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

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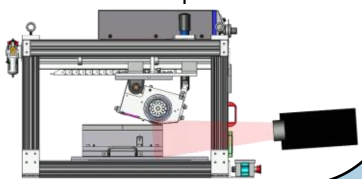
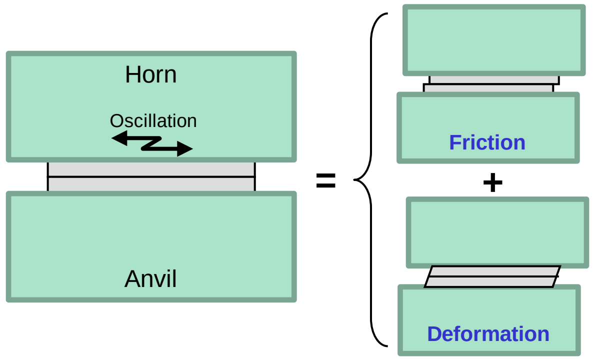
MOTIVATIONS

- 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

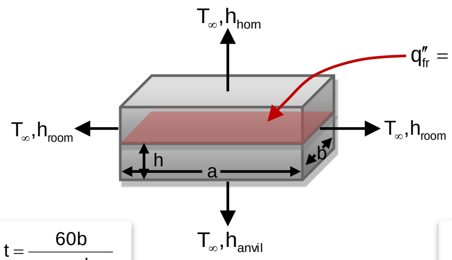


HEAT TRANSFER MECHANISMS



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

ANALYTIC FRICTION MODEL



$$q''_{fr} = \frac{\mu F_a 2\lambda f}{ab}$$

$$t = \frac{60b}{\omega_{hom}\pi d_{hom}}$$

$$V = 2hab$$

$$\dot{E}_{in} - \dot{E}_{out} = \dot{E}_{stored} = \rho C_p V \frac{dT}{dt}$$

$$\rho C_p V \frac{dT}{dt} = \dot{E}_{in} - \dot{E}_{out} = q''_{fr} \cdot ab - (h_{room}4hb + h_{hom}ab + h_{anvil}ab)(T - T_\infty)$$

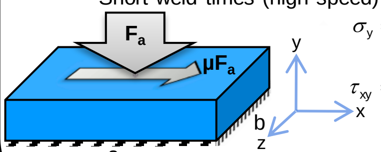
$$T = T_\infty + \frac{\mu F_a 2\lambda f}{H}\left(1 - e^{-\frac{H}{\rho C_p V}t}\right)$$

$$H = (h_{room}4h + h_{hom}a + h_{anvil}a)b \approx 1.4\left[\frac{W}{K}\right]$$

ISOLATE FRICTIONAL HEATING

To validate our friction model contributions from deformation must be minimized by preventing plastic deformation

- von Mises stress < yield stress (function of T)
  - Low-moderate applied force
- Prevent bonding between foils
  - Short weld times (high speed)



$$\sigma_y = \frac{-F_a}{ab}$$

$$\tau_{xy} = \frac{\mu F_a}{ab}$$

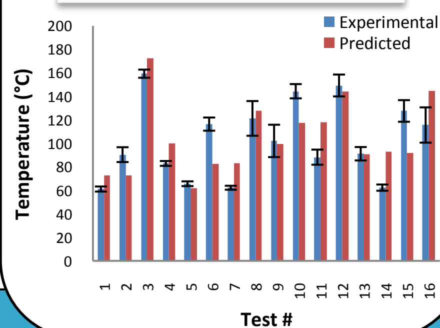
$$\sigma_{vm} = \frac{1}{\sqrt{2}}\sqrt{\sigma_y^2 + \nu\sigma_y^2 + (\nu - 1)^2\sigma_y^2 + 6\tau_{xy}^2}$$

EXPERIMENTAL PARAMETERS

Test #	Amplitude (um)	Applied Force (N)	Speed (mm/s)	Test #	Amplitude (um)	Applied Force (N)	Speed (mm/s)
1	9.4	1162	99	9	15.4	1162	123
2	12.4	874	99	10	18.4	1162	111
3	18.4	1739	87	11	12.4	1739	111
4	12.4	1451	123	12	18.4	1451	99
5	9.4	874	87	13	12.4	1162	87
6	15.4	874	111	14	9.4	1739	123
7	9.4	1451	111	15	18.4	874	123
8	15.4	1451	87	16	15.4	1739	99

EXPERIMENTAL RESULTS

Constant μ	Avg Error
0.175	19%



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 μ
  - Welder variables
    - Pressure
    - # Of cycles (time)
    - Slip amplitude
  - Material properties
    - Hardness
  - Contact geometry
  - Surface roughness

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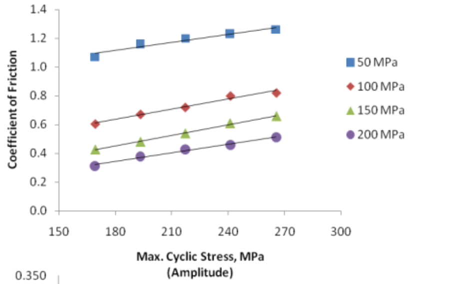
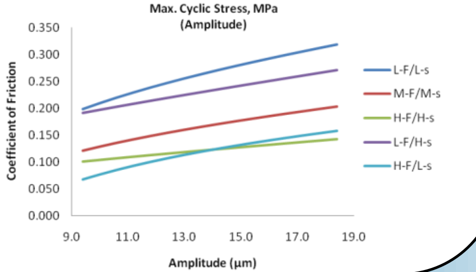
(Continued)

FRICTION COEFFICIENT VS. AMPLITUDE

Literature (Naidu & Raman)

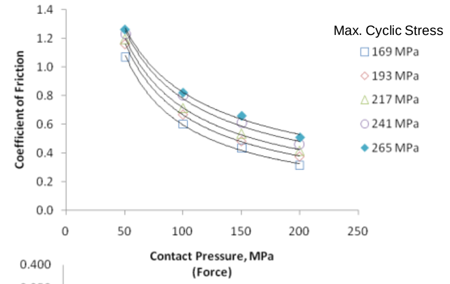


Response Surface Model

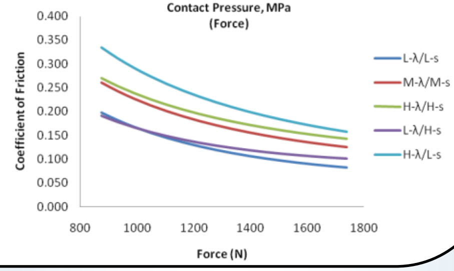


FRICTION COEFFICIENT VS. FORCE

Literature (Naidu & Raman)

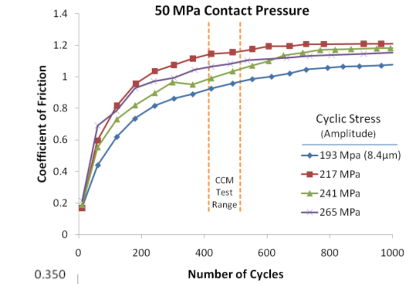


Response Surface Model

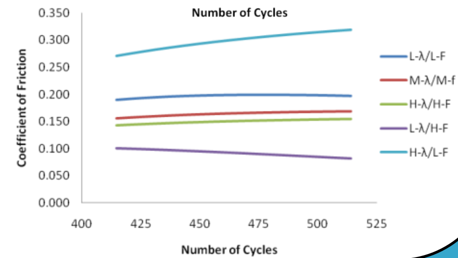


FRICTION COEFFICIENT VS. TIME

Literature (Naidu & Raman)



Response Surface Model



RESPONSE SURFACE MODEL

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

2. $T = T_\infty + \frac{\mu F_a 2\lambda f}{H}\left(1 - e^{-\frac{H}{\rho C_p V} t}\right)$

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

$$x_2 = \frac{(F - 1307)}{433}$$

$$x_3 = \frac{(s - 105)}{18}$$

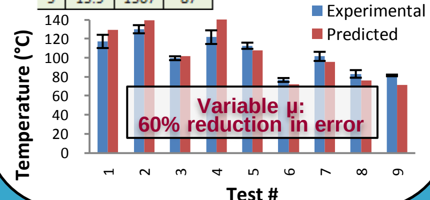
Solve 1. and 2. for μ to get:

$$\mu = f(\mathbf{b}, \lambda, F, s)$$

VARIABLE μ CONFIRMATION EXPERIMENT

Test #	Amplitude (μm)	Applied Force (N)	Speed (mm/s)
1	16.9	1595	111
2	16.9	1018	99
3	13.9	1018	111
4	16.9	1307	87
5	13.9	1307	87

Test #	Amplitude (μm)	Applied Force (N)	Speed (mm/s)
6	10.9	1018	123
7	13.9	1595	123
8	10.9	1307	99
9	10.9	1595	87



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 μ=f(F,λ,s)
  - ✧~19% if μ is constant
  - ✧~8% for parameter dependent μ

ACKNOWLEDGEMENTS

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REFERENCES

Naidu, N. & Raman, S. "Effect of contact pressure on fretting fatigue behaviour of Al-Mg-Si alloy AA6061." *International Journal of Fatigue* 27 (2005): 283-291