SFSA Fall Leadership Meeting

Foundry Automation: Tele-Gouging, Portable Robotic Grinding and Robotic Cutting

Sept 25, 2022

Connie Reichert LaMorte
Principal Engineer, EWI
creichert@ewi.org
614-688-5247

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Outline

- EWI Background
- EWI Projects with SFSA
  - Tele-Gouging
  - Portable Robotic Grinding
  - Automated Cutting
- Potential Areas of Interest
  - NDE
  - Arc DED
  - Data Science
  - Cold Spray process
- An Industry Trend
  - Convergent Manufacturing

Who is EWI

Advanced Manufacturing Engineering Services

Columbus
OHIO

Joining
Forming
Materials Engineering
Structural Integrity
Modeling
Inspection
Polymers
Testing

Buffalo
NEW YORK

Additive Manufacturing
Automation
Data Science
Metrology

Loveland
COLORADO

Sales
Office

90+
Technical Experts
14 PhD, 28 MS, 37 BS

$40M+
Capital Equipment

160,000
Total Square Feet

$27 Million
Annual revenues across range sectors

What EWI Does For Our Clients

Advance your ideas from concept to production
faster and with less risk

How EWI Does It

We solve your toughest problems
with world class experts and state of the art equipment

EWI Markets

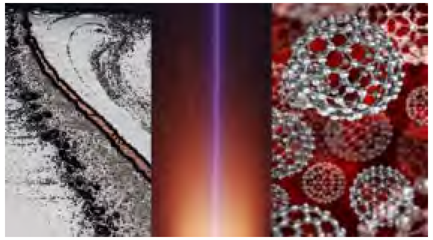
Aerospace

Oil & Gas

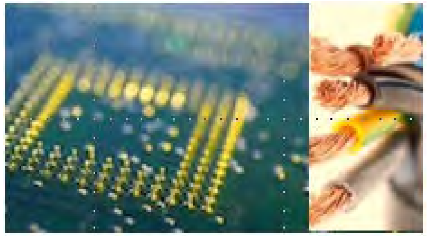
Medical Devices

Advanced Energy

Defense



Government



Consumer Electronics

Packaging

Automotive

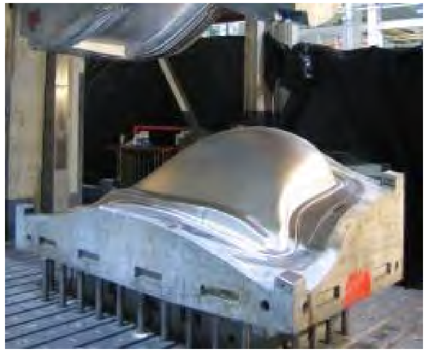
Heavy Industry

Transportation

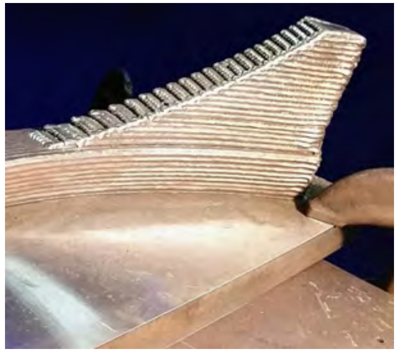
Space Exploration

EWI Technologies

Materials Joining



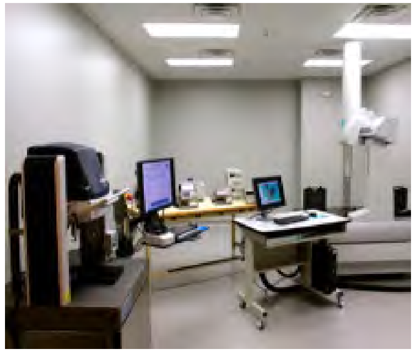
Forming



Additive Manufacturing

Structural Integrity

Inspection Technologies



Testing & Characterization

Advanced Automation

EWI Advantage

We are an extension of your team

Providing unbiased, cross-functional, solutions from a single source

Materials Joining

Metals
Polymers
Composites

Arc
Laser
Resistance
Solid State
Ultrasonic
Microjoining
Polymers
Soldering
Brazing
Diffusion

Forming

Universal Testing
Simulation
Stamping
Forming
Forging

Additive Manufacturing

All Powder Bed
All DED
Cold Spray
Solid State
Property Database

Structural Integrity

Static
Fatigue
ECA
Corrosion
Hydrogen

Testing & Characterization

Mechanical
Metallography
Nondestructive
Weld Consumables
Specialty

Inspection Technologies

Ultrasonic
Laser
Thermography
Radiography
Eddy Current

Advanced Automation

Remote Work
Machine Tending
Part Finishing
Inspection
Sensors

EWI Services

- Materials selection
- Manufacturability
- Formability
- Joining constraints

- Joint designs
- Process selection
- Design optimization DFx
- Analytical modeling
- Inspectability / NDE

- Process validation
- Automated systems development
- Process monitoring and controls
- Tooling development
- Onsite training and support

- Weldability analysis
- Process feasibility
- Joining trials
- Technology demonstration
- Property characterization

- Process optimization
- Rapid prototyping
- Testing and analysis
- Equipment specification

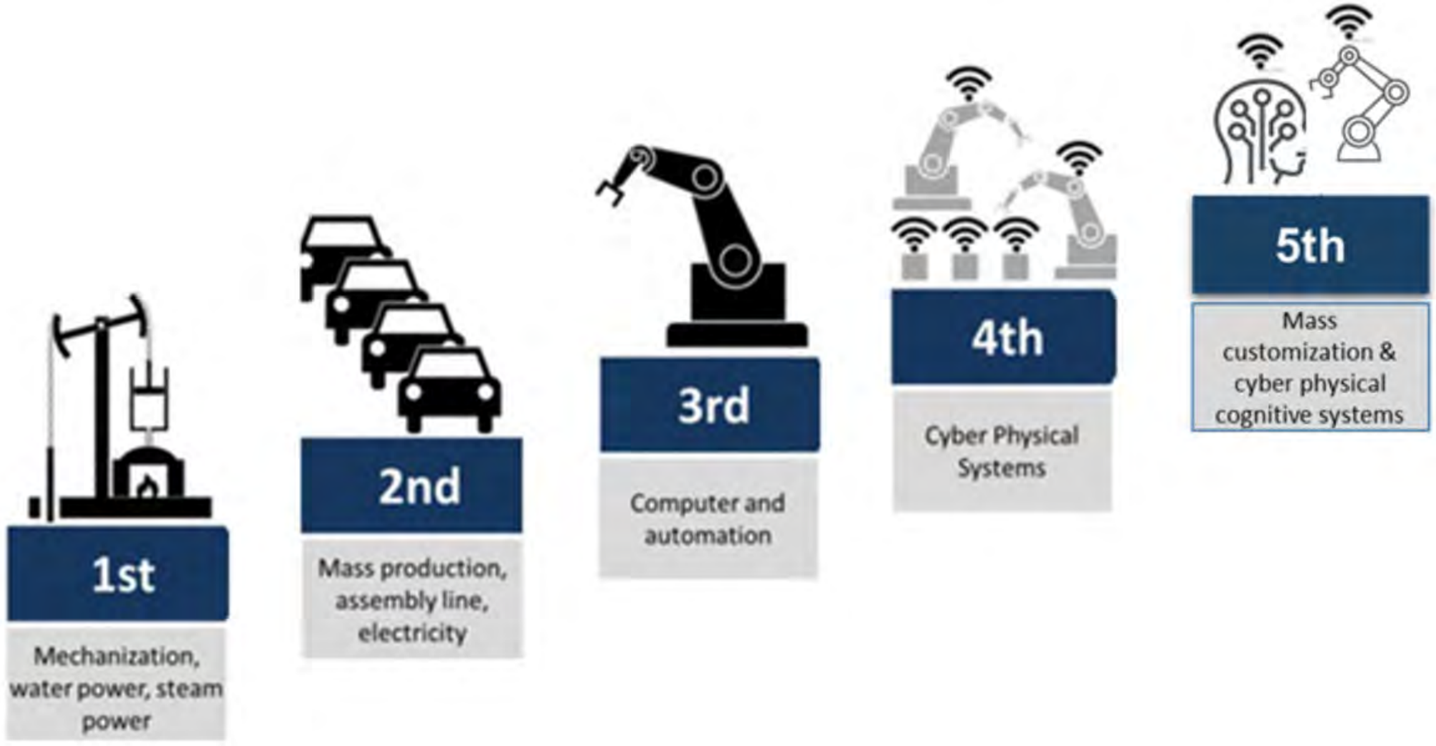
- Onsite troubleshooting
- Continuous improvement
- Failure analysis
- Service life inspection

Tele-Manufacturing

EWI Brief Background

Tele-Manufacturing is Industry 5.0

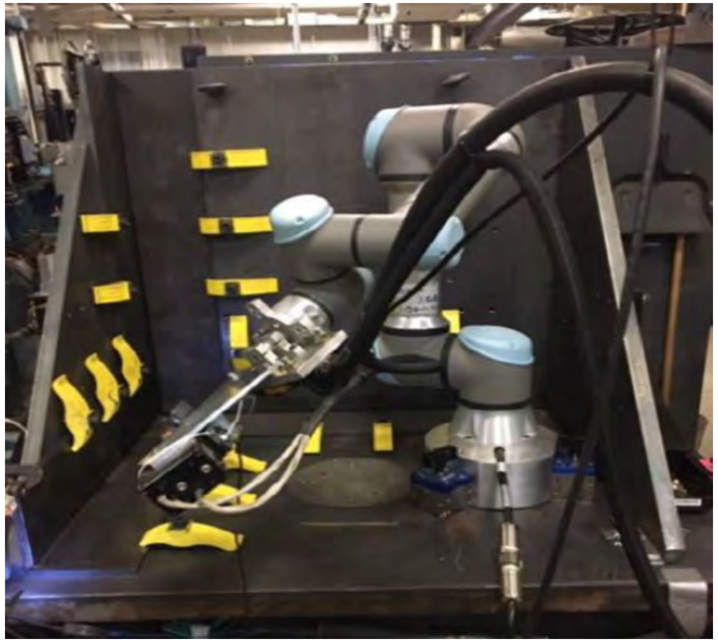
- Human-controlled remote processes
- Human-trained AI mechanism
- Haptic feedback
- AR/VR



Tele-Manufacturing

- Remotely operating machinery or fabrication processes, while still in control of the process.
  - Uses smart tools such as haptic feedback devices to convey information to the worker who is remote from the fabrication process.
  - Uses low-latency communication methods to livestream sound and video to the remote worker.
  - Employs smart sensors such as 3D digitizing of the remote environment to gather information to send to a remote worker.

NSRP
NATIONAL SHIPBUILDING RESEARCH PROGRAM
Taking Shipbuilding and Repair to the Next Level
Proudly Celebrating 50 Years of Innovation



Development of Tele-Welding for the Manufacturing Industry

- Develop a system that allows workers to operate welding equipment from a remote location yet be in complete control of the equipment
- Create a method for workers to gain exposure and confidence, and guide future efforts in remote-controlled manufacturing technologies
- Allow anyone, anywhere to be active participants in manufacturing enterprise

Tele-Inspection
Demonstrated with PAUT and Eddy Current Probes

SFSA 20SPI114
Tele-Gouging

Connie Reichert LaMorte
Principal Engineer, EWI
creichert@ewi.org
614-688-5247

Industry Challenge and Project Objective

- Background
  - Problem Statement: Steel foundries continue to face workforce issues, especially for hot-work and strenuous activities like gouging and grinding
  - Gouging is one of the most uncomfortable jobs due to the heat, arc light, sound volume of the arc gouging process and the protective gear the worker wears or uses to remain safe.
  - Most of this work is completed manually in a “job shop” mode of low-volume, high-mix parts, which means automating the process doesn’t create the ROI.

Tele-Gouging

Acknowledgement: This research is sponsored by the DLA-Troop Support, Philadelphia, PA and the Defense Logistics Agency Information Operations, J68, Research & Development, Ft. Belvoir, VA.

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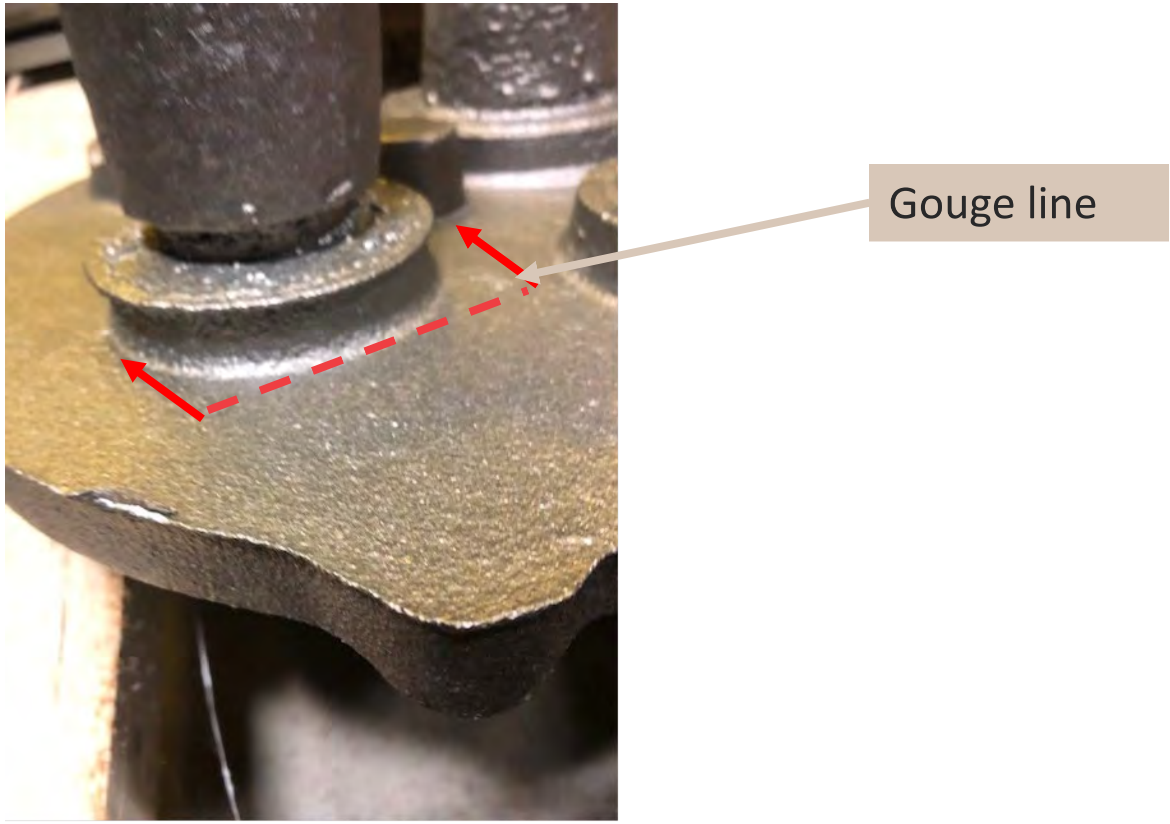
Objective and Approach

- Demonstrate a tele-operated arc air gouging method for removing risers from castings.
  - EWI will modify our tele-welding robotic hardware to enable arc gouging.
  - EWI will modify our tele-welding control software to enable an operator to perform tele-gouging on a sample part.

- Approach
  - Task 1 – Identify Sample Casting Part or Type
  - Task 2 – Integrate an Air Gouging Tool with EWI's Tele-Welding System
  - Task 3 – Integrate a Camera or Sensor for view of the Gouging Process
  - Task 4 – Demonstrate Tele-Gouging at EWI

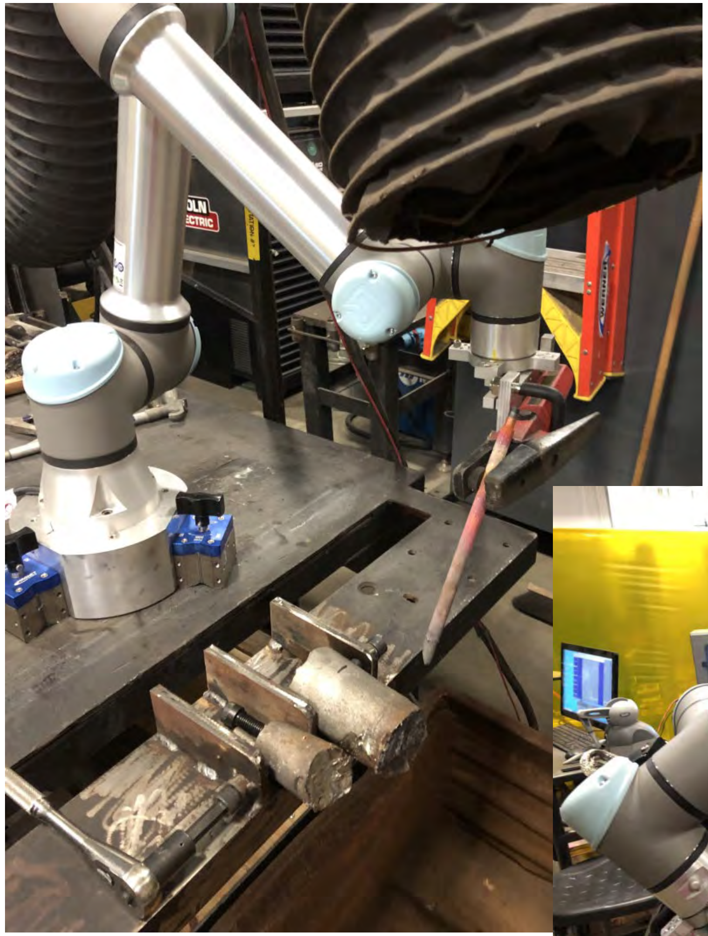
Task 1: Identify Sample Casting

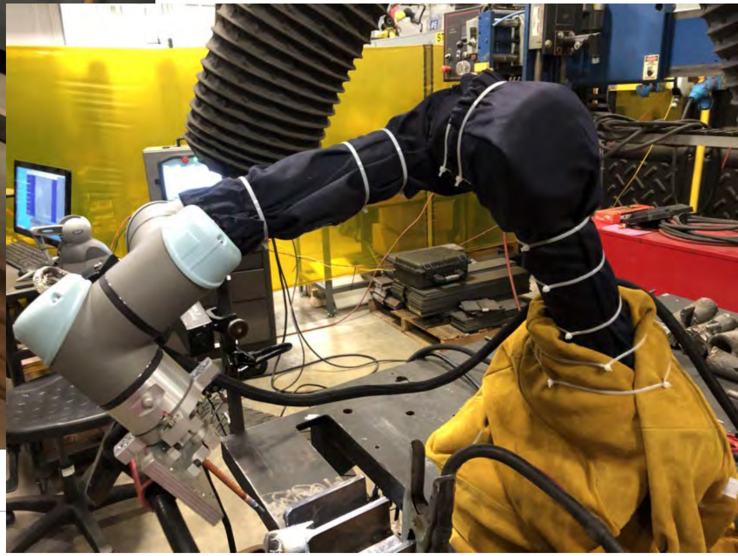
- Fisher provided sample casting and a sample part was selected for gouging.



Task 2: Integrate an Arc Air Gouging Tool with the Cobot

- Evaluated existing tele-equipment
- Modified hardware for gouging process
  - Protected robot with leather welding blankets
  - Used GMAW torch holder to attach gouging torch to robot
- Integrated gouging process onto tele-welding robot
  - Evaluated gouging with the system using two different methods for control of the process





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Evaluated Two Methods to Control Electrode Feed Rate

- The consumable carbon arc electrode required some modification to the tele-welding process.
- We evaluated feed rate control by the user and feed rate control by the robot.
  - *User Control*
    - User controls all robotic motions by using stylus device.
    - Feed rate under complete control of user.
  - *Robotic Assist*
    - User controls all robotic motions *except* electrode feed rate.
    - Feed rate is automatic but can be paused by user at any point.

Task 3 – Integrate a Camera or Feedback Sensor for Arc Air Gouging Process

- Investigated cameras for viewing the process and environment
  - Tested arc welding camera and speed-glass filter in front of common digital camera
  - Used low-cost webcams for line-up and environmental awareness
- Determined position of arc welding camera and mounted onto robot
  - Tested on and off robot
  - Found two positions that worked well
- Determined image resolution is appropriate for operator but could be better
  - Webcams have great resolution but cannot be used during the gouging process
  - Arc welding camera has lower resolution but is adequate for the live gouging process
- Testing and feedback from operators
  - Tested several locations for the view and placement of camera to aid in the gouging process
  - Tested a side view and a top-down view for line-up (webcam) and arc welding camera

Typical Video Feed from the Arc Process Camera

Tele-gouging Risers on Cover – Video of Final Pass

Task 4 – Demonstrate Tele-Gouging at EWI

- Goals
  - Demonstrate a new way to gouge using a tele-presence method to allow an operator to remotely perform gouging.
  - Encourage foundry personnel to test the system to gain exposure to haptic feedback devices and using them to perform a live arc process.
  - Provide guidance to foundries on next steps in evaluating tele-gouging technology.
- EWI hosted SFSA and demonstrated tele-gouging at EWI.
- Project team members from SFSA and Fisher Casting tested the tele-gouging on a sample part.

Future Phase Idea

- Evaluate what we learned from the demonstration system and create a prototype.
  - Determine how well the haptics could be used to curb or enforce the tele-operator's movements for finer control of the gouging pass depth or closeness to base material.
  - Determine ways to improve depth perception in images.
  - Evaluate technology developments from other organizations – partner with or include other technologies in the development of a foundry-ready, prototype system.
- Prototype testing at foundries for use and evaluation in the shop setting.
  - Foundries test out system and provide feedback on use and performance for foundry applications.
  - Team provides requested updates/changes or modification needed to suit the applications.
  - Continual evaluation of results – increased production and increase in job ease/job safety.

SFSA 20SPI112

Portable, Automated Blending for Precision Surface Contour

Connie Reichert LaMorte
Principal Engineer, EWI
creichert@ewi.org
614-688-5247

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Objective and Approach

- Objective
  - Demonstrate an automated method using a portable robot for blend grinding castings at a foundry.
- Approach
  - Task 1 – Identify Sample Casting Part or Type
  - Task 2 – Select and Integrate a Surface Scanning Sensor with a Portable Robot
  - Task 3 – Integrate a Grinder and Develop a Portable Method for Demonstration
  - Task 4 – Demonstration of a Portable Solution for Blend Grinding

Task 1: Identify Sample Casting

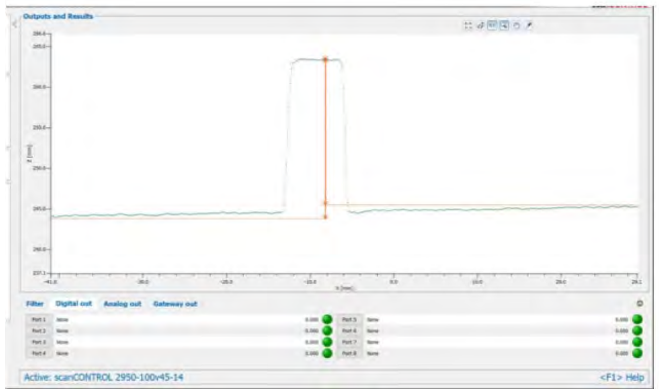
As cast

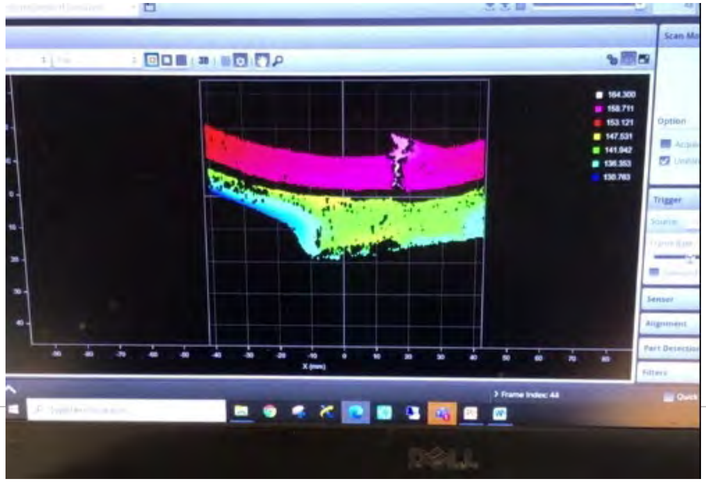
After gouging

After blend grinding

Task 2: Select and Integrate a Surface Scanning Sensor with a Portable Robot

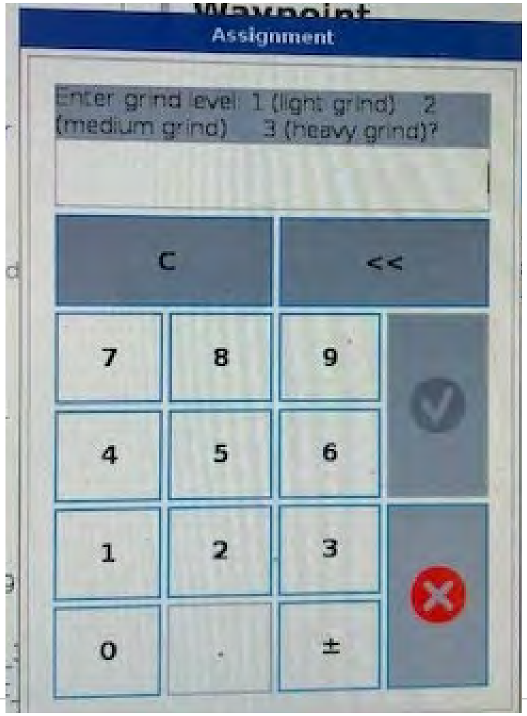
- Evaluated existing commercially available surface scanning tools for profiling the ground surface





Task 3 – Integrate a Grinder and Develop a Portable Method for Demonstration

- Evaluated grinder options and determine best approach for integration with robot
- Developed and programed a method of grinding using the system
  - Programing the robot
    1. Scanning
    2. Grinding
  - Determine operator involvement options:
    - Select area to grind
    - Verify grind or verify measurement from sensor
    - Pre-scan area with digital scanner



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Attached Grinder to Robot

- Used hand-held grinder typical of foundry tools
  - 3 HP hand-held grinder
  - 4.5-in. grinding wheel
- Attached to robot arm with simple fixture
- Added temporary solution for compliance to the grinder to prevent “chatter” or bouncing on surface.

Integrated Laser Scanner to Robot

- Laser sensor was mounted onto robot using temporary fixture.
- Laser was programed to measure multiple locations in the testing setup.
- Second Robot program was written for a “scan pass” to orient the laser into the correct position for scanning in between grind passes (1st robot program).
- Laser was used in this method to evaluate grind after sample bar tests.

Evaluated Robot Force using Sample Steel Bars

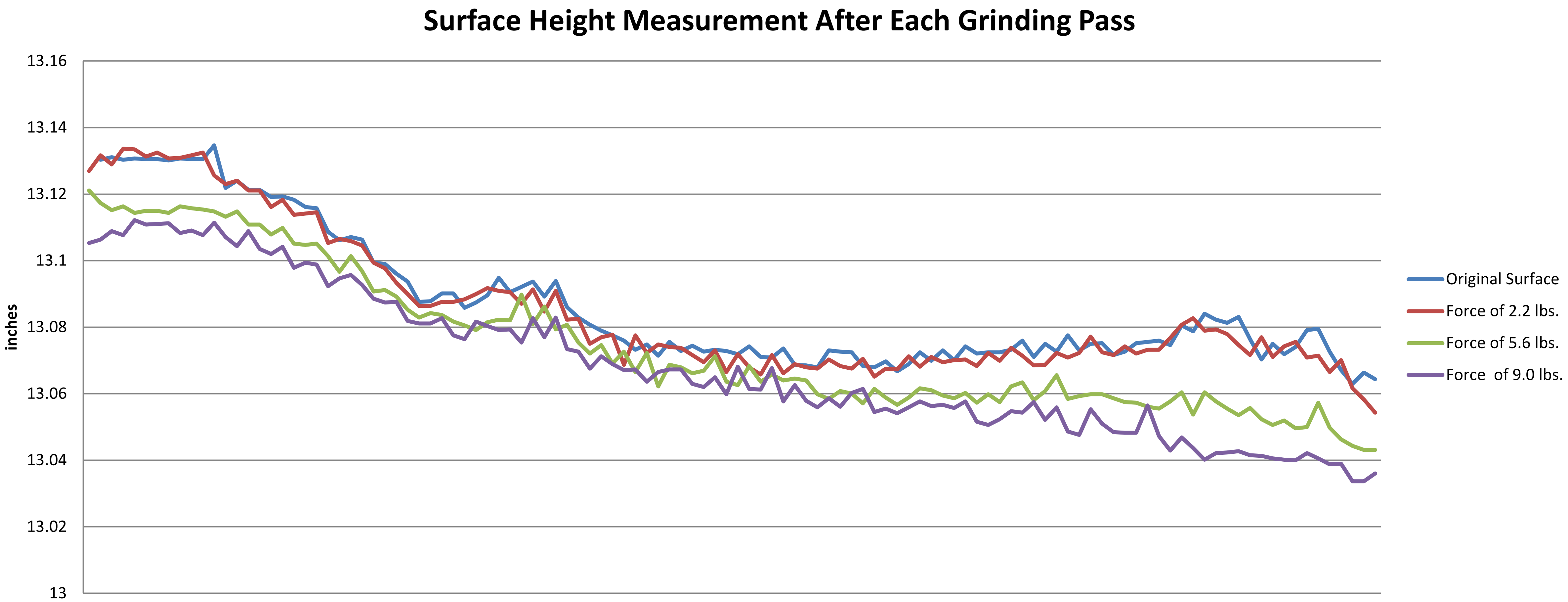
- Determined force vs material removal
  - Force levels varied 10 to 100 N (2 to 22 lbs.)
  - Speed of 8.5 mm/s (20 ipm)
- Performed testing matrix to determine parameters.
  - Robot force settings
  - Robot speed and standoff
- Laser sensor measured material removal between passes

Laser Scanner Integration with Robot

- Laser sensor hardware
  - Attached to plate in a set position
  - Robot moves laser into position
- Created laser measurement program
  - For demo, displaying it on the laptop
  - Laptop shows height measurements
- Triggering of laser completed by the robot
  - Trigger starts/stops the acquisition
  - Aligns the measurements of each pass

Laser Scanning Pass on Body Cast Part video

Laser Scan Height Measurement on Cast Part Segment



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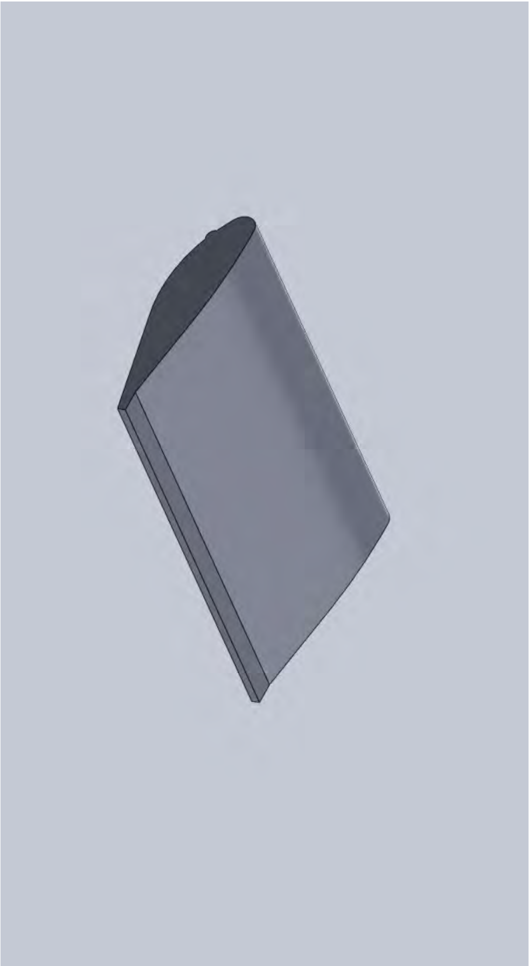
Task 4 – Demonstration of a Portable Solution for Blend Grinding

- Demonstrate portable grinding using a cobot at EWI
- Demonstrate portable grinding at a foundry for foundry personnel

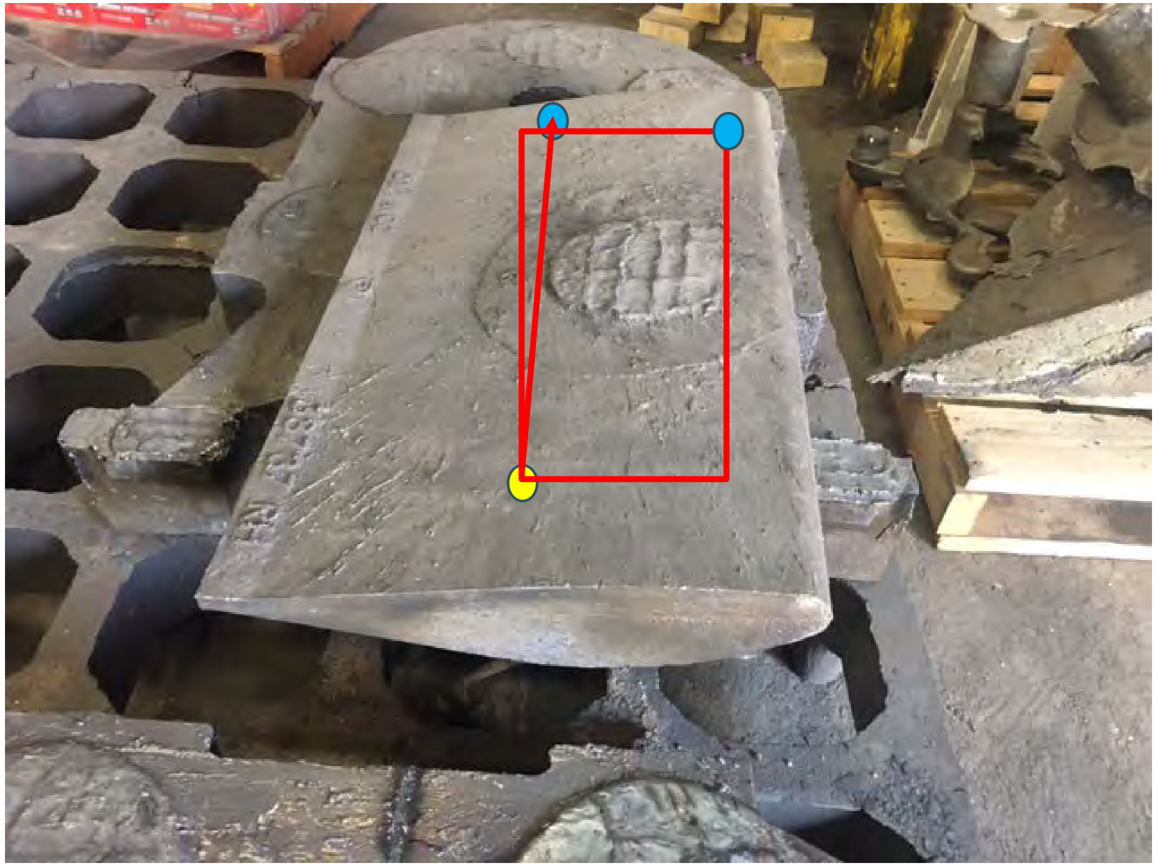
New Part for Demonstration



Suggested Changes for Improved Demonstration

- Change out laser line to laser spot sensor (sensor currently available at EWI)
  - Removes the laptop/PC from the system
  - Laser output is wired directly to the robot
- Laser spot only looks at single area that is being ground
  - Keeps it simple – does not try to fit curves, etc.
  - Laser does not care about the part shape – it commands the robot to continue grinding until a set surface height has been measured.
- User selects start and end point location
  - Robot grinds surface to match the start/end location points (or user enters amount to remove (inches))
  - Laser automatically measures surface height
  - Laser tells robot to grinds until desired amount has been removed from original surface.

Single Pass Demonstration Proposal



1 – User selects robot start and end location

2– User selects amount of material to remove (in.)

1 – Robot uses spot sensor to measure part height

2 – Robot automatically grinds the single pass until desired amount of surface has been removed

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Single Pass Demonstration Overview

- Remove a specified depth along a user defined path on any cast part
- Operator Tasks
  - Follow pendant prompts
    - Drag robot to start point
    - Drag robot to end point
    - Select amount of material to remove (0.010-in)
  - Repeat process when robot has completed pass
- Robot Tasks
  - Automatically set/adjusts the amount of force
  - Check the removed amount every pass or every n passes until the desired amount has been removed

- Advantages
  - Little training required – follow prompts on robot pendant to begin the process and then wait until robot has stopped
  - Can be applied to any part with a linear path*
  - User is free after setup to do other tasks until the robot has completed the precision grinding process
- Disadvantages
  - Robot will travel in a linear path*
  - User responsible for setting up each pass – indexing robot to the next pass location.

*Linear path is selected now for ease of demonstration on the demo part. To allow a curved path instead of linear would only require a few more teach points to be set by the operator.

Next Steps and Future Phase Idea

- Complete Demonstration at Fisher
- Evaluate what was learned from the demonstration system and create a prototype.
  - Determine range of parts that will use the portable grinding.
  - Determine level of automation desired/required based on part type.
  - Determine level of blend/grinding precision desired/required.
  - Evaluate technology developments from other organizations – partner with or include other technologies in the development of a foundry-ready, prototype system.
- Prototype testing at foundries for use and evaluation in the shop setting.
  - Foundries test out a system and provide feedback.
  - Provide continual feedback on use and performance of the system.
  - System updates/changes or modification needed to suit the jobs.
  - Continual evaluation of results – increased production and increase in job ease/job safety.

SFSA 20SPI113

Robotic Torch Cutting and Automation (Formerly Grinding)

J. Logan McNeil PhD, *Project Engineer*

lmcneil@ewi.org

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Objective Scope Change in Project

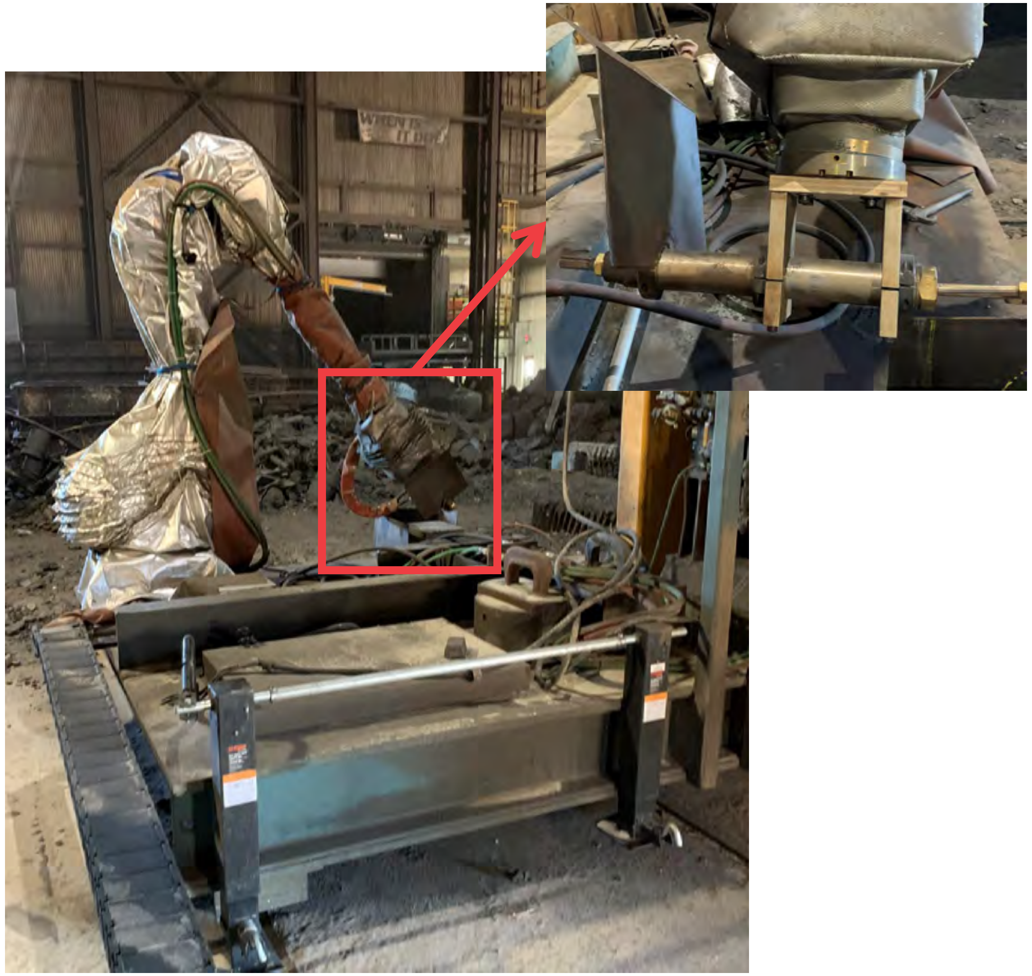
- **Original Goal:** Develop an agile automated grinding system that is controlled by low-level user interface in a robotic booth for foundry riser and gate casting scar removal
- **Reasoning for Change:** Grinding with large scale systems only useful for more limited parts and sizes; given need for low volume, high mix parts it makes sense to help explore automation opportunities for robotic torch cutting
- **New Goal:** Explore automation opportunities for robotic torch cutting of casted risers and gates which occur from the casting process, focusing on setting the state for more complex shapes and contoured robotic torch cutting with 6dof robot systems for either tele-cutting or fully automated processes

Tasks

- Task 1 – Sample Selection/Receipt/Visit to Maynard
- Task 2 – Develop Preliminary Cutting Procedure Specifications
- Task 3 – Evaluate Commercial Sensing and Torch Options
- Task 4 – Demonstrate Automated Torch Cutting Process

Task 1: Sample Selection/Receipt/Visit to Maynard

- Existing Torch Cutting Robot – not in operation due to technical difficulties
- Mounted on cart to be rolled out of the way for part movement
- Point to Point and manual operation not sophisticated enough to teach operators to use safely
- Mounting of torch perpendicular to the wrist causes un-intuitive movements of the robot to complete cutting movements and automation



Task 1: Sample Selection/Receipt/Visit to Maynard

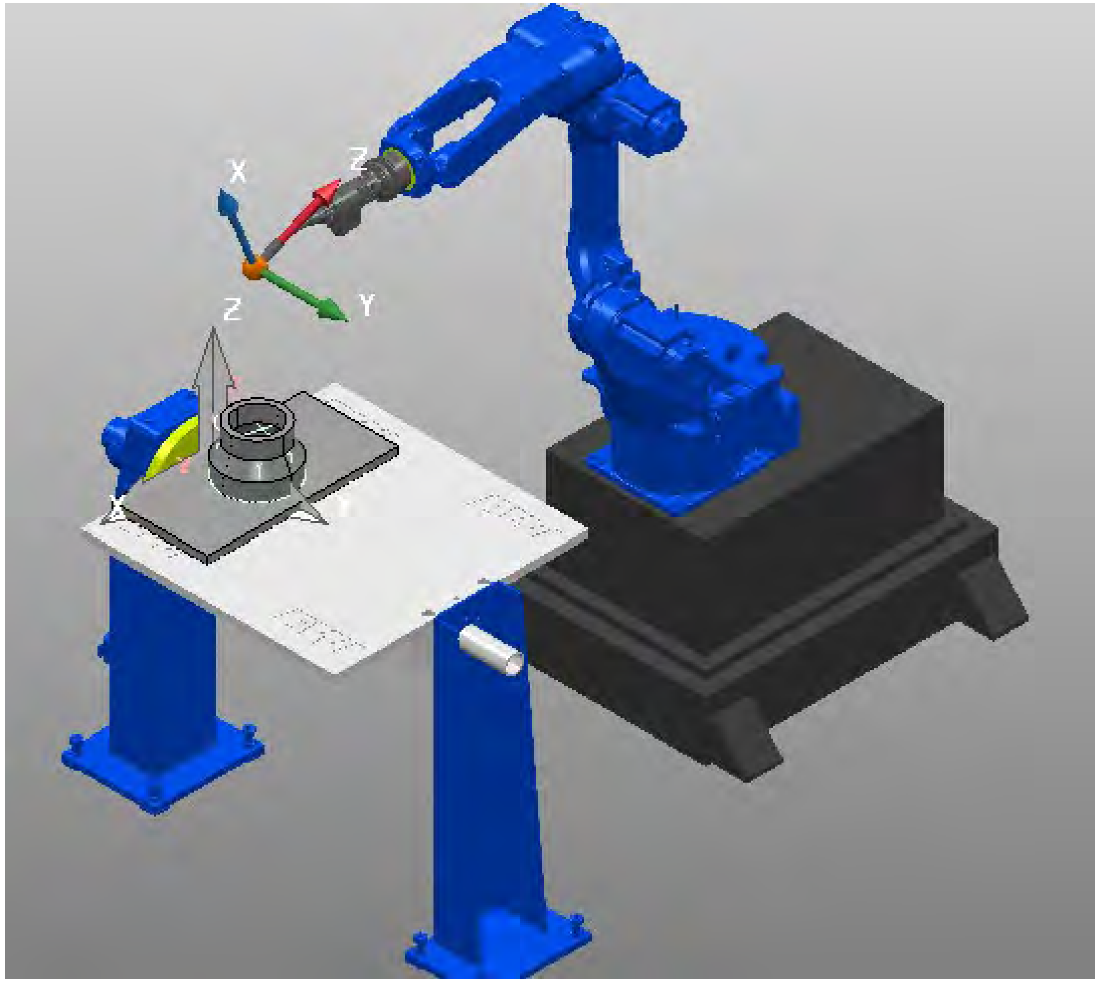
- Takeaways from visit to Maynard Steel Foundry:
  - Torch cutting is a very complicated artisan tasks, requiring juggling of operator inputs and various path planning to cut correctly
  - As well as the complicated motion, operators are constantly struggling with torch blowback, melting off slag to establish the cut, and preplanning cuts for material runoff
  - Either automation and/or tele-operation of the cuts could be useful for foundries
  - First step is establishing baseline on operation for further work, with a demonstration of cutting capabilities
  - Will explore best practices for establishing oxy cutting procedures, whether tele-operated or fully automated practices, as there is a low volume, high mix parts with various geometries and complexities

Task 2: Develop Cutting Procedure

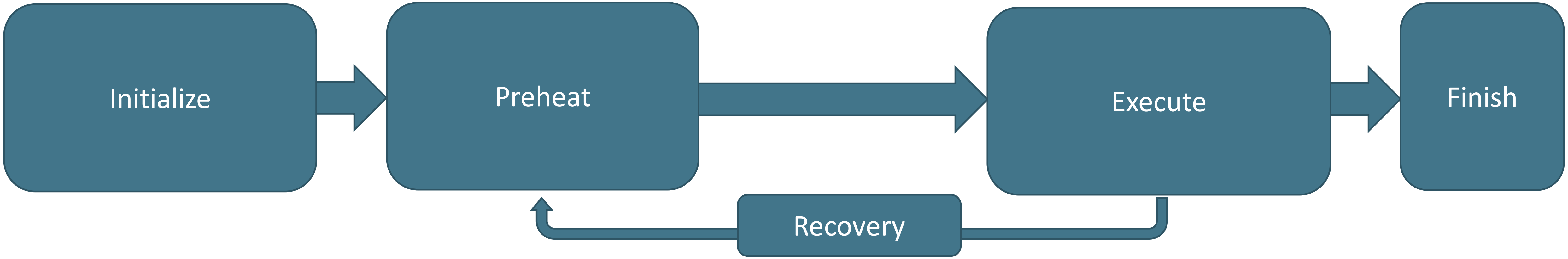
- Use industrial robot and acquire a robotic torch cutting apparatus to attach onto the robot system
- Develop automated programs to preheat/establish cutting. Develop sensing requirements for flashback detection and complex torch scanning and path planning
- Develop cut recovery program to ensure that cuts can be reestablished if issues arise
- Develop speed/thickness requirements

Task 2: Develop Cutting Procedure – Robot Selection

- To align with systems at Maynard, want to conduct the experiments on a Motoman Yaskawa system
- Smaller system – but will develop code for 1 to 1 transfer of information for future work
- Programs will include a startup, execute, and recovery subprograms for operations
- Motoman has custom program menus for customization for simple use



Task 2: Develop Cutting Procedure – Program Workflow



- Program two points to cut between (linear)
- Acknowledge safety and clearance
- Set surface cutting speed & angle

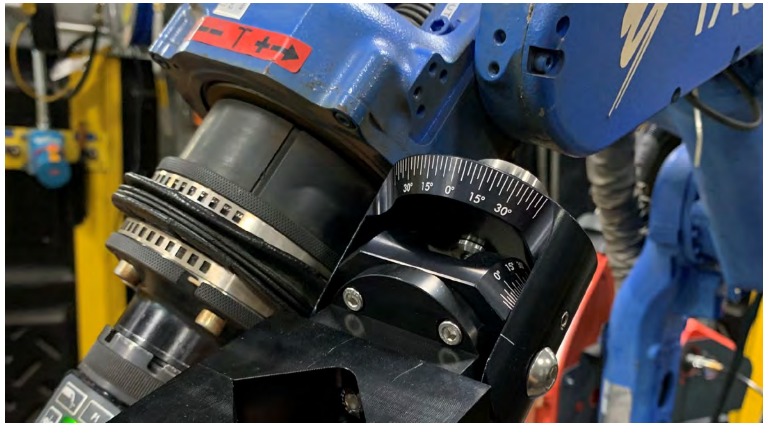
- Preheat cutting area automatically
- Preset oscillation on area to preheat
- Operator can activate oxy to check preheat, and confirms to move into cutting

- If error sensed (blowback, operator pause), system goes into recovery mode
- Program stores location, operator fixes error, then reactivates preheating routine

- Program continues cutting until it reaches programmed point
- After reaching point, oxy and torch are extinguished before retracting to safe position above piece

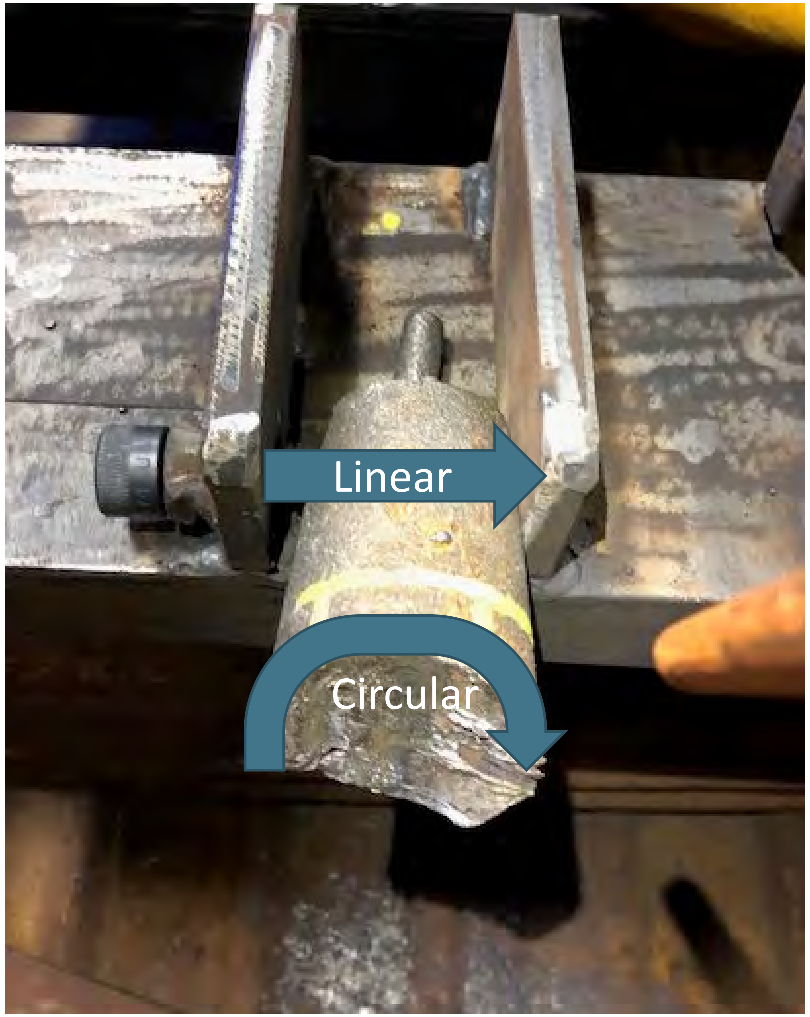
Task 2: Develop Cutting Procedure – Custom Torch Selection

- Desired an automated torch that can cut a variety of depths and tip sizes
- Desired a torch which had automatic lighting though Digital output and control
- Also has blowback and error sensing for the torch, low gas, etc.
- Ideal for robotic applications
- Adding torch mount for angles



Task 2: Develop Cutting Procedure – Test Plan

- Initial Tests on Cutting Parameters:
  - Linear Cutting
    - Speed of Torch Movement for Cutting
    - Ideal Torch Angle to ensure blowout
    - Preheat Time (Auto or User Enabled)
    - Adding Oscillation to torch end for cutting to help blowout
    - Automated recovery and location storage for recovery
  - Circular Cutting
    - Relative linear speed of torch used for cutting
    - Preheat Time (Auto or User Enabled)
    - Adding Oscillation to torch end for cutting to help blowout
    - Identifying changing torch angle to ensure blowout of material



Task 3: Evaluate Sensing Options for Torch Automation

- Have already evaluated Zivid RGB-D camera for part scanning and realignment
  - Color scanning can show discoloration of material to see if slag vs. part material
  - Scan to plan options for automation is possible with this system
- For cutting, a variety of inputs available for selection on automation of cutting – will require a combination of vision sensors and torch sensing on cutting
- Will evaluate the sensor requirements needed for tele or automated torch cutting based on experimentation with torch cutting setup

Task 4: Project Demonstration

- Demonstrate torch cutting on simple shape and recovery modes
  - Initially cutting simple single lines with reestablishment recovery protocol
  - Will move to complex thickness of cuts which will require different torch manipulation and changes
  - Show feasibility of automation of these processes
  - Work with SFSA to select a sample parts with thicknesses and defects to test
  - SFSA will send parts to EWI for test cutting and setup
- Goal is to take simplified torch cutting programs and sensing to foundry for a demonstration of the capabilities and discuss next steps for either automation or tele-cutting.
- Planning on visiting or transferring code to Maynard for use on their system in the foundry

Acknowledgement

- This research is sponsored by the DLA-Troop Support, Philadelphia, PA and the Defense Logistics Agency Information Operations, J68, Research & Development, Ft. Belvoir, VA.

Other Areas of Interest

NDE

Arc DED

Cold Spray

Data Science

Non-Destructive Measurement Method

Roger Spencer

Senior Engineer

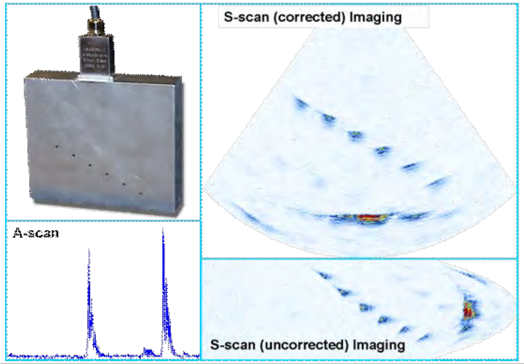
Non-Destructive Evaluation

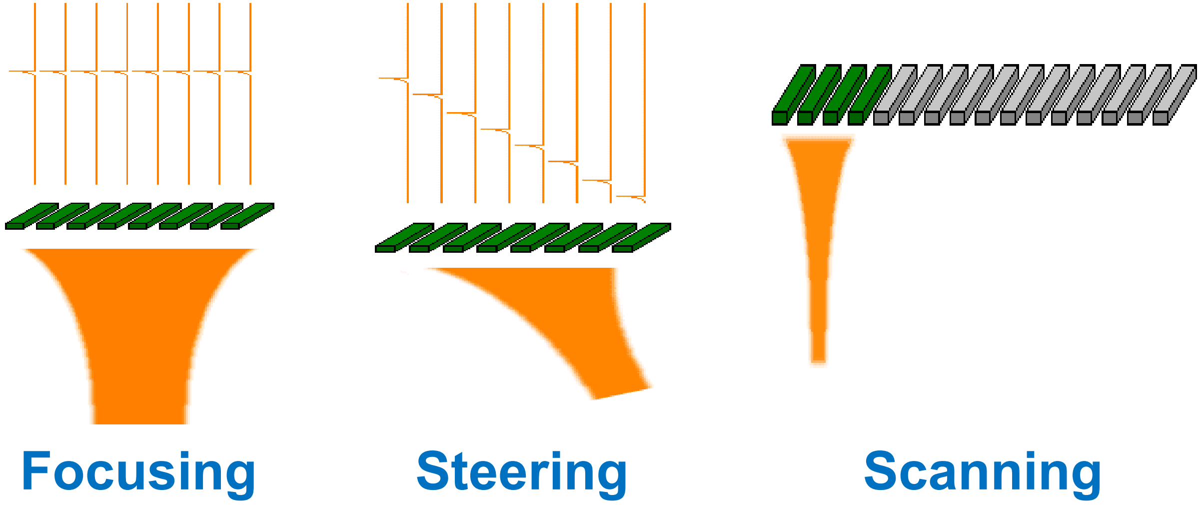
EWI Nondestructive Testing/Evaluation (NDT/NDE) Capabilities

- Conventional ultrasonic testing (UT)
- Advanced linear and matrix phased array ultrasonic testing (PAUT)
- Full matrix capture / Total Focusing Method (FMC/TFM) ultrasonic testing
- Conventional eddy current (EC) and array eddy current (AEC) system.
- Conventional X-ray radiography up to 320 KV
- X-ray computed tomography (CT)
- Thermography
- Modeling and inspection simulation software for test technique development and refinement

Phased Array Ultrasonic Testing (PAUT)

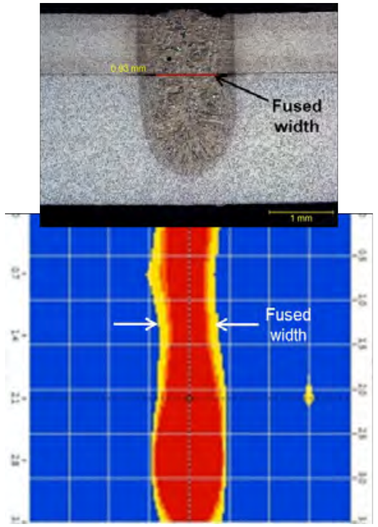
- Multiple elements in single probe housing
- Provides electronic focusing, steering, and scanning capabilities

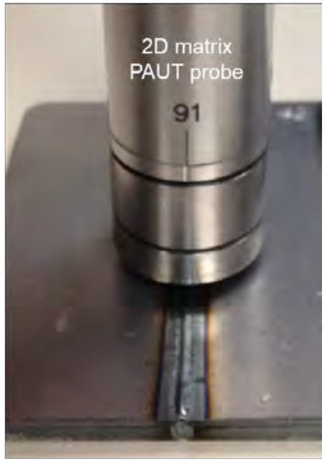


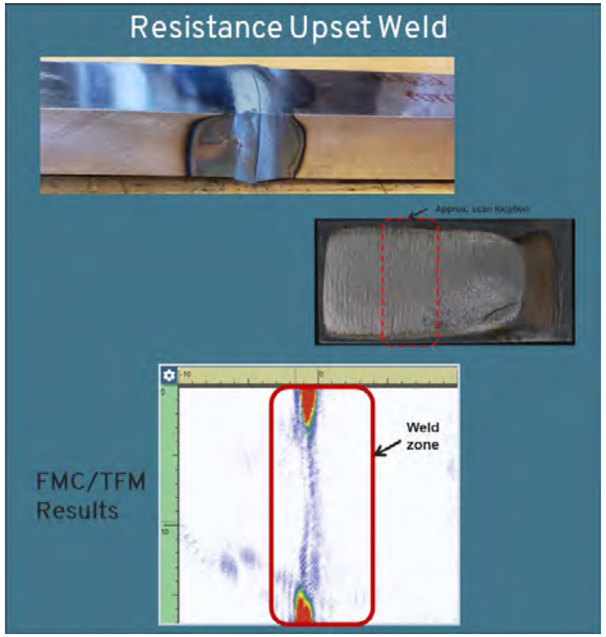


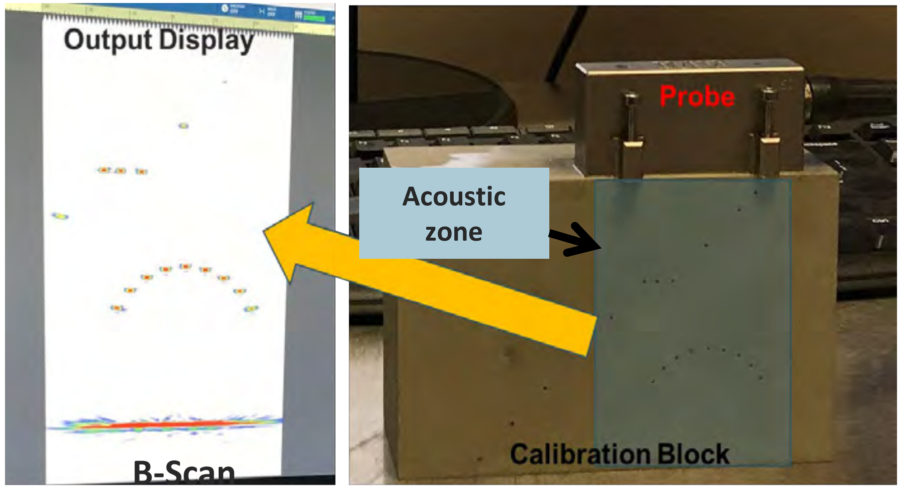
Ultrasonic FMC/TFM

- Uses multiple ultrasonic wave modes and combines resulting image into a cross-section (B-Scan) output
- Real time reconstructed output is focused on all points within the acoustic zone
- Provides more precise sizing of small flaws than can be obtained by most other UT techniques

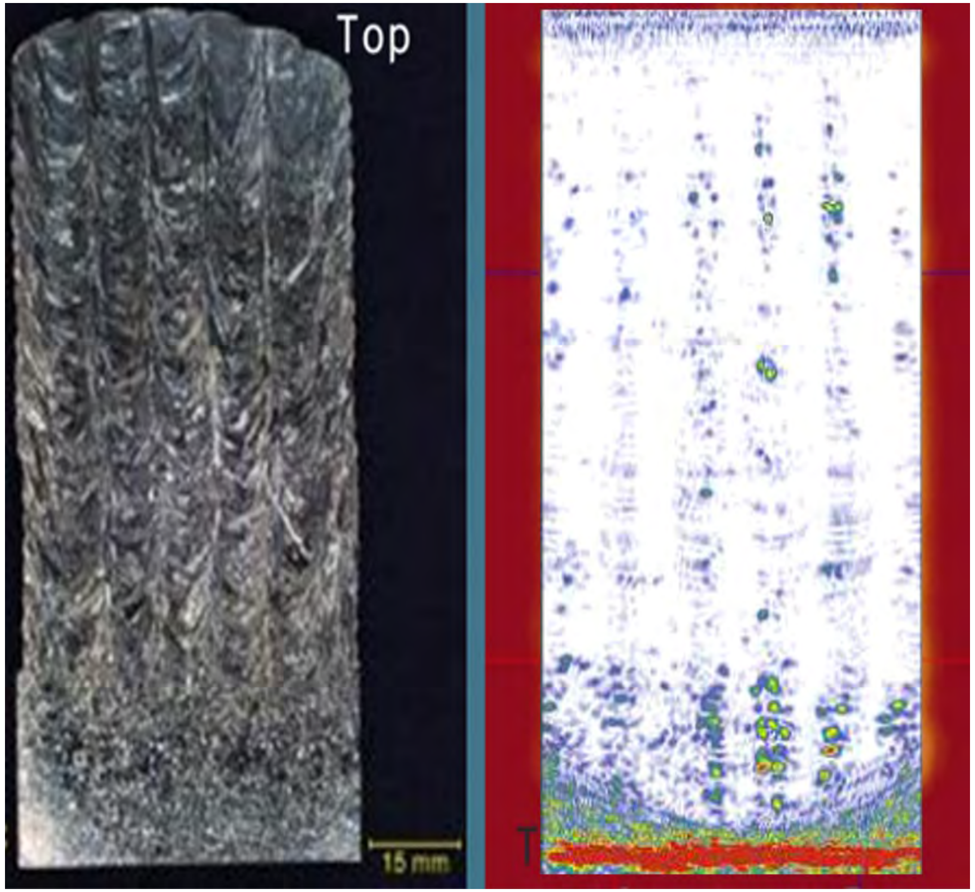




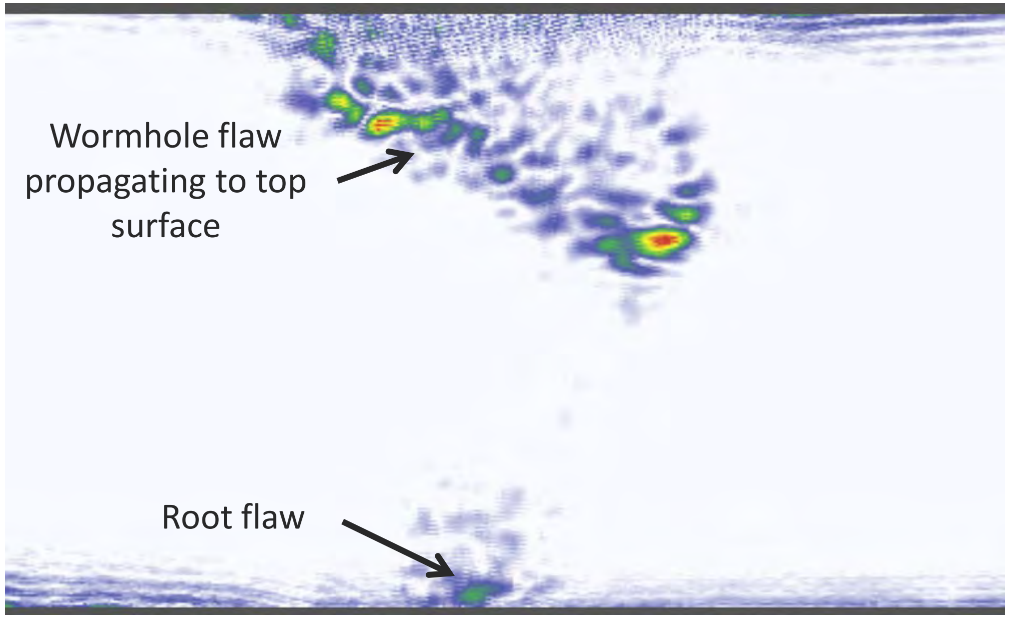




Examples of Matrix Ultrasonic Imaging



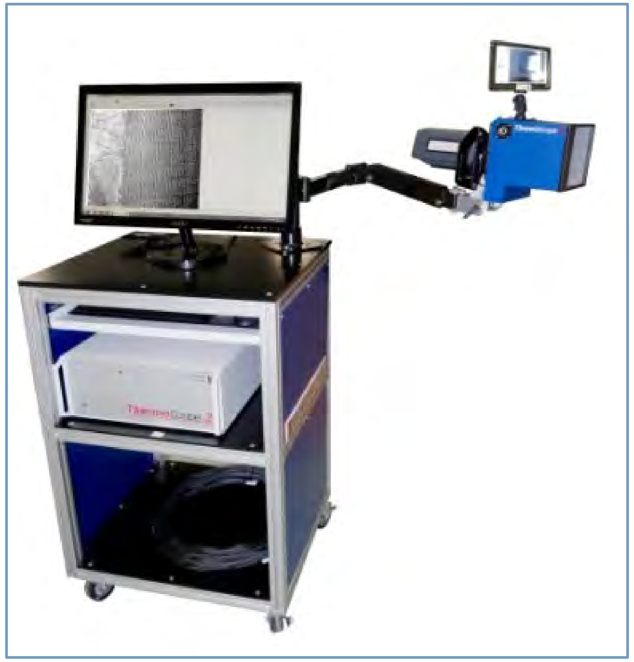
AM Build

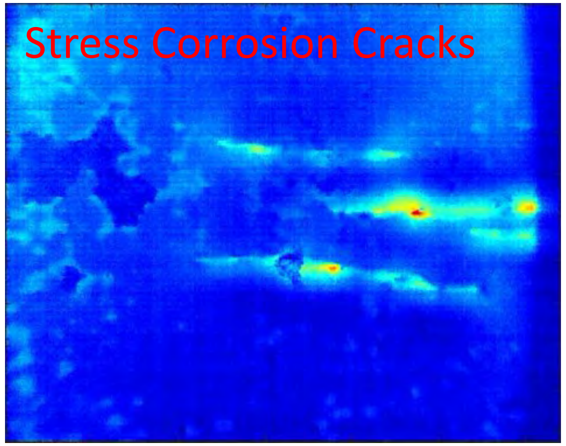


Friction Stir Weld (~ 1" thick)

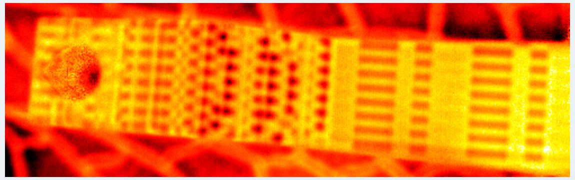
Advanced Thermography

- Pulsed thermography system with capability for defect reconstruction
- Ability to inspect and map large areas quickly
- Fast evaluation of large and small areas of plastics, composites, ceramics, and thin sheet metals





Measure of thermal conductivity variations



Pulsed Thermography

Advances in Robotic Arc DED AM

Dennis Harwig, PhD.
EWI Senior Technical Leader, Arc Welding & DED Processes
OSU Research Associate Professor, Welding Engineering Laboratory

August 2022

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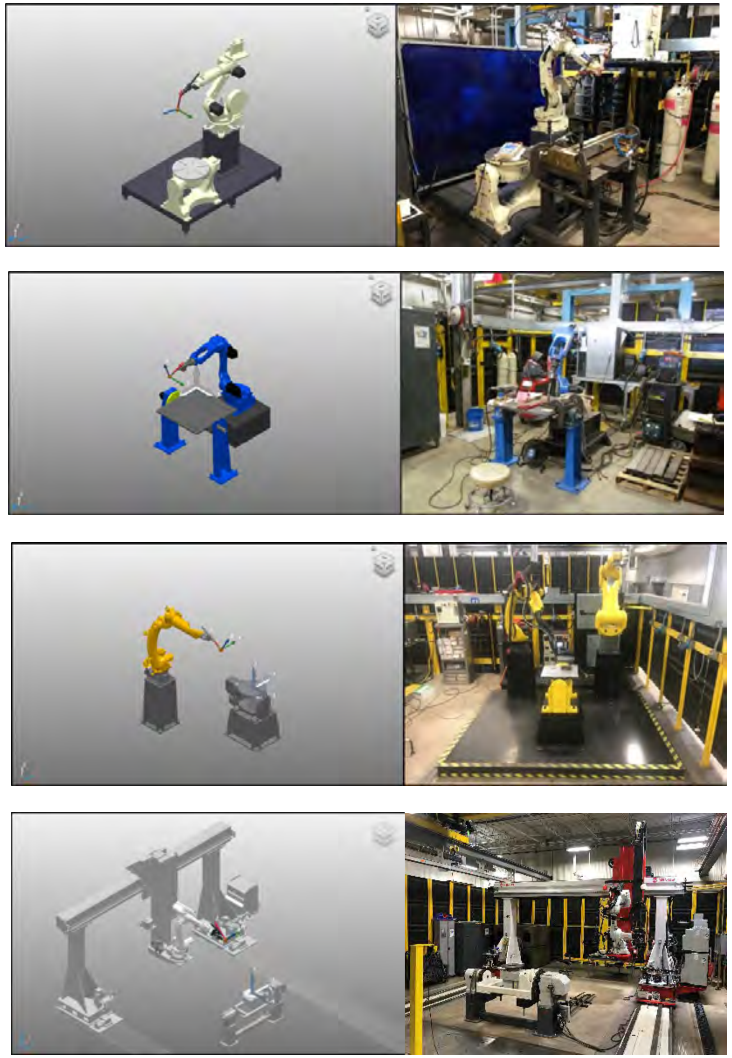
DED Metal AM Characteristics

- Two main types of metal AM:
  - Powder-bed
    - Melting, sintering, binder-jet variants
  - Directed Energy Deposition (DED)
    - Arc, laser, or electron beam with wire or powder
- DED Characteristics
  - CAD to Path Digital Manufacturing
    - Digital Twin of robotic welding systems
    - Post-processor - G-Code/program for specific system
    - Difference versus shape welding/structural buttering
  - Leverage welding processes & equipment
  - Leverage welding engineering technology
  - Leverage welding standards



4 of 7 DED Test-beds at EWI

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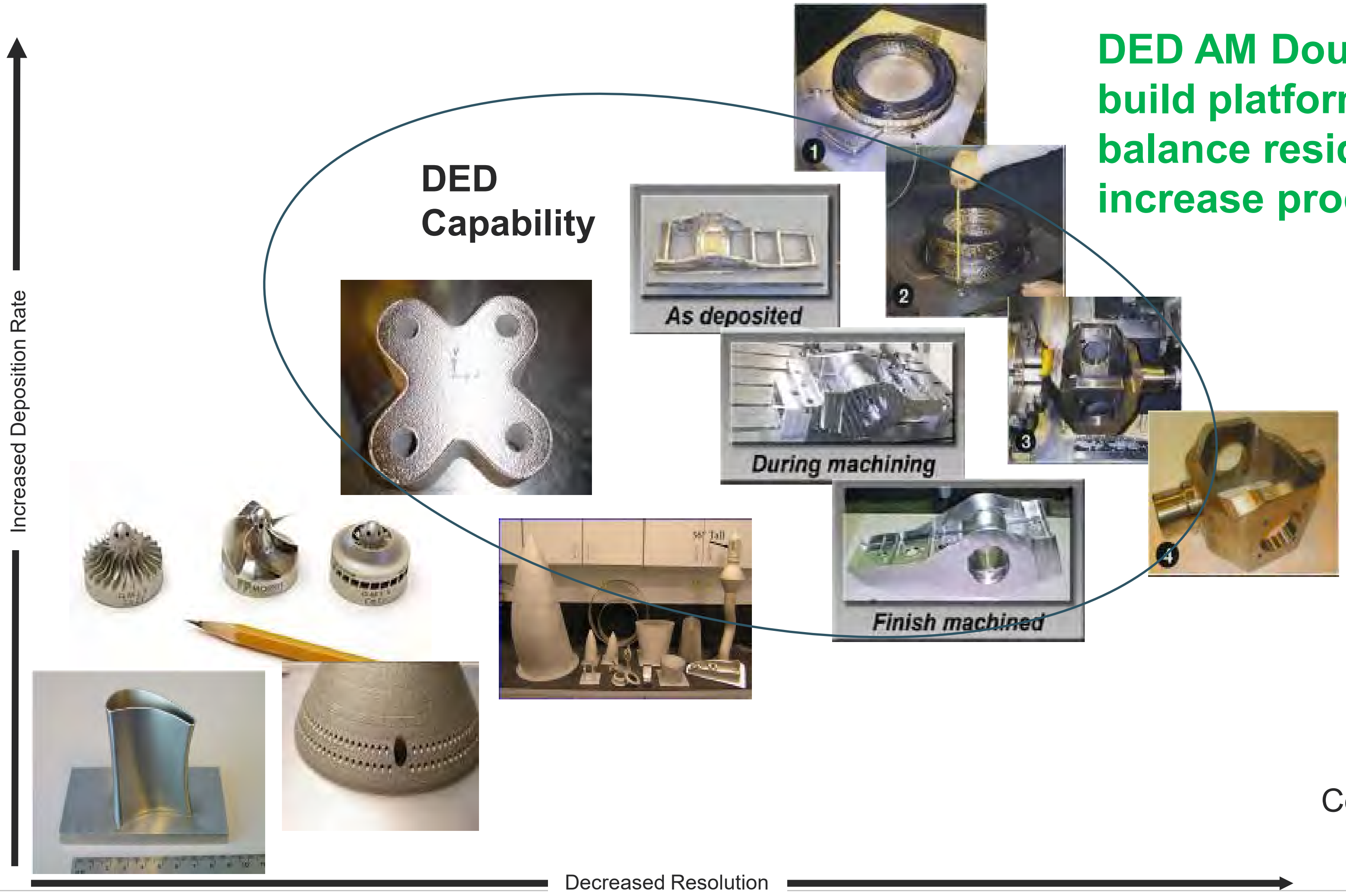
DED Deposition Rate vs Resolution



DED AM Double-sided integrated build platform (DS-IBP) used to balance residual stresses and increase productivity

Courtesy Boeing

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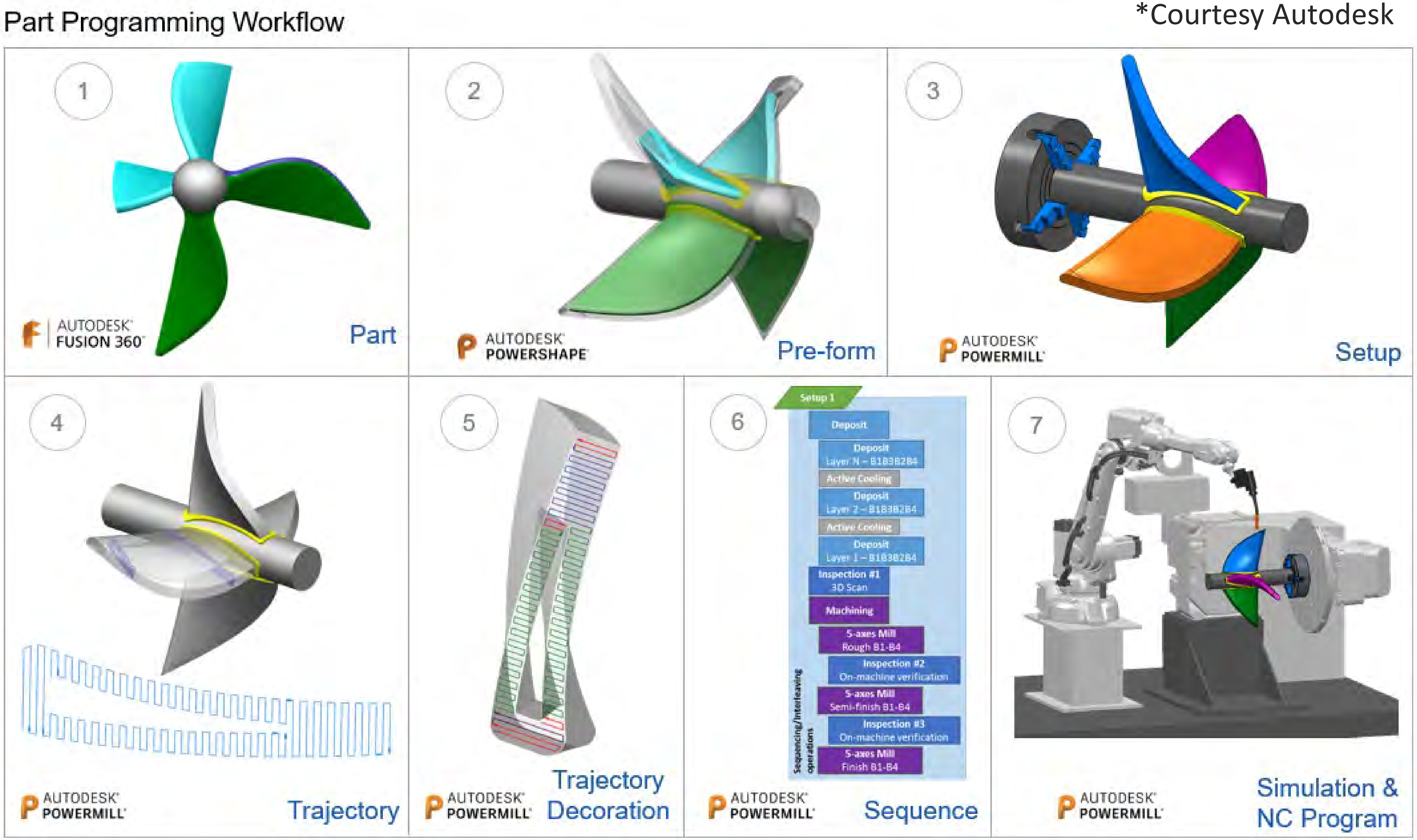
Digital Data Workflow

*Courtesy Autodesk



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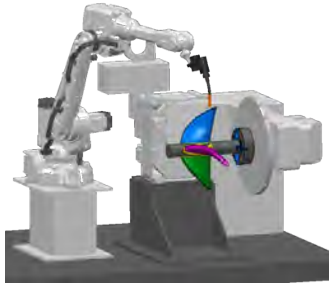
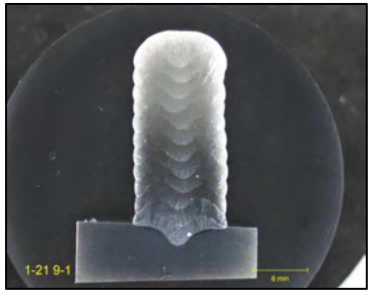
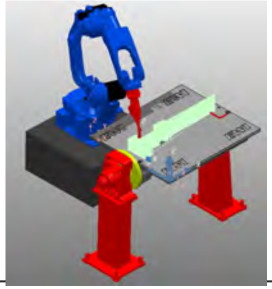
NSRP Robotic Arc Directed Energy Deposition (DED) Additive Manufacturing (AM) for Shipbuilding





Project Team
EWI – Project PI
Navus Automation
Austal USA
NSWCCD
ABS



"Lights-out" Robotic Arc DED AM

- Thermal management system
- Forced cooling system
- Hybrid Manufacturing
- Automated torch maintenance
- In-situ NDE / process quality monitoring
- Prototypes of increasing complexity
- Part verification scheme requirements

Objective Results:

- **Converted multiple robotic system to DED systems**
- **Designed standardized large-scale gantry DED system**
- **Developed digital data workflow processes**
- **Developed advanced training materials - workforce**
- **Demonstrated representative qualifications**
- **Provided standardized equipment & services**
- **Built prototypes of increasing complexity**
- **Identified implementation opportunities**

Reducing barriers to implement DED AM

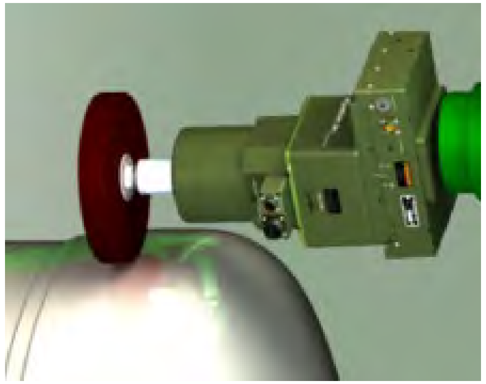
Project Period: June 2019 – July 2021

Large-scale Multi-process Robotic Gantry DED System –July 2020

Pre-engineered (COTS) System

- 8-10'high x 14' wide x 30' long
- 60 Kg ABB IRB 4600 Robot
- Multi-process
  - Fronius CMT, Lincoln Power Wave
  - Arc, Laser, Hybrid laser-arc
  - PushCorp Grinder/brusher/burring spindle
- 11-axis w /1-ton tilt/turn positioner
- Sensor platform for development of quality control and part certification technologies
- Unique resource for prototyping metal DED AM structures and components

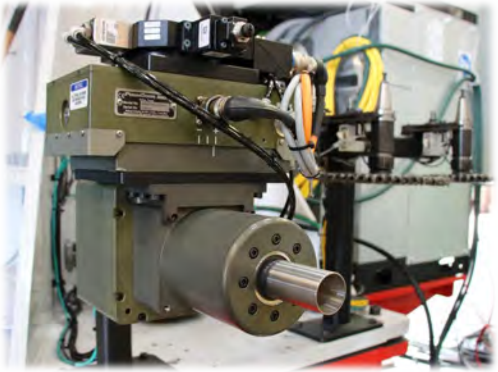
System available for large-scale DED application development

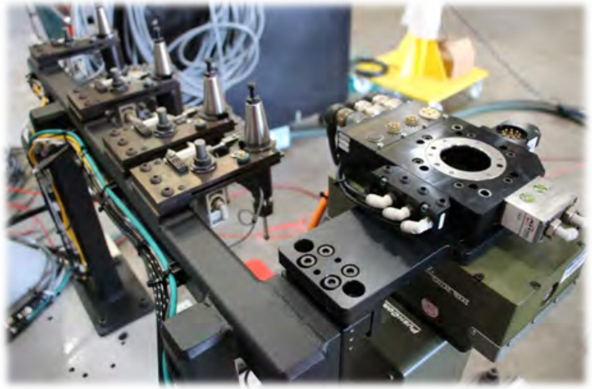


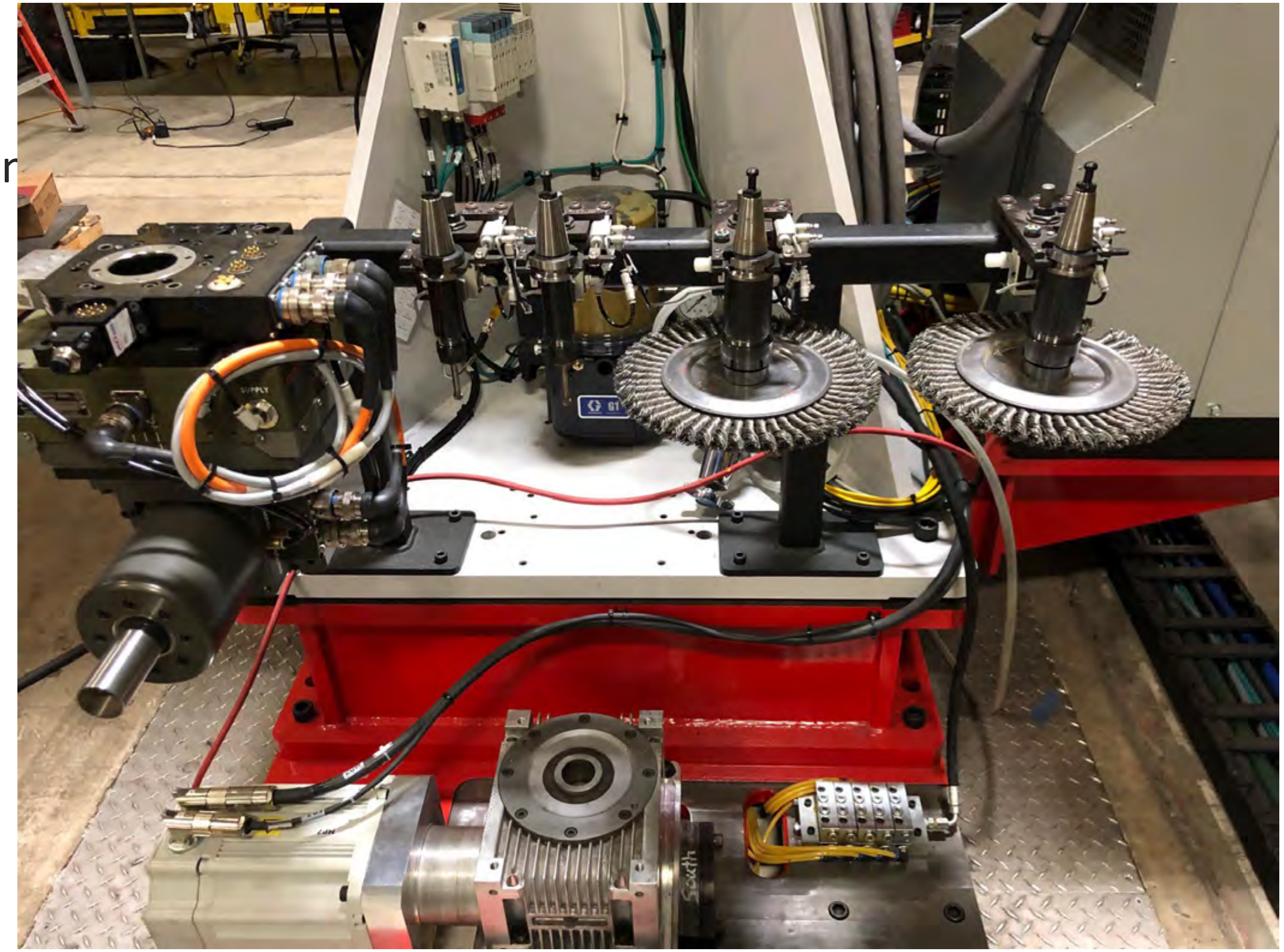
Large-scale Multi-process Robotic Gantry DED System

Metal Finishing Processes

- PushCorp 5HP spindle
  - Burring, brushing, drilling, grinding, sar
  - AFD340 Active Compliance
  - BT30 Tool Changing Station
- ATI Tool Changer







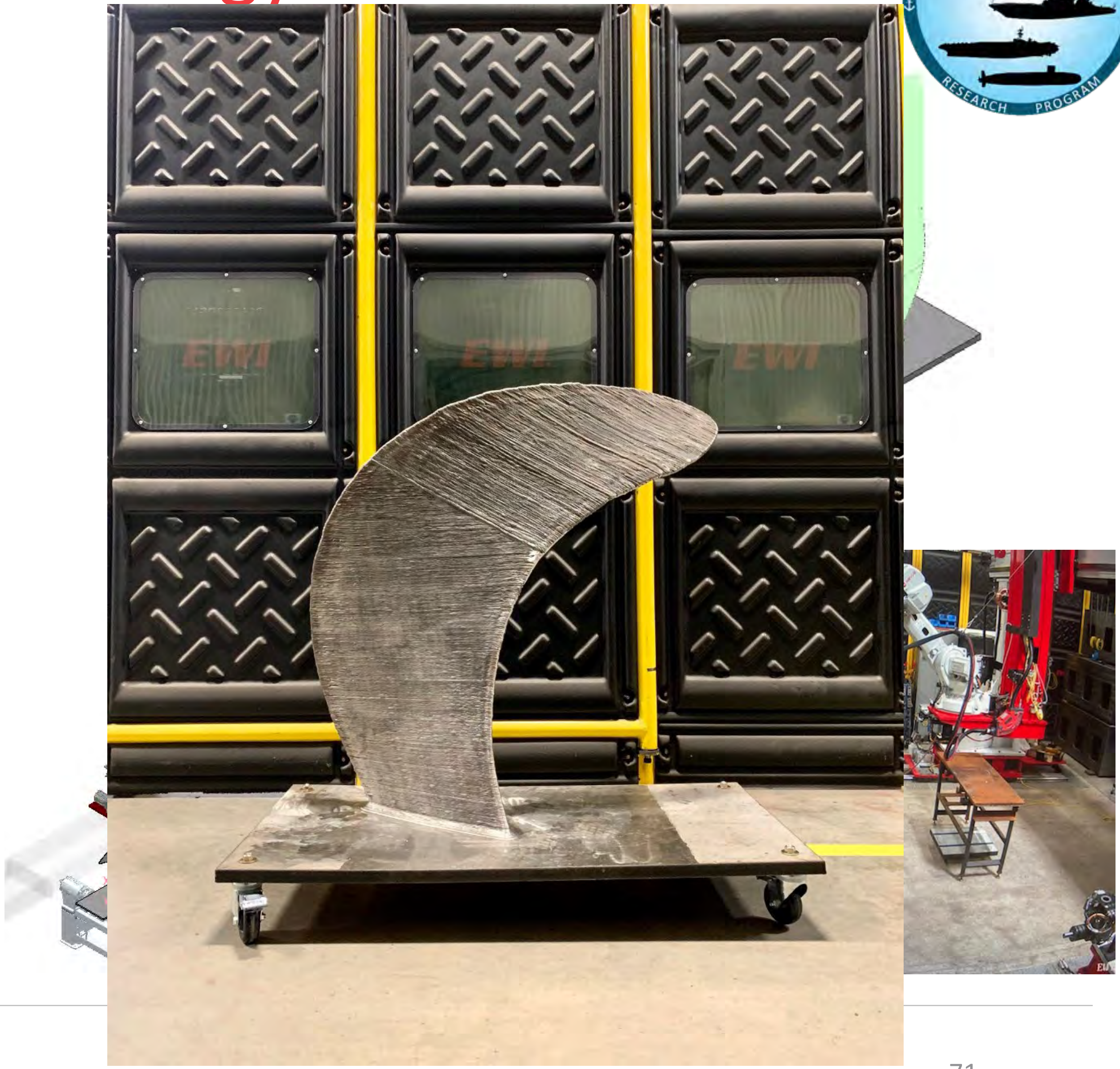
Large-scale Multi-process Robotic Gantry DED System

Monitoring Sensors

- Synchronized weld parameter data acquisition
- Melt Tools camera
    - Weld pool monitoring
- Micro-Epsilon TIM 640 Thermal Imaging Camera
    - Non-contact measurement of surface temperature from -4°F to 4442°F
    - Interpass Temperature control
- Binzel TH6D-GF Profilometer Sensor
    - Seam tracking and finding
    - Profile measurement and documentation during DED AM
    - Used with both welding systems
        - Mount for Binzel Torch
        - Mount for Fronius Torch

Hollow Propeller Blade Build – Strategy

- Build plate is initially flat.
  - At 25-in. high a 30-degree wedge was deposited
  - Part was tilted by 30 degrees and completed
- 4-Axis build (X, Y, Z, and E1)
- Single DED procedure
- Offset toolpath strategy
  - Three beads wide to obtain ¾-in. thick walls
  - Starts/stops are integral to the component and staggered.



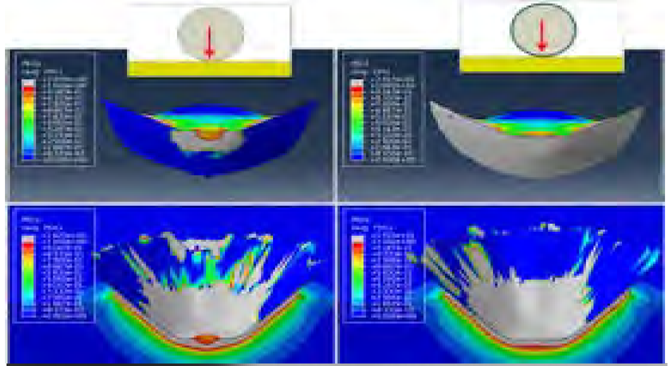
Cold Spray

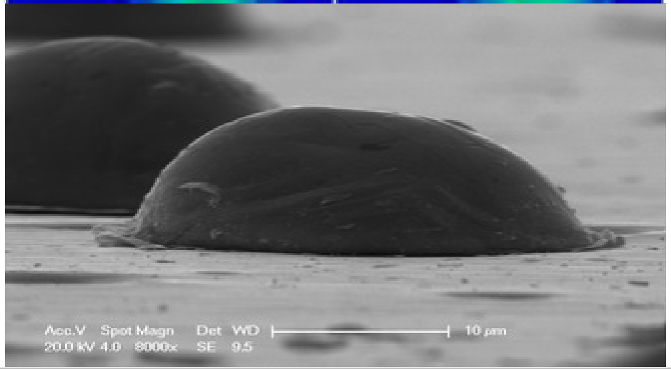
Howie Marotto

Business Director - AM

Focus Areas for Cold Spray Center of Excellence

- Advanced Coatings
- Joining of Dissimilar Materials
- Rapid Metal Additive Manufacturing
- Advanced Applications Development
- Chrome & Nickel Electroplating Replacement





Applications of Data Science – Weld Monitoring

Dr. Alex Kitt

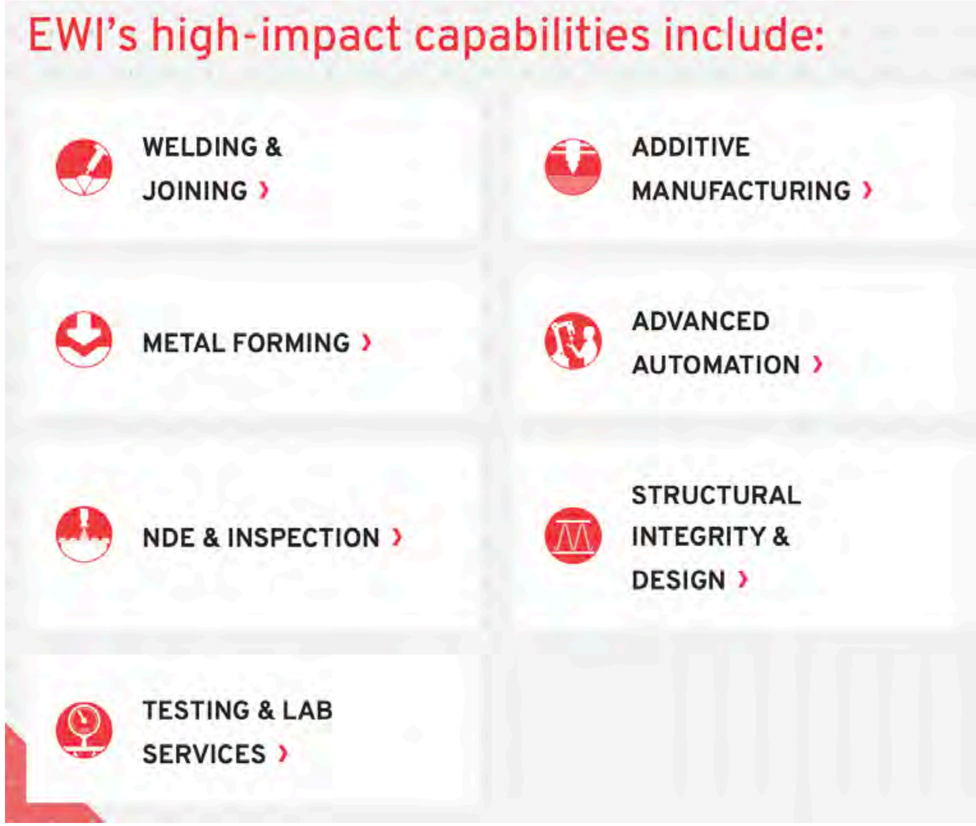
Director of Data Science

Dr. Luke Mohr

Data Scientist

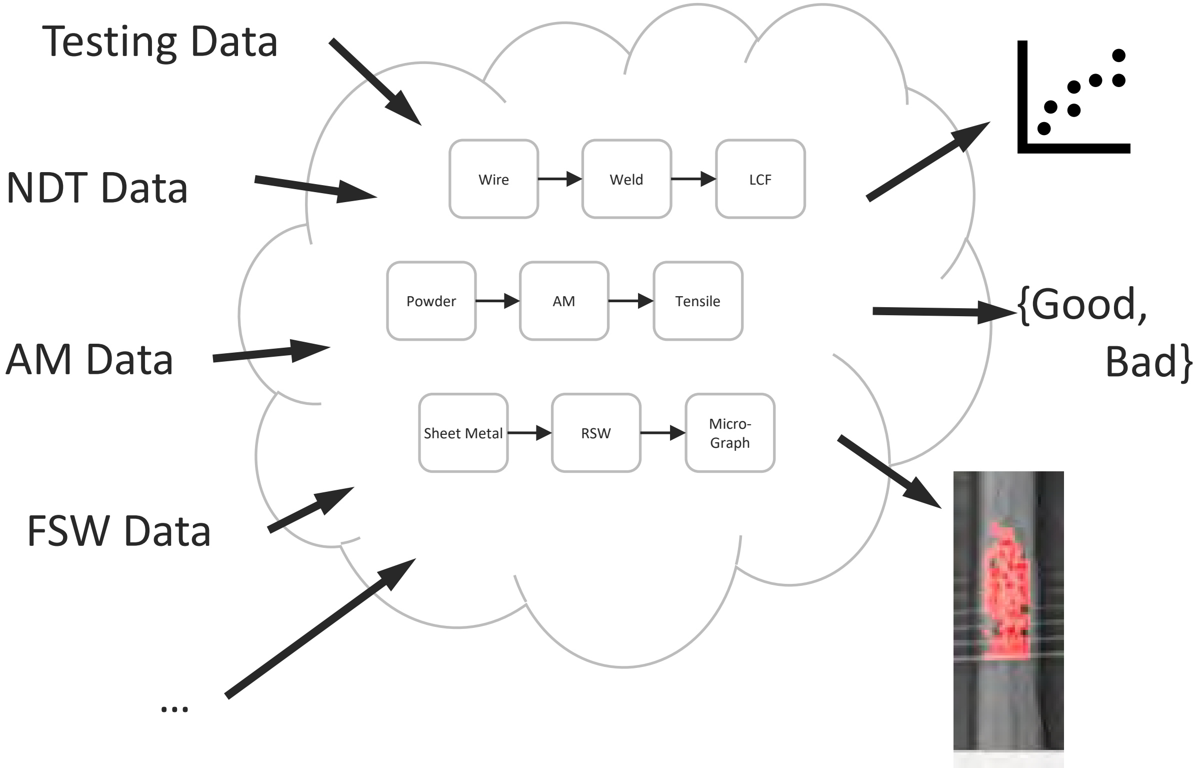
EWI's Philosophy for Data Science

EWI Process Expertise + Data Science


EWI's high-impact capabilities include:

- WELDING & JOINING ›
- ADDITIVE MANUFACTURING ›
- METAL FORMING ›
- ADVANCED AUTOMATION ›
- NDE & INSPECTION ›
- STRUCTURAL INTEGRITY & DESIGN ›
- TESTING & LAB SERVICES ›

IIoT | Digital Thread | ML/AI



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= **Explainable Machine Learning that Provides Manufacturing Value**

In-Process Control

Forming of Advanced
High Strength Steels

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Concept

Motivation:

- Vehicle light weighting is pushing automotive to lighter materials

Challenge:

- Advanced high strength steels(AHSS) and and aluminum alloys hard to manufacture
- Inconsistent material properties
- Narrow process windows
- Inconsistent throughput

Solution:

- Modify press-motion in real-time

Approach:

- Use Data Science to determine press settings

Good Defective

Process Flow

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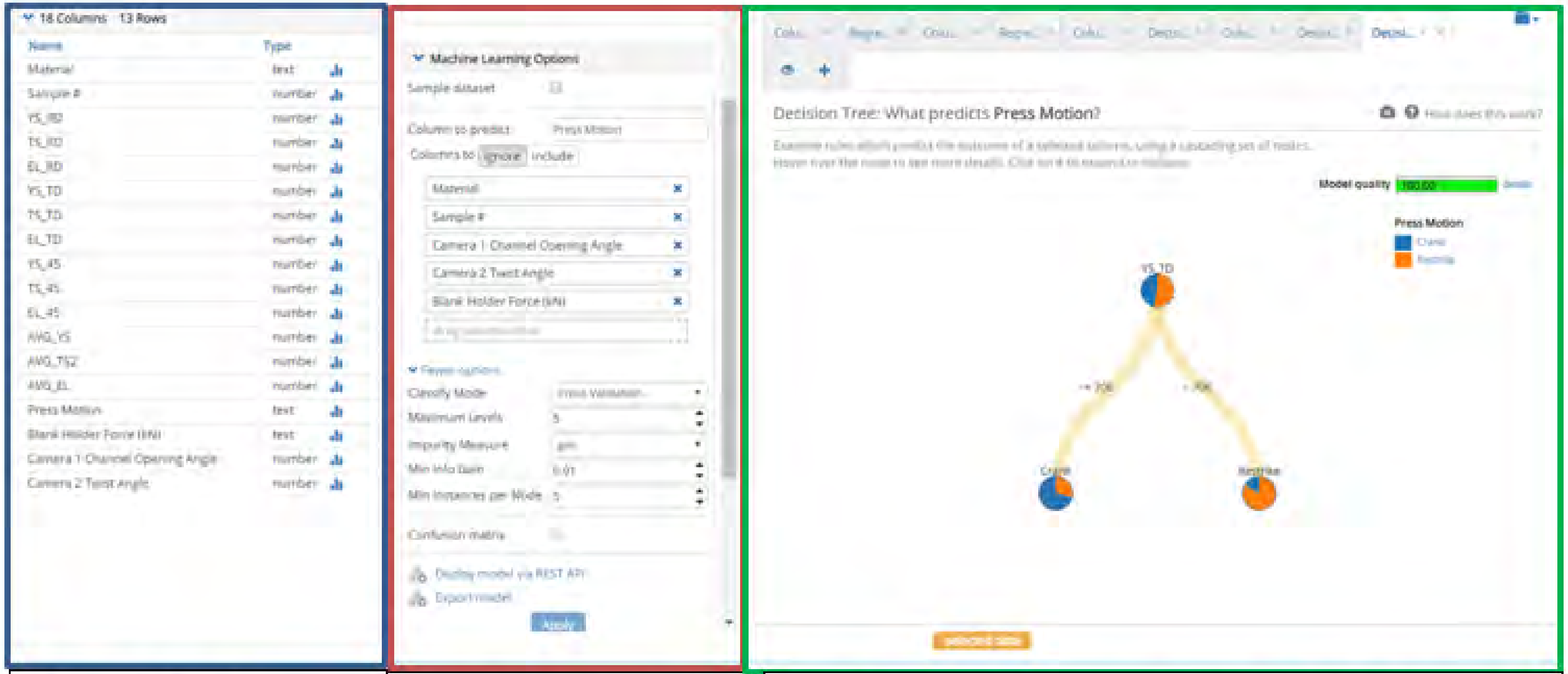
High Level Example of the Model for Press Setting



All available data types per each sample

Data types ignored and model options

Decision tree is used as the model which output is press motion prediction

Figure 1 Initial Prediction of Press Motion, filtered by Maximum Camera Angles and Descriptions of the Mineset Software Interface showing the Model Outputs and Options

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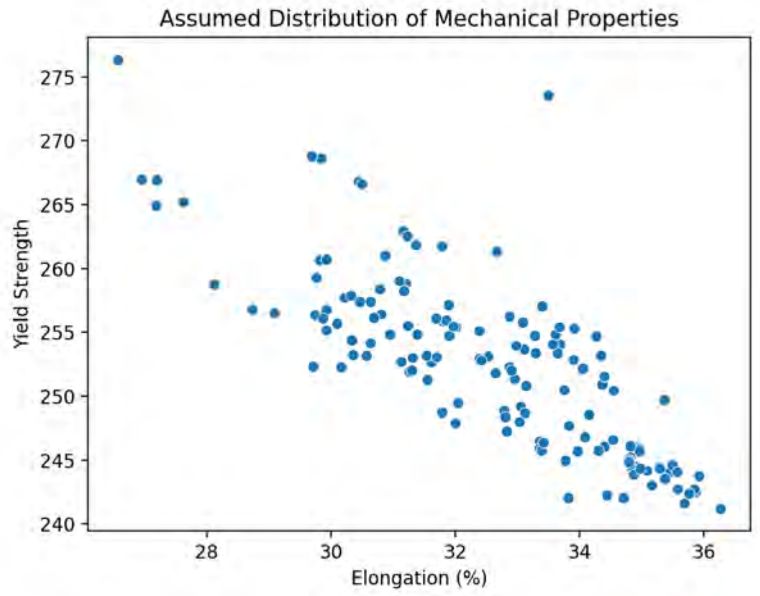
Smart Forming: Economic Use Case

Assume:

- Press running two shifts at 70% efficiency: 2800 hrs per year of uptime
- Stamping sells for $2, cost of bad part is $3
- Crank Motion: 2k SPH, LowHigh: 2k SPH, AD15: 1.5k SPH
- Material: BH340 steel, 0.75 mm thick
- Material changed every hour. Randomly sampled based on figure



	% Good
Crank	90.1
LowHigh	95.6
AD15	98.8

	Utility ($/hr)
Crank	3010.0
LowHigh	3560.0
AD15	2985.0
Stop	0.0

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Industry Trend

Convergent Manufacturing

Convergent Manufacturing Platform (CMP)

- Convergent manufacturing platform (ref. 1) is defined as a system that synergistically combines heterogeneous materials and processes (e.g., additive, subtractive, and transformative) in one platform.
  - Uses digital manufacturing tools and models and advances the digital thread for MRO operations.
  - Equipped with unprecedented modularity, flexibility, connectivity, reconfigurability, portability, and customization capabilities.
  - Easily reconfigured to output new functional solutions for complex & critical components.
- This manufacturing system also converges the integration of physical components and digital models along with sensor networks for process monitoring, production and in-situ inspection.

Ref 1 – "Convergent Manufacturing: A Future of Additive, Subtractive, and Transformative Manufacturing: Proceedings of a Workshop. Washington, DC: The National Academies Press. https://doi.org/10.17226/26524.

CMP Future State

- **Future State**
  - Automate sequential processing steps and minimize turnaround time for logistics of metal parts, components and structures.
  - Use digital manufacturing to automate inspection, material preparation (machining, cleaning), repair processes (DED, welding), structural improvement processes (cold spray, laser surface hardening), etc. to improve parts.
  - Use CAM models for each process that are integrated into agile robotic systems using tool-changers or multi-arm configurations.
  - Enable multi-process lights-out operations and wide-scale deployment of solutions across depots and supply chains by sharing model-based solutions.

- **Cross-cutting S&T Needs**
  - Robotics
  - Data Science (AI/ML)
  - Simulation / Digital Twin
  - Sensors / IoT

Thank you