Hot Rolling Scrap Reduction through Edge Cracking and Surface Defects Control

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

Project Period

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Project Objective

- Objectives
  - Develop integrated models that link properties of aluminum alloy plate to microstructure and 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 WARP3D.
- Complex structural aerospace components are high-speed machined out of thick hard alloy plate

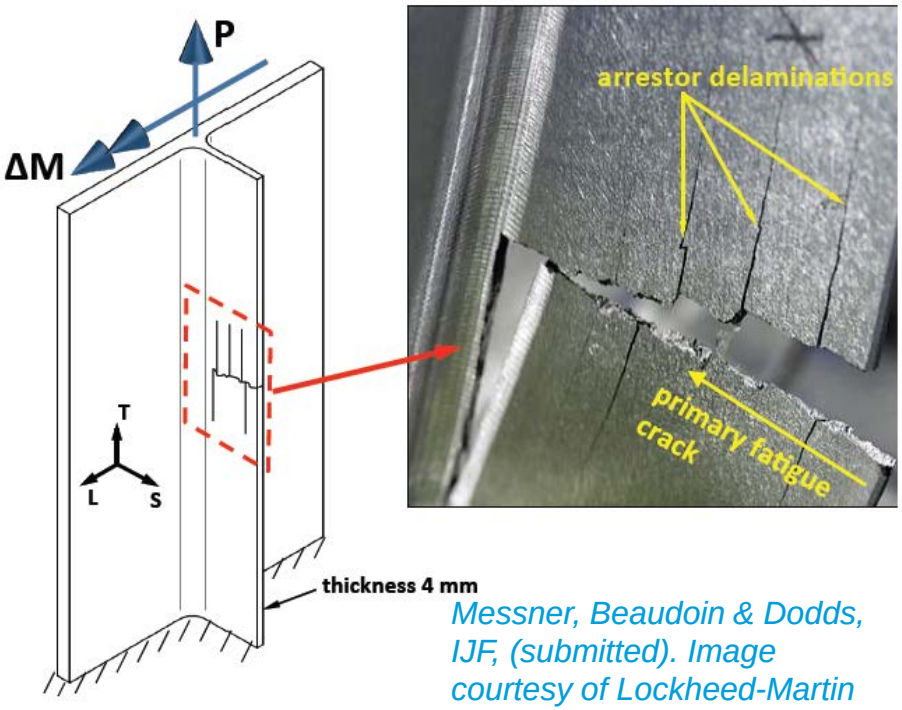
The problem?

  - A majority of the material is removed to form an integrated unit, providing considerable weight savings.
  - Part integration leads to 10% weight savings over a built-up structure
  - the push for increased performance and reduced weight has lead to more complex loading scenarios that activate different and more complex microstructure related failure mechanisms
  - *fault tolerant design depends on understanding of crack growth!*

Technical Approach

How is it done today?

- Current practice
  - Neither suppliers, nor OEMs, use anisotropic material properties as a routine part of design.
  - OEMs design typically with linear elastic fracture mechanics, isotropic crack direction criteria (maximum tensile stress)
  - In addition, traditional design is primarily concerned with in plane properties (L and LT directions).
- Our Approach
  - Use a precompetitive material to develop new modeling technology
  - account for the anisotropic behavior during crack growth.
  - validate model to demonstrate that it adequately represents the real world performance of the material



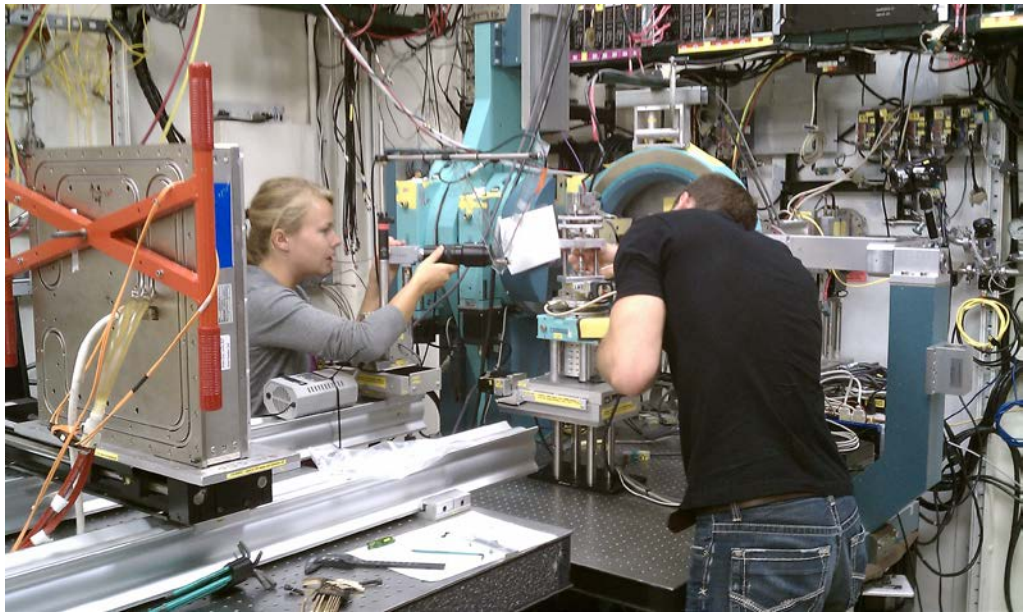
Messner, Beaudoin & Dodds, IJF, (submitted). Image courtesy of Lockheed-Martin

Technical Approach (Continued)

- 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
  - Open-source platform for analysis of fracture



Transition and Deployment

Who cares?

- FAA forecast (2013)
  - projects an average annual rate for growth for U.S. carriers of 2.9% through 2033 internationally, and 2.1% domestically
  - fuel costs were $0.96 in 2000 and $3.00 2012 (FY 2012 dollars)
  - the fuel consumption for the domestic fleet in Millions of Gallons is 18,500 in 2012E and projected to be 26,844 in 2033
  - *"Aviation currently accounts for 2 to 3 percent of global carbon emissions, but this percentage is expected to increase with the growth in operations unless mitigated with new technology."*
- fleet-wide fuel efficiency improvements of 1%/yr are typically adopted for forecast baseline calculation (Horton, G., 2006; Owen et al., 2010)
- CO_2 is emitted high in the atmosphere and may have a greater radiative forcing effect than CO_2 emissions at ground level (Burkhardt and Karcher 2011)

Transition and Deployment (Continued)

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 to provide theoretical foundation of model and approach to application
  - conference presentations
  - *sustained through open-source approach*

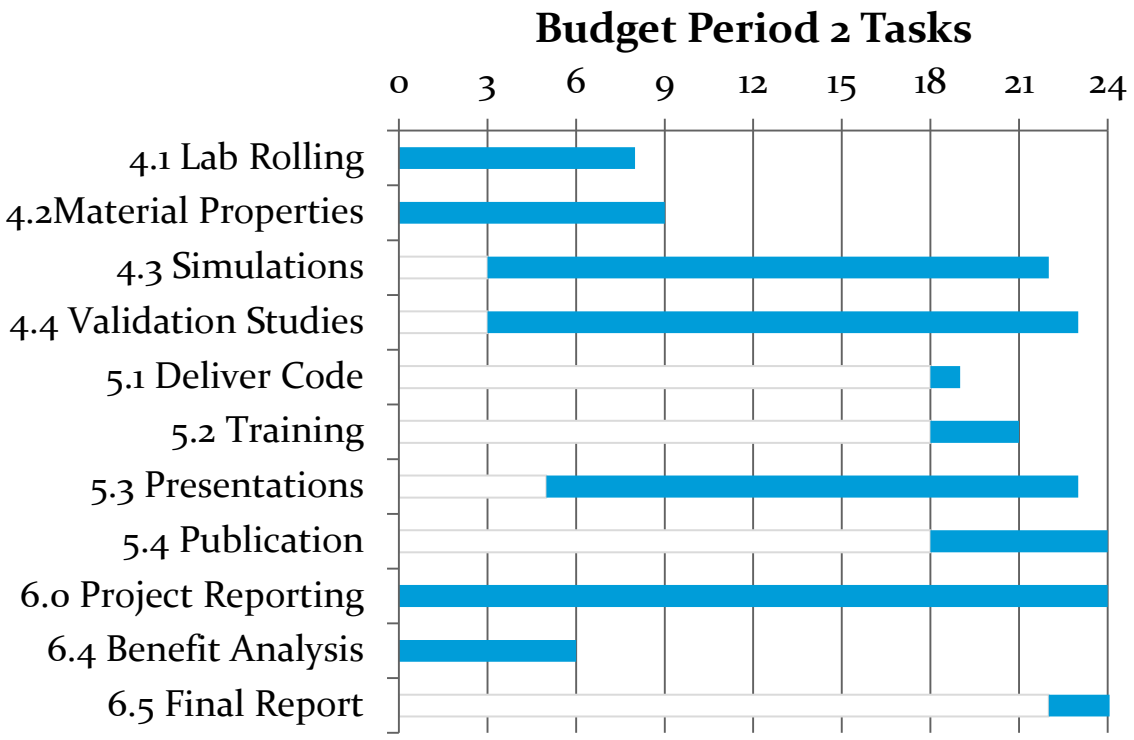
Measure of Success

- 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 2033
  - 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 * 26,844 million gallons
    - 26.8 million gallons of jet fuel annually
    - at a cost of $3.60/gal, (FAA current $ projection for 2033), this is a savings of $96 million/year.

Potential Energy Impact

Project Management & Budget

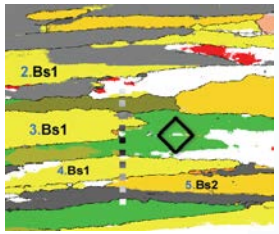
- Budget Period 1
  - 2005-2013
  - Integrated meso-/macro-scale model
  - *coded & validated*
- Budget Period 2
  - 2013-2015
  - Key milestone: accurately relate trends in crack growth in finished product with prior hot rolling practice

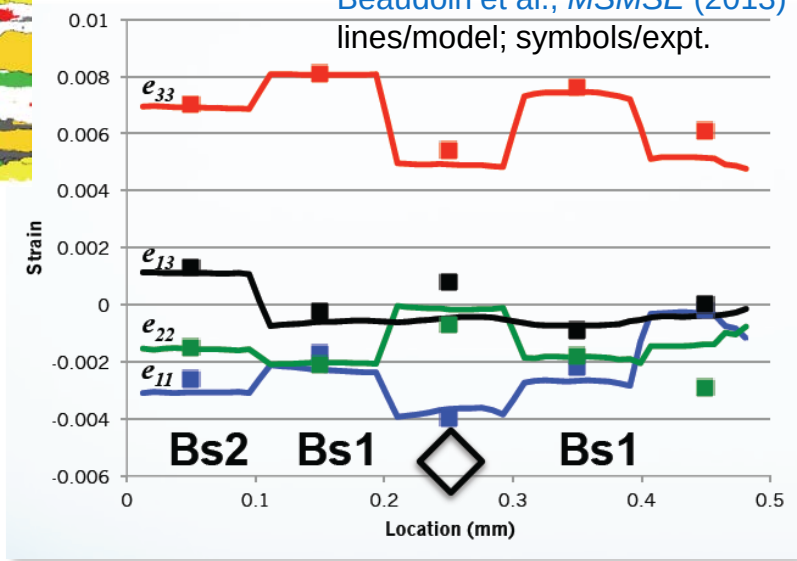


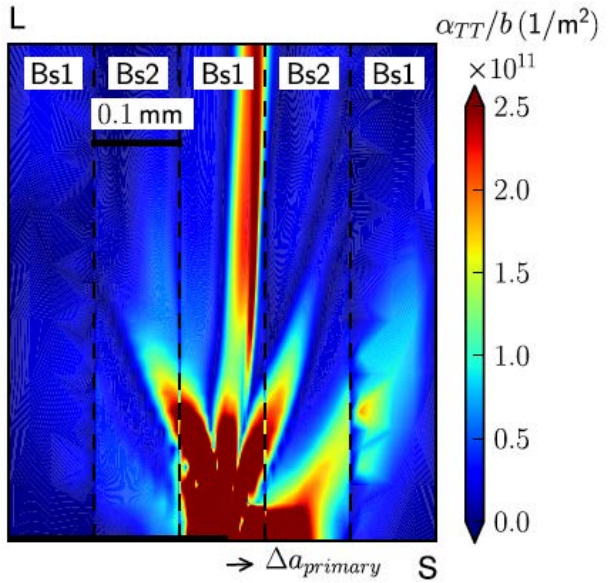
Total Project Budget	
DOE Investment	$2,183,965
Cost Share	$2,223,914
Project Total	$4,407,879

Results and Accomplishments

- Accomplishments
  - Validation of mesoscale (grain-scale) model using synchrotron radiation (APS)
  - Implementation of mesoscale model in open-source code for fracture analysis (WARP3D)
  - Successful prediction of driving forces for crack turning
- Future Work
  - Study of AA 7050
  - Predict crack turning trends following experimental matrix







Messner, Beaudoin & Dodds, *IJF*, submitted.

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