ROLE OF FRICTION IN ULTRASONIC CONSOLIDATION DURING PROCESSING OF METAL MATRIX COMPOSITES

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MOTIVATIONS

- UC has the ability to make metal matrix composite parts
- MMC’s offer exceptionally high stiffness and strength
- Low temperature welding process
- Underlying science is not well understood
- Lack of process maturity
- Bonding mechanisms are temperature dependent

HEAT TRANSFER MECHANISMS

- Frictional heat
  - Slip at the interface
  - Interfacial heating
- Deformational heat
  - Plastic work
  - Volumetric heating

ANALYTIC FRICTION MODEL

\[
\frac{q}{ab} = \frac{\mu F}{2a} \left( \frac{H}{V} \right)
\]

EXPERIMENTAL RESULTS

- Constant \( \mu = 0.175 \)
- Avg Error 19%

EXPERIMENTAL PARAMETERS

<table>
<thead>
<tr>
<th>Test #</th>
<th>Amplitude (um)</th>
<th>Applied Force (N)</th>
<th>Speed (mm/s)</th>
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</thead>
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<td>9.4</td>
<td>1162</td>
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</table>

FRICTION COEFFICIENT LITERATURE

- The friction coefficient for any material is very variable
- Typical friction coefficient values for aluminum are between 0.1 and 1.3
- Parameters present affecting \( \mu \)
  - Welder variables
  - Pressure
  - # Of cycles (time)
  - Slip amplitude
- Material properties
- Hardness
- Contact geometry
- Surface roughness

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(Continued)

**FRICITION COEFFICIENT VS. AMPLITUDE**

- Literature (Naidu & Raman)
- **Response Surface Model**

**FRICITION COEFFICIENT VS. FORCE**

- Literature (Naidu & Raman)
- **Response Surface Model**

**FRICITION COEFFICIENT VS. TIME**

- Literature (Naidu & Raman)
- **Response Surface Model**

**RESPONSE SURFACE MODEL**

1. \( T = b_0 + \sum_{i=1}^{3} b_i x_i + \sum_{i=1}^{3} b_{ii} x_i^2 + \sum_{i=1}^{3} \sum_{j=1}^{3} b_{ij} x_i x_j \)

2. \( T = T_0 + \frac{\mu F}{H} \frac{2\lambda f}{H} + \frac{\mu F}{H} \frac{2\lambda f}{H} \)

\( x_1 = \frac{\lambda - 13.9}{4.5} \)

\( x_2 = \frac{\lambda - 1307}{433} \)

\( x_3 = \frac{\lambda - 105}{18} \)

Solve 1. and 2. for \( \mu \) to get:

\[ \mu = f(b, \lambda, F, s) \]

**VARIABLE \( \mu \) CONFIRMATION EXPERIMENT**

<table>
<thead>
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<th>Test</th>
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<th>( \lambda )</th>
<th>( F )</th>
<th>( s )</th>
<th>Response</th>
<th>Predicted</th>
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**CONCLUSIONS**

- Frictional heating can be isolated, measured experimentally (via IR camera) and modeled analytically
- Friction coefficient is a function of the welder parameters and follows the same trends as the literature
- Model prediction error can be greatly reduced if \( \mu = f(F, \lambda, s) \)
- \(~19\% \) if \( \mu \) is constant
- \(~8\% \) for parameter dependent \( \mu \)

**ACKNOWLEDGEMENTS**

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**REFERENCES**