INTERFACE BY DESIGN FOR JOINING OF DISSIMILAR MATERIALS

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mat136

Pacific Northwest NATIONAL LABORATORY

OAK RIDGE National Laboratory

OVERVIEW

Timeline

- Project Start: Oct 2017
- Project End: Sept 2020
- 20% Percent Complete

Barriers

- Lack of reliable joining methods for dissimilar materials
- Lack of fundamental understandings on the interfacial bond formation mechanisms

Budget

- FY 2018: $850k
  - $650k ORNL
  - $200k PNNL
- FY 2019: $850k
- FY2020: $850k

Partners

- Oak Ridge National Laboratory
- Pacific Northwest National Laboratory

Any proposed future work is subject to change based on funding levels.

RELEVANCE AND IMPACT

- Technology gaps for lightweight metal body structures
  - Lack of proven technology for joining dissimilar metals (Steel-Al, Steel-Mg, Mg-Al, etc.)
  - The need to maintain the microstructure makes the use of conventional joining techniques nearly impossible.
  - Joining of thin sheet of AHSS is unreliable and fracture behavior is not understood
- Technology Gaps-Composite Body Structures
  - Lack of dependable joining technology for the integration of composite components into the body structure


U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy
VEHICLES TECHNOLOGIES OFFICE

WORKSHOP REPORT:
Light-Duty Vehicles Technical Requirements and Gaps for Lightweight and Propulsion Materials

February 2013

FINAL REPORT

PERSPECTIVE ON PROCESS DISCOVERY AND DEVELOPMENT FOR DISSIMILAR MATERIALS JOINING

- Fusion welding
  - Formation of large pockets of brittle intermetallic compounds
  - Limitations: very narrow process window
- Solid state joining
  - Friction stir-related methods (TWI, early 1990's, accidental discovery through machining)
  - Explosive/impact/pulse related methods (WWI, accidental discovery of shrapnel sticking to armor plate. DuPont patent 1964)
  - Ultrasonic related methods (Soloff, 1965, unintentional)
- Adhesive bonding
- Drawbacks of Edisonian approaches
  - Lack of fundamental understanding on interfacial bond formation mechanisms
  - Lack of knowledge on the desired interfacial mechanisms, only shoot for macroscopic strength through testing
  - Long time needed for process parameter development
  - Not conducive to new process discovery

APPROACH:
-- INTERFACE-BY-DESIGN

- Turning the equation around with validated computational models:
  - Key parameters determining the load-carrying capacity of a joint:
    - Effective bonded area, intrinsic bond strength
  - Inverse computational approach to quantify the key parameters for targeted joint load-carrying capacity:
    - Desired effective bonded area (including morphology) and bond interfacial strength
  - Perform massively paralleled molecular dynamics simulations validated by high throughput experiments to identify the associated interfacial characteristics needed in achieving the identified bond interfacial strength with:
    - Thermodynamics (chemistry driven) and kinetics (processing driven)
    - Diffusion and phase transformation
  - Perform process simulations (validated by experiments) to identify the joining methods and process parameters to achieve
    - Desired interfacial pressure, temperature history
    - Desire interfacial morphology

MILESTONES, PROGRESS AND ACCOMPLISHMENTS

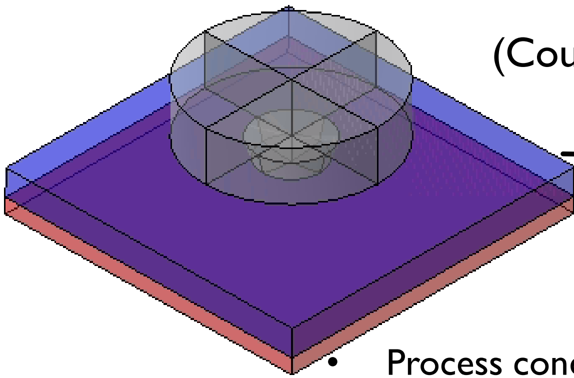
FY18 Milestones

1. Experimentally validated inverse prediction of process parameters window for friction stir-based joining processes for Mg and steel structural joints.
2. Establish the forward mapping joint performance prediction framework for ultrasonic-based joining processes for Mg and steel structural joints.

FY18 Progress and Accomplishments

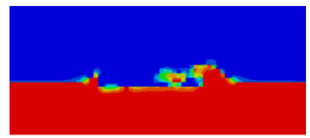
- Mg/Steel Interface
  - PNNL: Friction stir-based processes (Built on predictive framework verified and validated with previously funded experimental work)
  - ORNL: Ultrasonic welding (Built on previous experimental work in the area)
- CFRP/Steel Interface
  - ORNL: Adhesive-based technology with modified steel surface morphologies

ACCOMPLISHMENTS ON MG/STEEL INTERFACE -- PREDICTIVE FRAMEWORK LINKING PROCESS-STRUCTURE-PROPERTY FOR FSSW (PNNL)

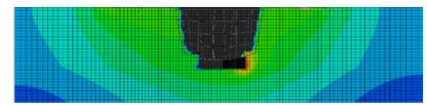


Process-Structure

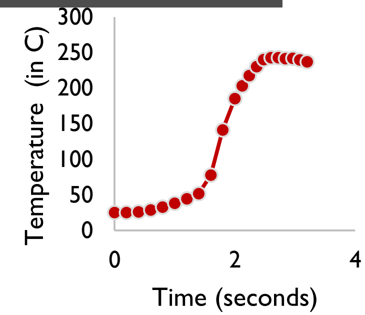
(Coupled Thermo-mechanical FEM based model)



Interfacial Morphology



Temperature Profile



Temperature History

Input:

- Process conditions
- Material Properties
- Model parameters

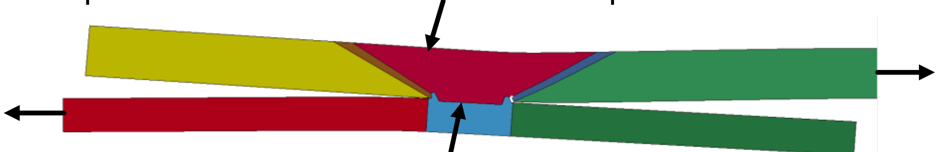
Output

[Temperature history will be utilized to perform diffusion and reaction calculations to predict interfacial chemistry and phase composition]

Model parameters calibrated based on feedback from experimental output

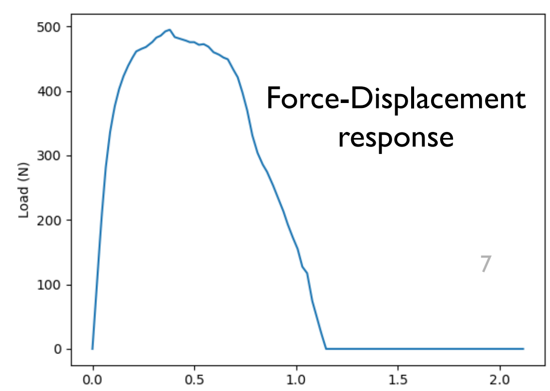
Structure-Property

Material properties of different identified regions obtained from experimental characterizations of welded specimens



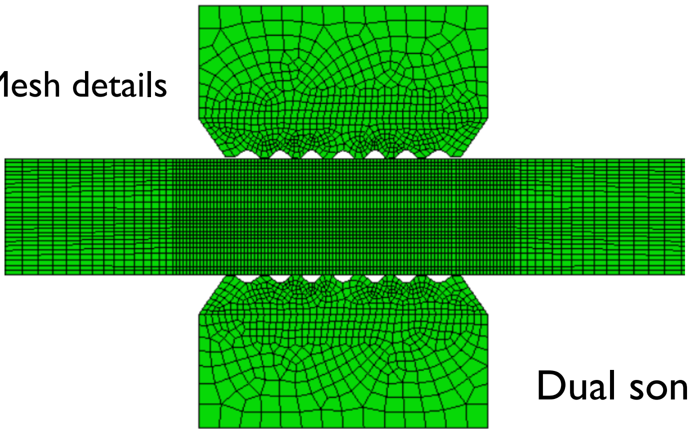
Interfacial strength = Unknown ?

- Parameterize for sensitivity analysis
- Micro-tensile or micro-shear testing

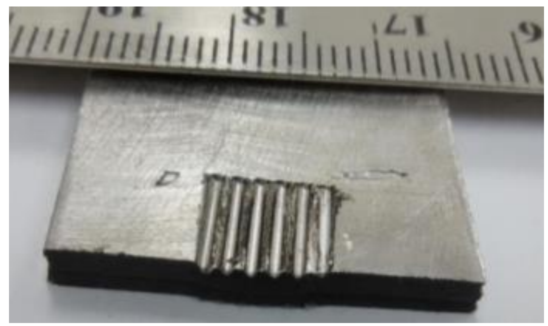


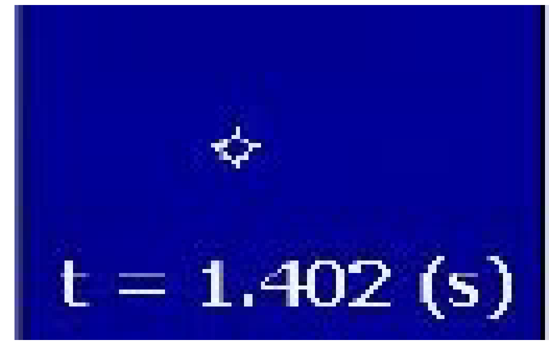
ACCOMPLISHMENTS ON MG/STEEL INTERFACE -- VALIDATED PREDICTIVE FRAMEWORK LINKING PROCESS-STRUCTURE FOR UW (ORNL)

Mesh details



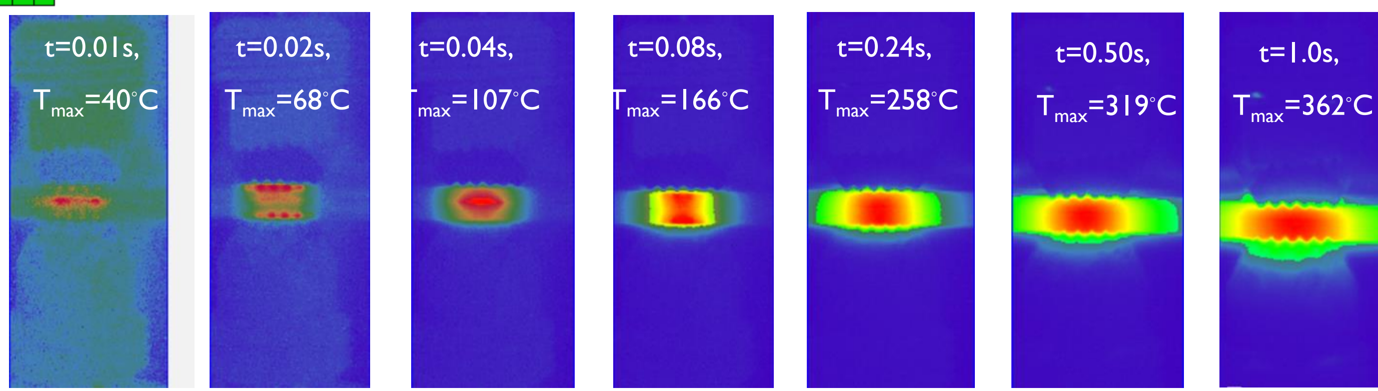
*Minimum element size **100μm** x **100μm***

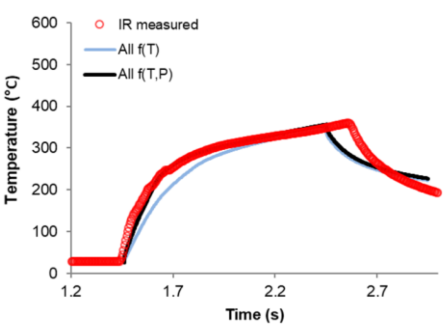




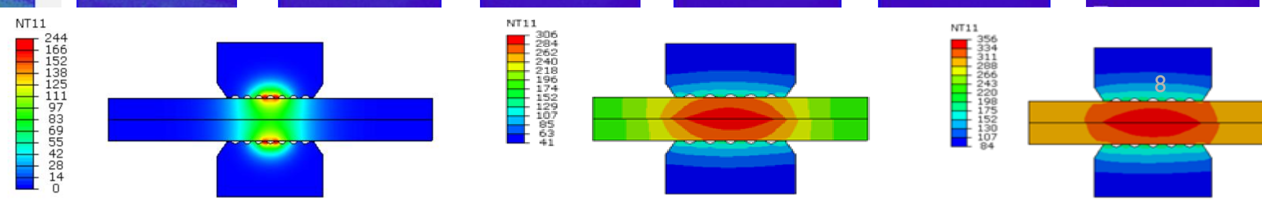
Dual sonotrode, Power=1000W, Frequency=20kHZ, Weld time=1sec

Exp.
Temperature contours at different time frames





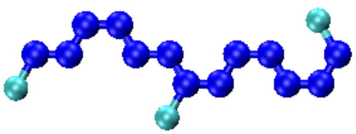
FEM



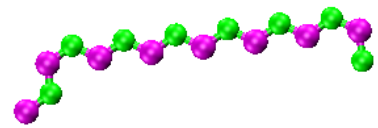
t=0.08s t=0.50s t=1.0s

ACCOMPLISHMENTS ON CFRP/STEEL INTERFACE -- PREDICTIVE FRAMEWORK LINKING PROCESS-STRUCTURE FOR POLYMER SYSTEMS (ORNL)

Coarse-Grained (CG) Molecular Dynamics (MD) Simulation

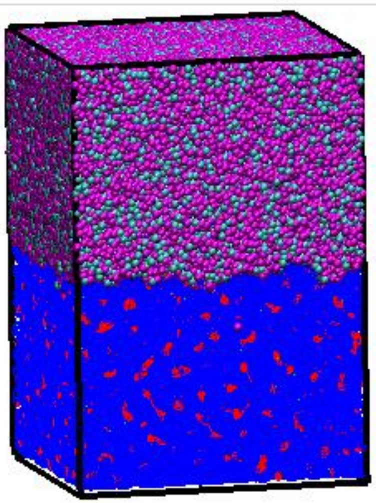


Adhesive: Coarse-Grained Structure of Epoxy-type polymer

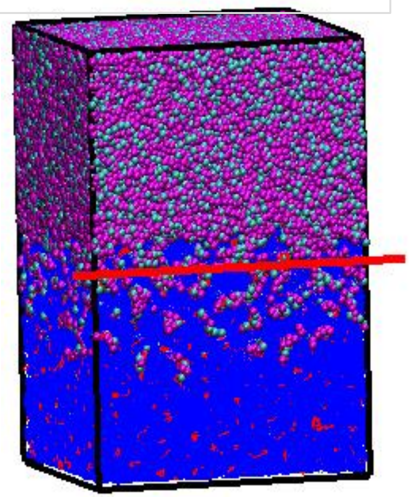


CFRP Matrix: Coarse-Grained Structure of Nylon-type polymer

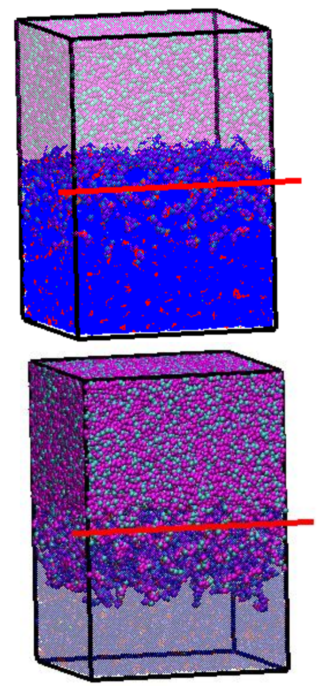
Interfacial stiffness depends on the inter-diffusion of the two systems at the interface



98.4% Epoxy crosslinked in 1 million time-steps assuming interaction



Large amount of Nylon in Epoxy Domain



Both nylon and epoxy phase color made transparent to visualize migration of one into the other

RESPONSE TO PREVIOUS YEAR REVIEW COMMENTS

- Project was not reviewed last year. This is the first year of the project.

COLLABORATIONS, TECHNOLOGY TRANSFER ACTIVITIES AND PROPOSED FUTURE WORK

- Collaborations:
  - ORNL and PNNL
    - Modeling team
    - Experimental team
- Technology Transfer
  - Results will be disseminated through journal publications, conference presentations and discussions with industry
  - Promising technologies will be further pursued through CRADAs with industry
- Future work
  - Focus on establishing the forward and inverse predictive framework of the process-structure-property relationship for the two materials interfaces with three different joining techniques
  - Develop tools that can be applicable to other materials combinations

Any proposed future work is subject to change based on funding levels.

SUMMARY

- Established the Joining Core Program
- Identified the material pairs and associated joining technologies to be investigated in FY18
- Established the modeling framework for two interfaces:
  - Mg/Steel Interface
    - Friction stir process
    - Ultrasonic welding
  - CFRP/Steel Interface
    - Adhesive bonding