths greater than traditional adhesives
- The objective is to relate UC process parameters to thermal development and bond strength

Weld Parameters

Amplitude, Force, Speed → Thermal Development → Mechanical Properties (Bond Strength)

THERMAL DEVELOPMENT DURING UC

- Friction Heat Generation

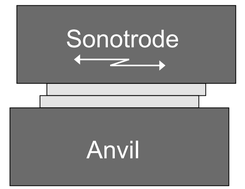
$$q_{fr} = \frac{2\mu F \lambda f}{A_c}$$

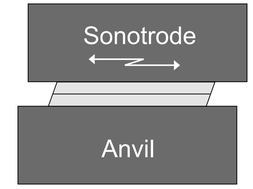
μ (Friction Coefficient)
F (Normal Force)
λ (Amplitude)
f (Frequency)
A_c (Contact Area)

- Volumetric Heat Generation

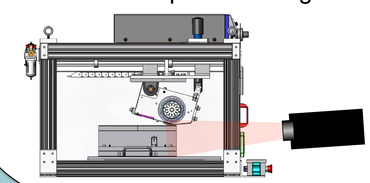
$$q_{vol} = \beta \sigma_j \dot{\varepsilon}_j^p$$

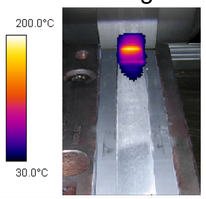
β (Plastic Heat Fraction)
σ_j (Stress)
$\dot{\varepsilon}_j^p$ (Plastic Strain Rate)





- Thermal development during UC is measured using an IR camera

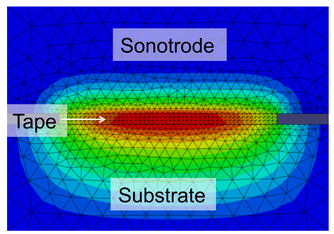




THERMAL-MECHANICAL MODEL OF UC

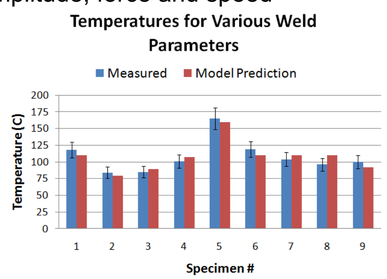
- Abaqus 6.9-2
- Can model contributions to thermal development from friction and/or volumetric heat generation
- Plastic deformation during UC can be modeled
- Model includes a parameter dependent friction coefficient using a response surface model (S. Koellhoffer)

Temperature Distribution:



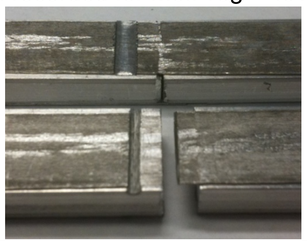
RESULTS AND VALIDATION

- Parameter dependent friction coefficient trends:
  - $\mu\uparrow$ as $\lambda\uparrow$
  - $\mu\downarrow$ as $F\uparrow$
  - $\mu\uparrow$ as $S\uparrow$
- Model was validated by measuring temperatures for nine welds - each with different combinations of amplitude, force and speed



BOND STRENGTH EVALUATION

- Lap shear test (MMC tape ultrasonically consolidated to aluminum substrate)
  - The tape is welded across two substrates and then notched to cause shear failure
- Initial results show UC bond strengths can be greater than traditional epoxy adhesives
  - Shear strengths of up to 35.6 MPa have been recorded for MetPreg™ to Al 6061-T6



FUTURE WORK

- Update the parameter dependent friction model to include volumetric heat generation
- Use the coupled thermal-mechanical model of UC to determine the ratio of friction heat generation to volumetric heat generation
- Complete bond strength evaluation of MetPreg™ welded to an aluminum substrate
- Relate the UC process parameters to temperature development and bond strength

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