



# **REPAIR ENGINEERING FRAMEWORK: METROLOGY, REVERSE DESIGN AND ADDITIVE MANUFACTURING**

**Tanbir Sarowar (PhD Student)**

**Advisor: Dr. ChaBum Lee**

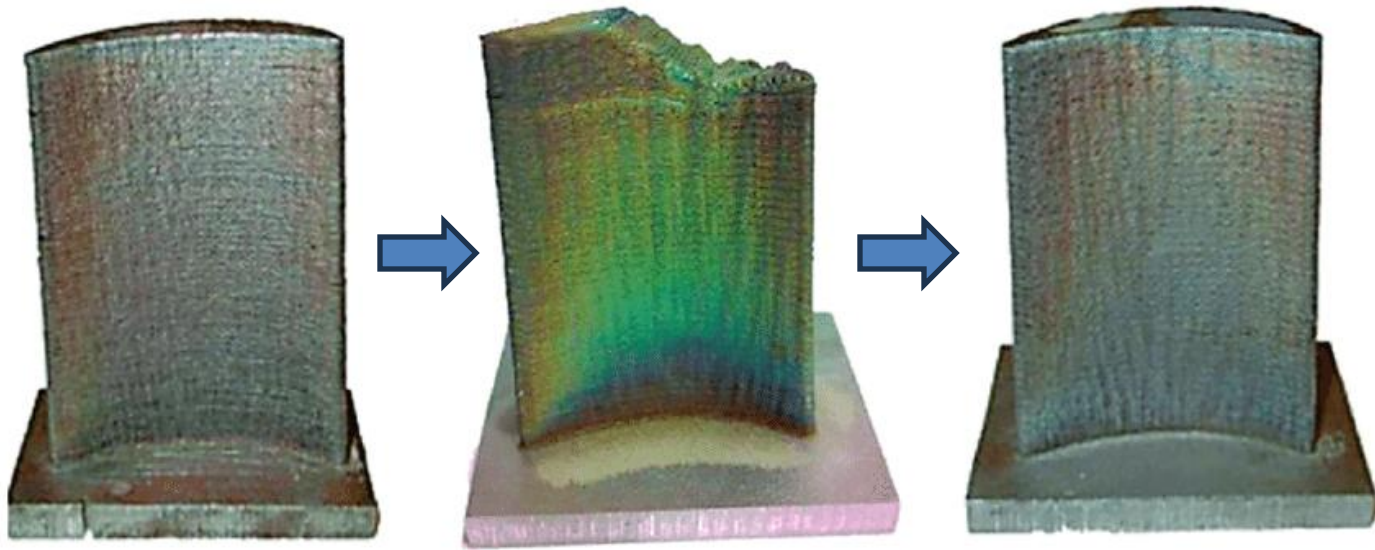
**Precision Metrology and Instrumentation Group**

**J. Mike Walker '66 Department of Mechanical Engineering**

**Texas A&M University, College Station, TX**

# Why Turbomachinery Repair Needs Better Inspection?

**Repair vs. Replace: a multi-million-dollar decision per part**



**Thesis:** Part damage/failure can be detected and diagnosed early by observing changes in material properties, enabling repair with improved performance.

# Repair Engineering

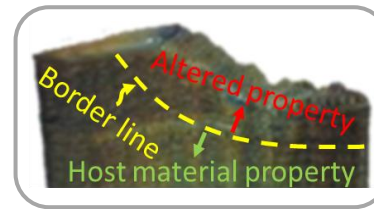
**Requires authoritative, objective, reliable information**, including 3D computer-aided design (CAD) data, material properties, surface properties or dynamic models, and diagnosis and prognosis of the part.

**This project** aims to establish the foundation for **(1) metrology, (2) reverse design, and (3) additive repair process technology** capable of corrective, preventive, diagnostic, and predictive maintenance of both geometry- and material-level part defects.

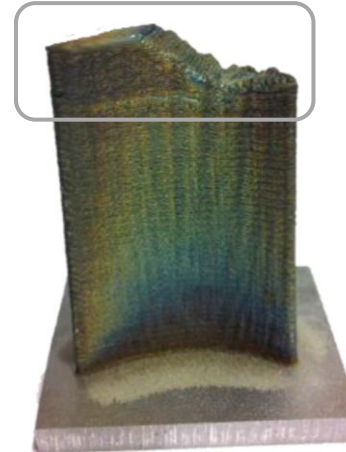


# Part Repair

## High-Value Components Subject to Extreme Wear



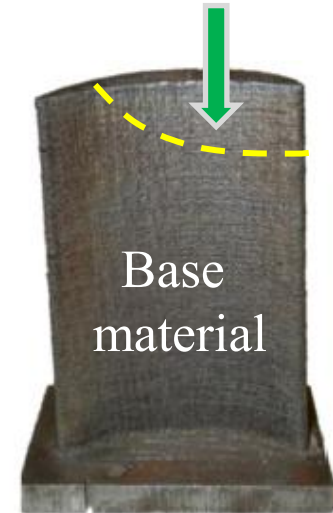
↑ Magnified



Damaged Part



Repair



Repaired Part

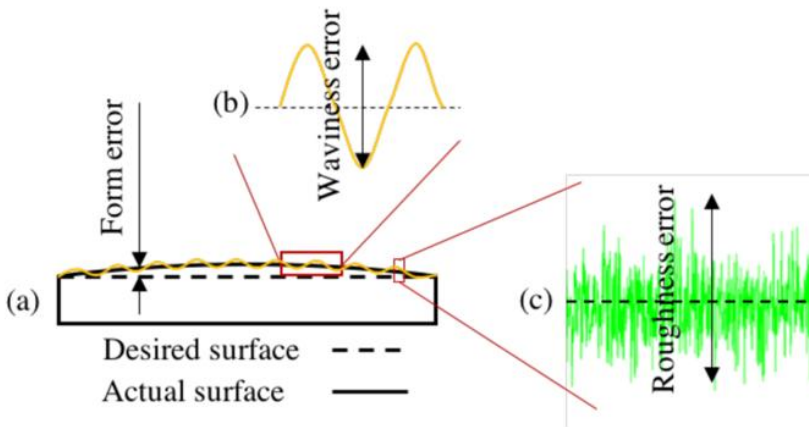
**Bottleneck:** No single NDT tool simultaneously captures geometric distortion AND material integrity.

# Part Repair

## Defect Types: what to repair?

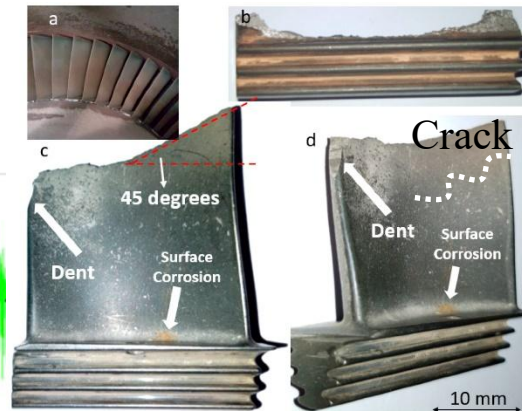
### Part Geometry

- Form error,
- Waviness
- Surface roughness,
- etc.



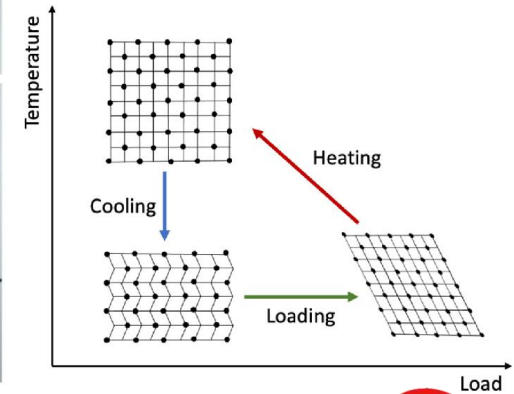
### Geometric Defects

- Crack,
- Distortion,
- Wear,
- Corrosion,
- etc.



### ✓ Material Defects

- Phase transformation,
- Residual stress,
- Material information,
- Density distribution,
- etc.

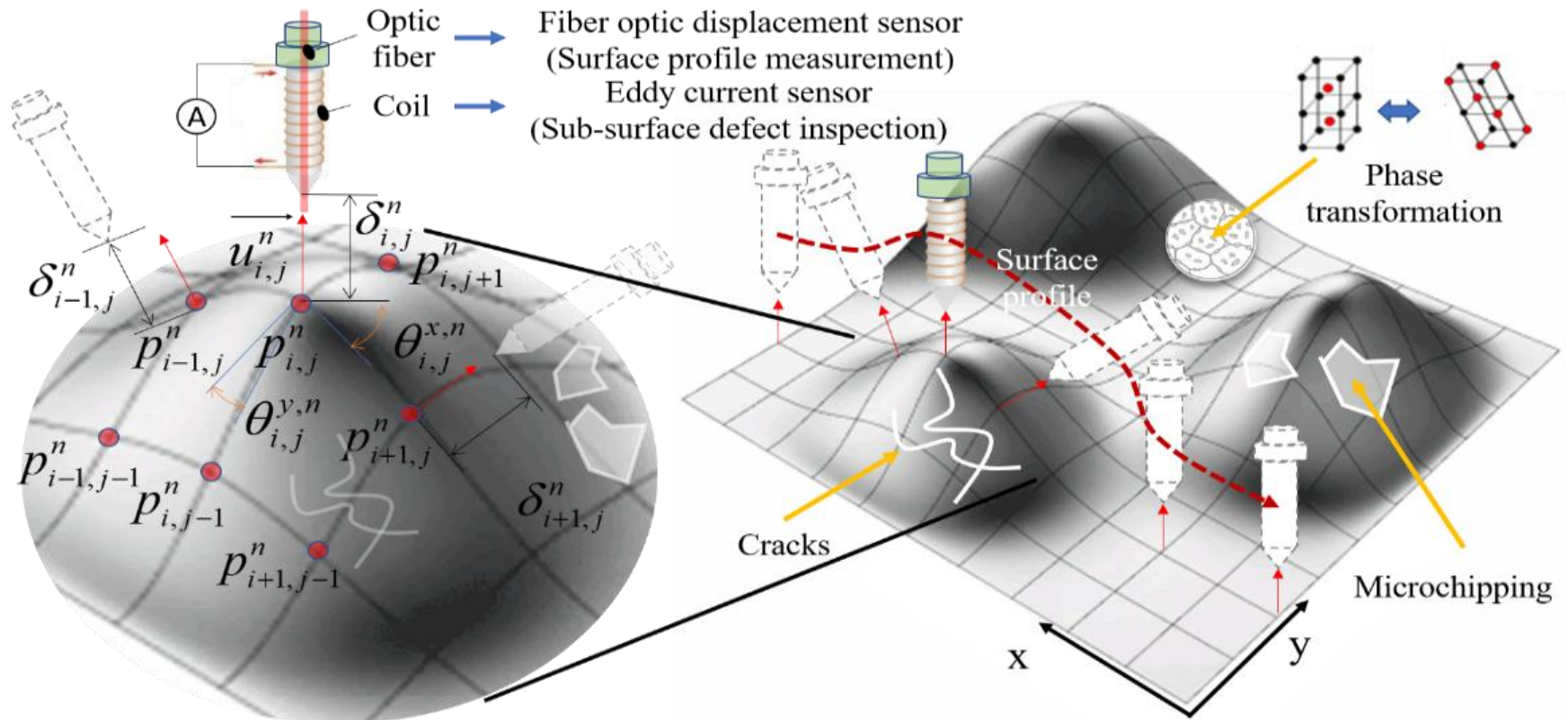


How to extract mechanical/material defect features?



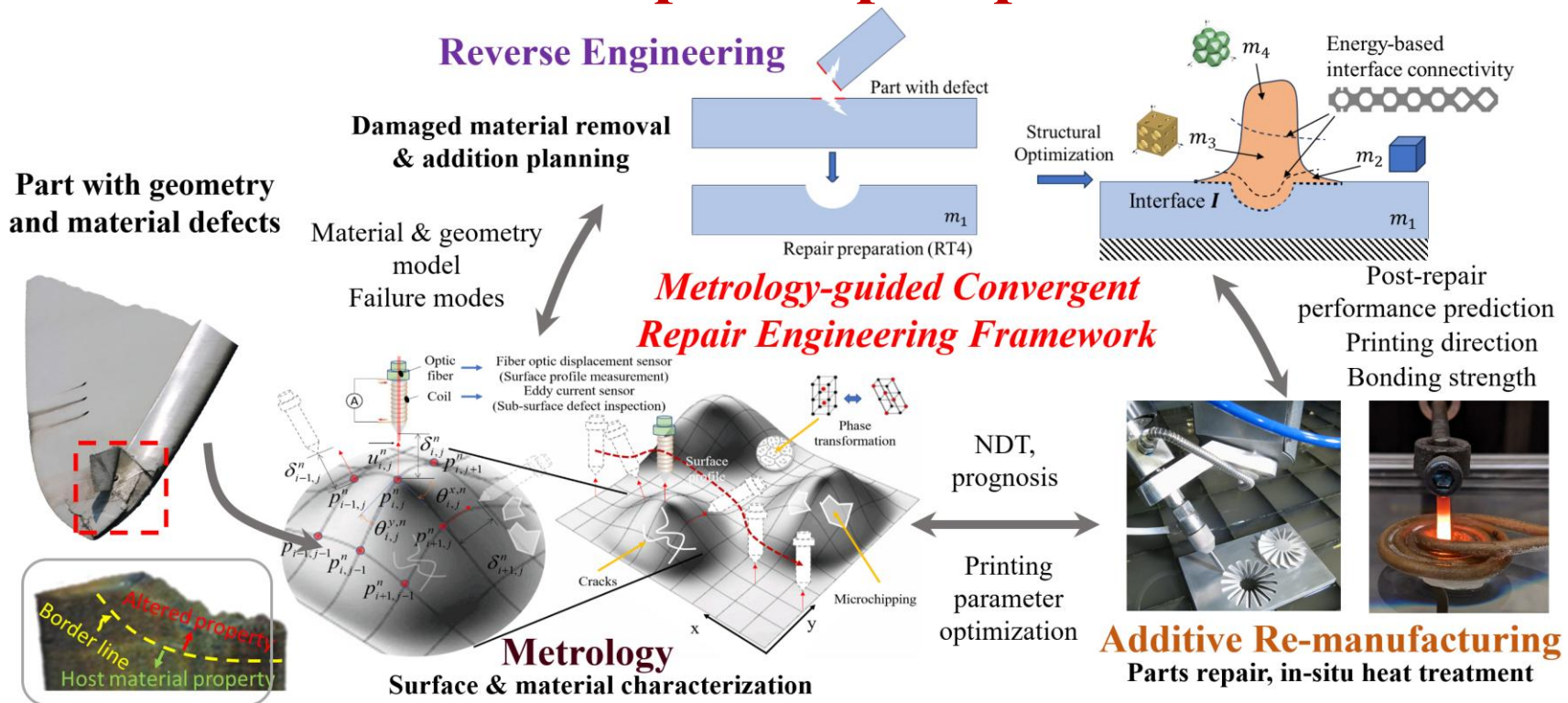
# Key Technological Challenges

**Mechanical/Material defect measurement of freeform surfaces (e.g., turbine blades, combustion chambers, etc.)**



# Project Concept

To establish a freeform part repair process.



## Task #1: Metrology

FECS: simultaneous geometry + material

## Task #2: Reverse Design

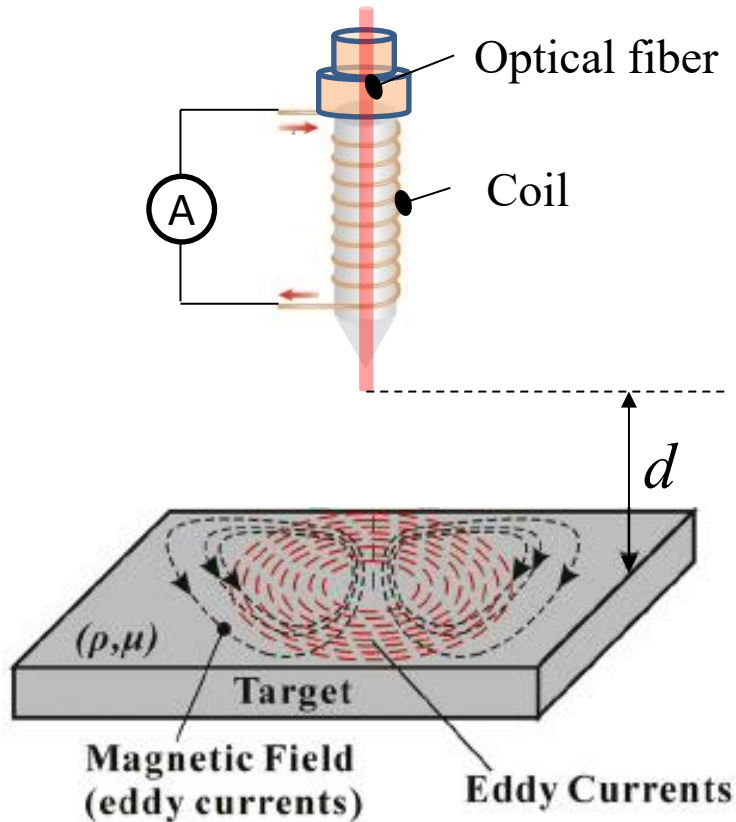
Topology optimization from defect maps

## Task #3: Additive Repair

Closed-loop AM with FECS feedback

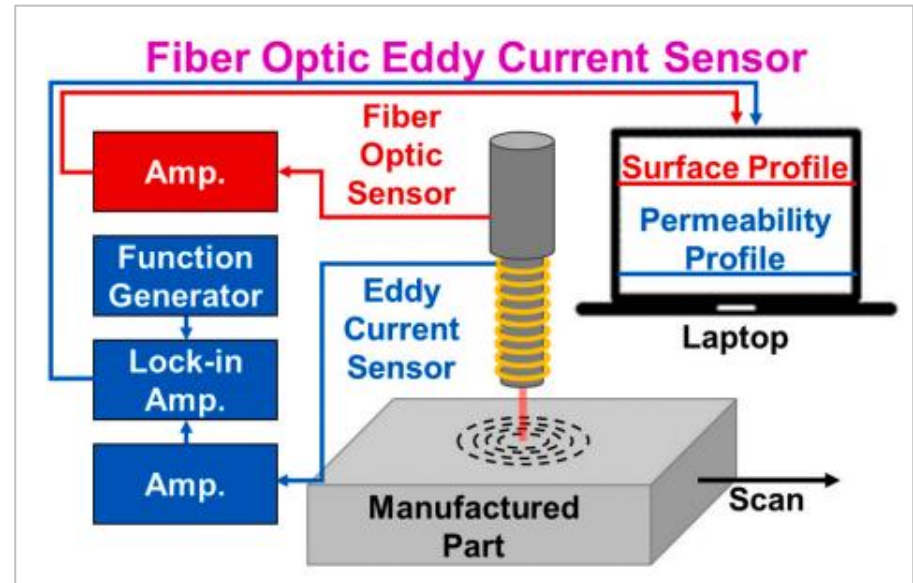
# Task #1: Metrology Breakthrough

Single probe: fiber optic (geometry) + eddy current (permeability)

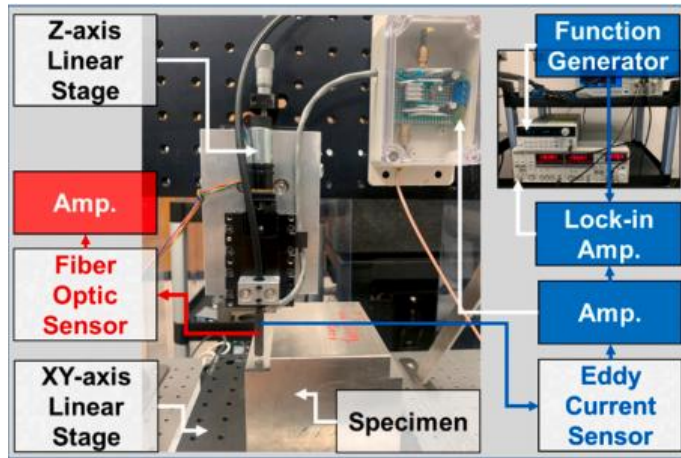


Fiber optic displacement sensor  
(Surface profile measurement)

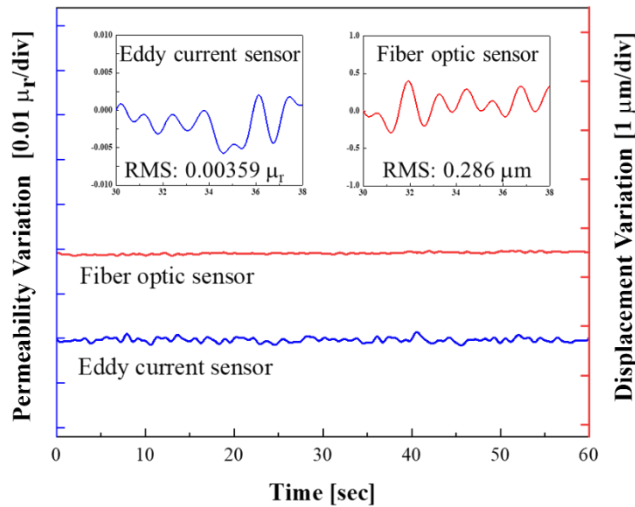
Eddy current sensor  
(Material density/orientation measurement)



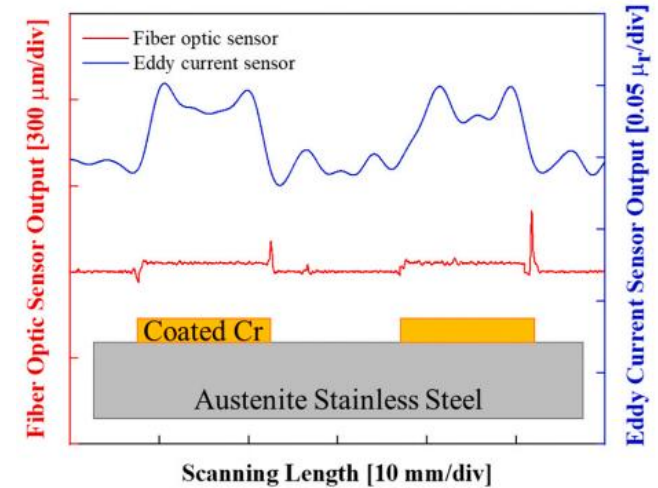
# Preliminary Results (1)



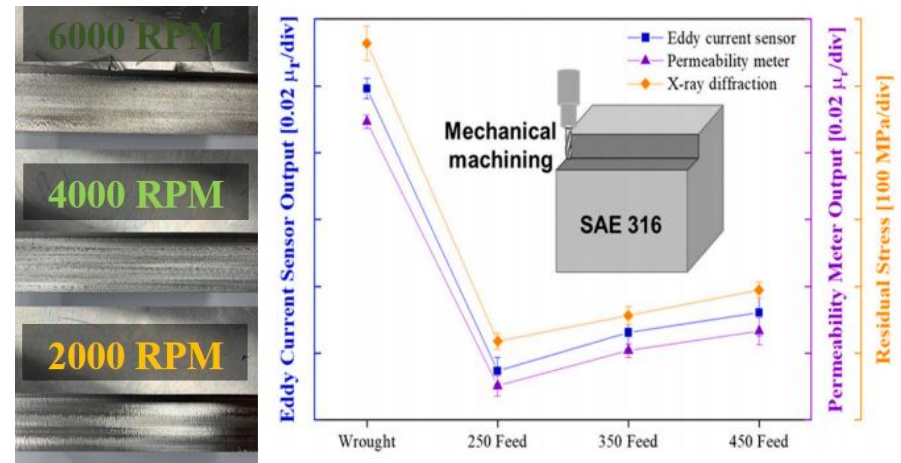
Scanning system



## (1) Coated Surfaces

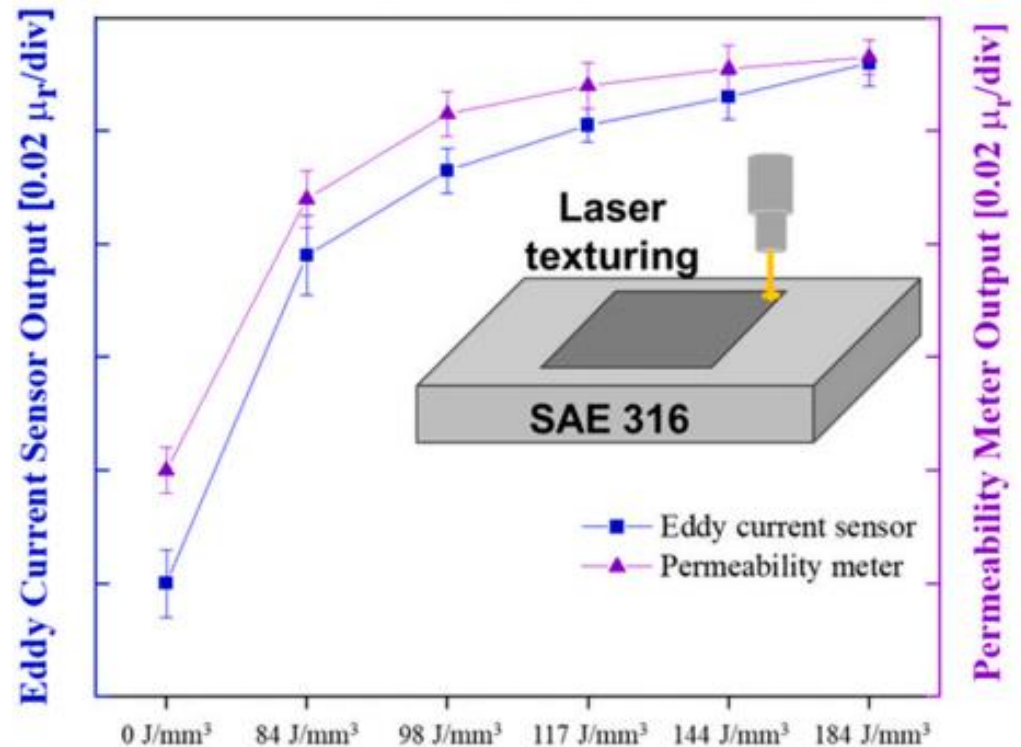
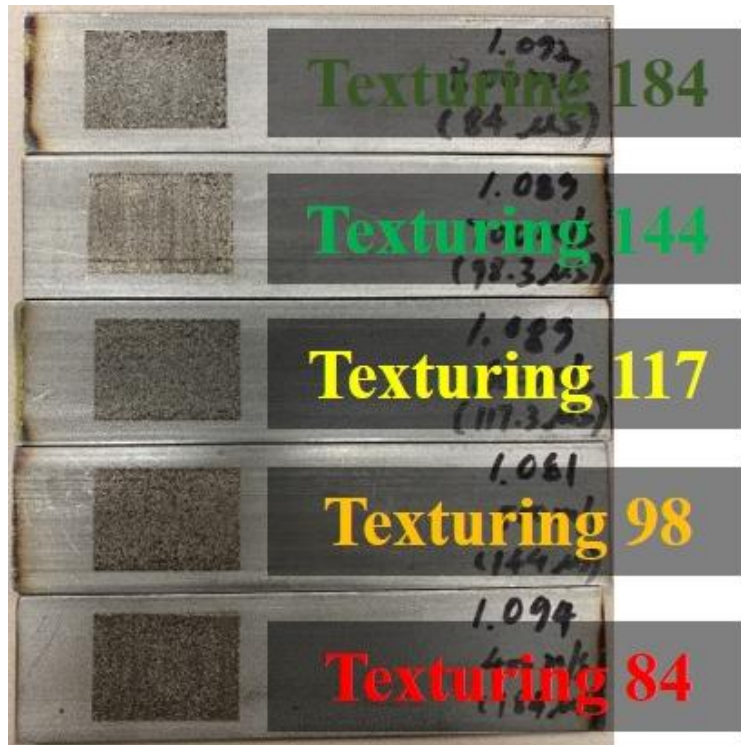


## (2) Machined Surfaces

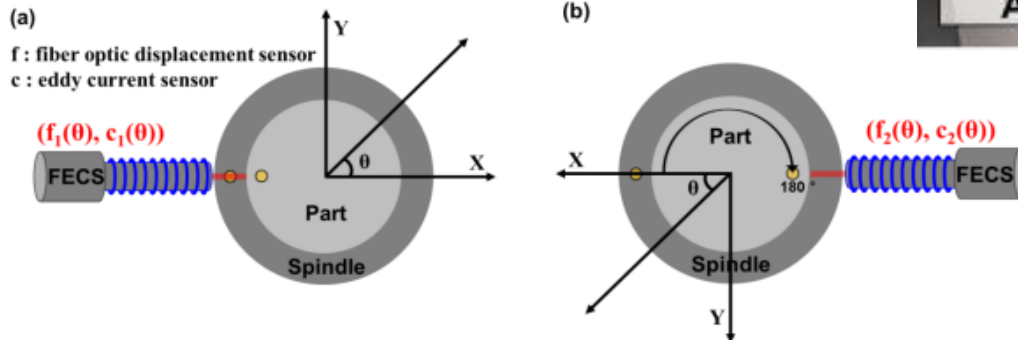
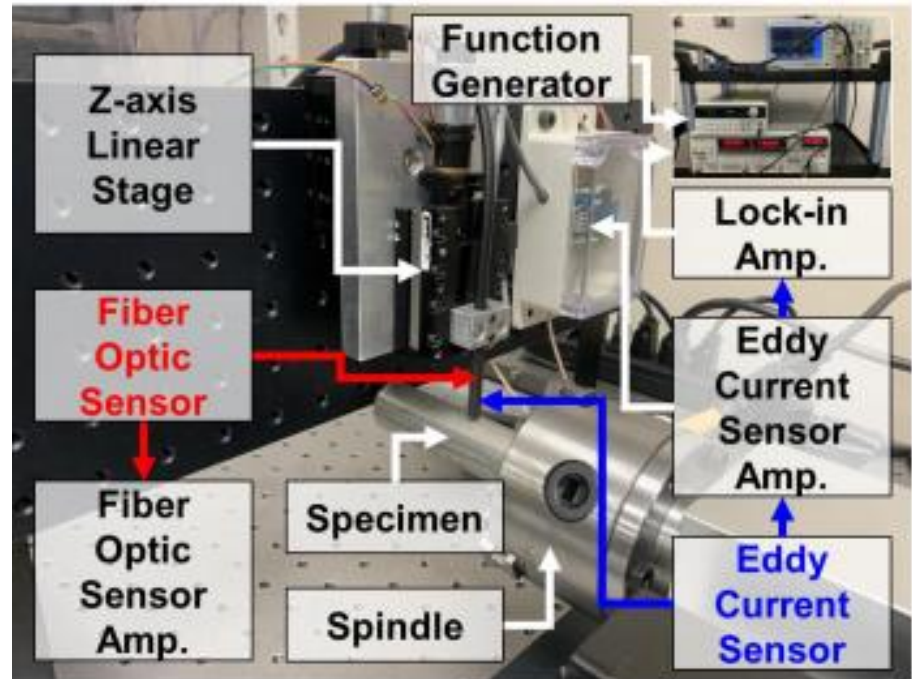
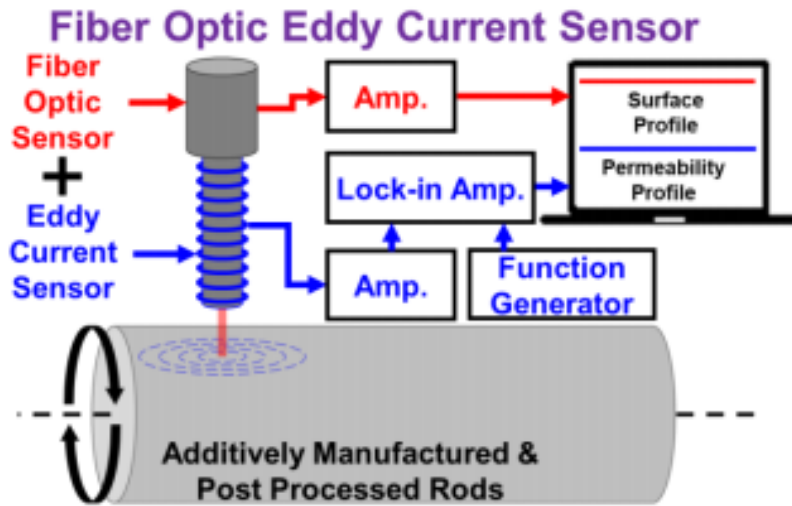


# Preliminary Results (2)

## (3) Metal-AM



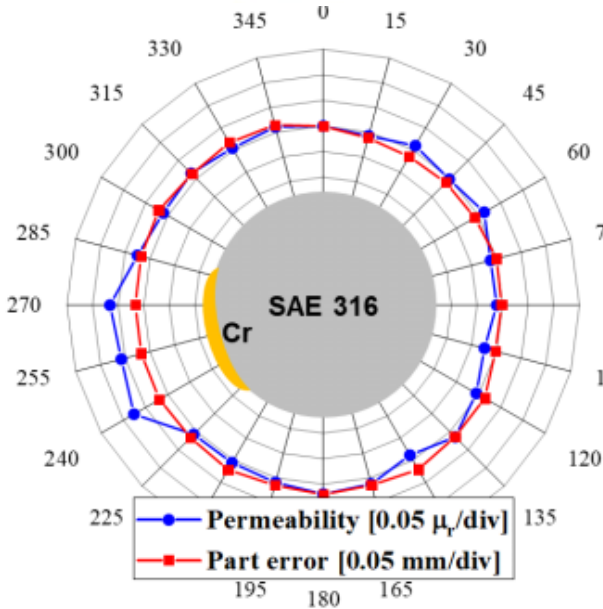
# Preliminary Results (3)



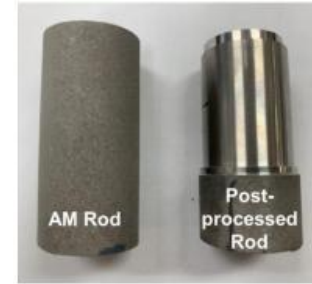
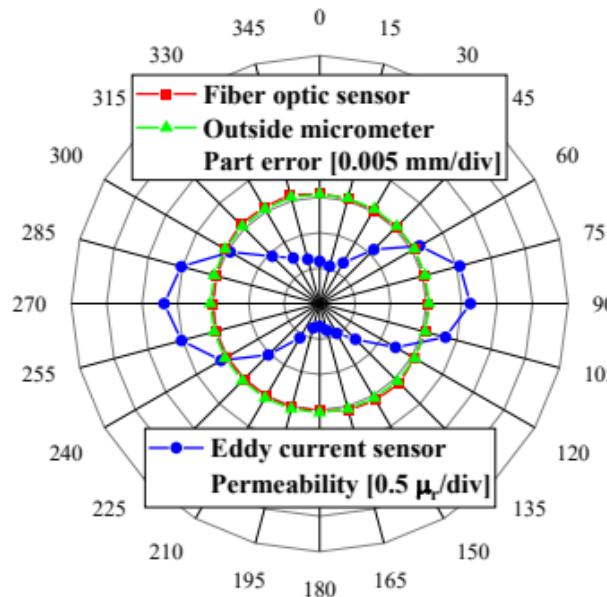
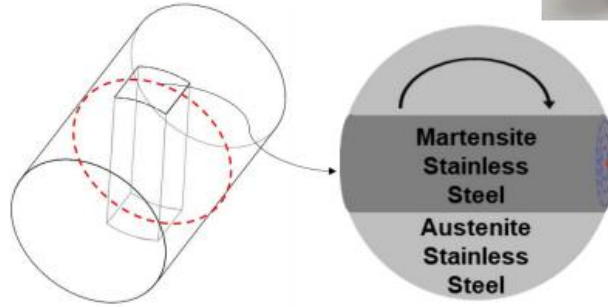
**Error separation  
by using  
reversal method**

# Preliminary Results (4)

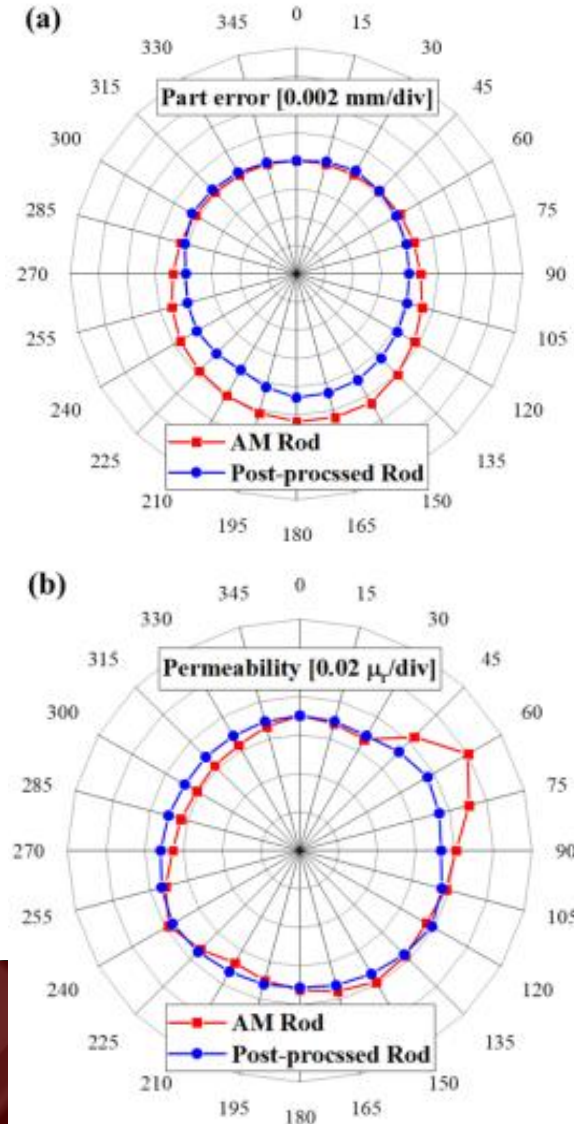
## Case I



## Case II

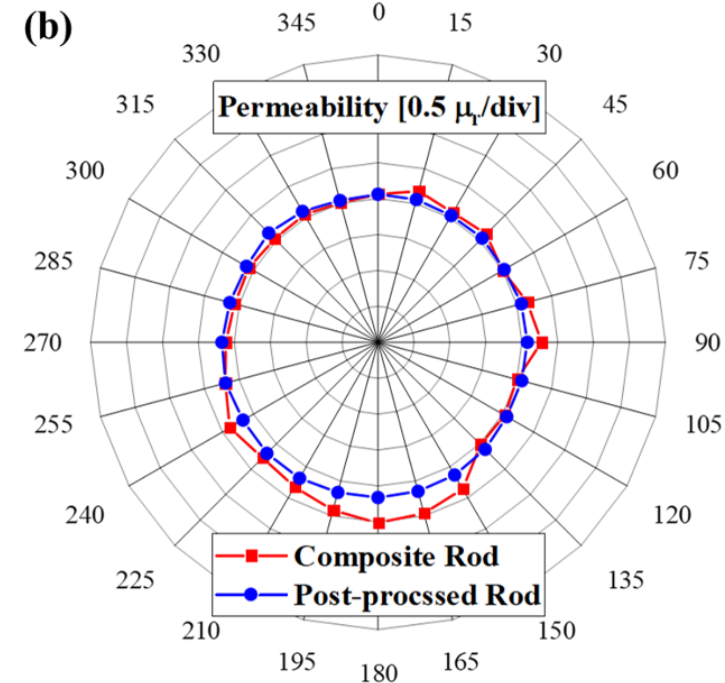
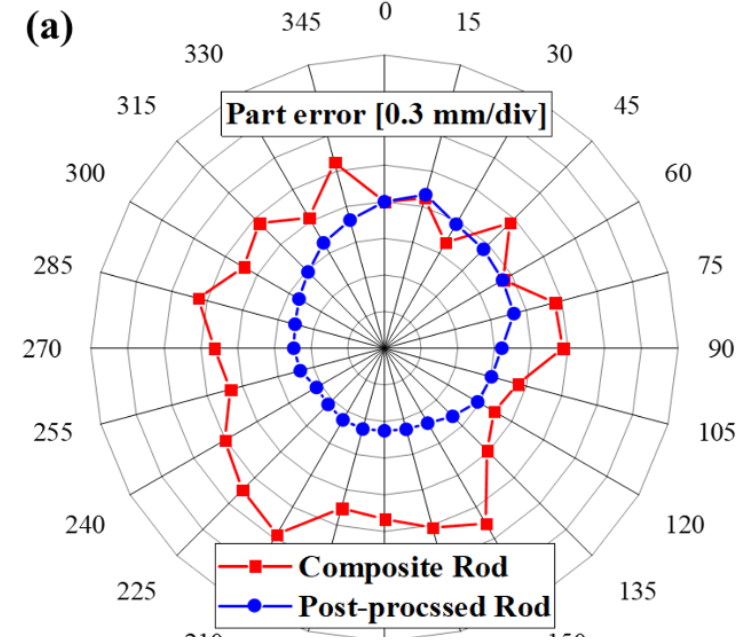
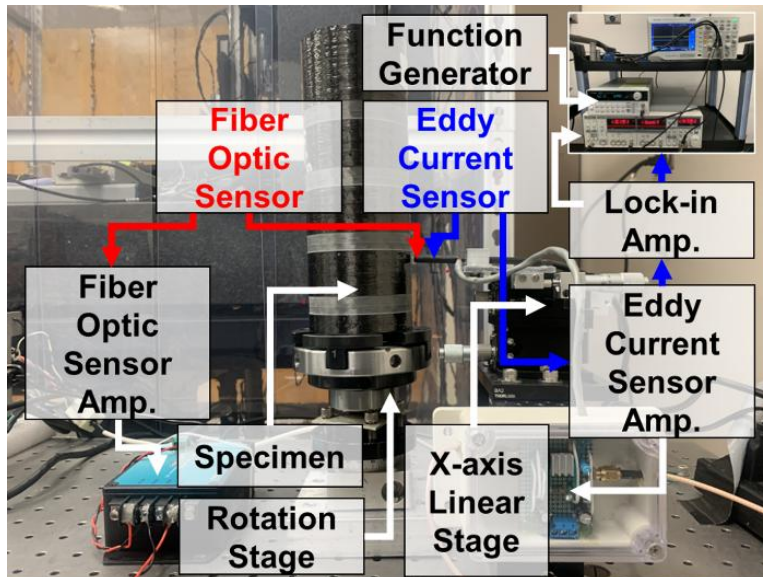
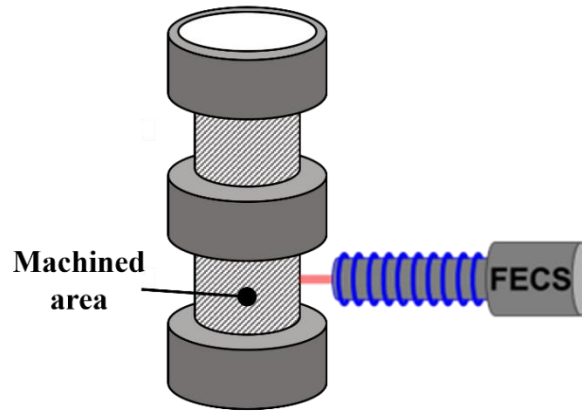


## Case III



# Preliminary Results (5)

## Case IV : CFRP Rod



# Freeform Surface Metrology

## Freeform surface measurement introduces cosine error

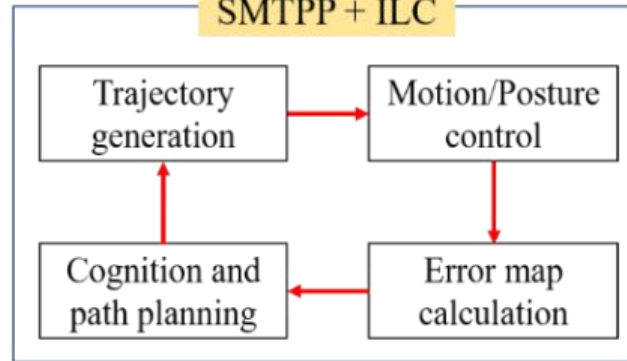


Unknown arbitrary part

Geometry?  
Defects?  
Material?



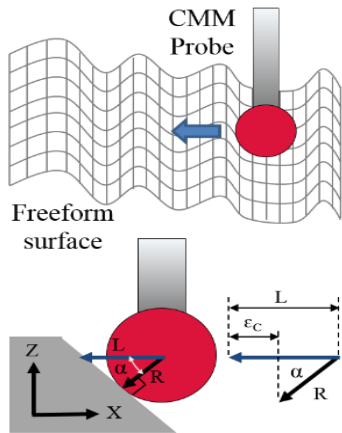
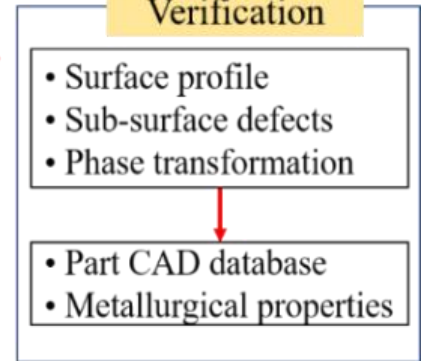
### SMTTP + ILC



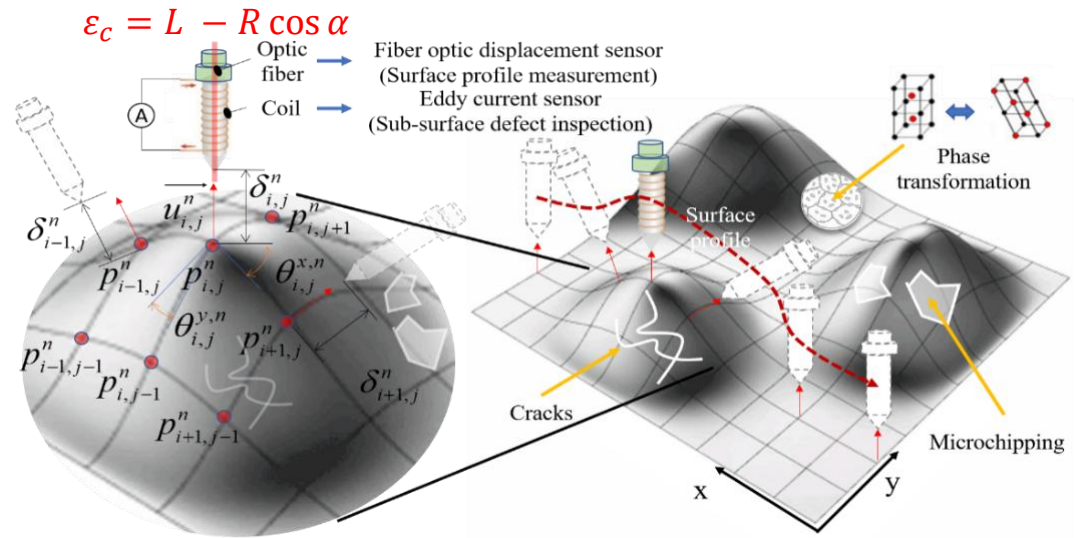
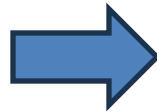
Cosine error  
removal



### Verification

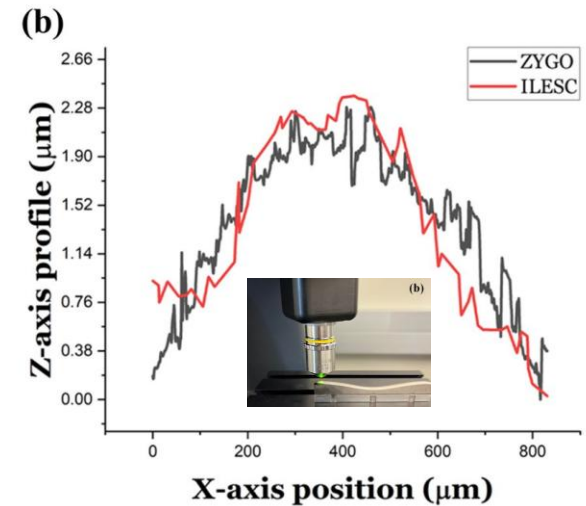
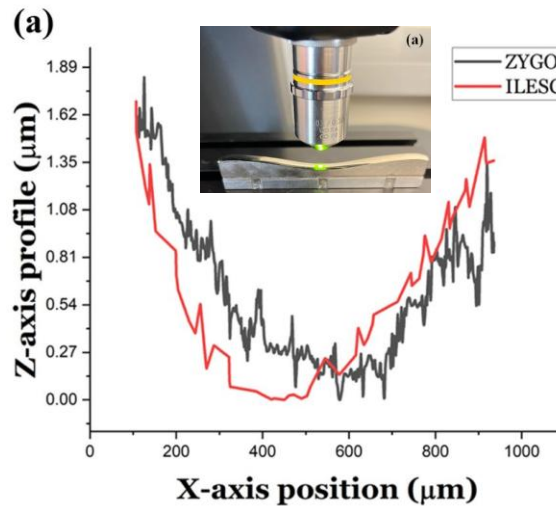
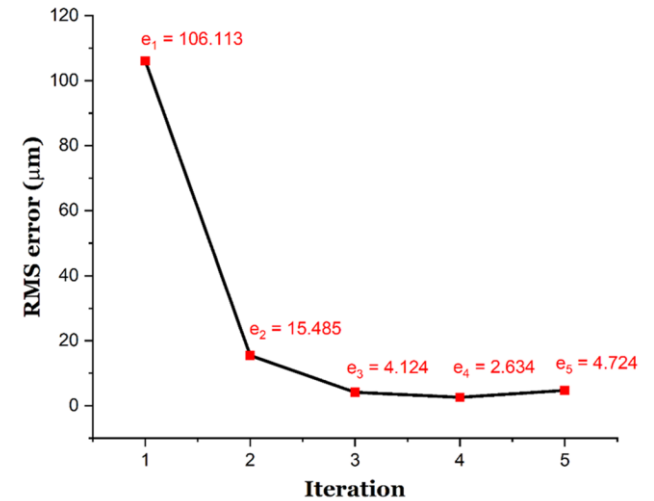
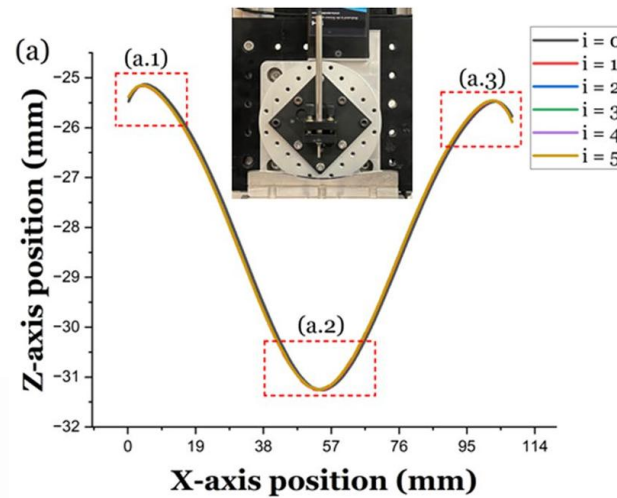
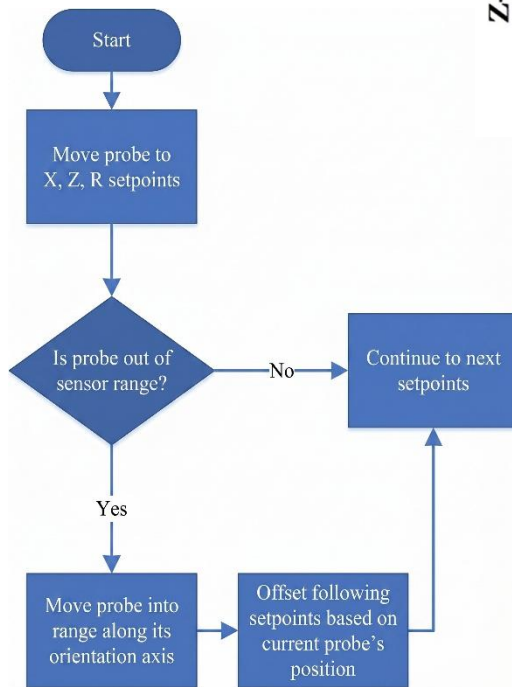


$$\epsilon_c = L - R \cos \alpha$$

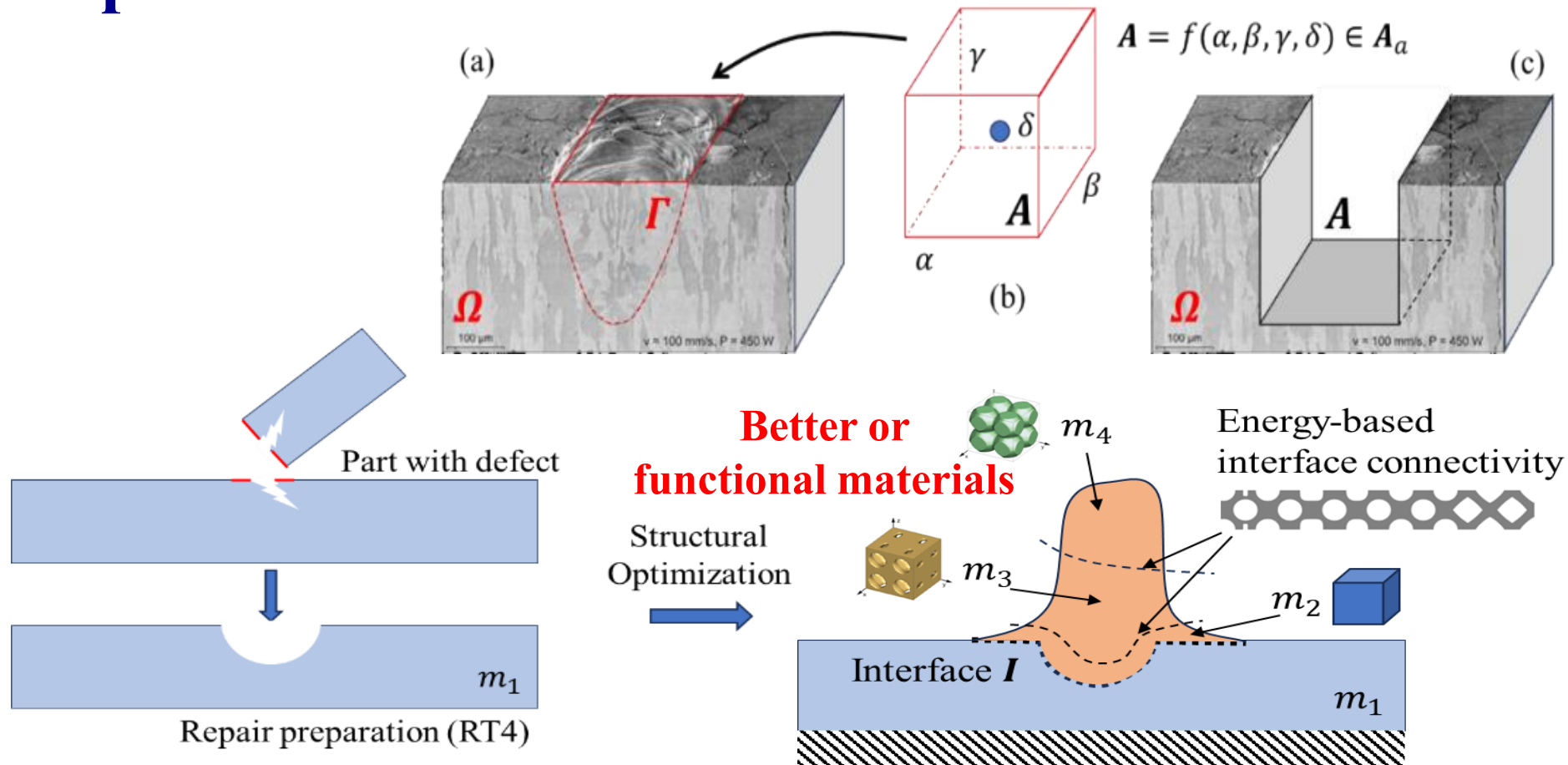


# Preliminary Results (6)

**ILC**  
+  
**ESC**



## Task #2: From FECS Defect Map to Repair Deposition Plan



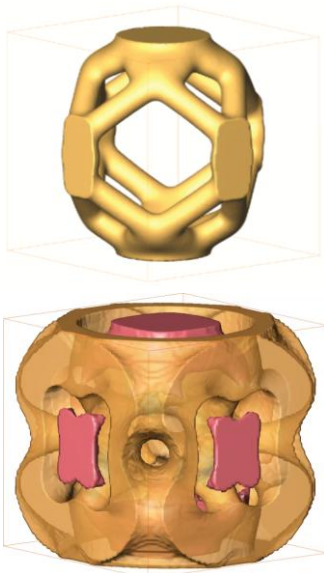
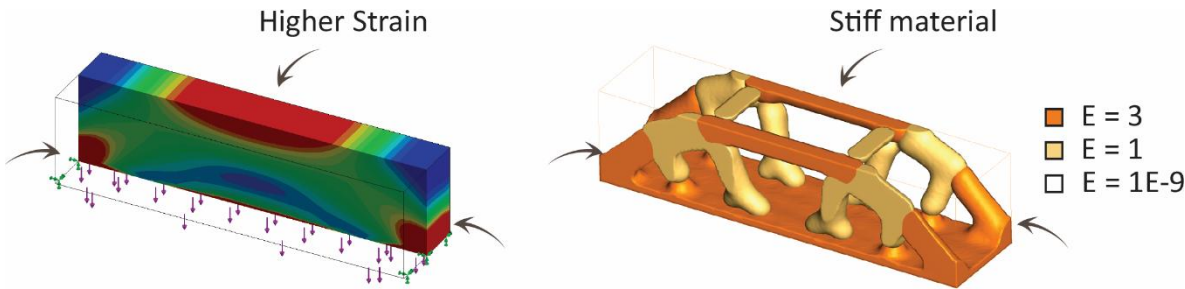
# Requires geometry and material design!

# Task #2: Reverse Engineering

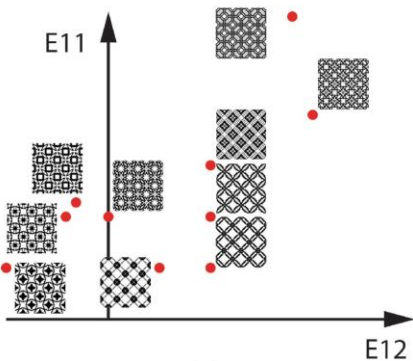
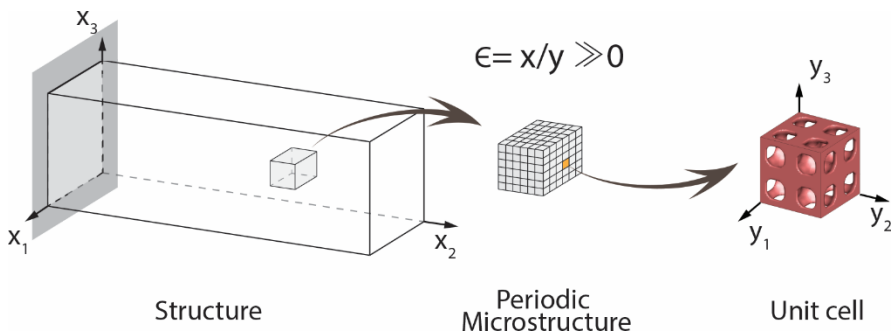
## Efficient multi-material topology optimization

-Mechanically strong, dynamically responsive, thermally stable...

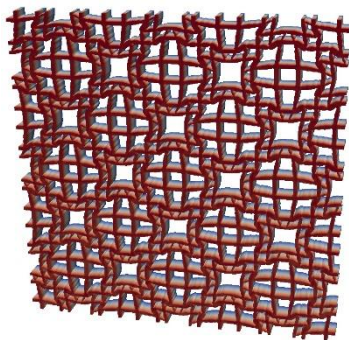
- Bridge 10X10X40 B8 n125 mesh



## Functional material design

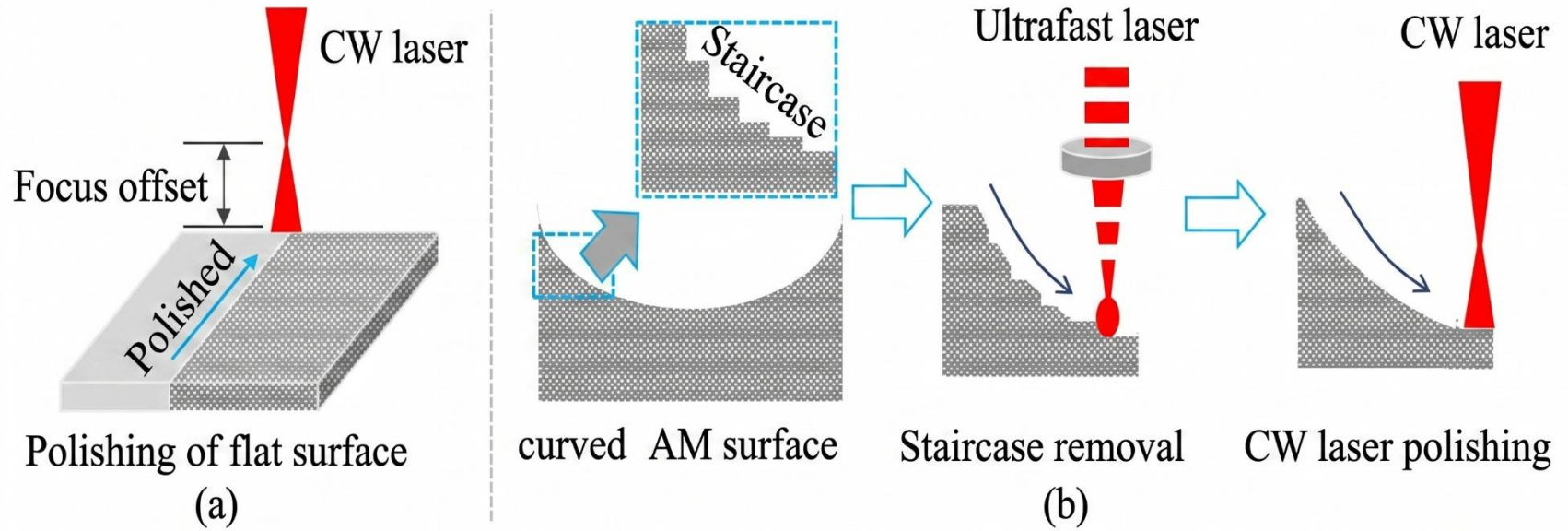


• Material library



• Auxetics

# Task #3: Additive Repair



- Requires a post-process for material property enhancement!
- Increases bonding strengths!

FECS Pre-scan



Topo. Opt.



AM Deposition



FECS Re-scan

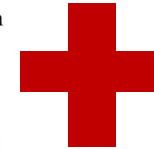
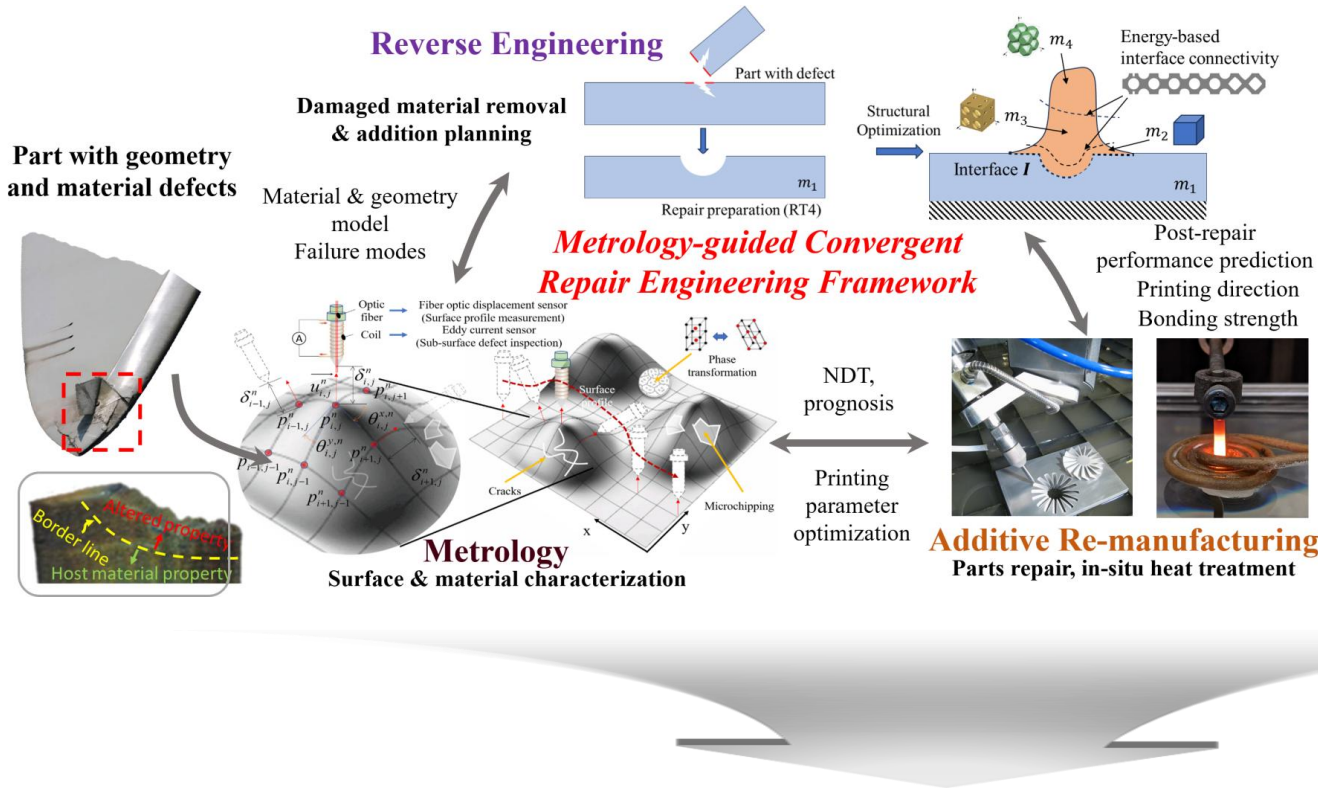


Iterate ↺

# Repair Manufacturing System Integration

**Metrology, Design, Materials, and AM**

**Robotics**



**Ubiquitous Repair Manufacturing System**

# Timeline

| Tasks                                  |                                                                  | Q1 | Q2 | Q3 | Q4 |
|----------------------------------------|------------------------------------------------------------------|----|----|----|----|
| <b>Task #1<br/>Metrology</b>           | RT1. Metrology tool path planning for part failure qualification |    |    |    |    |
|                                        | RT2. Part geometry and material failure mode analysis            |    |    |    |    |
|                                        | RT3. AI-based failure modes and effects analysis                 |    |    |    |    |
| <b>Task #2<br/>Reverse Engineering</b> | RT4. Metrology-guided part reconstruction process planning       |    |    |    |    |
|                                        | RT5. Optimization-driven AI for reverse design                   |    |    |    |    |
|                                        | RT6. Post-repair performance prediction/diagnostics/prognostics  |    |    |    |    |
| <b>Task #3<br/>Additive Repair</b>     | RT7. In-situ heat treatment-additive repair/remanufacturing      |    |    |    |    |
|                                        | RT8. Reverse design-guided AM process planning                   |    |    |    |    |
|                                        | RT9. Surface property enhancement by laser post-processing       |    |    |    |    |

# Thank You!

## REPAIR ENGINEERING FRAMEWORK: METROLOGY, REVERSE DESIGN AND ADDITIVE MANUFACTURING

**PI: ChaBum Lee**

**PhD Student: Tanbir Sarowar**