GO BEYOND

POTENTIAL INDUSTRY STANDARD APPROACH TO MEASURE AND QUANTIFY MICROSTRUCTURES AND MICROTEXTURE IN TITANIUM

RYAN NORAAS
MATERIALS & PROCESSES ENGINEERING
PRATT & WHITNEY

DATE: SEPTEMBER 24,2019

U.S. EXPORT CLASSIFICATION: NO TECHNICAL DATA

A UNITED TECHNOLOGIES COMPANY

This document is approved for public release

© United Technologies Corporation 2019

AGENDA

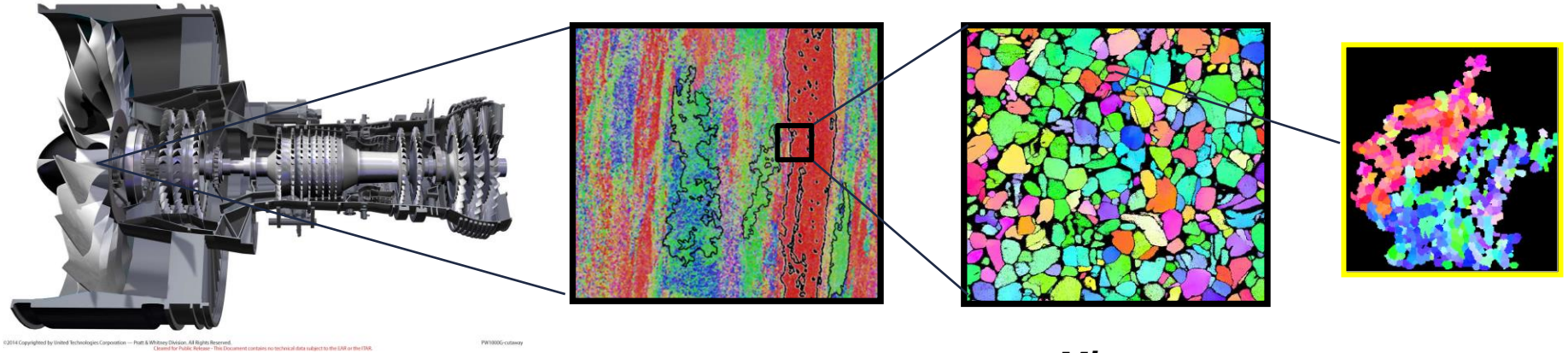
LET'S GET STARTED

Background	03
Cold Dwell Fatigue and Microtexture	04
Processing Effects on Microstructure	05
Method for Quantification of Microtexture	06
Future State	09
Conclusions	11

© United Technologies Corporation 2019

BACKGROUND

- Titanium is a work-horse material in aerospace industry
- As applications for titanium increase, enhancements and control of microstructure must evolve
  - Case study: High cycle fatigue improvement through microstructure control
  - In progress: Low cycle (dwell) fatigue improvement through microstructure + texture control



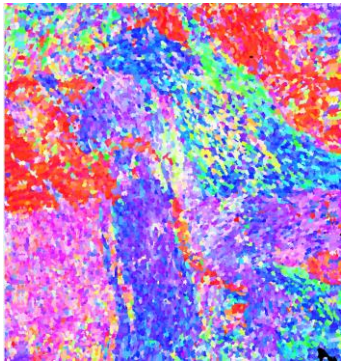
Meters ***Millimeters*** ***Microns***

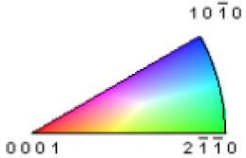
Need industry standard methods to quantify microstructure and microtexture in titanium

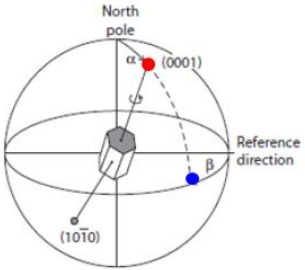
© United Technologies Corporation 2019

MICROTEXTURE AND DWELL FATIGUE

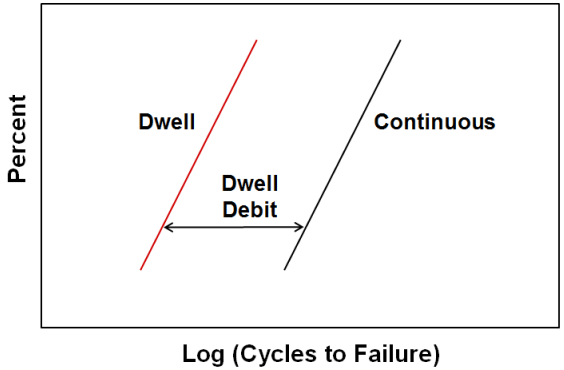
- **OIM (Orientation Image Microscopy)** provides crystal orientation information
  - Not possible to do quantitative assessment by eye
  - Not all textured regions impact component fatigue properties equally
- **“Texturing” or “Micro-Textured Region (MTR)”**
  - Small, localized regions where grains are aligned in similar direction
  - High stresses can develop at grain boundaries of hard regions leading to crack nucleation
  - High levels of microtexture can lead to significant dwell debit







Example of Normal Projections for HCP Crystal

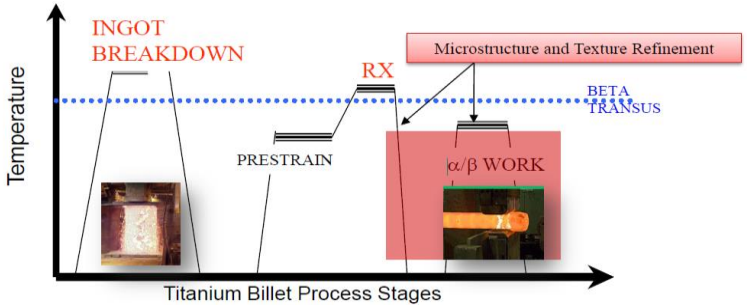


Dwell fatigue capability heavily influenced by microtexture.
Need standardized methods for its control in titanium product.

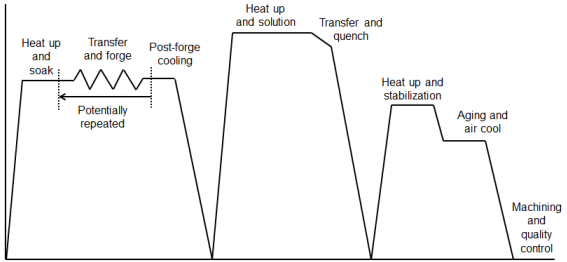
© United Technologies Corporation 2019

MANUFACTURING EFFECTS ON MICROSTRUCTURE

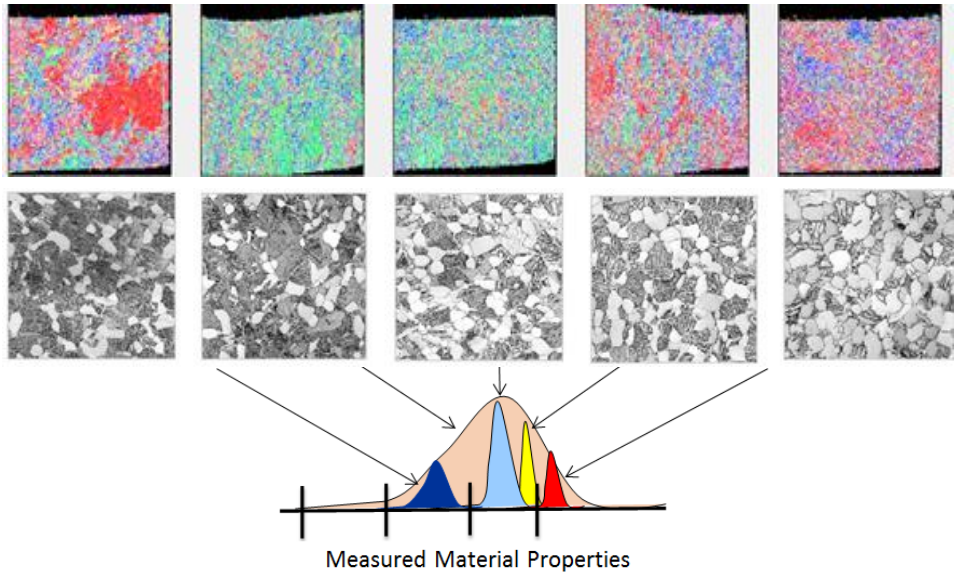
Billet Conversion Process



Forging + Heat Treat



Microstructure Variability

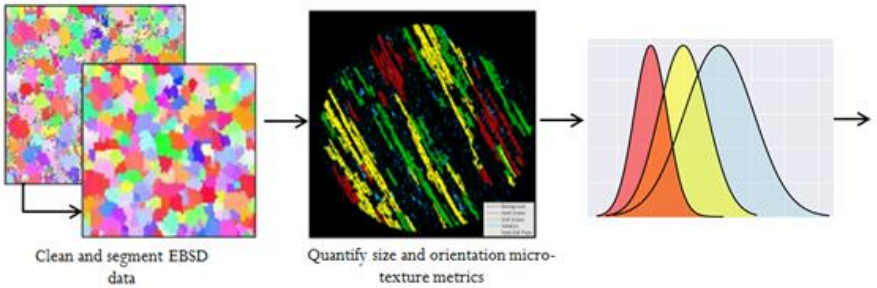


Microtexture and microstructure is process-dependent – not random.
Standardized methods have been developed quantify and model evolution during processing.

© United Technologies Corporation 2019

POTENTIAL METHOD FOR MICROTEXTURE QUANTIFICATION

DREAM.3D

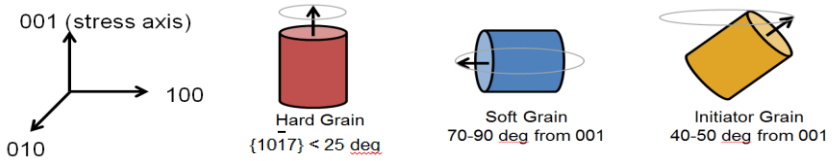


- ❑ A / B comparisons
- ❑ Quality Control
- ❑ Property Prediction
- ❑ Life Assessment

Key Input Parameters:

- Pixel C-Axis Misalignment Tolerance
- Minimum Size for MTR

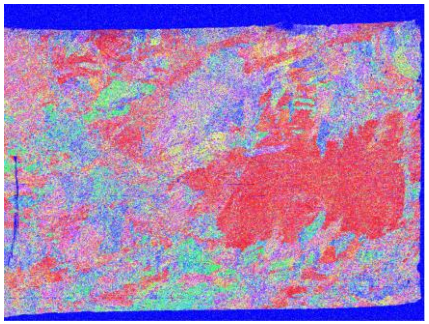
Geometric:	Orientation:	Neighbor Interactions:
• MTR Size (μm^2) • Aspect ratio • Solidity (%) • MTR Intensity • MTR Density (#/area)	• Avg. Misorientation (deg) • Stress axis misalignment (deg) • MTR class label	• Spatial relations/frequency • Hard/Soft Pair Intensity • Pair Contact Lengths (μm)
		Total Metrics: 76 per scan



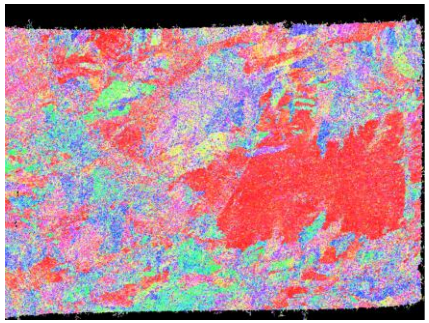
DREAM3D is free, open-source software that is well-suited for OIM data analysis.
Prevalent use in aerospace industry for quantification of microtexture.

© United Technologies Corporation 2019

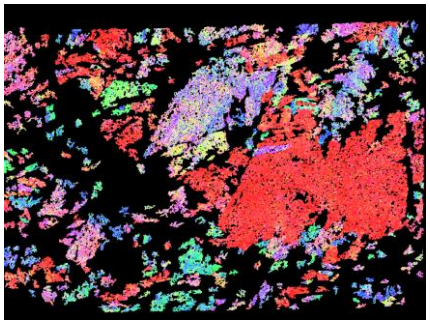
POTENTIAL METHOD FOR MICROTEXTURE QUANTIFICATION



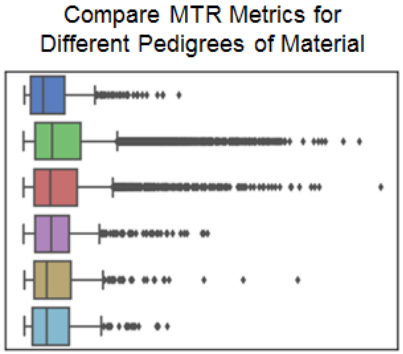
RAW DATA

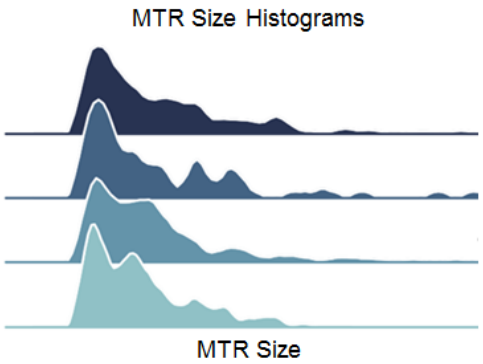


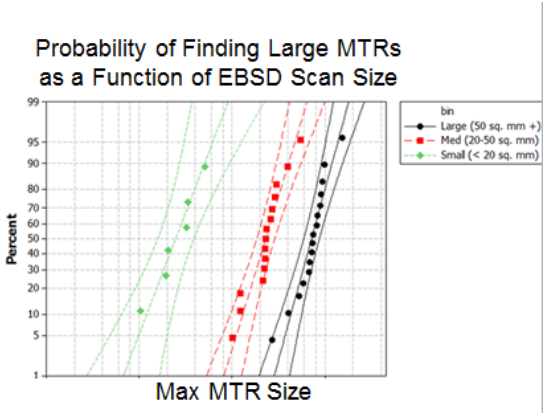
CLEANED DATA



MTRS ONLY





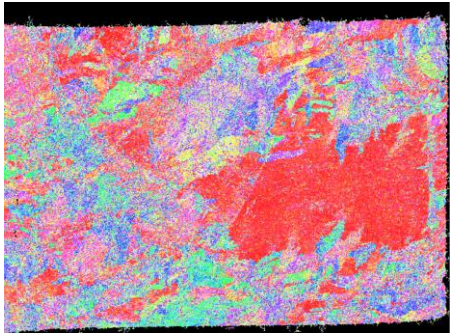


Dream3D enables statistical analysis and comparison of microtexture data

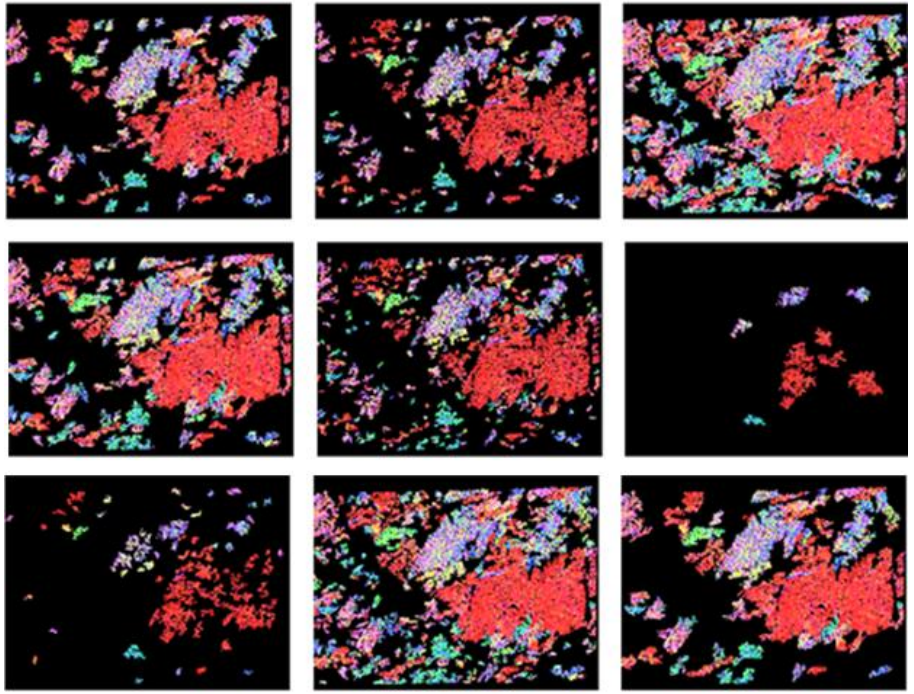
© United Technologies Corporation 2019

POTENTIAL METHOD FOR MICROTEXTURE QUANTIFICATION

CLEANED EBSD DATA



OUTPUTS USING DIFFERENT DREAM3D SEGMENTATION PARAMETERS



Analysis of OIM data is sensitive to certain Dream3D parameters and can significantly affect results. Industry standards improve ability to compare results and develop quality criteria.

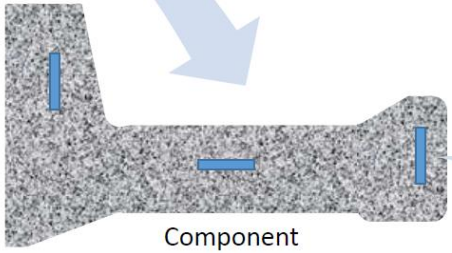
© United Technologies Corporation 2019

FUTURE STATE

Billet

MTR Evolution Model from Billet to Forging

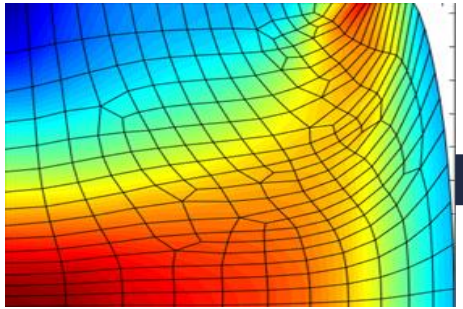
Inputs: Forging strain, temperature, billet texture & microstructure metrics



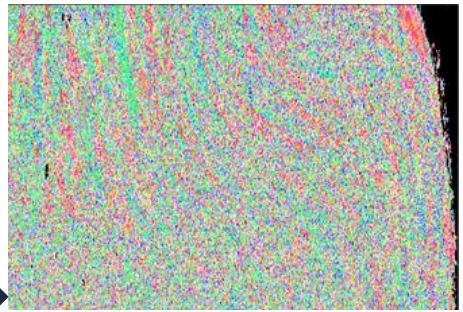
Component

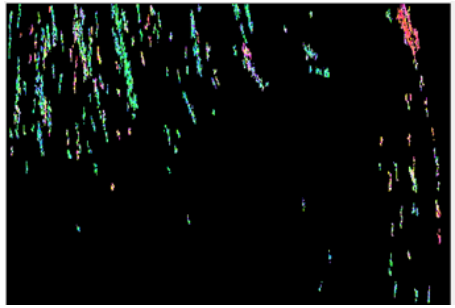
LCF and MTR Location Based Properties

Inputs: Location based MTR Metrics and Loading condition



Microtexture is a function of forging strain





ICME approach to predicting microtexture evolution during manufacturing and location-specific properties will help define billet and forging level criteria to minimize effects of microtexture

© United Technologies Corporation 2019

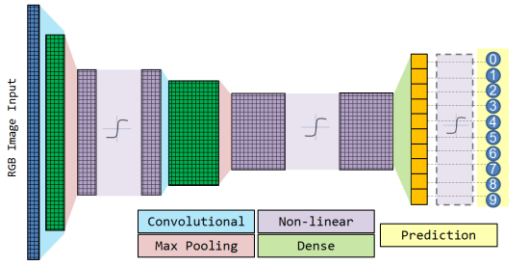
LONG TERM CHALLENGES IN MATERIALS CHARACTERIZATION

Current state:

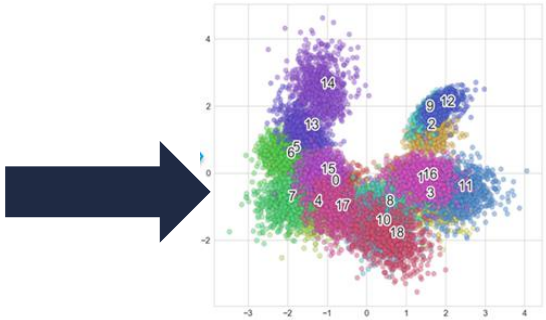
- Volume of data collected is increasing rapidly (automated scopes, new methods, etc)
- Current models based on simple metrics like grain size or volume fractions

Viable options moving forward:

- Fast, scalable, accurate, flexible techniques are needed
- Examples: machine-learning or image-based neural networks



Convolutional neural networks (CNN)
(enable image recognition)



Predicting material pedigree or
properties using CNNs

Applications & Benefits:

- ✓ Fast (analyze 1000's images per second)
- ✓ Repeatable, transferrable
- ✓ Automatically learn important features
- ✓ Predict material pedigree from images
- ✓ Image visual similarity lookup
- ✓ Quality control (defect recognition)

Machine learning and AI are enabling rapid materials characterization and improved modeling capability

© United Technologies Corporation 2019

CONCLUSION

- A method to quantitatively characterize texture has been developed.
- The developed method has potential to be an INDUSTRY STANDARD
- In order for titanium to be applied to future demanding applications, further control of microstructure and microtexture will be required

© United Technologies Corporation 2019

ACKNOWLEDGEMENTS

- U.S. Air Force through the Metal Affordability Initiative (contract FA8650-13-2-5203)
- MAI PW9 program team:
  - Pratt & Whitney
  - GE Aviation
  - Rolls-Royce Corporation
  - ATI Forged Products
  - Titanium Metals Corporation
  - Air Force Research Lab
  - Arconic
  - Wyman Gordon
  - Materials Resources, LLC

© United Technologies Corporation 2019

©2014 Copyrighted by United Technologies Corporation — Pratt & Whitney Division. All Rights Reserved.

Cleared for Public Release - This Document contains no technical data subject to the EAR or the ITAR.