Public Quarterly Report

Date of Report: *1st Quarterly Report, January 31, 2025*
Contract Number: *693JK32410012POTA*
Prepared for: *PHMSA*
Project Title: *Development of a Blade Toughness Meter (BTM) for In-situ Pipe Toughness Measurement*
Prepared by: *Massachusetts Materials Technologies*
Contact Information: *Simon Bellemare, s.bellemare@bymmt.com,*
For quarterly period ending: *March 31, 2025*

1: Items Completed During this Quarterly Period:

Table 1 shows a list of items that were completed this quarterly period. The 2nd quarterly report was the only item expected for completion this quarter.

Table 1 – Tasks completed and invoiced this quarterly period

Item #	*Task #*	*Activity/Deliverable*	*Title*	*Federal Cost*	*Cost Share*
6	***N/A***	***2nd Quarterly Report***	***Submit 2nd quarterly report***	***0.00***	***0.00***

2: Items Not-Completed During this Quarterly Period:

Table 2 shows a list of items for which work started or continued to take place on following the first quarter, and which have yet to be completed. Initial findings from work conducted in Quarter 2 for all ongoing tasks were presented to the TAP committee on April 7th, 2025. Progress for Task 1.2 is on track as originally defined in our proposal. Task 1.3 has completed the majority of its outlined work and is projected to be completed during quarter 3. Work has begun ahead of expected schedule for Task 2.1 and Task 2.3, though time allocation to them during this quarter has remained minimal.

Table 2 – Items started but not completed this quarterly period

Item #	*Task #*	*Activity/Deliverable*	*Title*	*Federal Cost*	*Cost Share*
2,4,7	***1.2***	***Develop a finite element model for the planing-induced microfracture process***	***A report on findings from the finite element models which include (1) blade optimization design and (2) measurables and their correlations to fracture toughness submitted***	***$22,698.50***	***$22,698.75***
5	***1.3***	***Manufacture blades with optimized design and adjust tool accordingly***	***A summary of blade and tool design changes submitted***	***$21,535.66***	***$21,536.00***
9	***2.1***	***Conduct field trials and modify the tool according to trial feedbacks***	***A summary of findings and results from field trials submitted***	***$36,452.62***	***$36,452.67***
17	***2.3***	***Optimize the field procedure***	***Developed field procedure submitted***	***$15,705.14***	***$15,705.33***

3: Project Financial Tracking During this Quarterly Period:

The total amount billed for ongoing work can be seen in Figure 1, along with a projected invoice schedule for the entire project. As described in Section 1, there were no newly completed tasks this quarter. The total invoiced to PHMSA will be $36,793.52 in keeping with applicable cost share. We are below the expected expenditure at quarter 2 close, which reflects the slight delay from quarter 1 in Task 1.2 as well as some faster than expected progress in Task 1.3. With the initiation of tasks for Milestone 2 (see section 4), the 3rd quarter should come in slightly above budget, bringing overall spending back in line with projections.

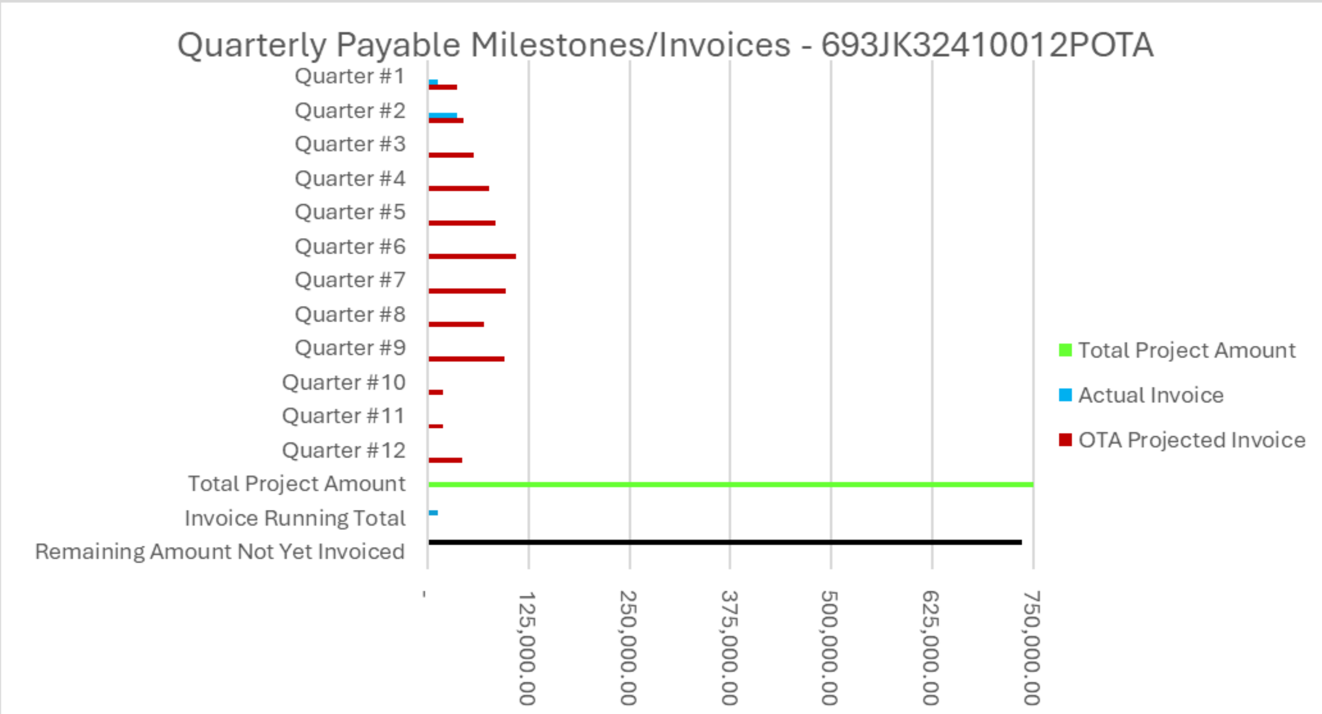


Figure 1 – MMT quarterly payable milestones and invoices

4: Project Technical Status –

Table 3 shows a complete summary of all project progress to date listed by Task as originally defined in our proposal. For each task we have listed the percentage achieved and percentage complete. A percentage achieved less than 100% with a percentage complete of 100% indicates we did not complete all tasks as defined in our original proposal but we are stopping all work associated with the task.

The project has successfully selected and begun work with a vendor for Task 1.2 BTM Finite Element Model Development. A summary of the agreed scope of work and the current progress can be found in Attachment 1. Work that began in quarter 1 on Task 1.3 has seen significant progress, which has been summarized in Attachment 1. The final completion of Task 1.3 is aligned with Project Deliverable 3 outlined in the original project submission's Attachment #2. The expected blade manufacturing and summary report for Project Deliverable 3 is expected to take place during quarter 3.

Table 3 – Complete project progress summary

Scope of Work			% Achieved	% Complete
Milestones	**Type**	**Tasks**		
Milestone 1: Blade Optimization for Better Accuracy and Safety	Deliverable	1.1 Literature Review	100	100
	Method	1.2 BTM Finite Element Model Development	33	33
	Hardware	1.3 Blade Design Optimization	75	75
Milestone 2: Field Trials and Evaluation	Hardware	2.1 Field Device Development	20	20
	Software	2.2 Data Process and Analytics Optimization	0	0
	Procedure	2.3 Field Procedure Optimization	33	33
	Deliverable	2.4 Third-Party Validation	0	0
Milestone 3: Test Instrument Design and Evaluation	Hardware	3.1 Field Device Optimization and Automation	0	0
	Software	3.2 Software Development	0	0
	Procedure	3.3 Training Program Development	0	0
	Deliverable	3.4 Engineering Specification for Manufacturing	0	0
Milestone 4: Proof-of-Concept for In-line Adaption	Method	4.1 Feasibility Study	0	0
	Hardware	4.2 Proof-of-Concept Development	0	0
	Deliverable	4.3 Laboratory Mock-up Testing	0	0

Items from Task 2 have begun ahead of schedule. The decision to proceed ahead of schedule with items from Task 2 reflects progress and confidence gained since the project start. Specifically, initial success in physical modeling and improvements in analytics have led to earlier than expected competitive toughness prediction capabilities. This capability is further supported by progress in Task 1.3 - Blade Optimization which will allow any upcoming field trials to utilize a blade loadout which can be backward compatible with future improvements to instrumentation and toughness prediction modelling.

5: Project Schedule –

A complete project progress summary can be seen in Table 3. This summary includes all tasks that have not been started yet as well as percentage progress for ongoing tasks. It is anticipated that at the time of quarter 3 report submission that task 1.2 will be approximately 50% complete. Task 1.3 should reach 100% completion. All Task 2 items are expected to have begun work and progressed forward by the end of quarter 3. Reporting in quarter 2 has cut down the project reporting delay from quarter 1 to two weeks. Reporting for quarter 3 is anticipated to be fully aligned with expected delivery dates.

Attachment 1 – Task 1.2, Task 1.3, Task 2 – Summary Report

R&D Project:
Development of the Blade Toughness Meter (BTM) for In -Situ Pipe Toughness Measurement

Co-sponsored By PHMSA
(Project # 1043)

Q1 2025 – Progress Report
04/07/2025

Agenda

- Task 1.2 updates (FEA)
- Task 1.3 updates (Blade Optimization)
- Milestone 2 updates (Initial field pilot work)
- End

Task 1.2 Finite Element Model Development (Physical modeling)

Proposal: MMT plans to develop an FE model internally or with external academic partners to understand better the science behind the planing-induced fracture method, including the stress-strain state of the material within the stretch passage and the stress on the cutting blade. The FE model, a simulation of a real -life BTM test, will utilize material models with a wide range of strength and toughness properties, allowing geometric characteristics of the pipeline ligaments measured in the field to be better related to their toughness properties.

New this report (Reached 35% of milestone completion on MMT work):

- 1.2.1: Retrieve and re-interpret prior FEA work done by MMT
- 1.2.2: Detailed review and insight from prior FEA work by Bai et al. and select physical experiments
- 1.2.3: First tangible outcome: Initial physical modeling completed
- 1.2.4: Ongoing: Additional review of material response during tests (Significant effort added to the initial plan)
- 1.2.5: Next step: 3D simulation without stretch passage ← This phase of work without stretch passage skipped (See FEA vendor selection)
- FEA Consultant selected and under contract
  - Scope of work and initial details on next slide
- Custom set up for FEA validation testing in progress (load data, blade speed check)

Task 1.2.6 FEA vendor selection

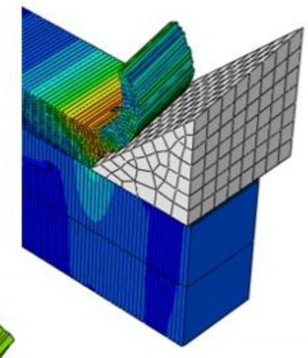
- Academic versus Industrial consultant
  - Difference in projected time frame of work (mapping to academic semesters)
  - Difference in expertise of individual executing work product
  - Difference in cost
- Criticality of approach to damage model
  - Several suggestions were made by interviewed consultants
    - Gurson-Tvergaard-Needleman
    - Bao-Wierzbicki
    - Ramberg Osgood / Hollomon
    - Other, less well known models (usually from academic consultant interviews)
  - Approaches must be able to anchor back to parameters known through NDE methods, along with material response to BTM test
- Taking a bet with the Abaqus (detailed in next pages)

Task 1.2 Finite Element Model Development (Physical modeling)

Scope of Work has three stages

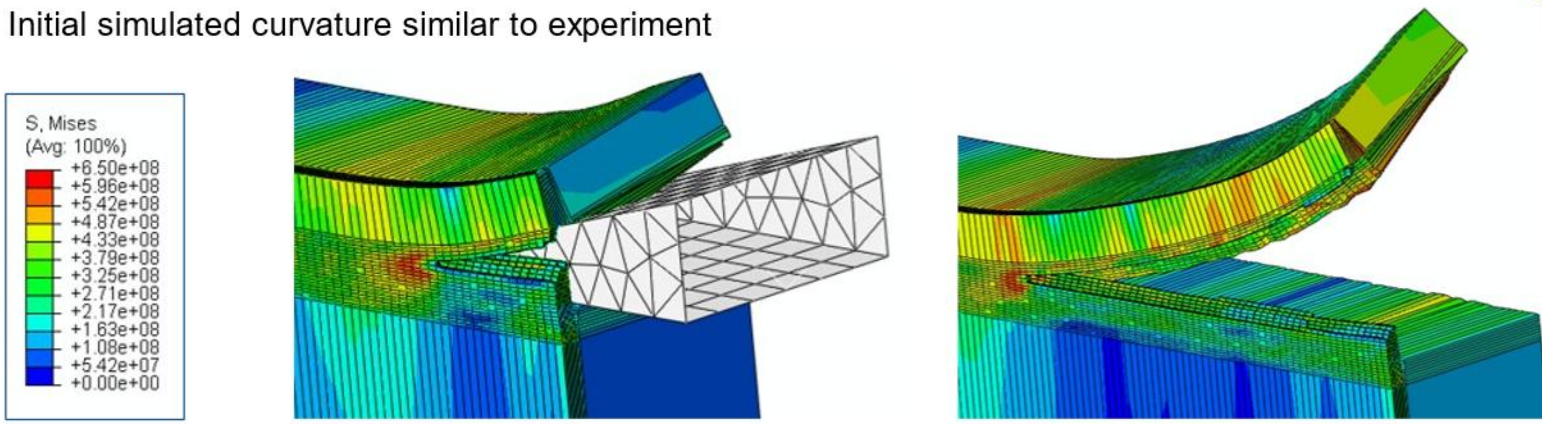
1. Development of a basic working model
   - Abaqus model using built -in (Ramberg Osgood / Holloman) ductile damage models.
   - These model inputs can be related to the Bao -Wierzbicki parameters to allow a comparison of equivalent materials behavior
   - Single blade geometry considered. Surface of 'island' assumed to be flat (curvature effects of pipe diameter not considered).
   - Success of stage 1 defined by: Abaqus damage models run successfully, good correlation between ligament dimensions & K1c
2. Simulation of seven MMT Cases
   - MMT provides material and inputs and measurement results for 7 case studies (selected pipes on next slide)
   - FEA consultant runs the simulations and performs direct comparison of results
   - Success of stage 2 defined by: generated simulation results match physical test results within some margin
3. Extended test matrix
   - FEA consultant and MMT will develop a test matrix to explore a wider variety of material properties as inputs.

Task 1.2 Finite Element Model Development (Physical modeling)



Preliminary proof -of-concept for general approach with damage model

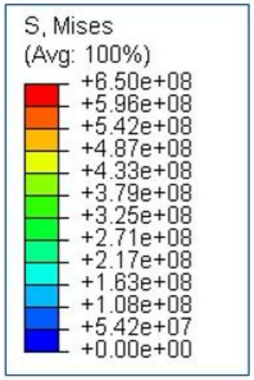
- Shear lip & flat fracture can be generated
  - Must be mindful of mesh refinement for feature resolution
- Chip curvature is influenced by blade angle
  - Initial simulated curvature similar to experiment

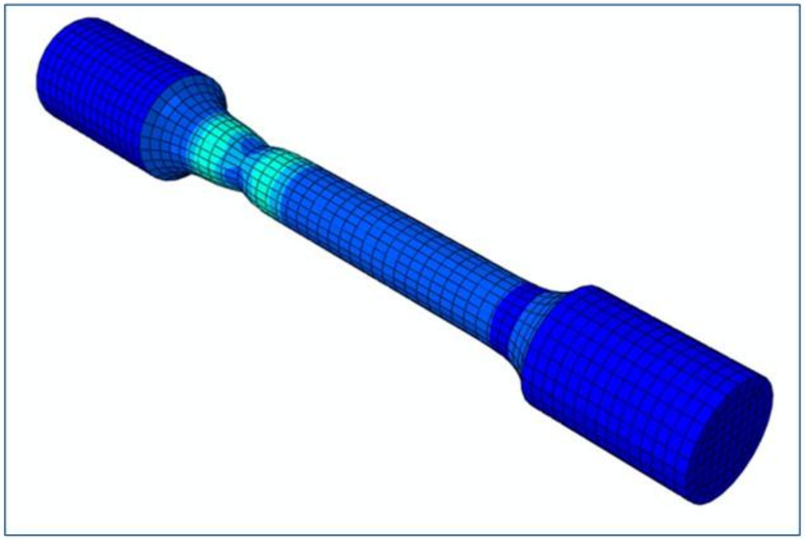


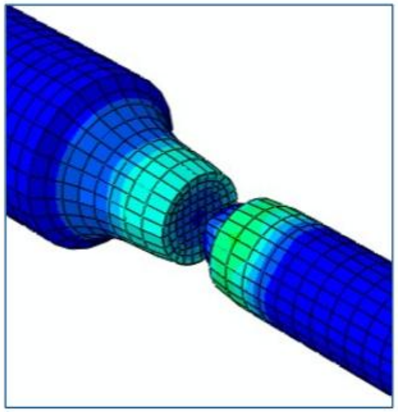
Task 1.2 Finite Element Model Development (Physical modeling)

Initial feasibility work is under way

- Clarifying validity and limitations of Abaqus ductile failure damage models with Tensile Test model
- Will follow with planing induced micro -fracture models to re -create machining damage behavior







Task 1.2 Finite Element Model Development (Physical modeling)

Proposed materials for 7 case studies in stage 2

Sample ID	K (ksi*sqrt(in))	YS (ksi)	UTS (ksi)	Steel Type	Seam Type
1	Low: 68	45	69	Rimmed/Capped	LF-ERW
2	Med: 91	56	81	Si Killed	Seamless
3	High: 139	63	81	Rimmed/capped	LF-ERW
4	Low: 90	75	84	Semi-killed	HF noPWHT-ERW
5	Med: 125	72	83	Si Killed	SAW
6	High: 162	72	79	Rimmed/capped	HF PWHT-ERW
7	High: 169	91	91	Si Killed Al added	HF PWHT-ERW

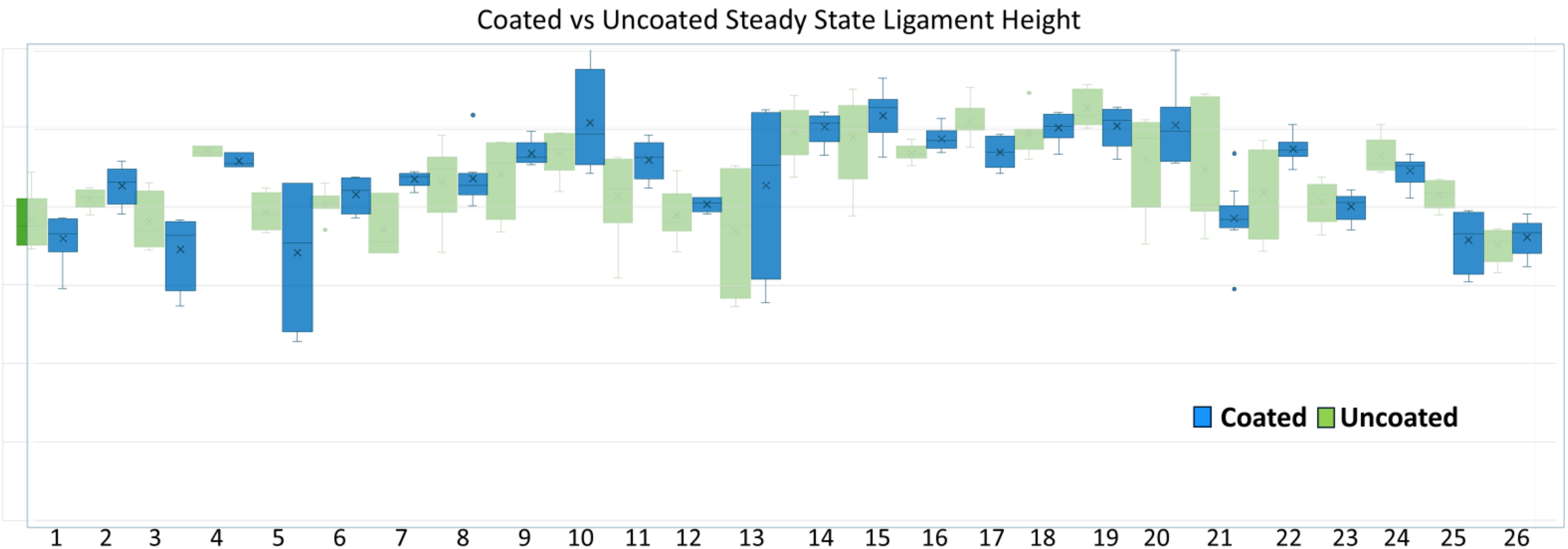
Task 1.3 Blade Design Optimization

Work started in January report, continued into Q1 2025. (Estimated completion 75%)

- Task 1.3.1: Optimize material response for consistency and dependence on fracture toughness
  - Evaluate influence of coating on material response (completed)
    - Do coatings reduce test to test variation?
  - Draw on learnings from completed FEA (pending)
- Task 1.3.2: Reduce cut depth to minimize the invasiveness of the test without sacrificing accuracy
  - Evaluate efficacy of sharper blades (completed)
  - Draw on learnings from completed FEA (pending)
- Task 1.3.3: Optimize blade life to reduce test cost
  - Evaluate influence of coating on blade life (completed)

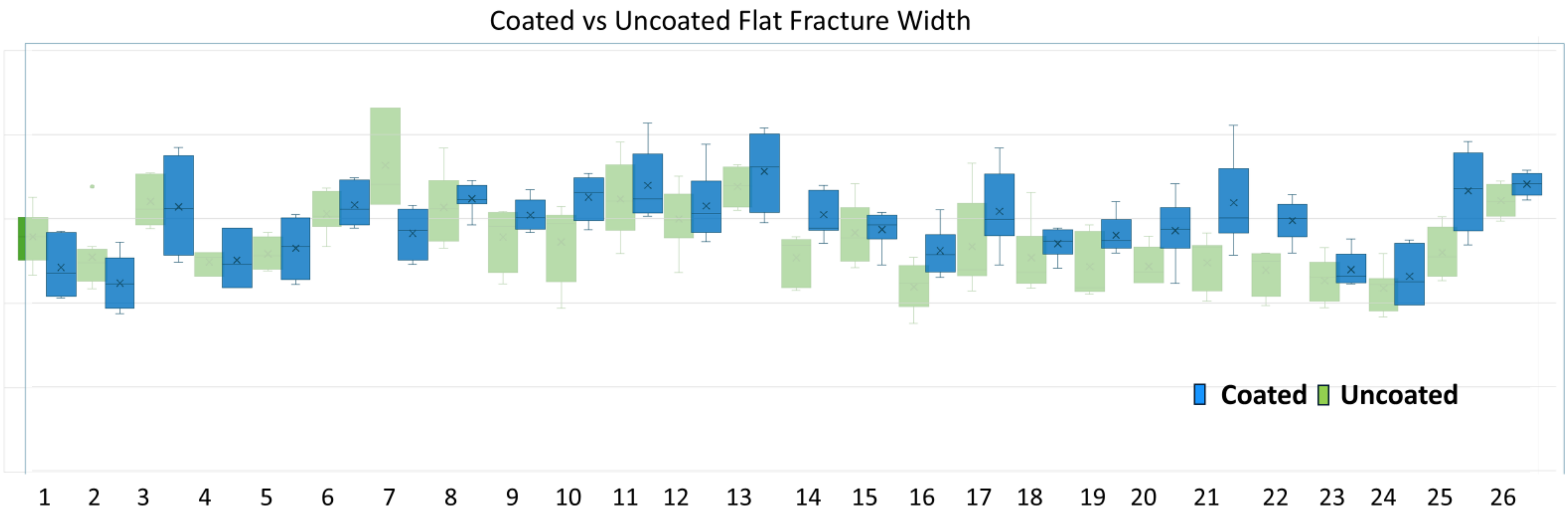
Task 1.3 Blade Design Optimization

Task 1.3.1 & Task 1.3.3: Effect of coating on material response



Task 1.3 Blade Design Optimization

Task 1.3.1 & Task 1.3.3: Effect of coating on material response



Task 1.3 Blade Design Optimization

Task 1.3.1: Effect of coating on material response

Summary of findings shown in box plots

- Impact to ligament height: not discernable from typical test -to-test variation
- Impact to flat fracture width: coating causes approximate increase of 10% in width of flat fracture

Task 1.3.3: Optimize blade life to reduce cost

General approach explored the implementation of a coating on the existing tungsten carbide blade

- Parallel testing of uncoated and coated blade
- Blade Life Comparison:

	Uncoated Blade	Coated Blade
blades used	36	3
tests produced	105	163
tests per blade	2.9	54.3
samples per blade	0.4	6.8
Improvement	17x	

Task 1.3 Blade Design Optimization

Task 1.3.1/1.3.2: optimize material response & reduce cut depth

- General approach is to explore some variations of blade geometry
  - Various tip sharpness, sharper should enable shallower test depths
  - Various curvatures leading into stretch passage could improve material response for test consistency

Initial testing of these parameters has been carried out. Results as follows:

- Standard blade sharpness used as reference. All blades were coated.
  - Blade w/4x sharpness broke upon interaction with a single test island. Could not generate good test.
  - Blade w/2x sharpness successfully tested 11 islands utilizing 6 blades
  - Blade w/1.5x sharpness tested 12 islands utilizing 5 blades

- Conclusions
  - Move to implement 2x sharpness with a more cost -effective blade holder / blade manufacturing geometry
  - Utilize sharper blade opposite historical blade during initial work to ensure backward compatibility

Milestone 2 Items Beginning

Milestone 2 tasks beginning ahead of schedule

Following success with early physical model development (cumulative strain model) and general testing, work is underway to enable first field pilot tests

- Task 2.1: Field Device Development (originally Q2 2025, started in March)
- Task 2.2: Data Process and Analytics Optimization (originally Q3 2025, expected in Q2)
- Task 2.3: Field Procedure Optimization (originally Q4 2025, started in March)

Findings from prior tasks will be incorporated to enable backward compatibility of initial pilot work

- Task 1.3 Blade findings will be brought into first pilot work
  - Historical blade and new coated blades utilized in parallel
- Task 1.2 FEA findings will work hand in hand with data collection procedures in place for first pilot work

Milestone 2 Items Beginning

Why: January 2025 Breakthrough

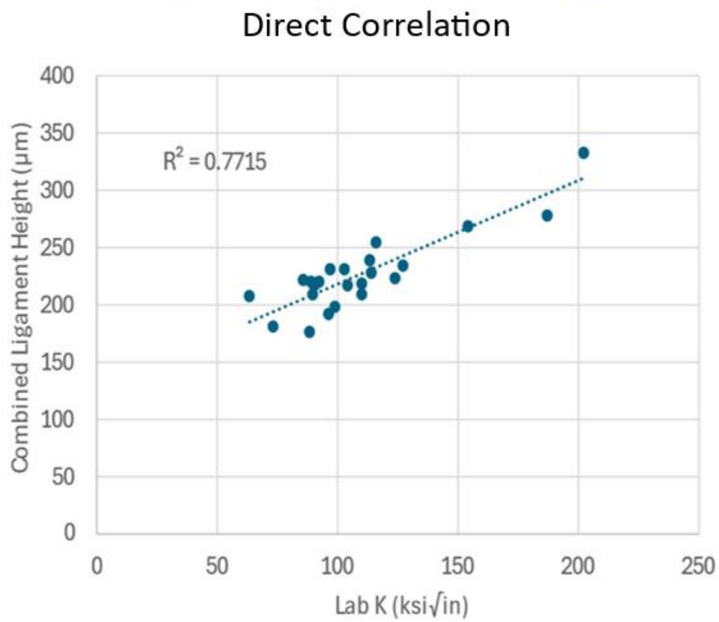


Figure 3. Correlation between Combined Ligament Height (y-axis) and Lab K (x-axis).

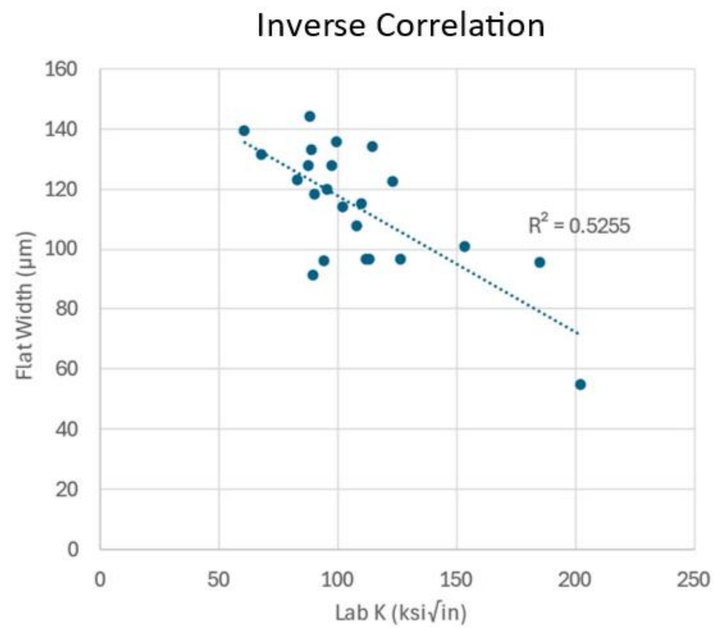


Figure 6. Correlation between Flat Width (y-axis) and Lab K (x-axis).

JIP Milestone Summary: Blind #20250123

Why: February Milestone with Joint Industry Program

- Input parameters: 3
- Database size: 34
- Blind testing samples: 9
- Result:
  - 1 outlier: Led to process improvement
  - The 1-sided 90 pct certainty prediction interval for remaining 8 samples was **11.6 ksi√in**. (Conservative shift of **20 ksi√in**. remains the suggested approach)

- Next steps:
  - Growing database size / blind testing size
  - Field pilot projects (Hence the need to kick -start project Milestone 2)

Milestone 2 Items Beginning

Milestone 2 tasks beginning ahead of schedule

- Following success with early physical model development (cumulative strain model) and recent blind testing, work is underway to enable first field pilot tests
- Task 2.1: Field Device Development (originally Q2 2025, started in March)
  - Initial improvements are being made to the blade holder, electronics box, and tester attachment system
  - These improvements are aimed at improving the reliability, durability, and ease of use of the tester
  - These improvements are expected to satisfy mechanical needs until commercial tool design starts in q4 of 2025
  - Some time has been put to this end so far
- Task 2.2: Data Process and Analytics Optimization (originally Q3 2025, expected in Q2)
  - Effort has been put into laying out a specification and overall work flow for ongoing improvement of the prediction models and analytics
  - Minimal time has been put toward this at this time
- Task 2.3: Field Procedure Optimization (originally Q4 2025, started in March)
  - Work on this has started significantly ahead of schedule as it has acted as a roadblock to the enablement of early pilot work in field