Investigation of the Mechanics of Rail Seat Deterioration (RSD) and Methods to Improve the Abrasion Resistance of Concrete Sleeper Rail Seats



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Outline

- Objectives
- Rail seat deterioration (RSD) background
- Large-scale abrasion test
  - Evaluation of frictional properties
- Small-scale test for abrasion resistance
  - Results
- Conclusions and future work

Objectives

- Understand the mechanics of the most critical failure modes
  - Investigate parameters that affect abrasion mechanism
  - Characterize frictional forces between rail seat and rail pad
- Propose methods of mitigating the critical failure modes
  - Quantify abrasion resistance of various concrete mix designs, curing conditions, and surface treatments

2012 International Survey Results

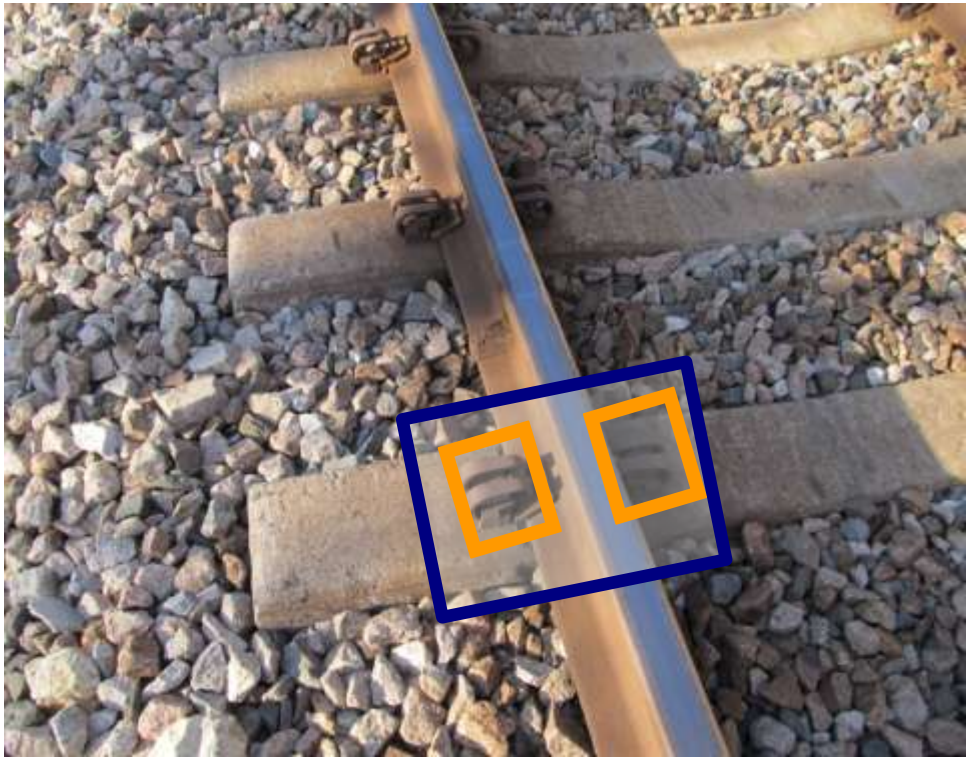
Criticality of Problems – North American Responses

Failure Mode	Average Rank
Deterioration of concrete material beneath the rail	6.43
Shoulder/fastening system wear or fatigue	6.38
Cracking from dynamic loads	4.83
Derailment damage	4.57
Cracking from center binding	4.50
Tamping damage	4.14
Other (e.g. manufactured defect)	3.57
Cracking from environmental/chemical degradation	3.50

Research Topic	Average Rank
Prevention or repair of rail seat deterioration	3.60
Fastening system design	3.60
Materials design	3.00
Optimize crosstie design	2.80
Track system design	2.00

Rail Seat Deterioration (RSD)

- Degradation of concrete material under rail and pad
  - Increases maintenance costs
  - Shortens service life



Plan view of concrete sleeper track

Plan view of deteriorated rail seat

Profile view of damaged rail seat

Mechanics of Abrasion

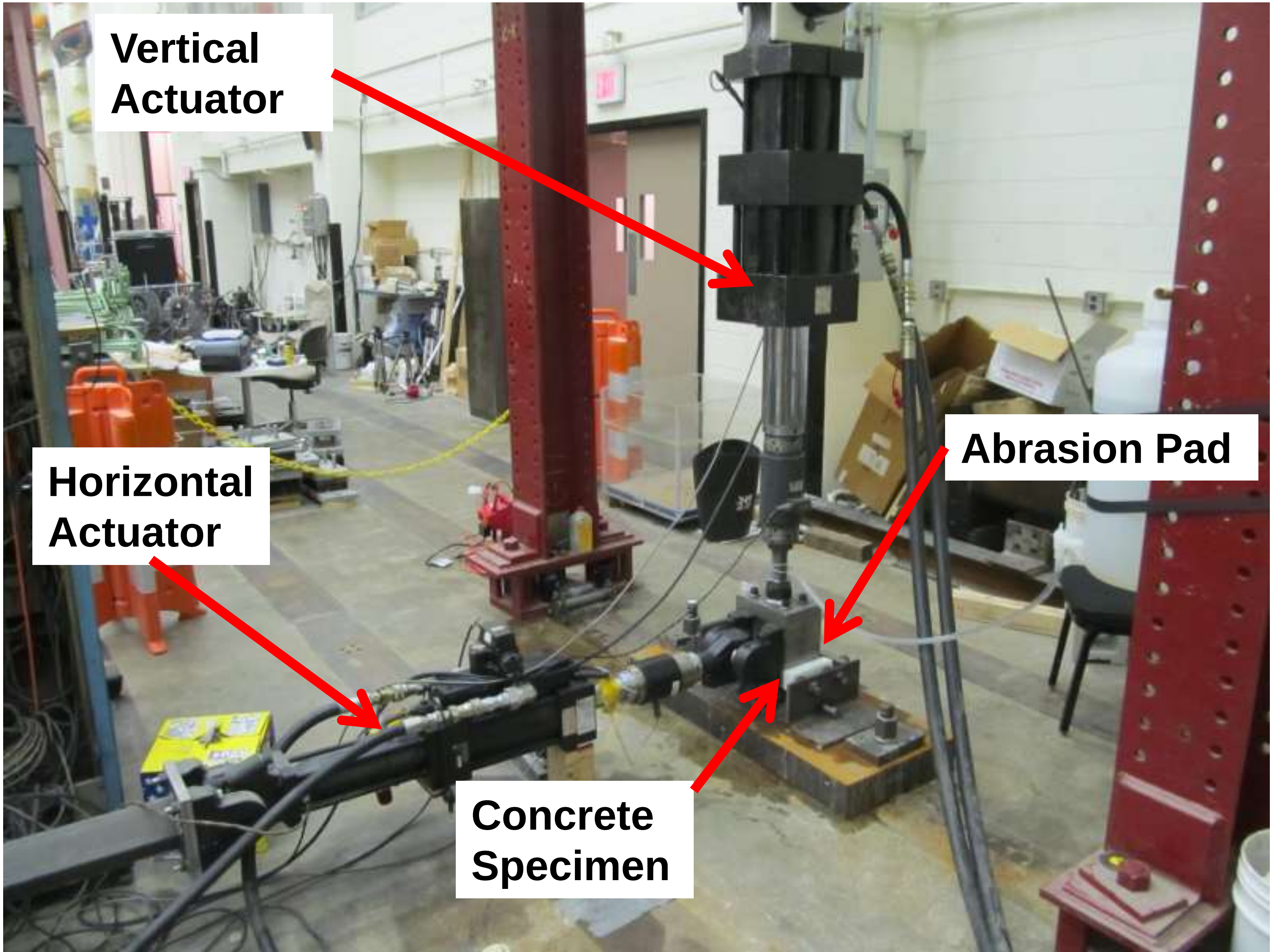
- Abrasion is a progressive failure mechanism that occurs when:
  - Frictional forces act between two surfaces in contact
  - Relative movement occurs
  - Harder surface cuts or ploughs into the softer surface

- Progression of abrasion at the rail seat
  1. Cyclic motion of rail base under wheel loads induces normal and shear forces
  2. Shear forces overcome static friction and the pad slips relative to the concrete
  3. Strain is imparted on concrete matrix
     - Abrasion involves 3-body wear: two interacting surfaces (rail pad assembly and rail seat) and abrasive slurry (water and fines)

Large-Scale Abrasion Test (LSAT)

- Objectives:
  - Isolate abrasion mechanism
  - Maintain representative contact mechanics
  - Understand effect of variables on abrasion rate
    - Load magnitude, displacement, water, sand, **friction**
  - Establish most abrasive parameters to evaluate rail seat materials and surface treatments
- Test Setup: 1:4 scale
  - Normal force: 13 kN – 44 kN (53 kN – 180 kN rail seat load)
  - Displacement: 2-3 mm
  - 152 mm x 152 mm x 76 mm concrete specimens (>48 MPa)
  - 76 mm x 102 mm x 19 mm stock pad materials
    - Nylon 6/6, polyurethane
  - Contaminates: laboratory sand, water

Large-Scale Abrasion Test Experimental Setup



Large-Scale Abrasion Test Experimental Setup

Loading head and concrete specimen fixed to strong floor

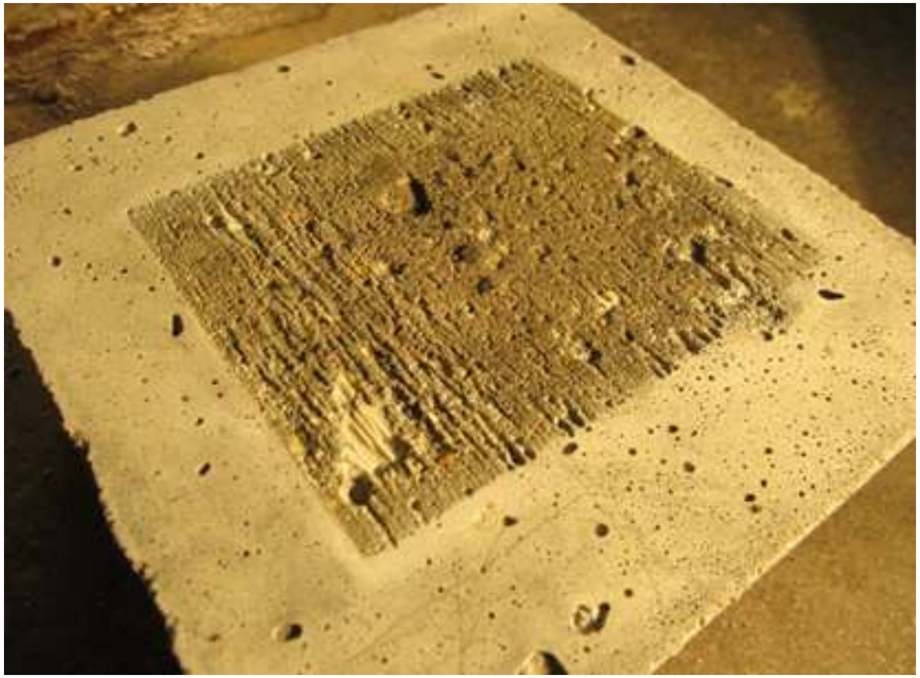
Pad material confined to cavity in loading head

Large-Scale Abrasion Test
Sample Results from Deterioration Tests

Concrete abraded with nylon 6/6

After 64,800 cycles,
Average wear depth = 0.028”

Concrete abraded with polyurethane



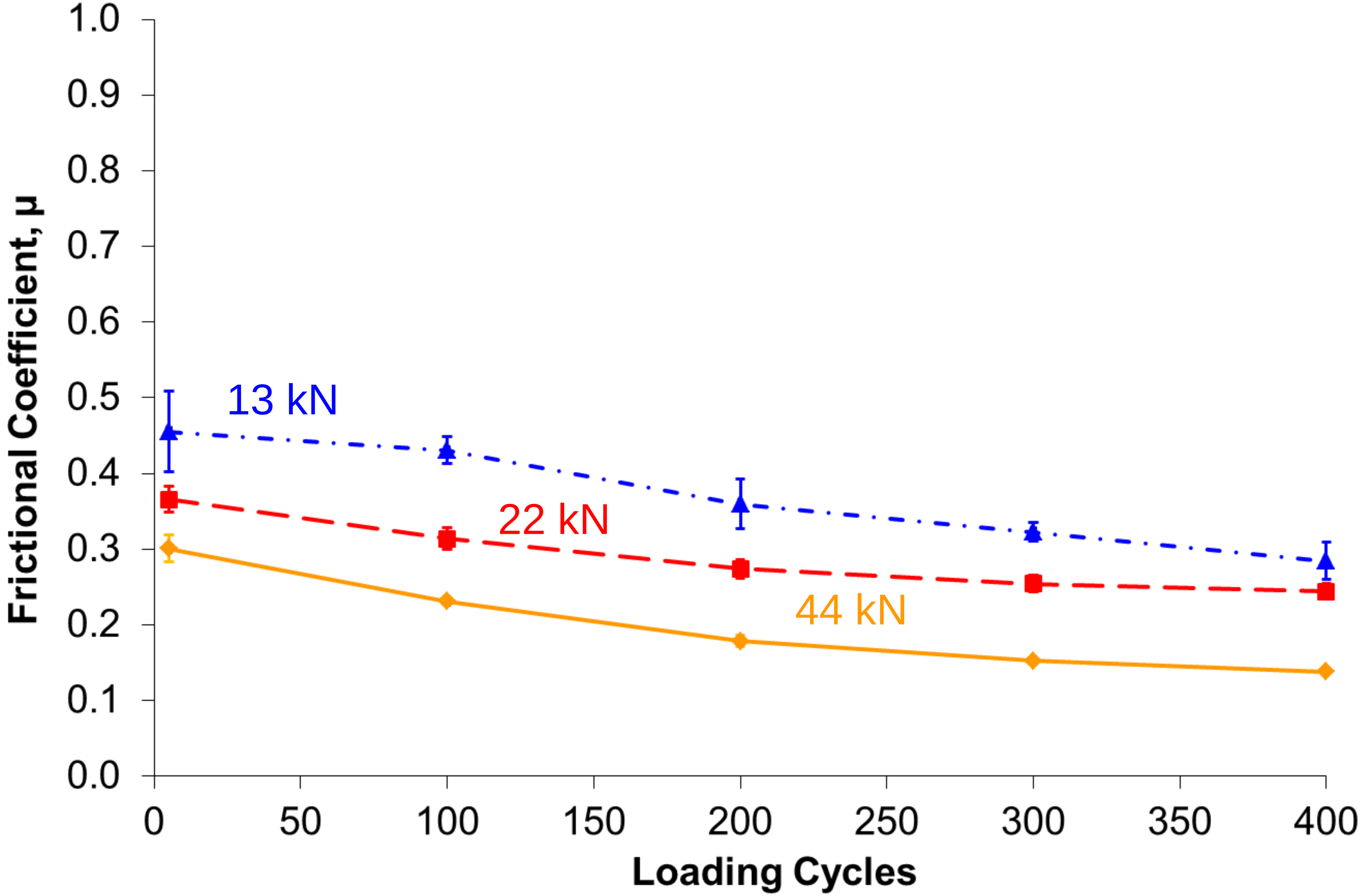
After 64,800 cycles,
Average wear depth = 0.012”

Large-Scale Abrasion Test
Sample Results from Deterioration Tests

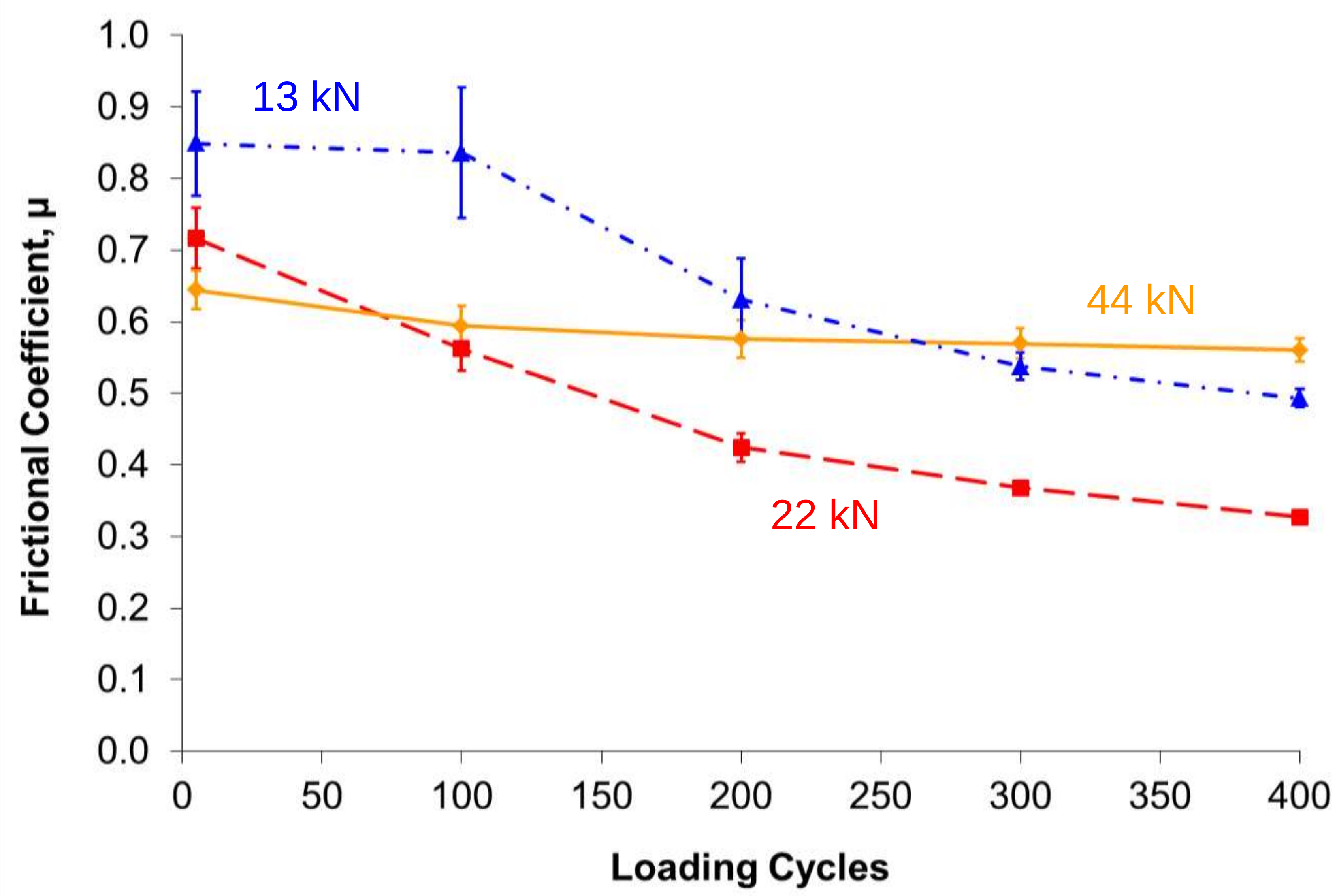
Nylon 6/6 Pad

Polyurethane Pad

Effect of Increasing Normal Load on Nylon 6/6

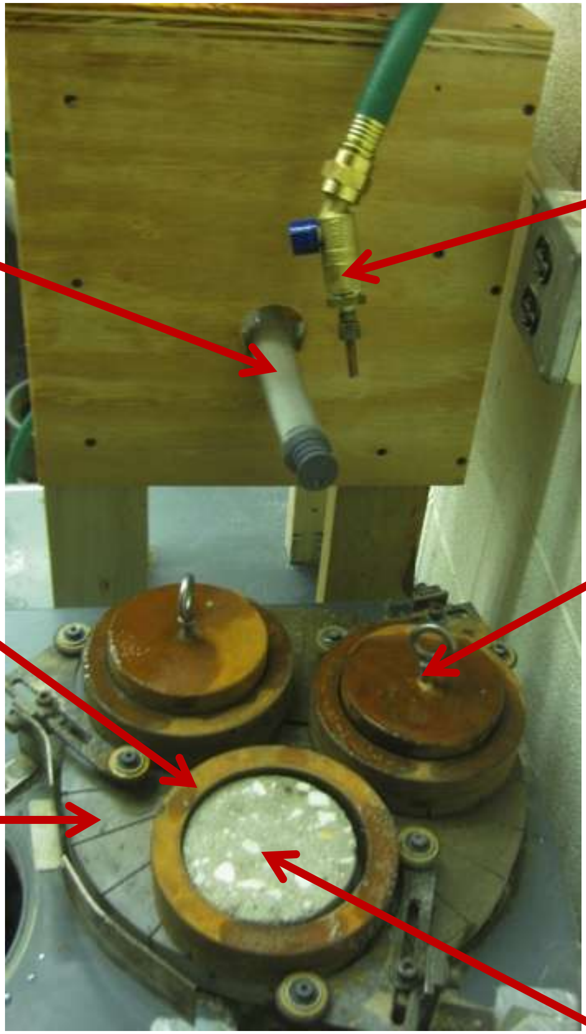


Effect of Increasing Normal Load on Polyurethane



Small Scale Test for Abrasion Resistance (SSTAR): Test Setup

- In general, similar to other standard abrasion tests
- Consists of a powered rotating steel wheel with 3 lapping rings
  - Lapping rings permitted to rotate about their own axis
  - Vertical load applied using the dead weights
  - Abrasive sand and water dispensed during testing



SSTAR Test Protocol

- Each test can evaluate 3 specimens
- Multiple tests are run to evaluate more than 3 specimens
- Specimen dimensions:
  10 cm (diameter), 2.5 cm (thickness)
- Duration: 120 minutes
- Wear depth measurements taken every 20 minutes
- Speed: 60 revolutions per minute
- Abrasive fine: Ottawa 20-30 sand

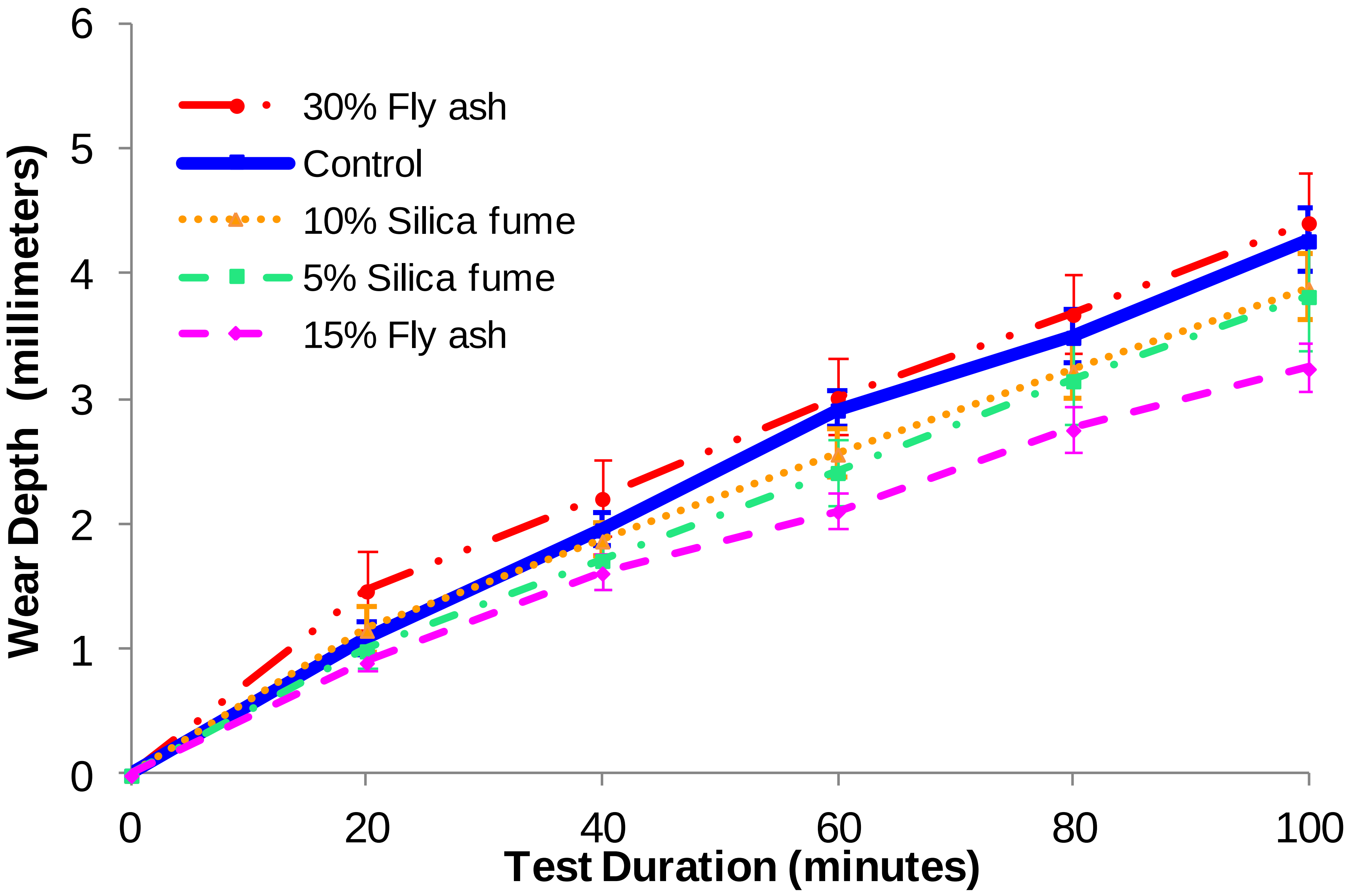

Before


After

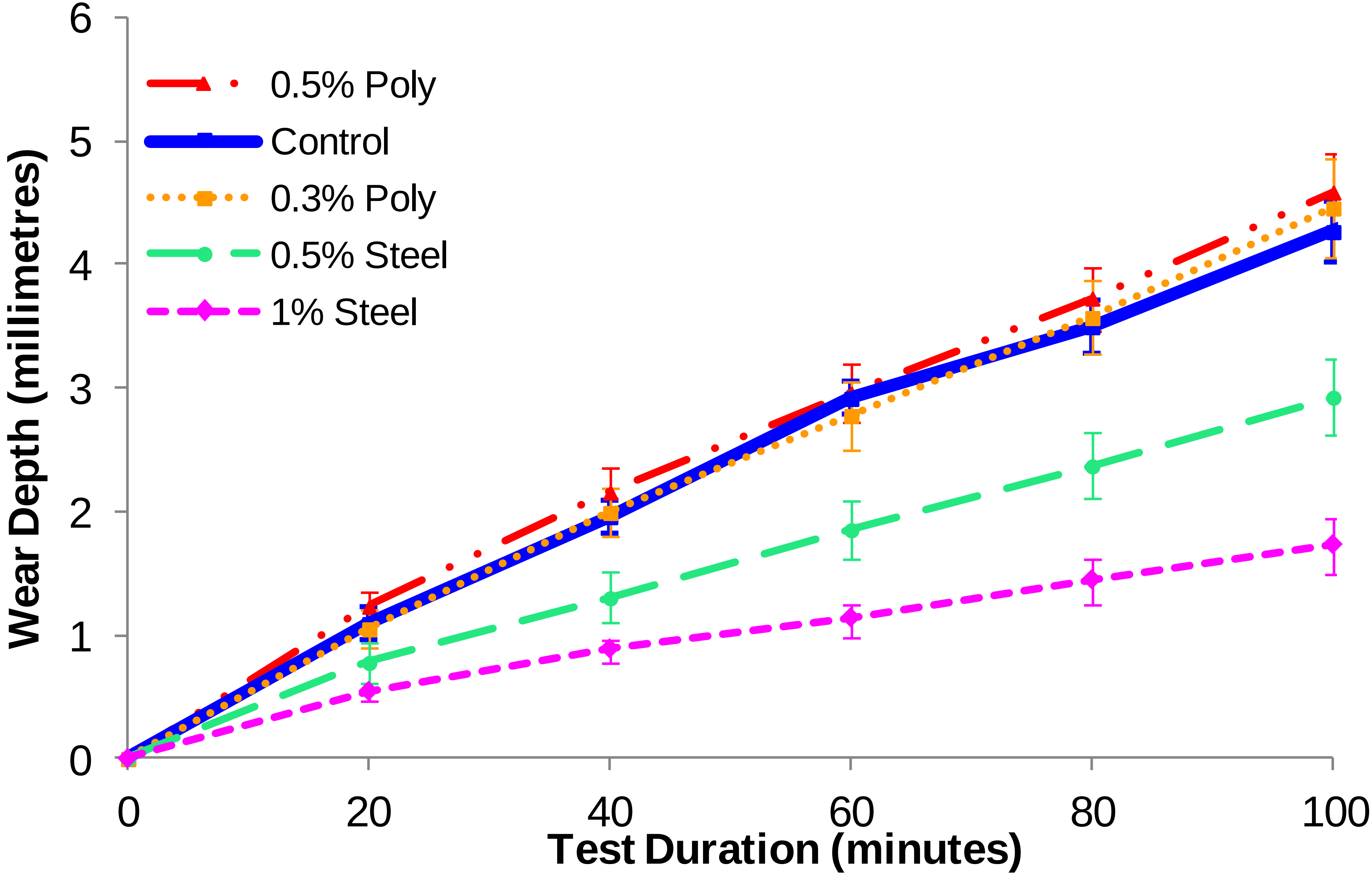
Experimental Methods of Mitigating Abrasion

- Mineral Admixtures
  - Silica fume: 5%,10%
  - Fly ash: 15%, 30%
- Curing Condition
  - Moist
  - Submerged
  - Oven dry
  - Air
- Fiber Reinforced Concrete (FRC)
  - Polyurethane
  - Steel
- Surface Treatments
  - Epoxy
  - Exposed aggregate

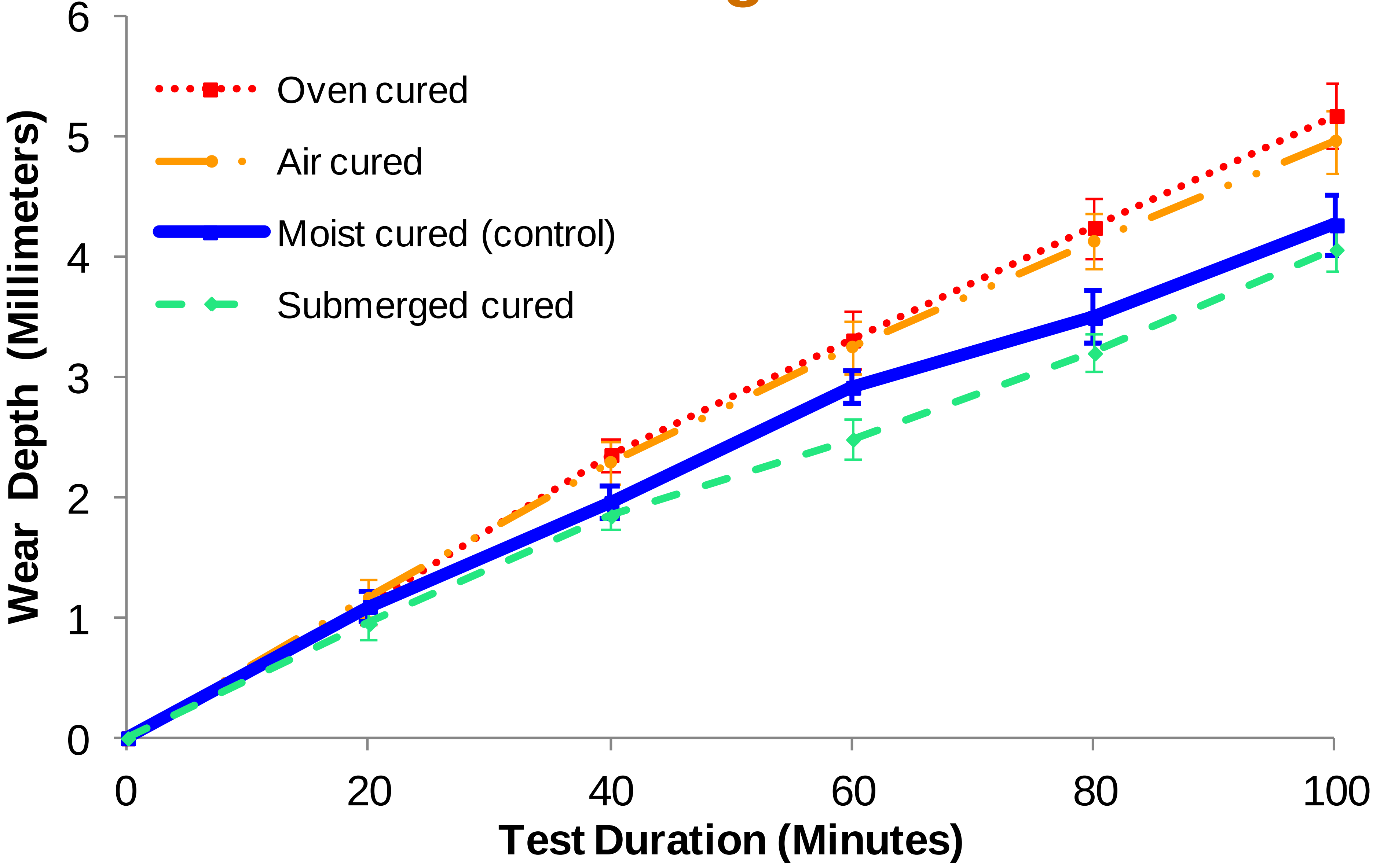
Effect of Mineral Admixtures



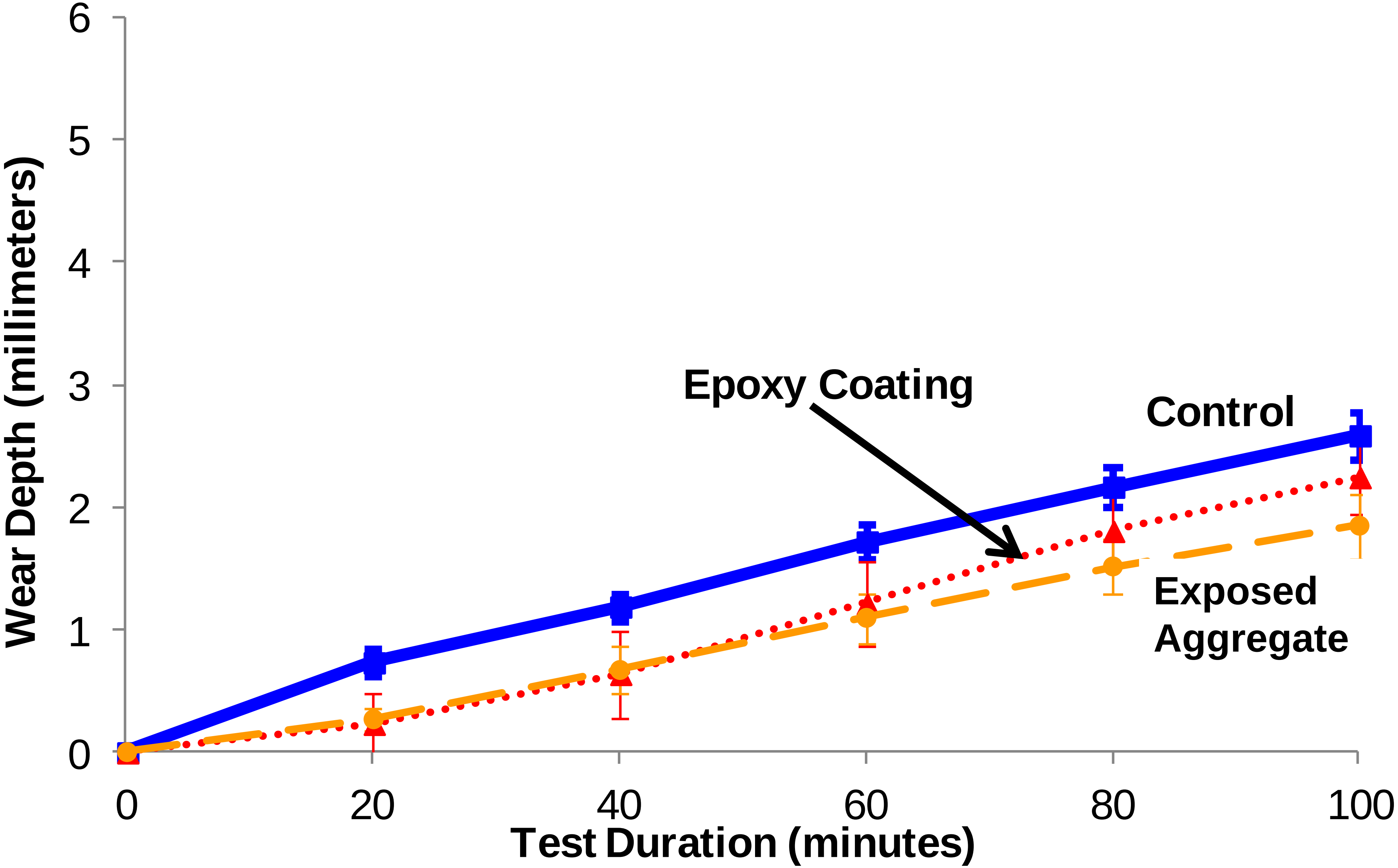
Effect of Fiber Reinforcement



Effect of Curing Conditions



Effect of Surface Treatments



Conclusions

- LSAT:
  - Confirmation of abrasion as a feasible RSD mechanism
  - Shear behavior of pad assembly may impact abrasion
    - Transfer of forces likely affected by coefficient of friction
      - Pad material, normal force, temperature, water/sand
- SSART:
  - – Successfully compared 13 approaches to improving abrasion resistance of rail seat through material improvements
  - – Improve abrasion resistance of concrete with:
    - Optimal amounts of fly ash
    - Proper curing condition
    - Addition of steel fibers
    - Exposed aggregate

Future Work

- Large-Scale Testing
  - Determining the optimal shear design at each interface of multi-layer rail pads (top, bottom, and between layers) could:
    - Reduce movement at critical interfaces, influence slip
    - Delay the onset of abrasive wear and extend rail seat life
    - Extend to other fastening system components
- SSTAR:
  - Perform image analysis to characterize the effect of exposed of coarse aggregate in abrasion resistance
  - Study the effect of air entrainment and quality of aggregates on abrasion resistance of rail seat
  - Optimize concrete mix design and surface treatments to mitigate abrasion
- Heavy haul railways that continue to build capacity by increasing axle loads should be aware of the potential of RSD

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Questions

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