Hot Rolling Scrap Reduction through Edge Cracking and Surface Defects Control

DE-FG36-05GO15049

University of Illinois at Urbana-Champaign (UIUC)/ ALCOA

2013-2015 (Budget Period 2)

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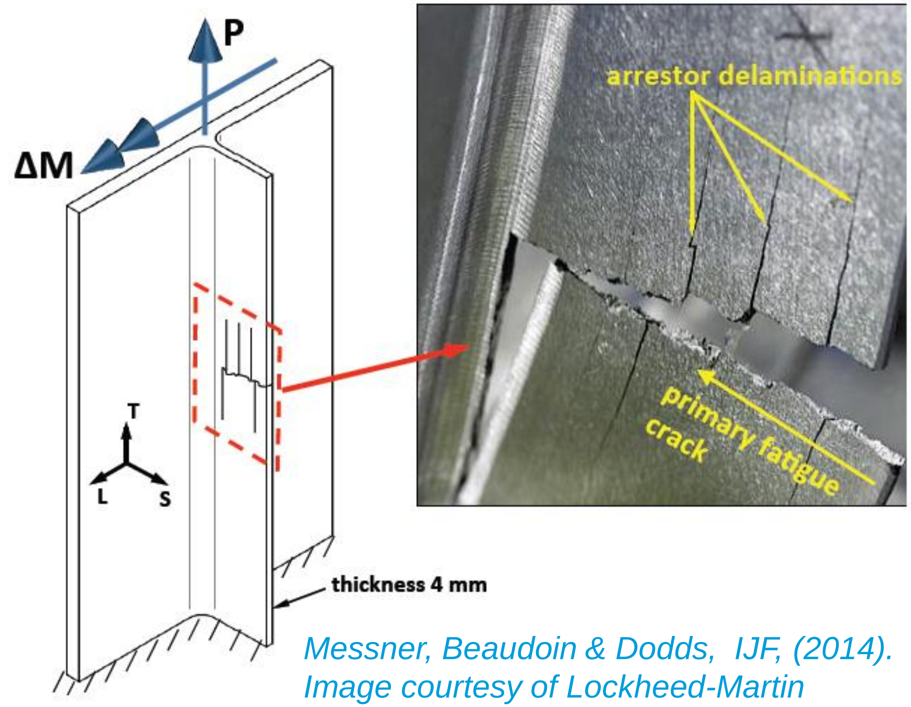
Project Objective

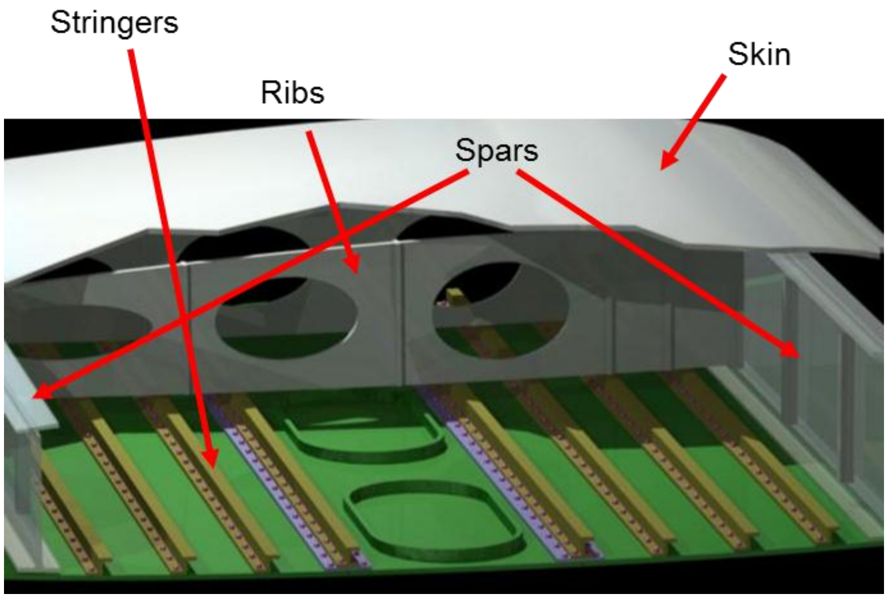
- Improved Performance Demanded of Future Aircraft
  - significant weight savings needed to reduce fuel consumption and emissions
  - longer inspection intervals over baseline
  - lower life-cycle cost
  - *fault tolerant design depends on understanding of crack growth!*



Messner, Beaudoin & Dodds, IJF, (2014). Image courtesy of Lockheed-Martin

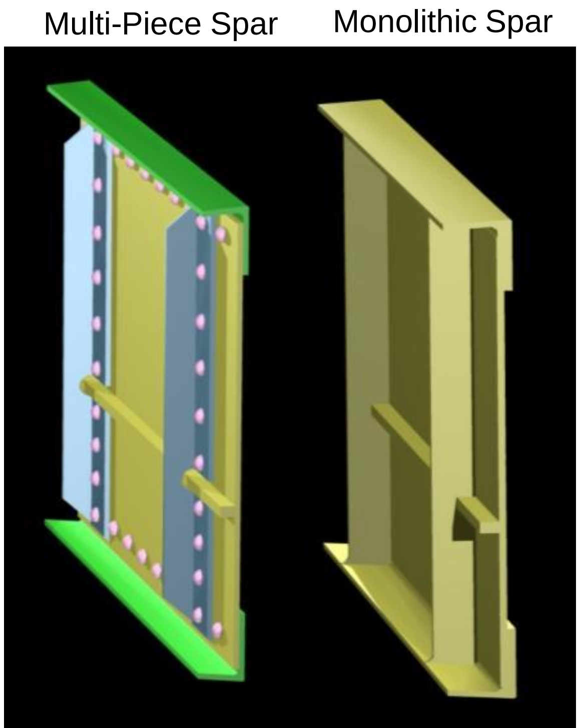
- Objectives
  - Develop integrated models that link properties of aluminum alloy plate to microstructure to rolling process parameters.
  - Validate the model by predicting the stress intensity factor at onset of crack branching in hard alloys within 20%.
  - Provide a technology delivery mechanism to industry through implementation of the integrated model in open-source software

Technical Approach



- Transition from multi-piece to monolithic structure
  - requires understanding of microstructure/crack interaction
  - OEMs typically design with linear elastic fracture mechanics & isotropic crack direction criteria (maximum tensile stress)

- **Our Approach**
  - use a precompetitive material to develop new modeling technology (AA-7050)
  - account for the anisotropic behavior during crack growth.
  - validate model to demonstrate that it adequately represents the real world performance of the material



Use of fasteners requires additional "pad up" features

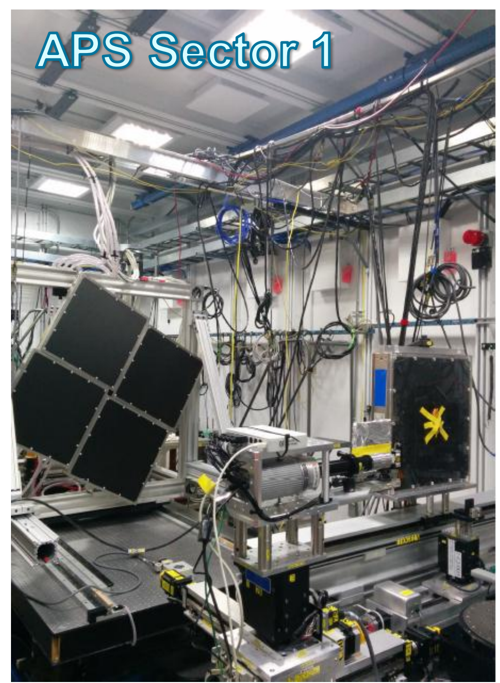
Willing to sacrifice up to 90% of material to gain weight savings

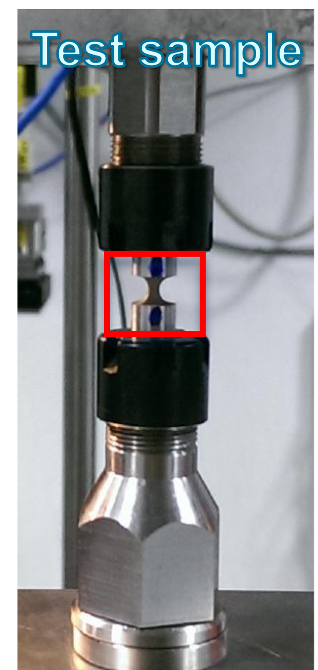
Technical Approach

- We will provide an open-source code for the engineering analysis of fracture, validated through state-of-the-art experiments
  - UIUC (software & experiments)
  - Alcoa (experiments of crack growth in pre-competitive alloy)
  - Advanced Photon Source of Argonne National Laboratory (experiments on response in the microstructure)

What is innovative?

- Unique combination of open-source model and experimental validation
  - Validated "mesoscale" model for directional response of hard alloys using synchrotron
  - Open-source platform for analysis of fracture using WARP3D





Transition and Deployment

Who is the end user?

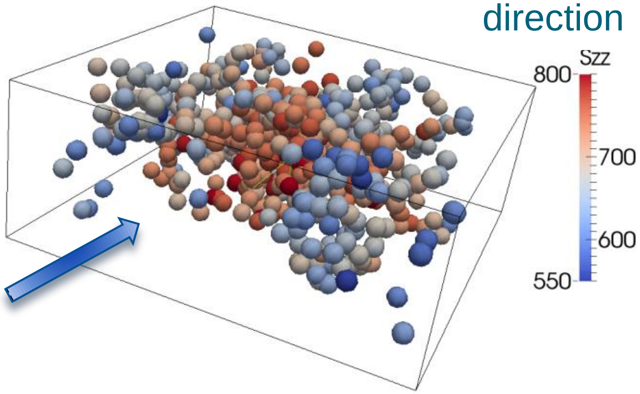
- Material suppliers will
  - bring the modeling technology in-house
  - adapt to other current and future (proprietary) alloys to better understand alloy behavior
  - design new alloys with different behavior
  - work with OEMs to understand how best to take advantage of the alloy characteristics
- Commercialization Approach
  - open-source software (WARP3D)
  - peer-reviewed publications
    - provide theoretical foundation of model and approach to application
    - provide details & procedure for getting properties into model
  - sustained through open-source approach *including procedures for analysis of material test data*

Transition and Deployment

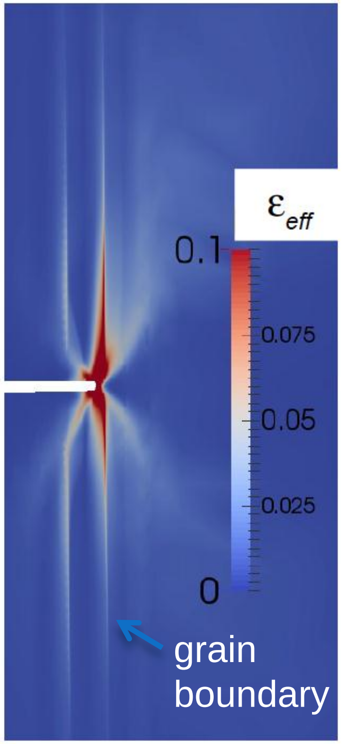
- Synchrotron studies
  - map out stress at the scale of the microstructure (sub-grains)
  - identify "grain pairs" associated with localized stress gradients
  - ***relate synchrotron results to laboratory procedures used by industry***

Sample used in synchrotron experiment

Stress in loading direction



- WARP3D
  - validate approach using synchrotron results
  - for transition industry
    - ***provide input (meshes) for crack geometry including features of microstructure***
    - ***develop support software(python scripts) for characterization of (industrial) laboratory material properties data***



Microstructure crack interaction:
crack "turning" along grain boundaries perpendicular to crack indicated by localized strain

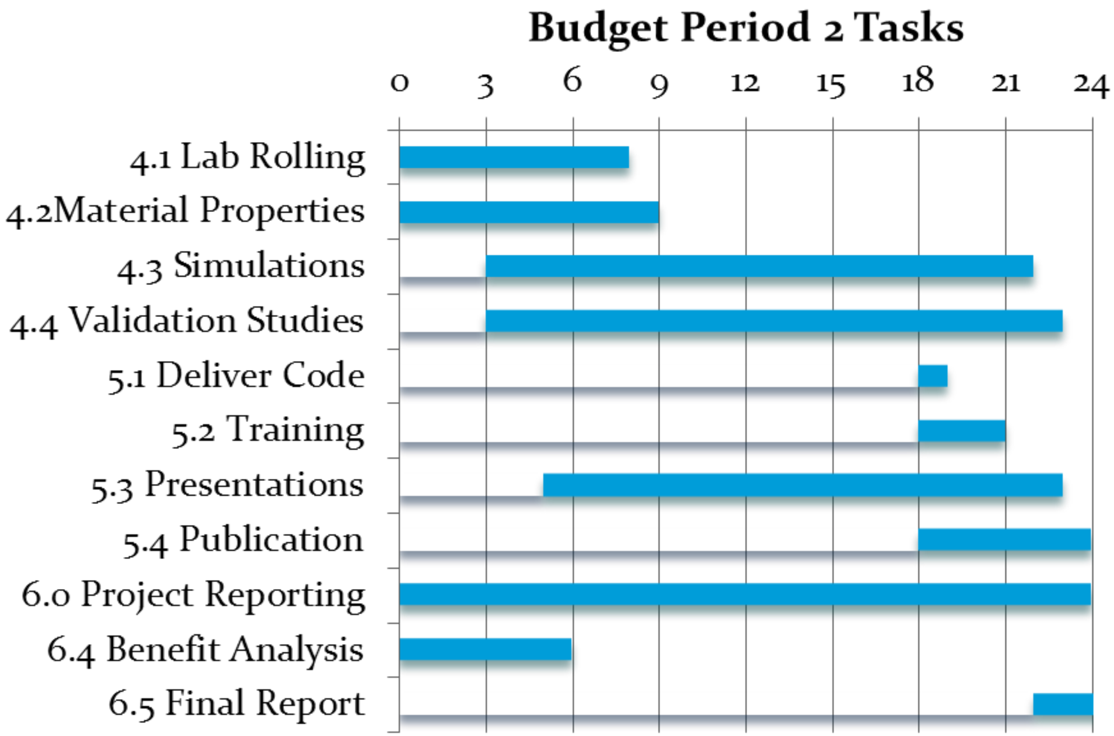
Measure of Success

- Prediction the stress intensity factor at onset of crack branching in hard alloys within 20%
- Adoption of model technology by material supplier
- Assume an additional fuel savings of 0.1% by 2034
  - in the domestic fleet
  - achieved through light-weighting using advanced fabrication of next-generation aluminum alloy plate in structural aircraft components
  - facilitated by the present work
  - would save
    - 0.001 * 26,237 million gallons
    - 26.2 million gallons of jet fuel annually
    - at a cost of $4.01/gal, (FAA current $ projection for 2034), this is a savings of ~$100 million/year.
- Other applications possible (not limited to airframe materials)

Potential Energy Impact

Project Management & Budget

- Budget Period 1
  - Integrated meso-/macro-scale model
  - *coded & validated*
  - *discovered mechanism of load sharing between grains*
- Budget Period 2
  - Key milestone: accurately relate trends in crack growth in finished product with prior hot rolling practice

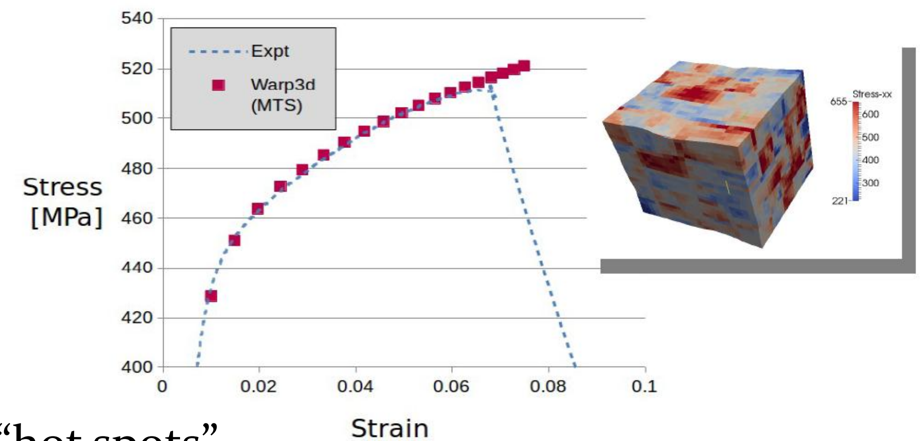


Total Project Budget	
DOE Investment	$2,183,965
Cost Share	$2,223,914
Project Total	$4,407,879

Results and Accomplishments

- Accomplishments
  - experimental matrix complete

Weak anisotropy Temper Practice 1	Strong Anisotropy Temper Practice 1
Weak anisotropy Temper Practice 2	Strong Anisotropy Temper Practice 2



  - synchrotron studies indicate stress “hot spots”
  - implementation of mesoscale model in open-source code for fracture analysis (WARP3D), with quantitative validation
  - code transferred to Alcoa
- Future Work
  - introduce properties from the four experimental simulations and examine crack turning
  - **key milestone**: July 31, 2015
    - **Milestone:** accurately relate trends in crack growth in finished product with prior hot rolling practice
    - **Verification:** validate model through prediction the stress intensity factor at the onset of crack branching in hard alloys within 20%.