INVESTIGATING THE ACOUSTIC SOFTENING EFFECTS IN ULTRASONIC ADDITIVE MANUFACTURING

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Introduction

What Is Ultrasonic Additive Manufacturing (UAM)?
- Additive process
  - Solidica Form-ation machine
    (Source: Corbin Kolehmainen)
- Subtractive process

Motivation - Height to Width Ratio Issue
- The H/W ratio issue with UAM [1]

Evidences of Significant Plastic Deformation in UAM
- Nonlinear distribution of oxides at bond interface [3]
- Encapsulation of fiber due to plastic deformation [4]
- Theorized schematics assuming little plastic deformation [4]

Acoustic Softening Effects
- Stress strain relations under different ultrasonic irradiation intensities (left) and temperatures (right)

Preliminary Result

Experimental investigation of acoustic softening
- Setup Design
  - MTS hydraulic Tensile tester
  - Branson Ultrasonic welder
  - Supporting frame
  - Ultrasonic horn
  - Aluminum frame
  - Tensile specimen
  - Load cell
  - Tensile tester actuator

Experimental Observation
- Load Speed | Irradiation Time | Vibration Frequency | Vibration amplitude
  - 0.1 mm/s | 10 seconds | 20 kHz | 5 µm (left) | 0 – 48 µm (right)

Analytical Modeling of Acoustic Softening
- Plasticity Model
  \[ \sigma = K\varepsilon^p \] (Isotropic hardening)
- Acoustic Softening Model
  Assumption: \( \varepsilon = \varepsilon_{Acoustic} \)
  Stress reduction ratio: \( \eta = \frac{\varepsilon_{Acoustic} - \varepsilon_{Linear}}{\varepsilon_{Acoustic}} = 1 - \frac{\sigma}{E} \), \( E \) is ultrasonic energy input

Incorporate acoustic softening to plasticity model
- \( \sigma_{soft} = \eta K\varepsilon_i^n = (1 - \varepsilon_{Acoustic}) K\varepsilon_i^n \) below 3000 W/cm² (multi-linear)
- \( \sigma_{soft} = \eta (2\varepsilon_i^n + b) = (1 - \varepsilon_{Acoustic})(2\varepsilon_i^n + b) \) above 3000 W/cm² (bi-linear)

Conclusions
- An experimental setup is designed to investigate acoustic softening in Al 6061
- The acoustic softening in Aluminum 6061 is experimentally observed and analytically modeled.
- The acoustic softening model is incorporated into a power law plasticity model and the prediction from the plasticity model agrees with experimental data

Future Work
- Perform experiments on Al 3003 – H18 which is also extensively used in UAM, try to generalize the acoustic softening model
- Improve the current plasticity model by using cyclic plasticity model, which characterize both isotropic hardening and kinematic hardening.
- The proposed plasticity model will be incorporated to a comprehensive UAM material model which also considers other influencing factors (ex. thermal effects and friction) that are not included in this poster.

References

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