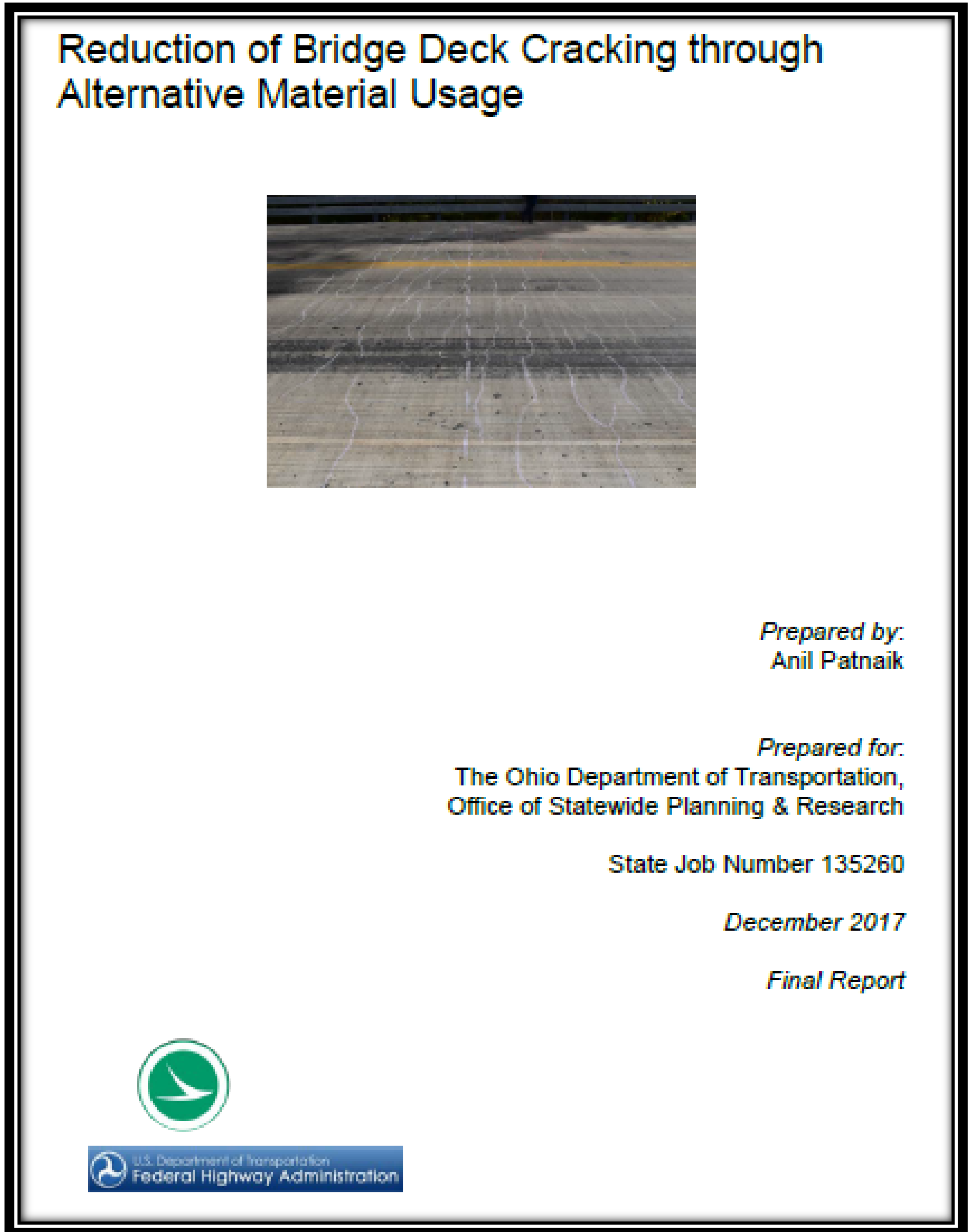
Reduction of Cracking in Concrete with Corrosion Resistant Reinforcement with and without Fibers

Mike Stroia

AZZ GalvaBar



Reduction of Bridge Deck Cracking through Alternative Material Usage

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Final Report

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Federal Highway Administration

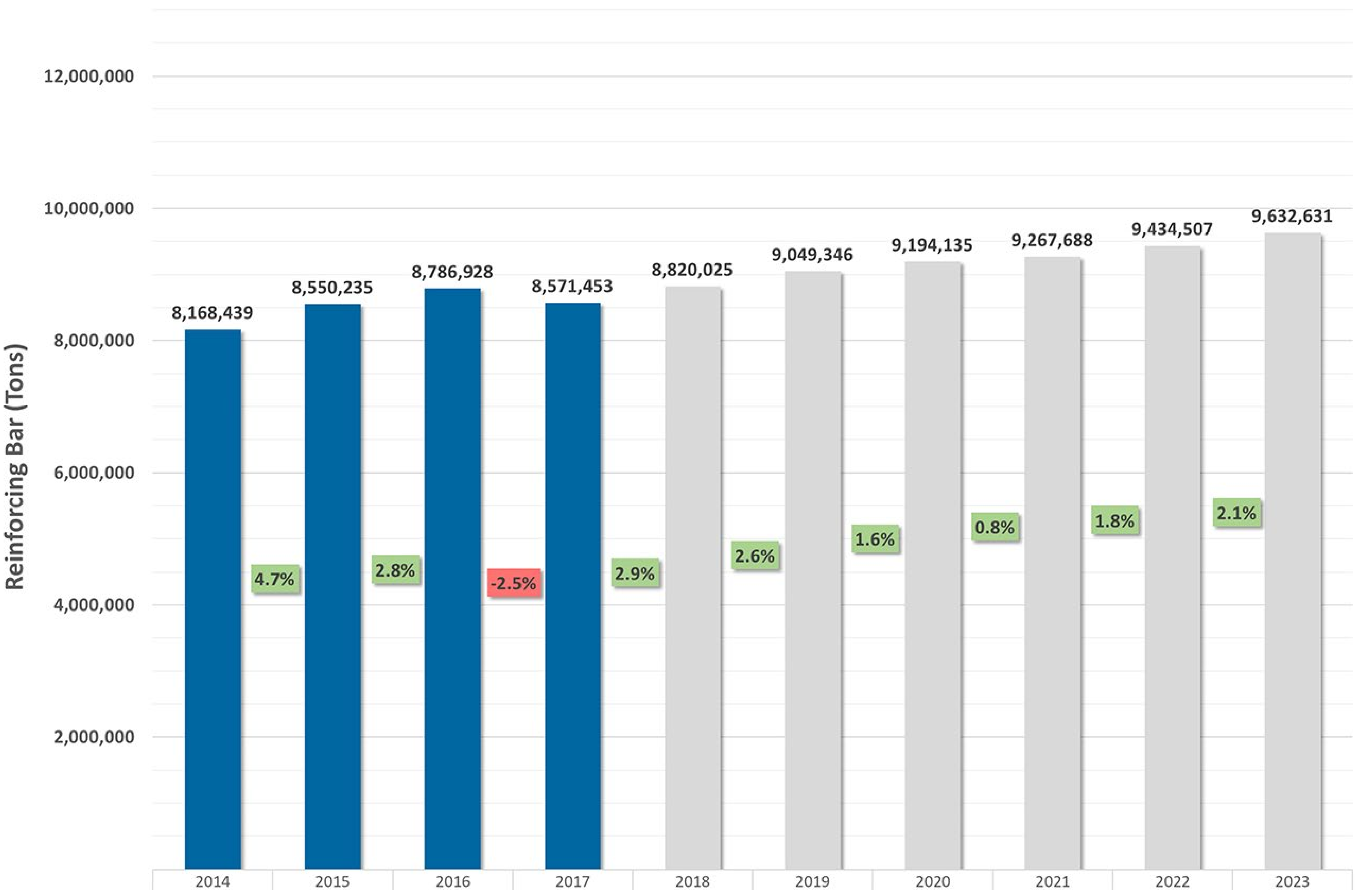
- Dr. Anil Patnaik is currently a professor of structural engineering and the associate chair of the Department of Civil Engineering at The University of Akron in Ohio, USA. He earned his Ph.D. from the University of Calgary, and Master's degree in Structural Engineering from the Indian Institute of Technology in Kanpur, and a Bachelor's degree in Civil Engineering from National Institute of Technology, Rourkela in India. He has held academic positions at South Dakota School of Mines and Technology (SDSM&T) in Rapid City, Curtin University in Perth (Australia) and currently, at the University of Akron in Ohio for over twenty years.
- His current and recently funded research projects are on corrosion of reinforced concrete and steel structures, reinforced concrete members subjected in impact loads; synthetic and basalt fiber reinforced concrete (FRC); fiber reinforced polymer (FRP) materials for structural concrete applications; repair and strengthening of existing structures; construction and long term performance monitoring of bridge decks; structural slab bridges; prestressed concrete adjacent box-beam bridges, and carbon footprint assessment and life cycle analysis (LCA).
- He is the author or co-author of over 120 technical papers, and 100 research and design reports. He also co-edited two conference proceedings on high volume fly ash concrete and high performance high strength concrete, and authored a design guide book on basalt FRP reinforced structural concrete. He also worked as a practicing engineer for several years in design and construction of large industrial, commercial and offshore structures, and tall buildings. He taught and continues to teach several courses on structural engineering including reinforced and prestressed concrete design, FRP reinforced concrete design, senior design, tall building design, steel design and structural analysis at the undergraduate and graduate levels.

Survey Says………

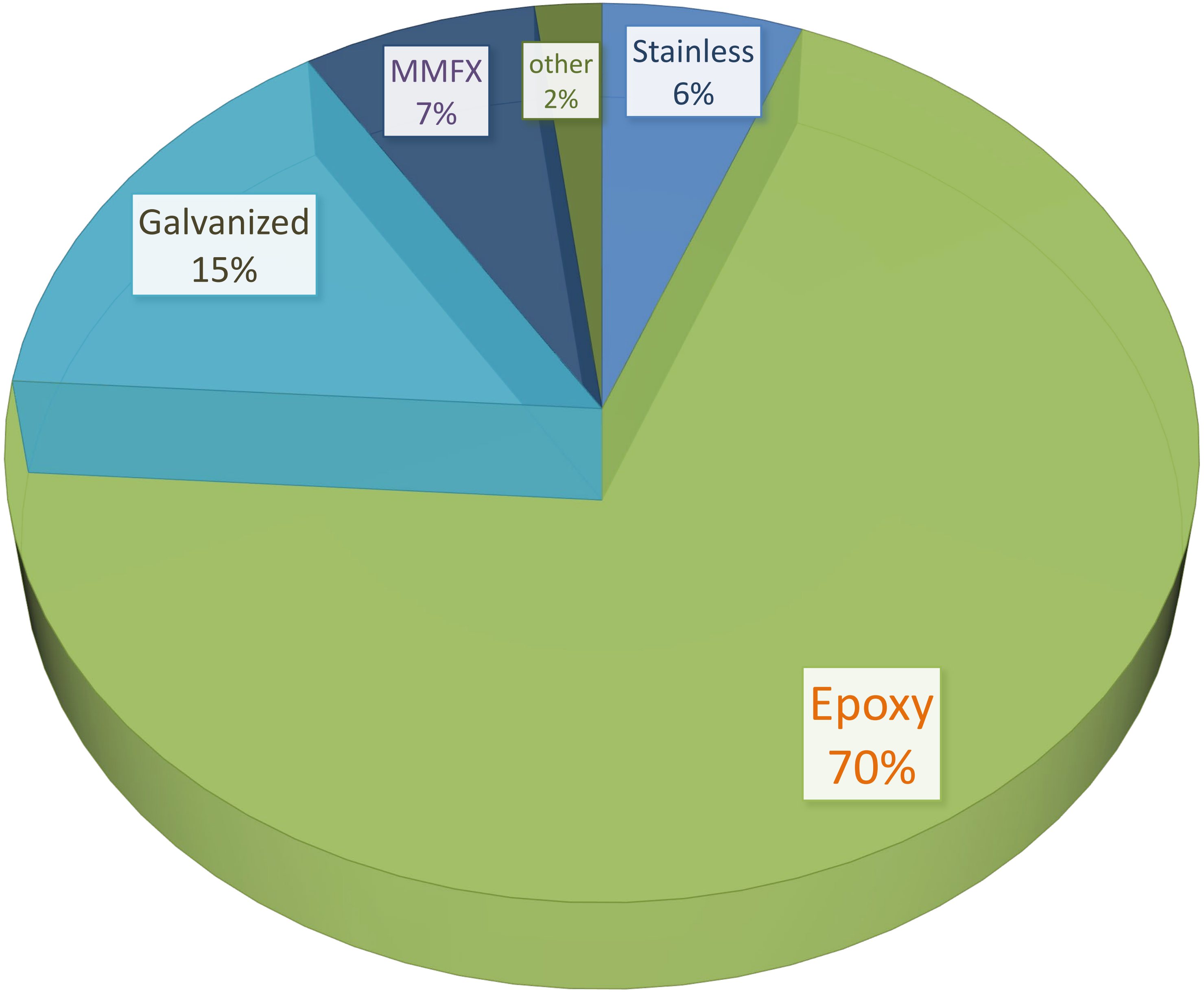
- ODOT routinely deploys a large number of continuous span structural slab bridges designed to strictly satisfy all the relevant AASHTO and ODOT BDM requirements
- Bridge decks show transverse cracks, with widths greater than those predicted using AASHTO 2012 and ACI 318-14 guidelines, after being in service for less than one year.
- The addition of polypropylene fiber to deck concrete has the potential to reduce such cracking. The overall goal of this project was to identify materials and methods to reduce the extent and severity of deck cracking for structural slab bridges and determine the effectiveness of fiber for this purpose.
- From the crack surveys of 30 bridges in various ODOT districts it was found that crack widths of transverse cracks were in excess of the recommended limit of 0.007" on 26 of the surveyed bridges.
- Meeting the maximum crack width limit of 0.007" for bridge decks reinforced with epoxy-coated bars is unrealistic and unachievable with current ODOT practices, and this limit may need to be reconsidered.
- The addition of fiber to deck concrete without any changes to the reinforcement details of continuous span structural slab bridges was determined to reduce the extent and the severity of cracking by a factor of about 3 to 4, making it plausible to reduce crack widths in future bridge decks.

- As very little research has been performed on the use of corrosion-resistant bars as a means for reducing cracks on bridge decks, various experiments were designed to gain insight specifically into the effects of each reinforcement type on bridge deck cracking.

CRSI Reinforcing Bar Forecast – USA Total



CORROSION RESISTANT REBAR MARKET %



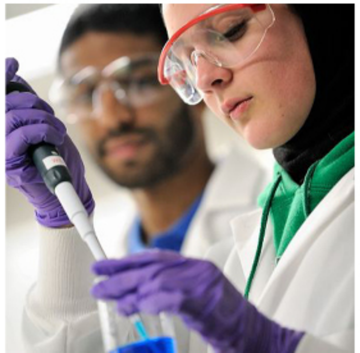
1 Million Tons

Comparison of Concrete Reinforcing Bar Performance Using Pull-Out and Corrosion Tests

Anil Patnaik, PhD

Professor, Dept. of Civil Engineering

August 3, 2018



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Significance of Pull-out Tests

The pull-out test provides a good indication of the performance of the corresponding corroded or uncorroded reinforced structural concrete in:

(i) Bond strength, development and anchorage in structural concrete

(ii) Moment strength of beams and slabs

(iii) Cracking potential of beams and slabs

(iv) Fatigue loading of beams and slabs

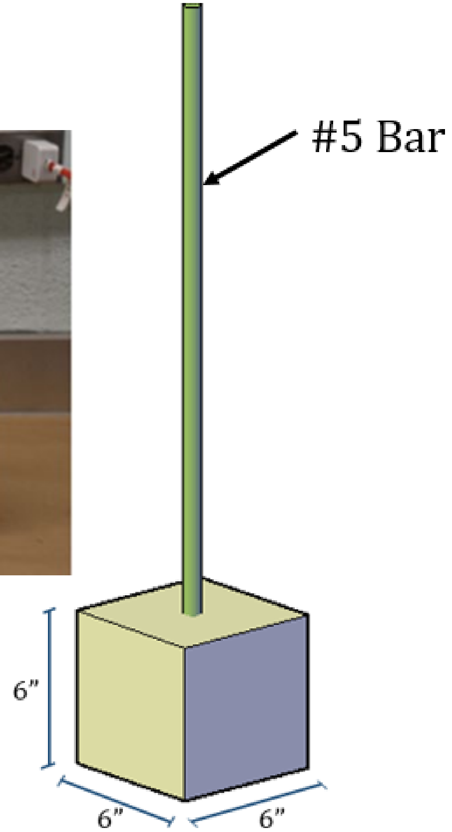
(v) Impact loading on concrete structures

This test is cost-effective and particularly useful for comparison between different reinforcing bars and different concrete types

Pull-out Tests

For comparison, pull-out tests were conducted using prism specimens under identical conditions for all the bar types

Typical Cast Specimens



Test Specimen Dimensions

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Types of Reinforcing Bars Compared

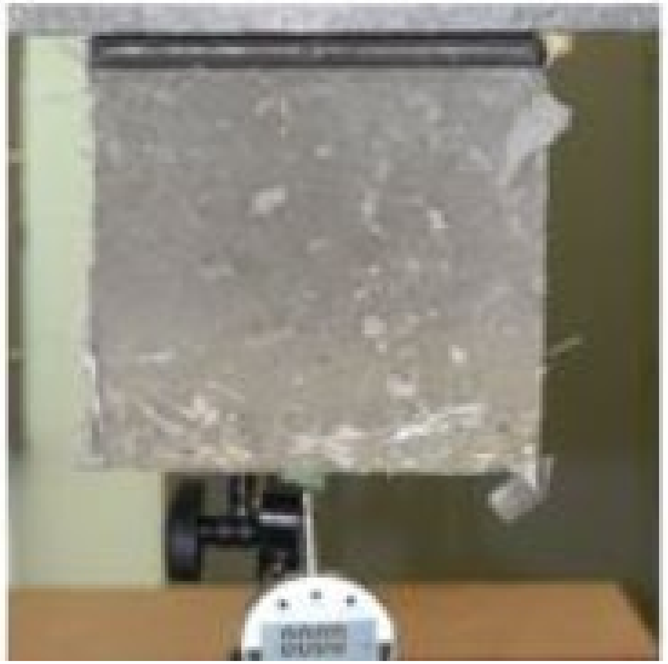
- CGR – continuously galvanized rebar
- MMFX – ChromX 9100 ASTM A1035-CS Grade 100
- SS – Stainless Steel ENDURAMET 2304 Hot Finish Unannealed Pickled Yield Min 60.0 ksi
- Black bars - Grade 60 uncoated black bars
- HDG – hot-dip galvanized
- ECB – Epoxy-coated bars

Typical Bar Types

Factors Considered

- Different bar types
- Concrete with and without polypropylene fiber (10 lb/yd^3)
- Specimens with and without being subjected to accelerated corrosion

Accelerated Corrosion Test Set-up

Test setup for pull out Specimen and dial gauge setup

Results Presented and List of Figures

Group I: Comparison between all six bar types:

- Fiber with no Corrosion (FNC)
- Corrosion with Fiber (CWF)
- No Fiber no Corrosion (NFNC)
- Corrosion with no Fiber (CNF)

Group II: Comparison between corrosion-resistant bars only (CGR, MMFX, SS, ECB):

- Fiber with no Corrosion (FNC)
- Corrosion with Fiber (CWF)
- No Fiber no Corrosion (NFNC)
- Corrosion with no Fiber (CNF)

Group III – Comparison between common bars only (CGR, Black, ECB):

- Fiber with no Corrosion (FNC)
- Corrosion with Fiber (CWF)
- No Fiber no Corrosion (NFNC)
- Corrosion with no Fiber (CNF)

Group IV – Effects of fiber and corrosion for common bars

- CGR, Black Bar, ECB

Test Results

Group I: All Bars

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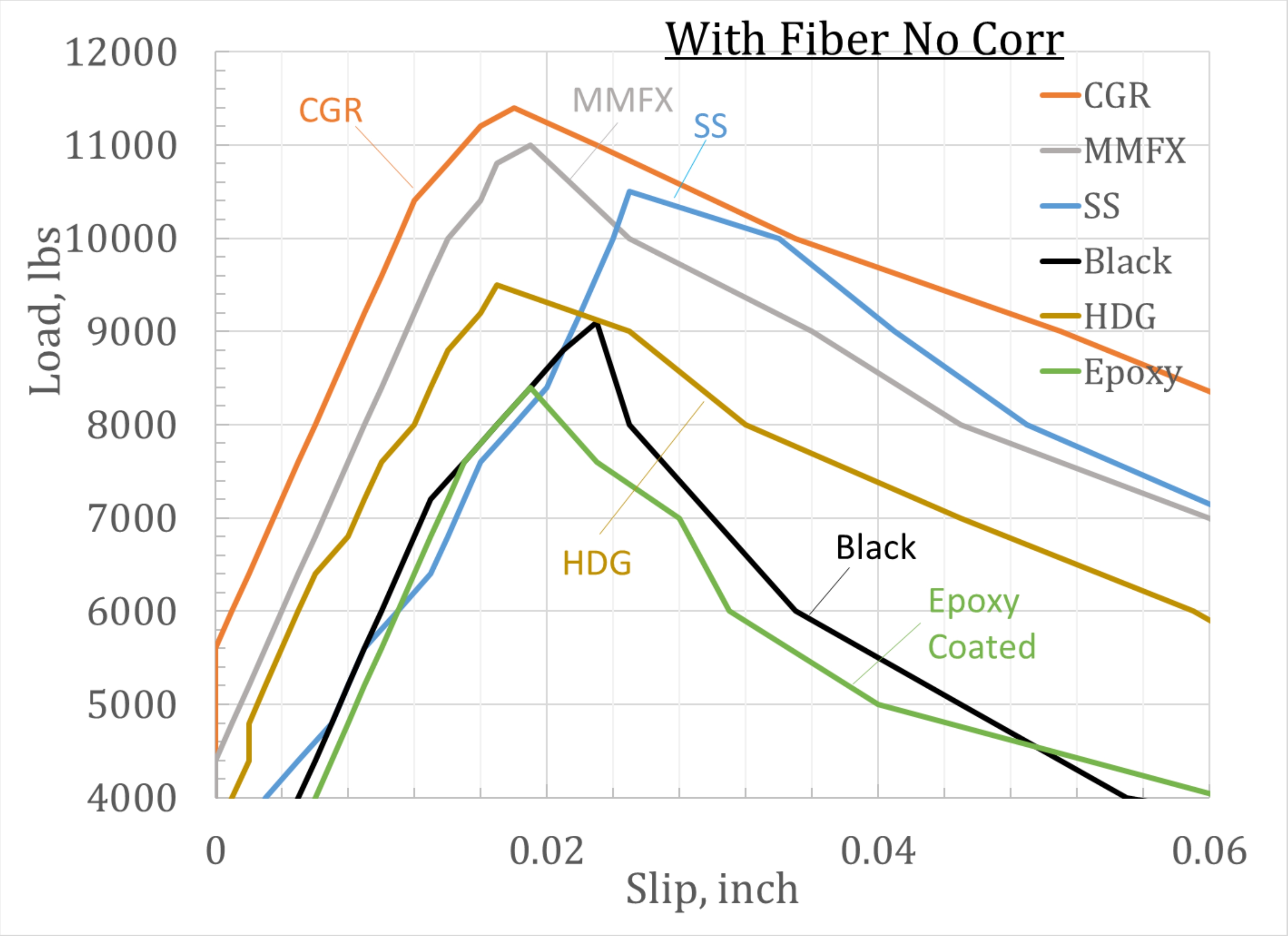
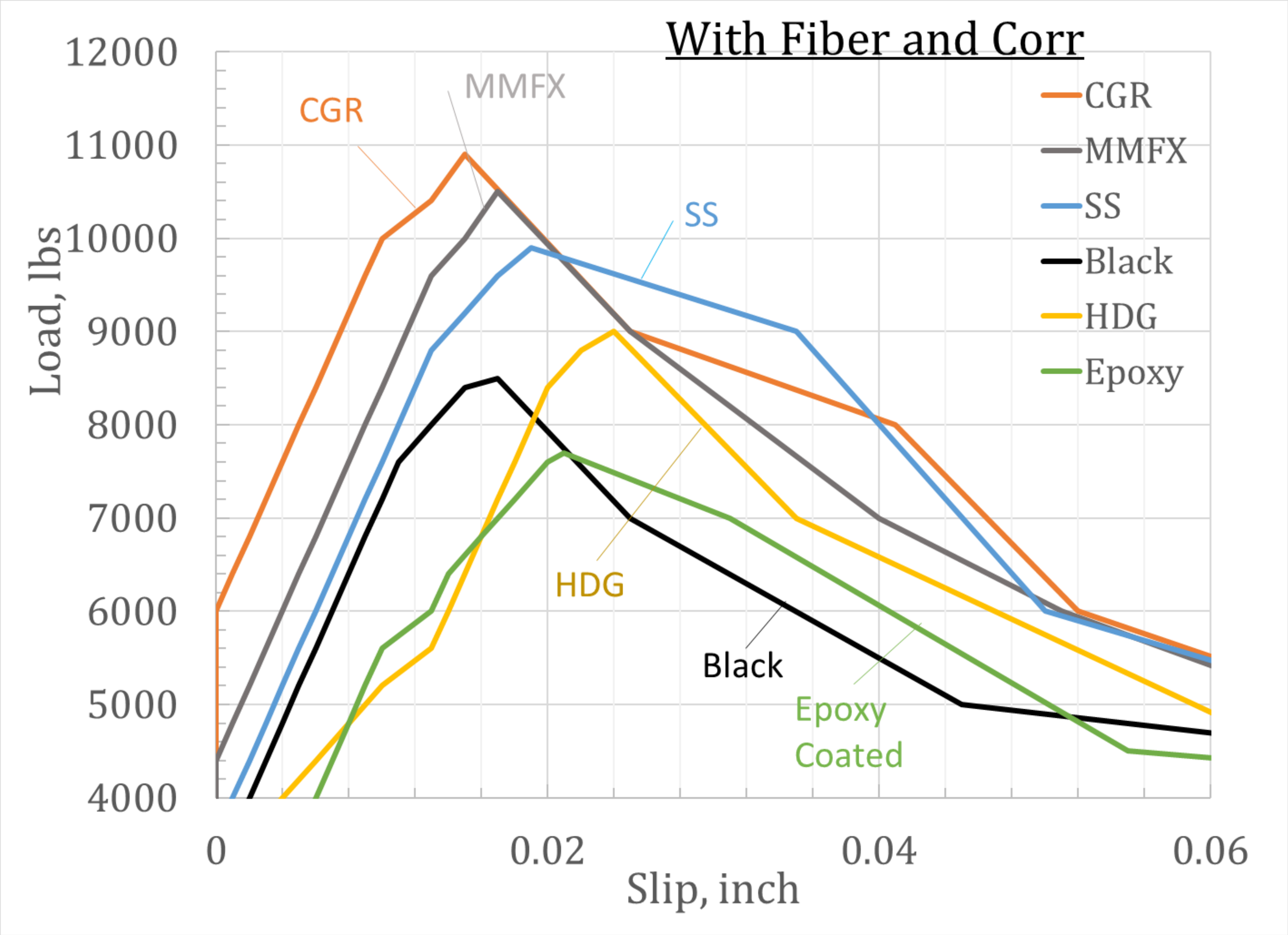
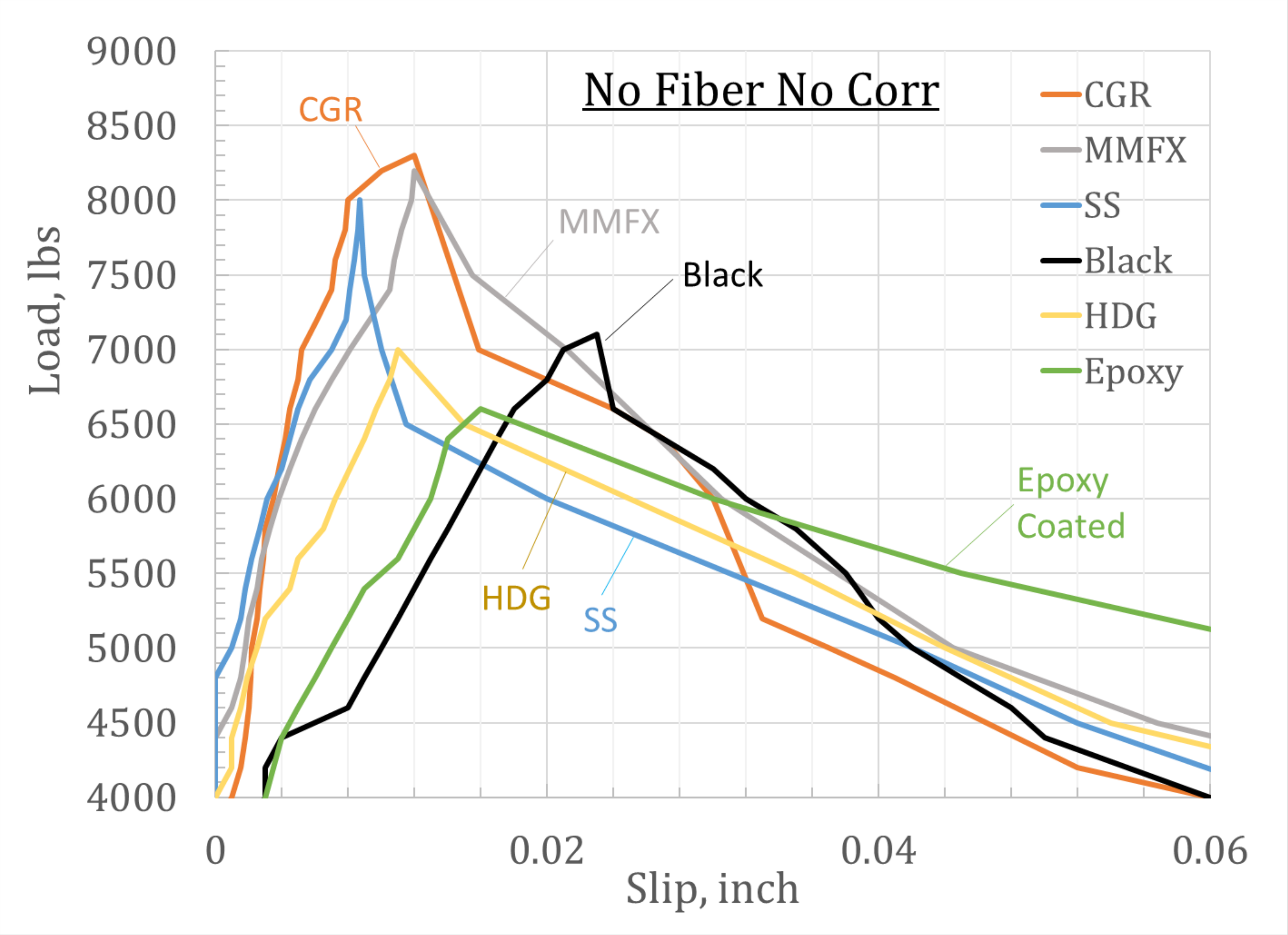
Fiber with No Corrosion



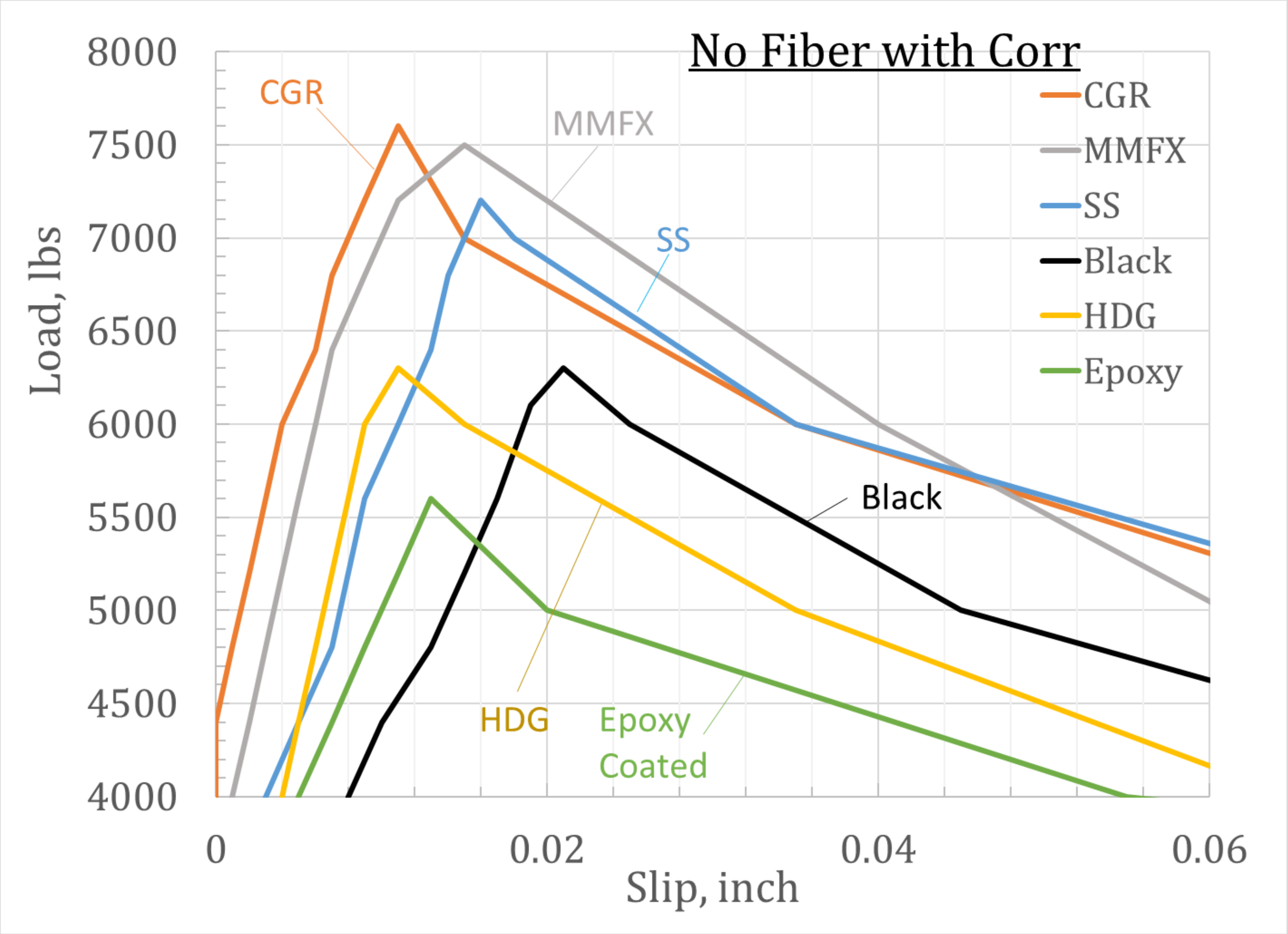
Corrosion with Fiber



No Fiber No Corrosion



Corrosion with No Fiber



Test Results

Group II: Corrosion Resistant Bars

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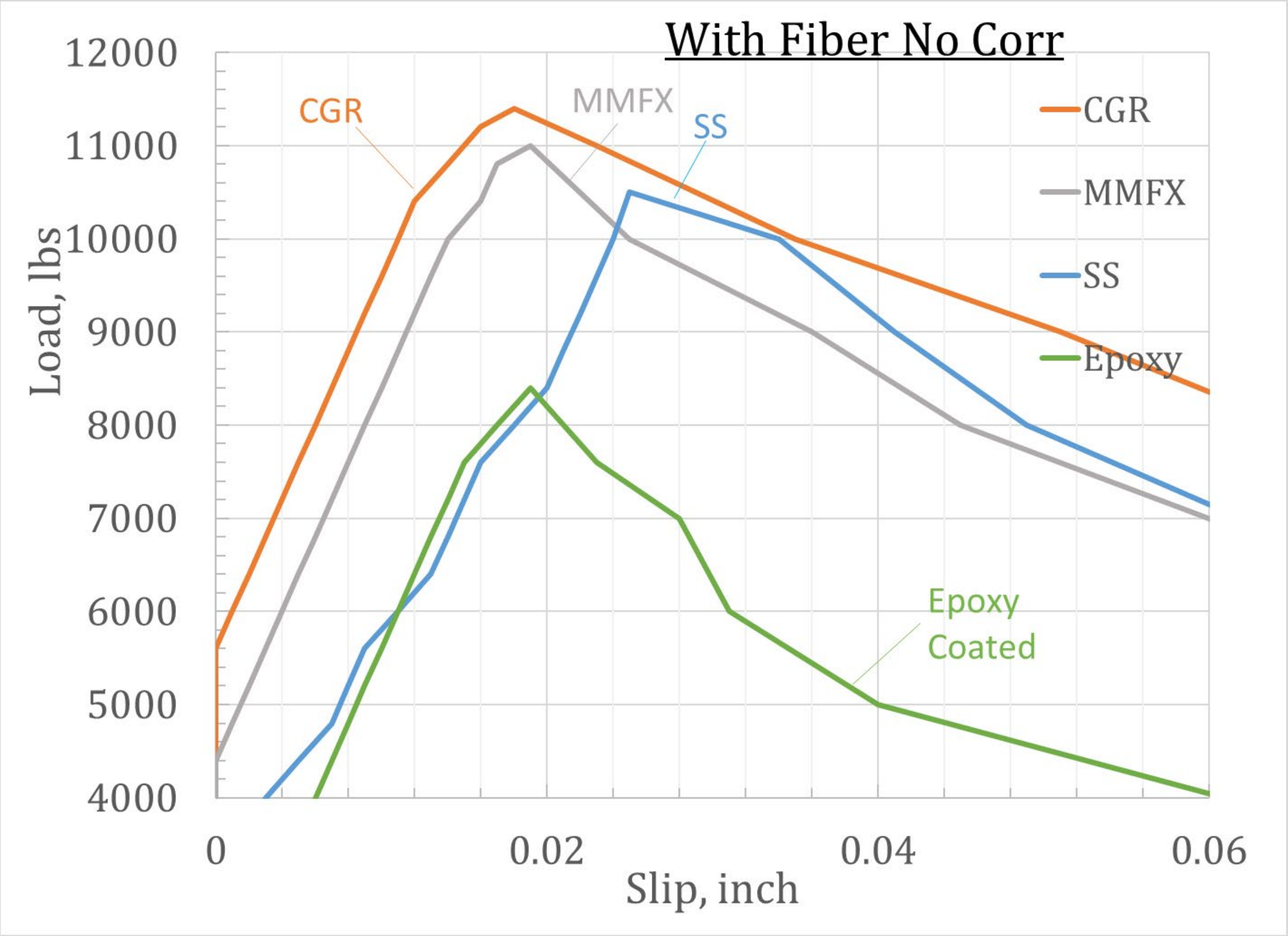
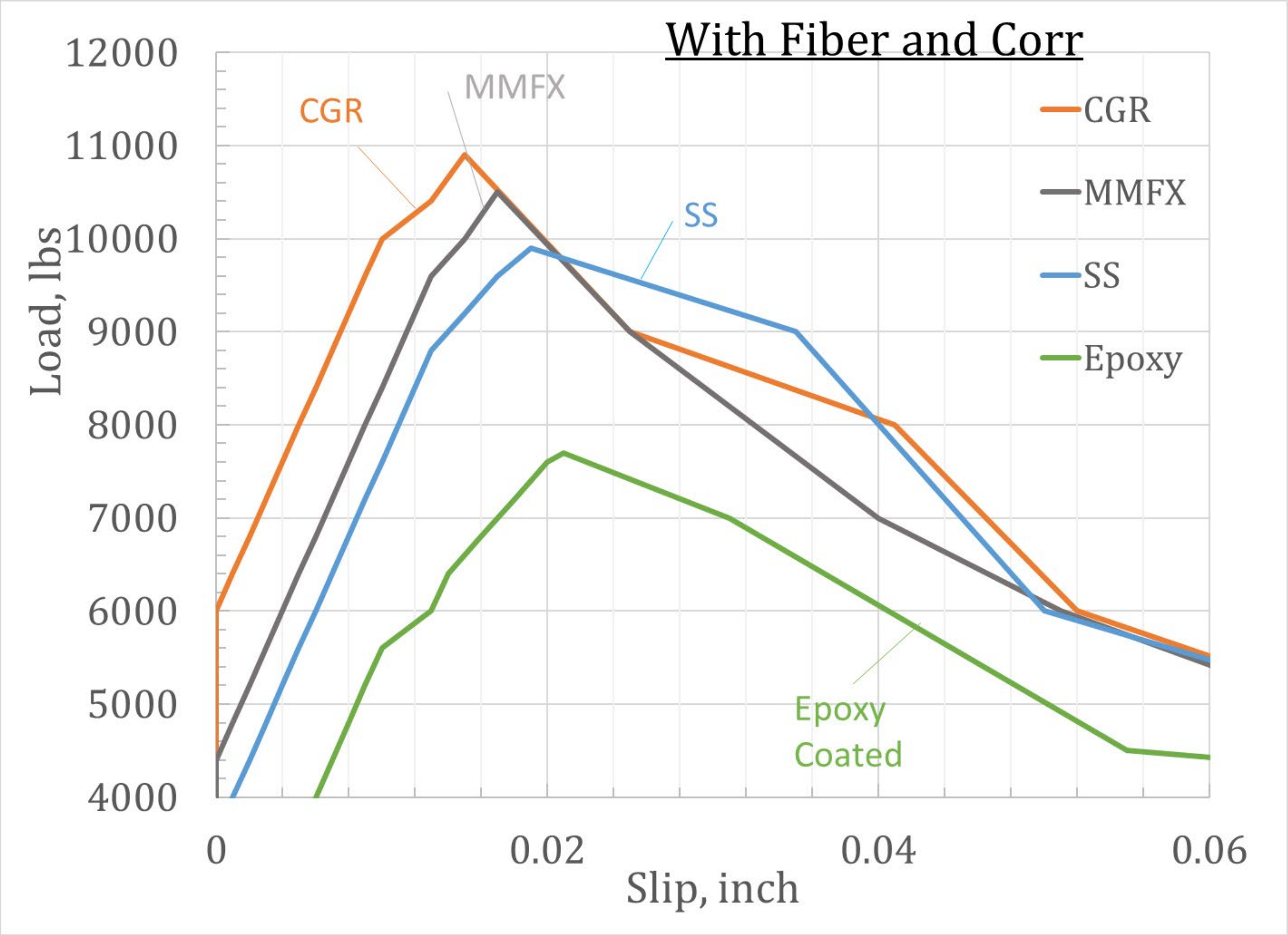
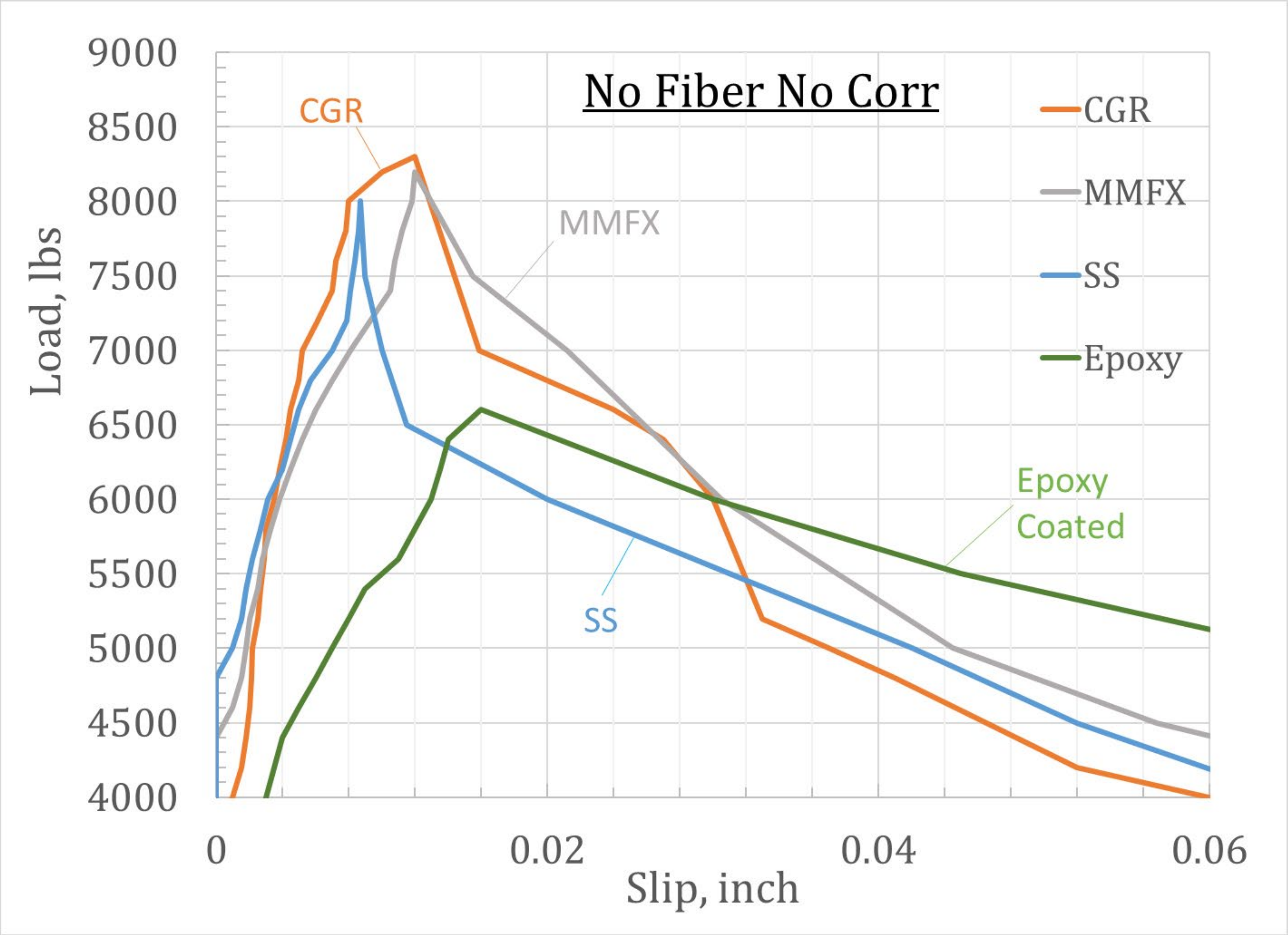
Fiber with No Corrosion



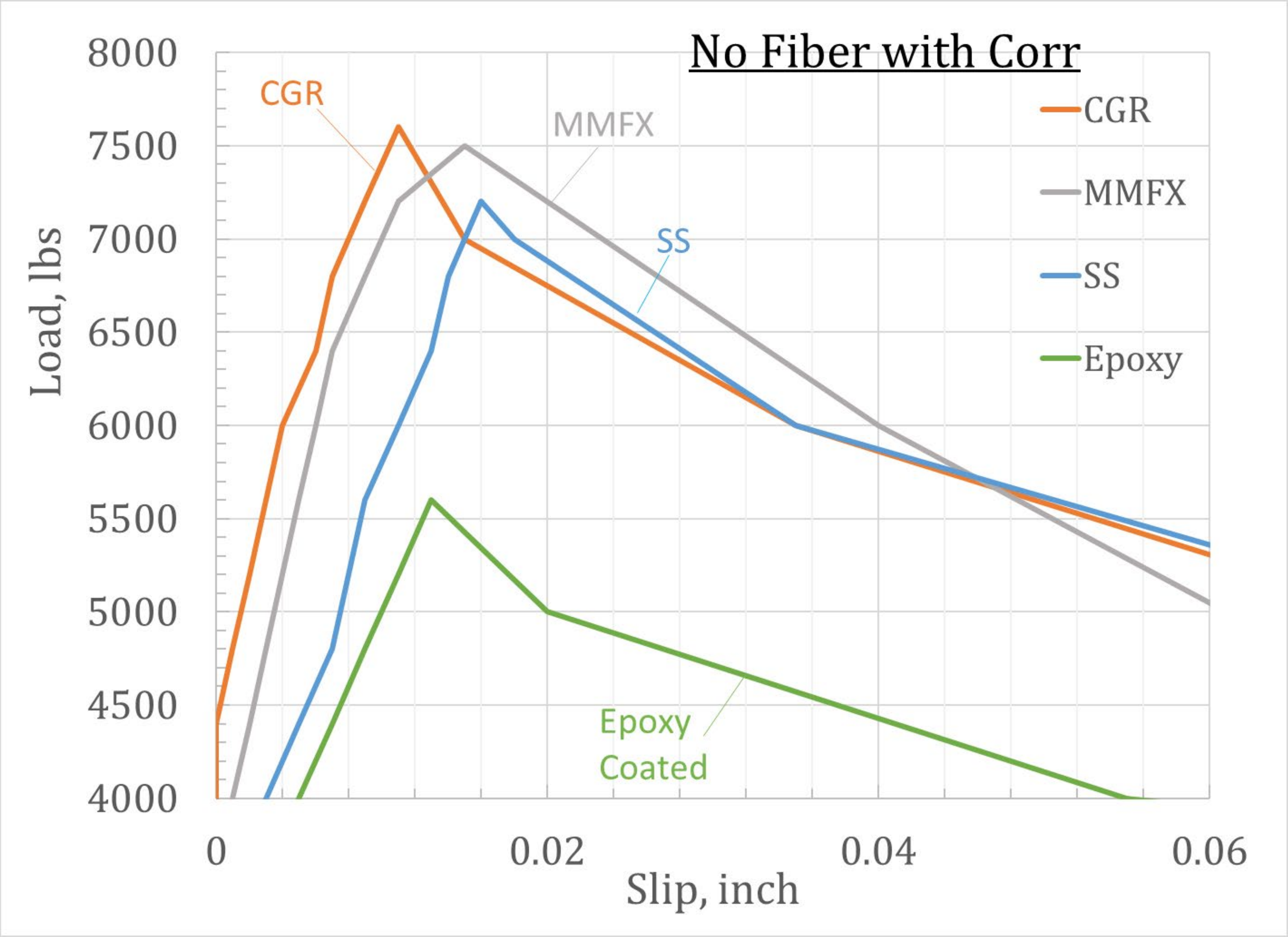
Corrosion with Fiber



No Fiber No Corrosion



Corrosion with No Fiber



Test Results

Group III: Common Bars

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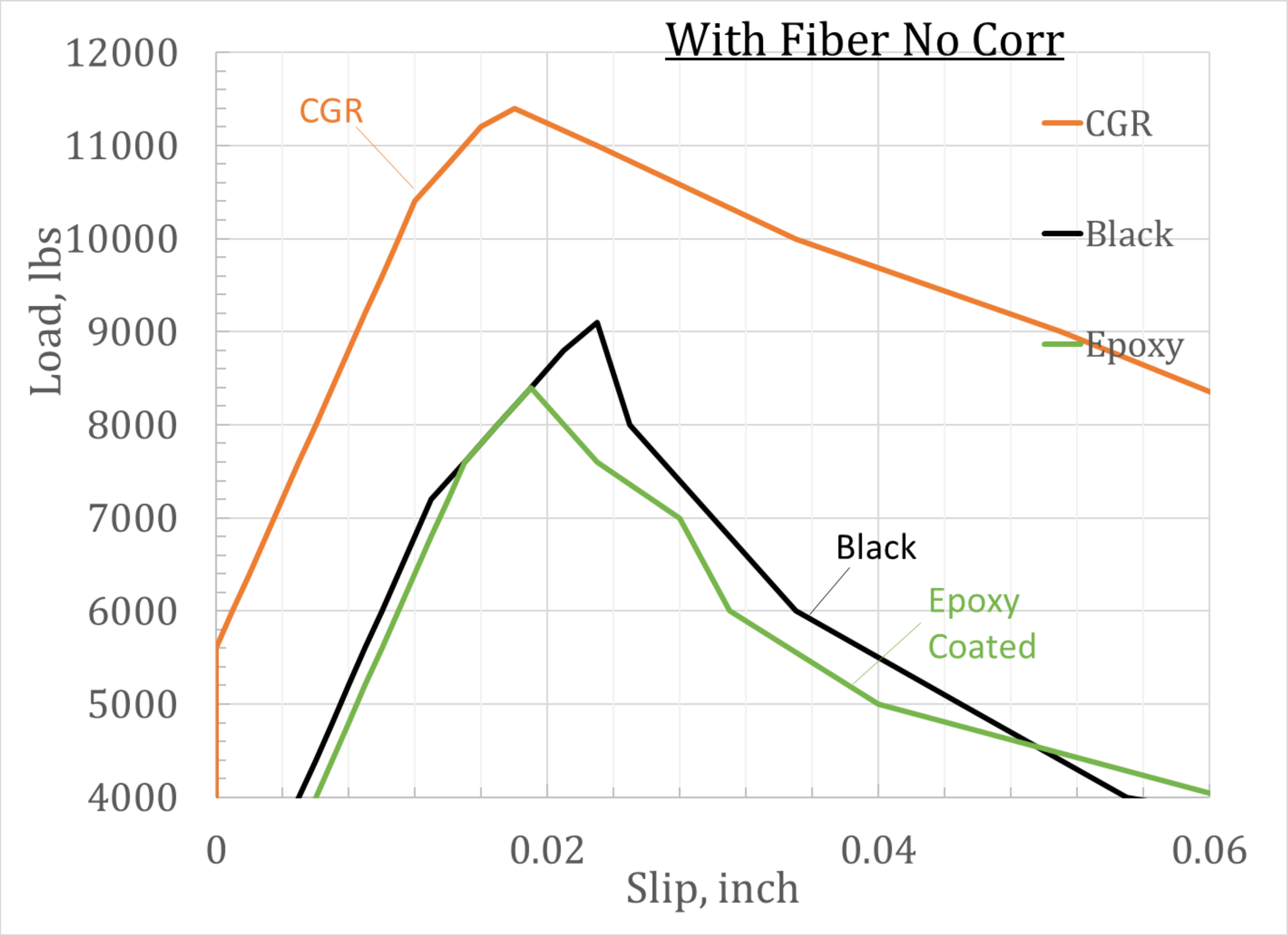
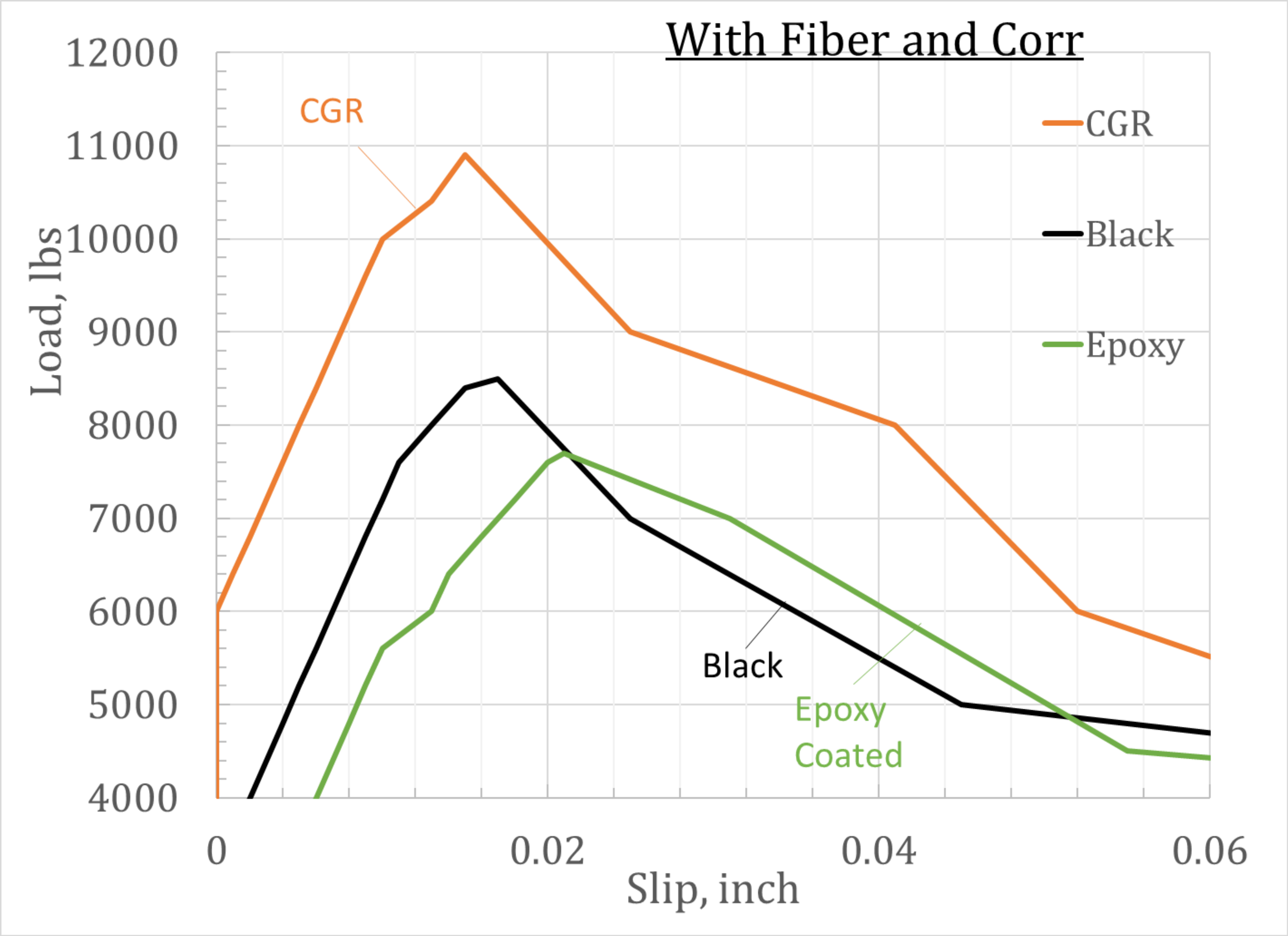
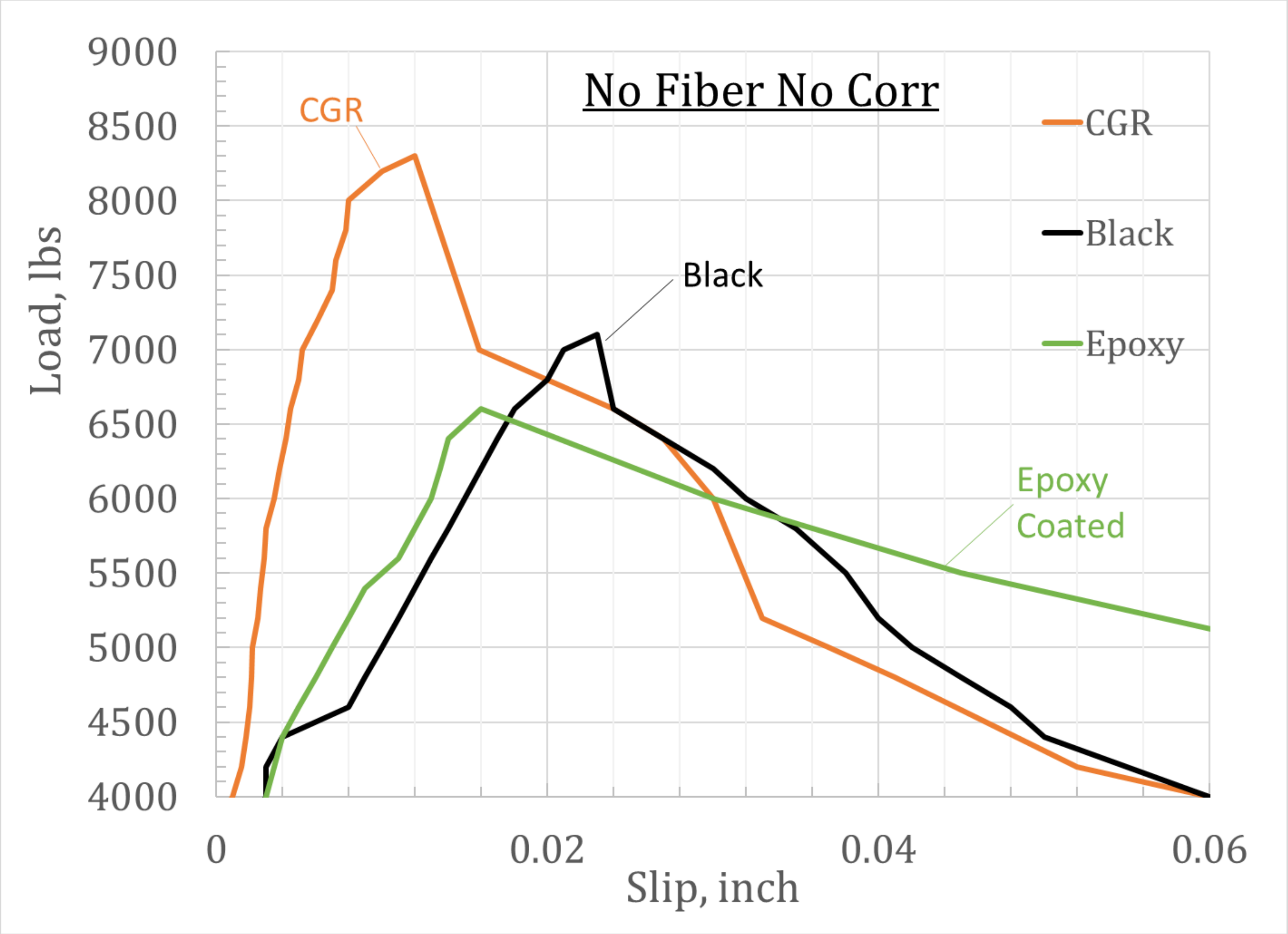
Fiber with No Corrosion



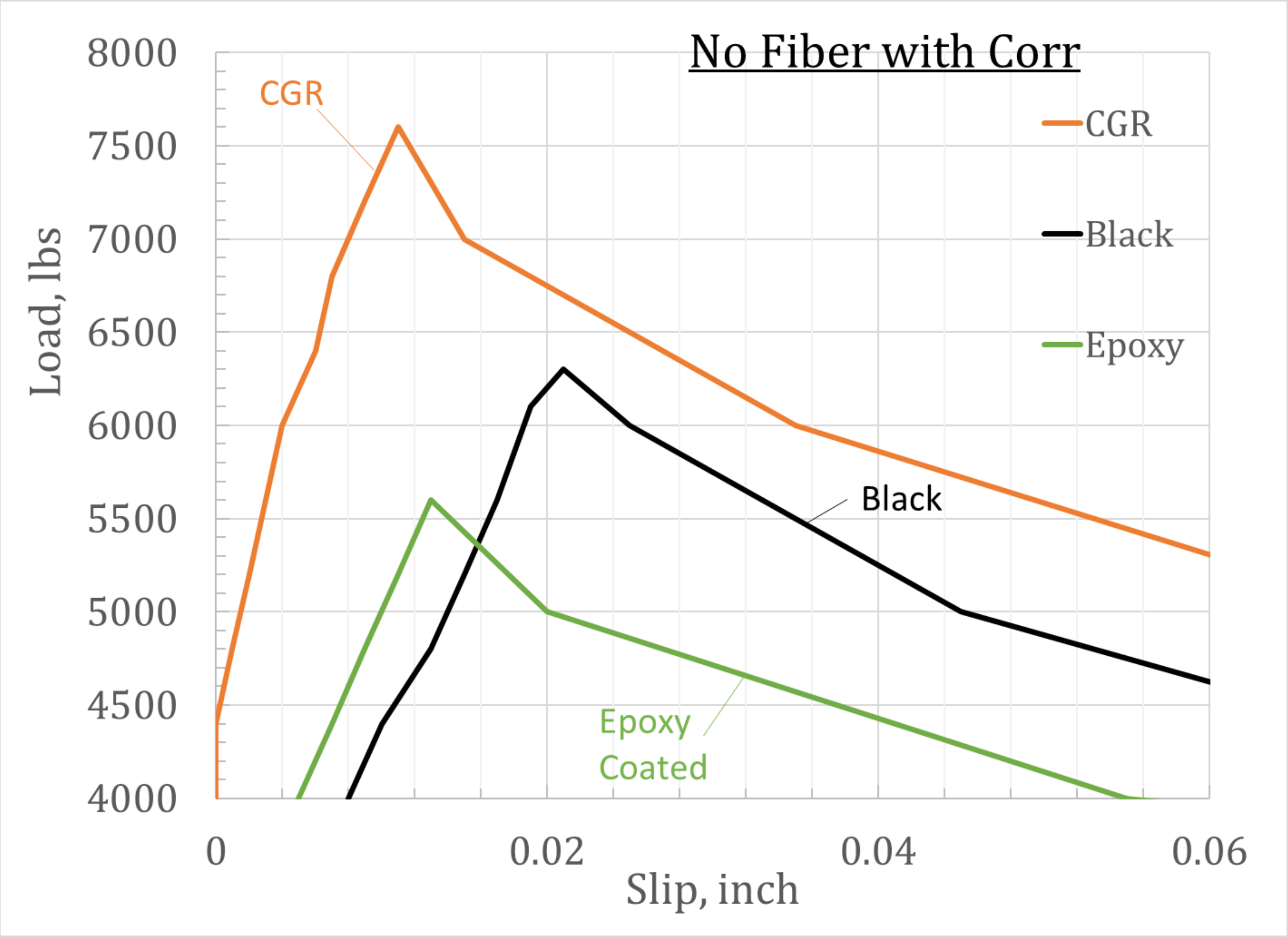
Corrosion with Fiber



No Fiber No Corrosion



Corrosion with No Fiber



Test Results

Group IV: Effects of Fiber and Corrosion for Common Bars

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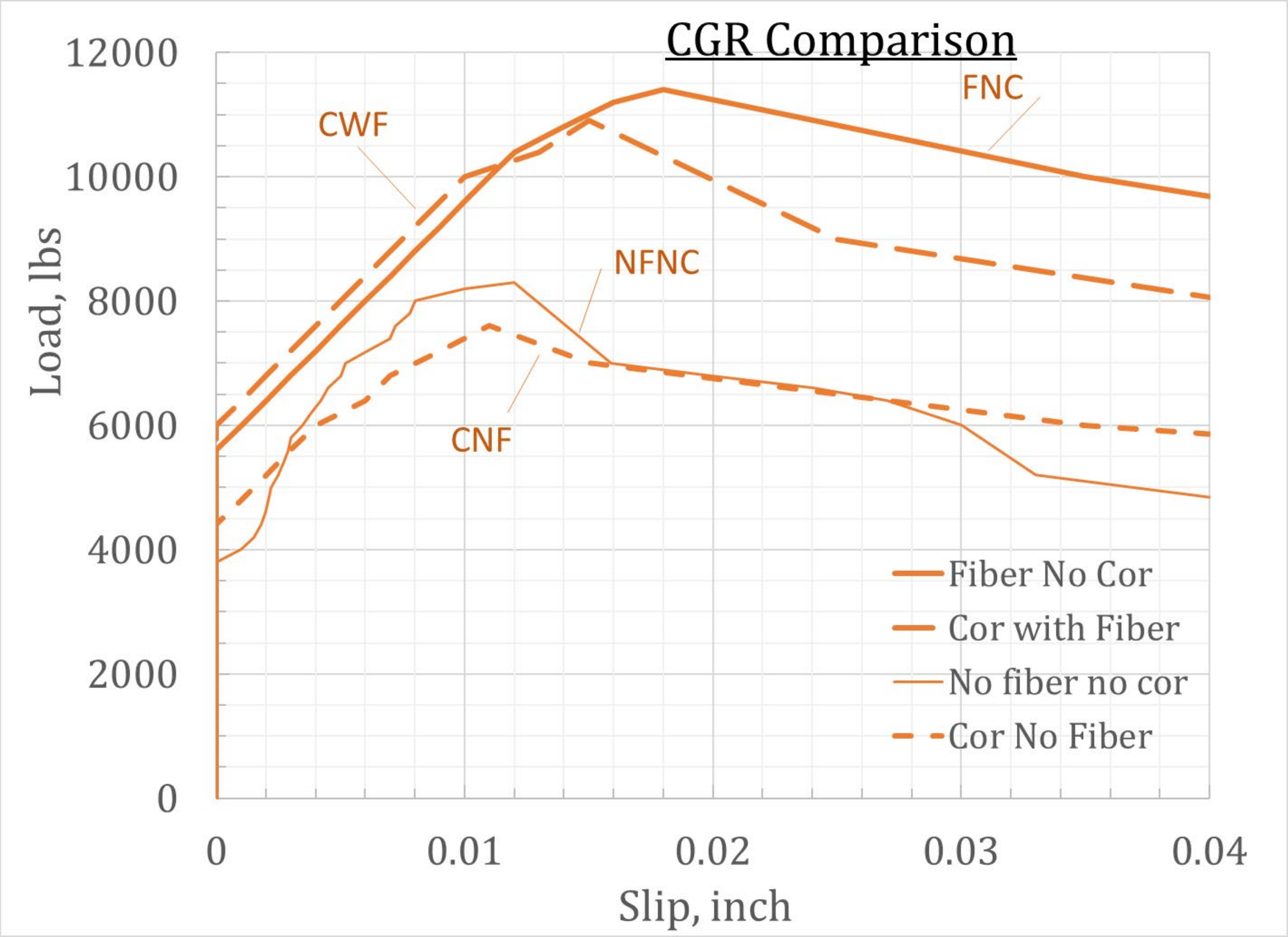
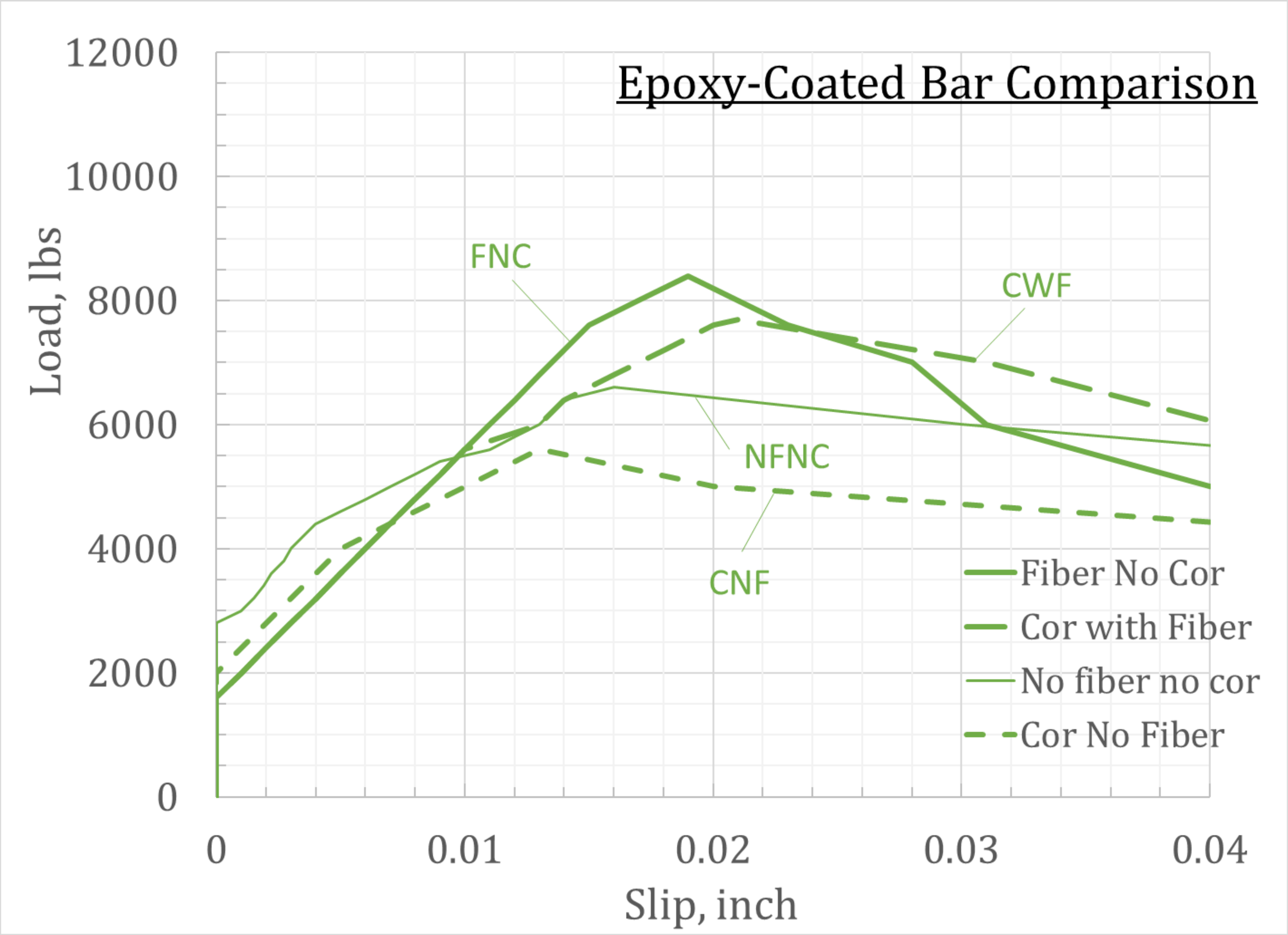
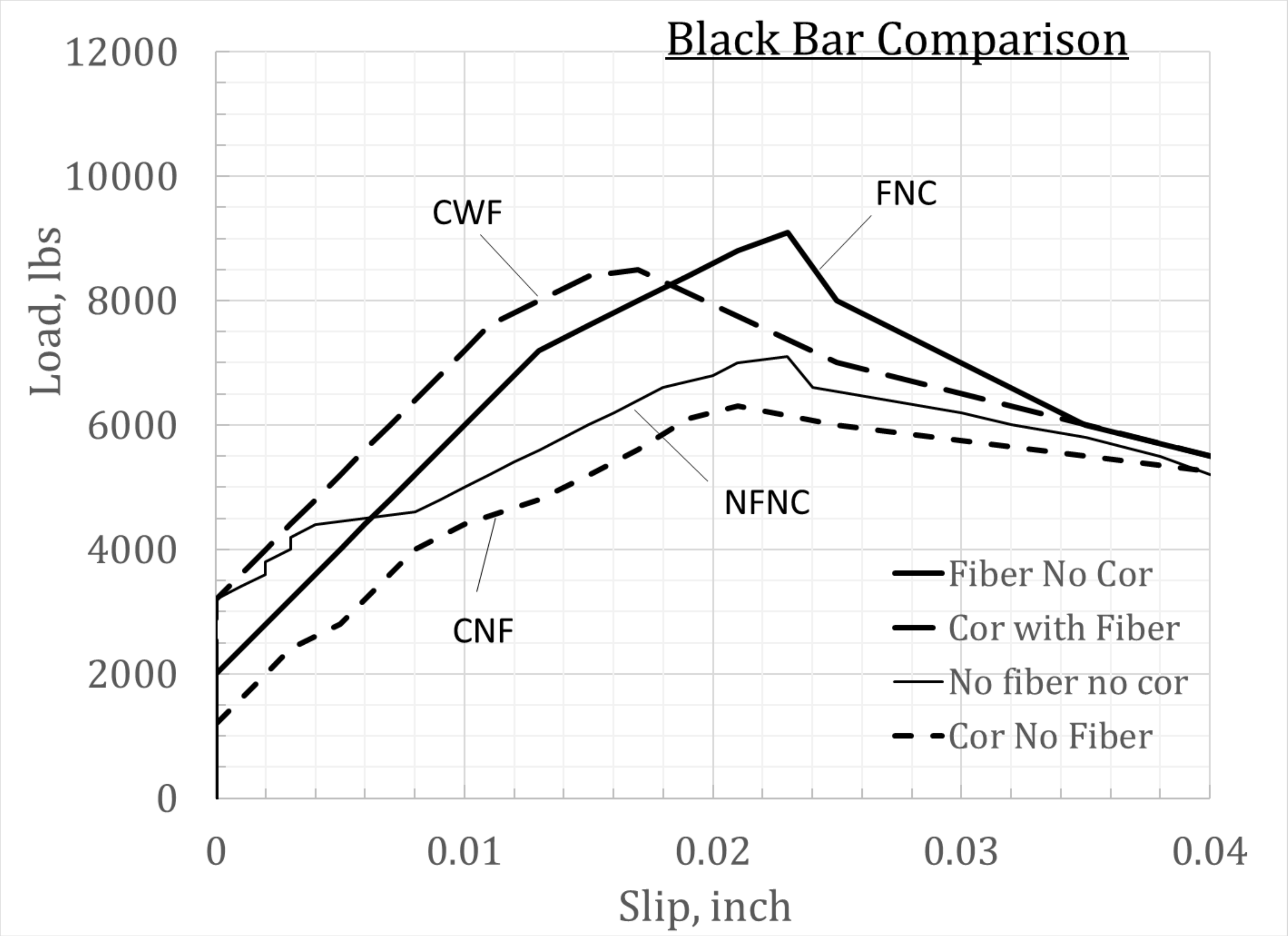
CGR


CGR Comparison
12000
10000
8000
6000
4000
2000
0
Load, lbs
0
0.01
0.02
0.03
0.04
Slip, inch
FNC
CWF
NFNC
CNF
Fiber No Cor
Cor with Fiber
No fiber no cor
Cor No Fiber

ECB


Epoxy-Coated Bar Comparison
Load, lbs
Slip, inch
0
2000
4000
6000
8000
10000
12000
0
0.01
0.02
0.03
0.04
FNC
CWF
NFNC
CNF
Fiber No Cor
Cor with Fiber
No fiber no cor
Cor No Fiber

Black Bar



Black Bar Comparison
12000
10000
8000
6000
4000
2000
0
Load, lbs
0
0.01
0.02
0.03
0.04
Slip, inch
CWF
FNC
NFNC
CNF
Fiber No Cor
Cor with Fiber
No fiber no cor
Cor No Fiber

Direct tension tests

- Direct tension tests were performed to study crack development in prism specimens with different type of reinforcing bars.
- These tests were performed to determine how well the reinforcing bar is bonded to the surrounding concrete and to compare the crack widths and the distribution of cracks along the length of the prism for different bar types.
- The data collected in this test are applied load, stress in the bar, crack widths, and crack spacing.
- The average concrete strength was 4,800 psi on the day of testing. Crack widths were measured and recorded manually using crack gage at every 0.5 kips of load.

Significance of Prism Tests

The prism test provides a good indication of the cracking potential of structural concrete reinforced with different types of bars:

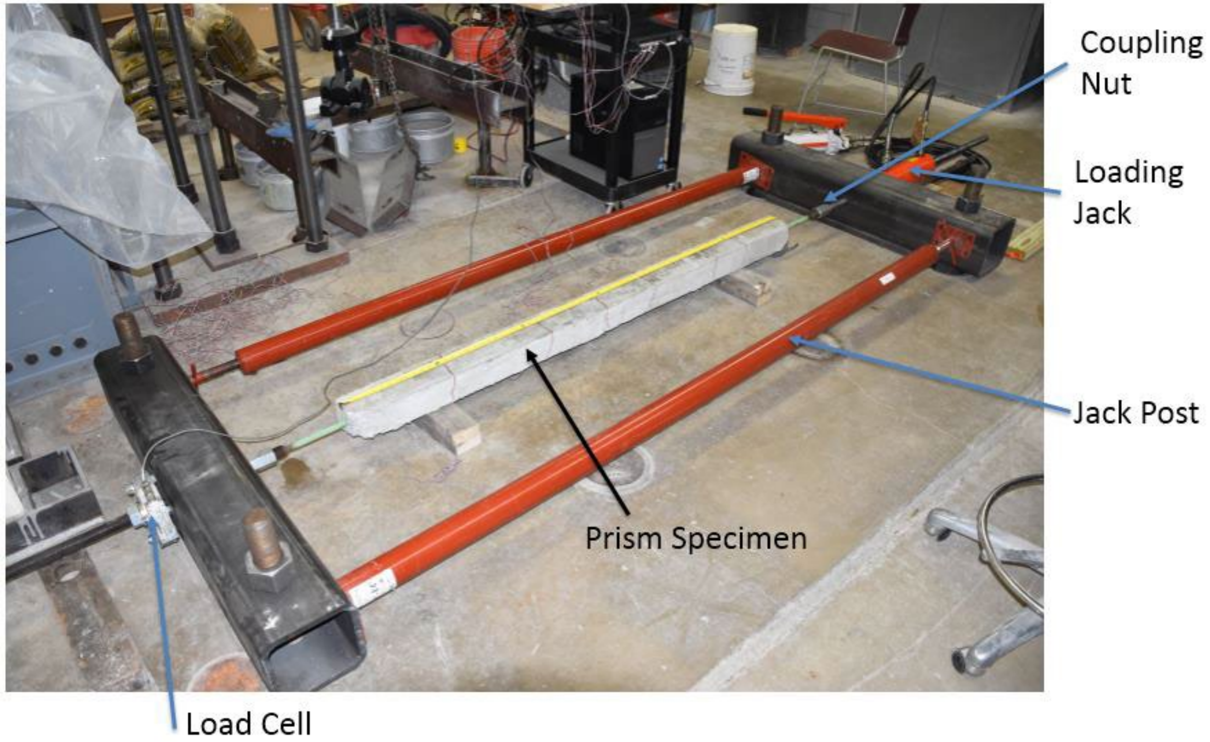
(i) Bond strength, development and anchorage in structural concrete

(ii) Cracking potential of beams and slabs

Comparison between different reinforcing bars is demonstrated.

Long Prism Crack Width Tests

For comparison, crack width tests were conducted using long prism specimens under identical conditions for all the bar types



Typical Cast Specimens

Test Results

Long Prism Specimens

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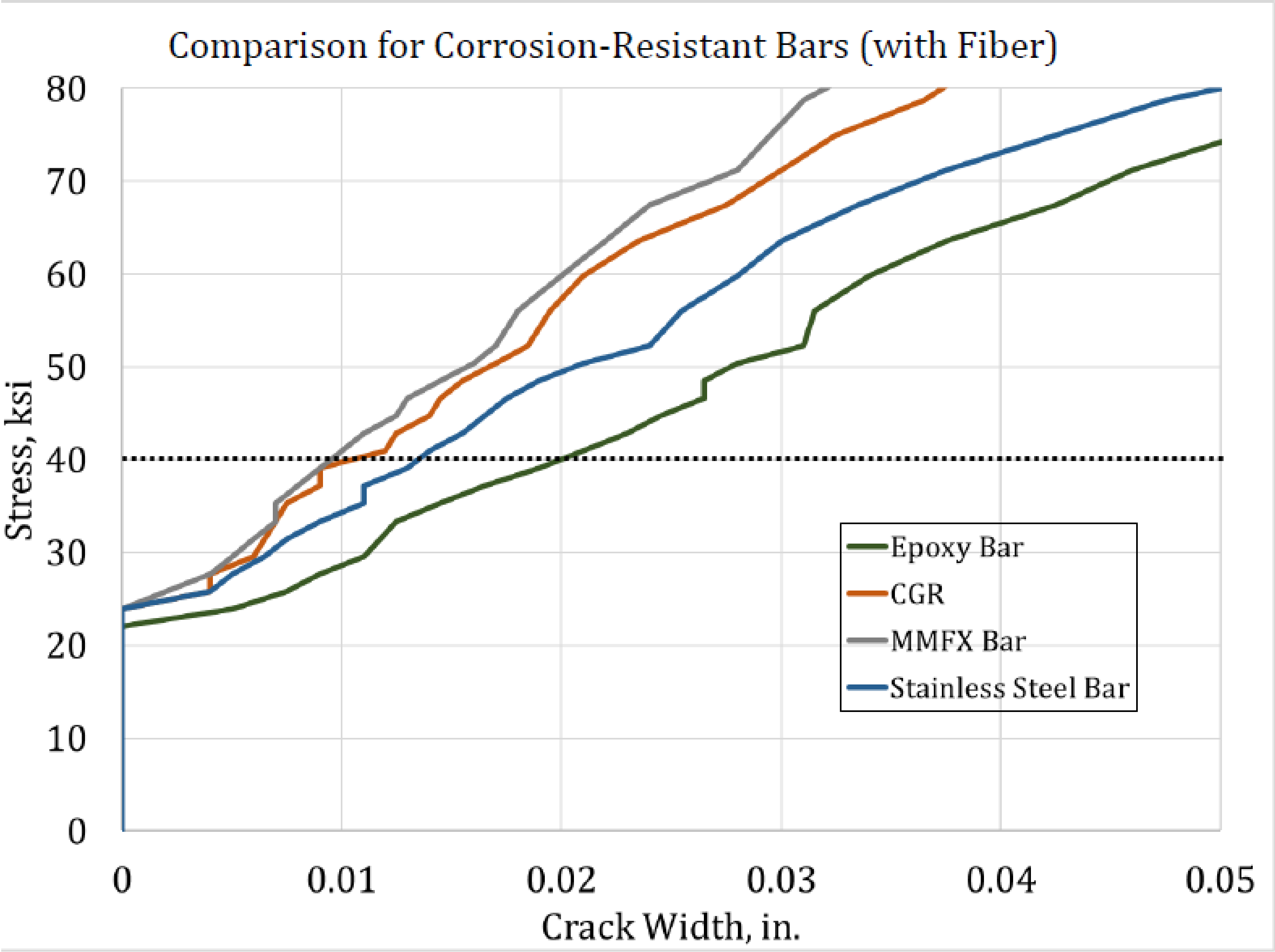
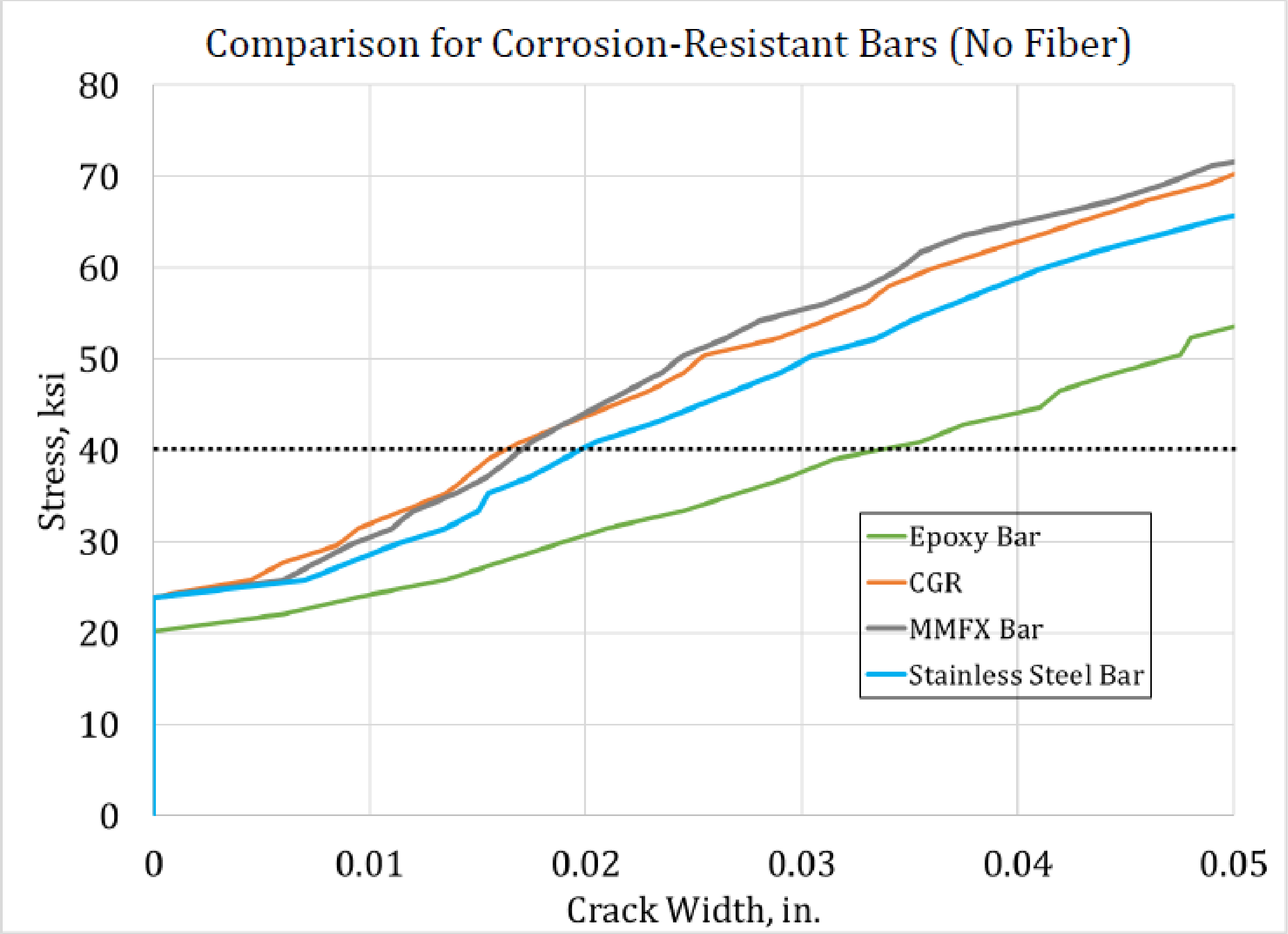
Stress Vs. Crack Width Plots for Common Bars



Stress Vs. Crack Width Plots for CRR



3 Span Bridge Hinkley, Ohio

Three-span continuous slab bridge deck with a span configuration of 24 ft.–30 ft.–24 ft. with a deck thickness of 16 inches. The bridge was designed with a cap and pier connection at the two pier cap locations and semi integral abutments at the ends.

Conclusion

- Fibers reduce cracking and crack widths
- Certain types of corrosion resistant reinforcement can reduce cracking in concrete with and without fibers

Thank You WBPP

Conclusions

1. CGR Out-performed all other types of bars tested in this study in both corroded and uncorroded conditions, with and without fiber
2. CGR out-performed all the corrosion resistance steel bars:
    - Better than ECB by a huge margin
    - Clearly better than stainless steel bars
    - Relatively marginally better than MMFX
3. Addition of fiber helped CGR (like with other bars) by at least 10 to 15% both in corroded and uncorroded conditions
4. From these test results, it is evident that CGR will provide better structural and corrosion performance in reinforced concrete than the other bars tested in this study

Beam Tests

For comparison, crack width tests were conducted using beam specimens under identical conditions for all the bar types

Typical Specimen

Test Results

Beam Specimens

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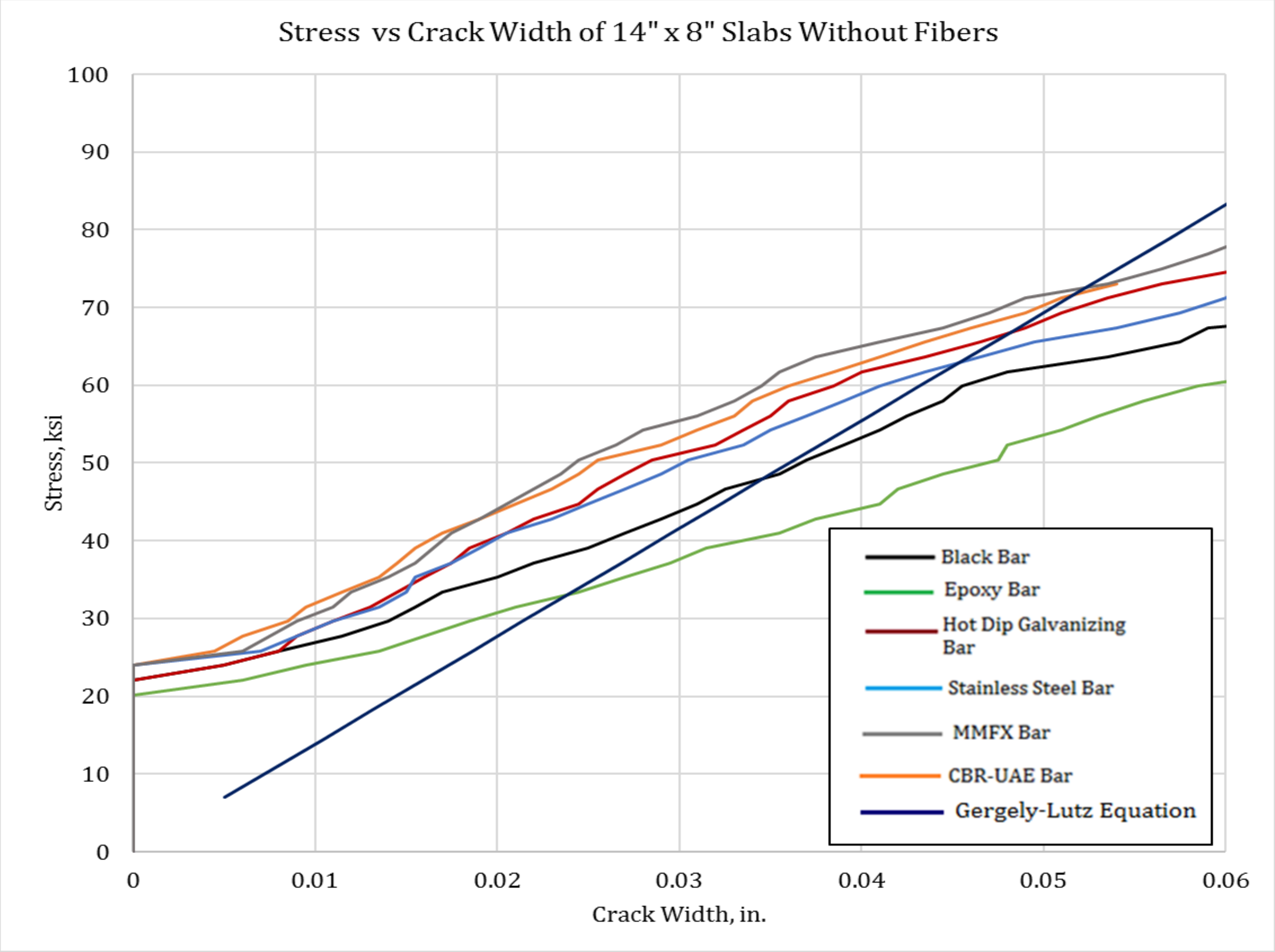
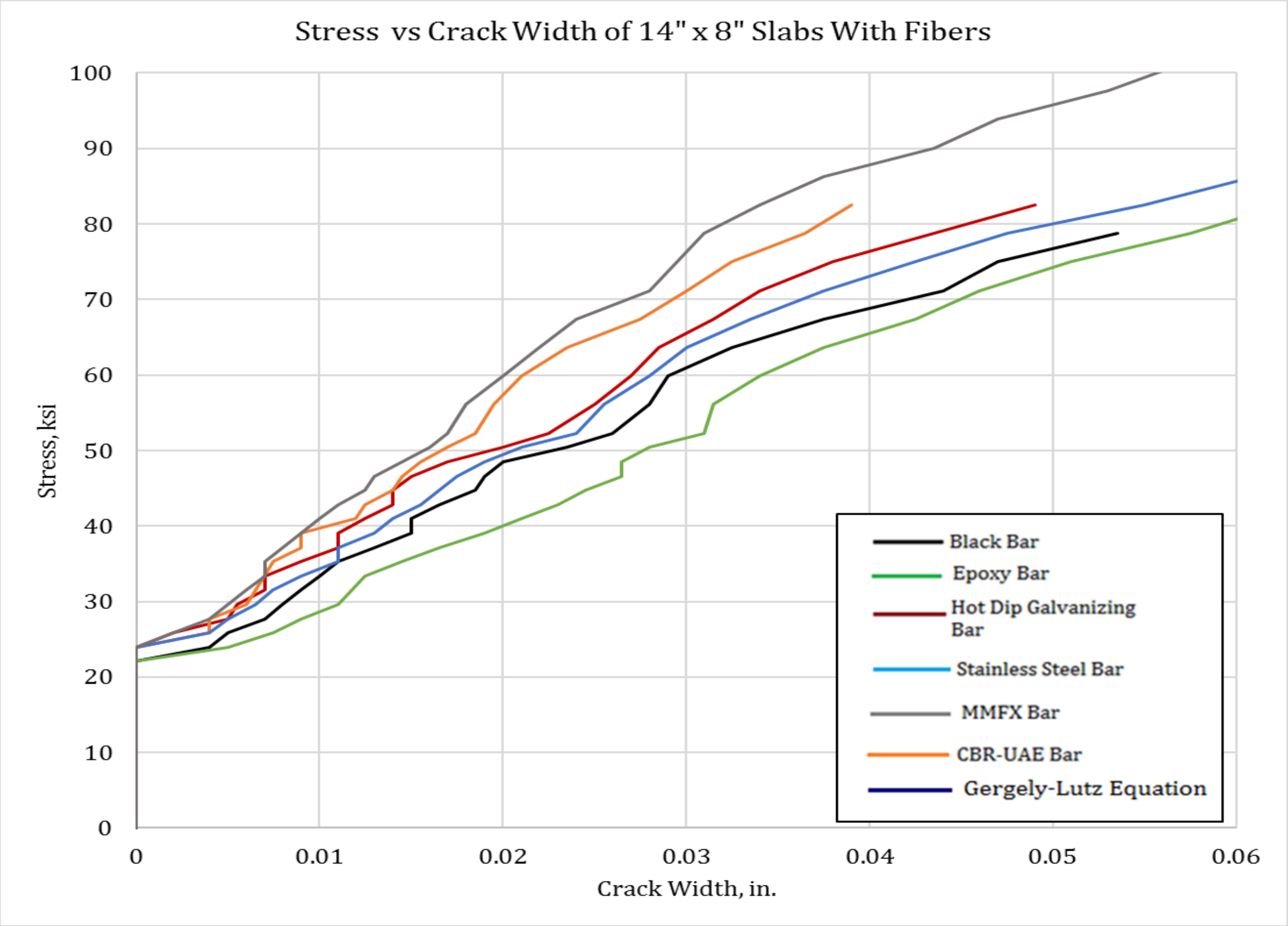
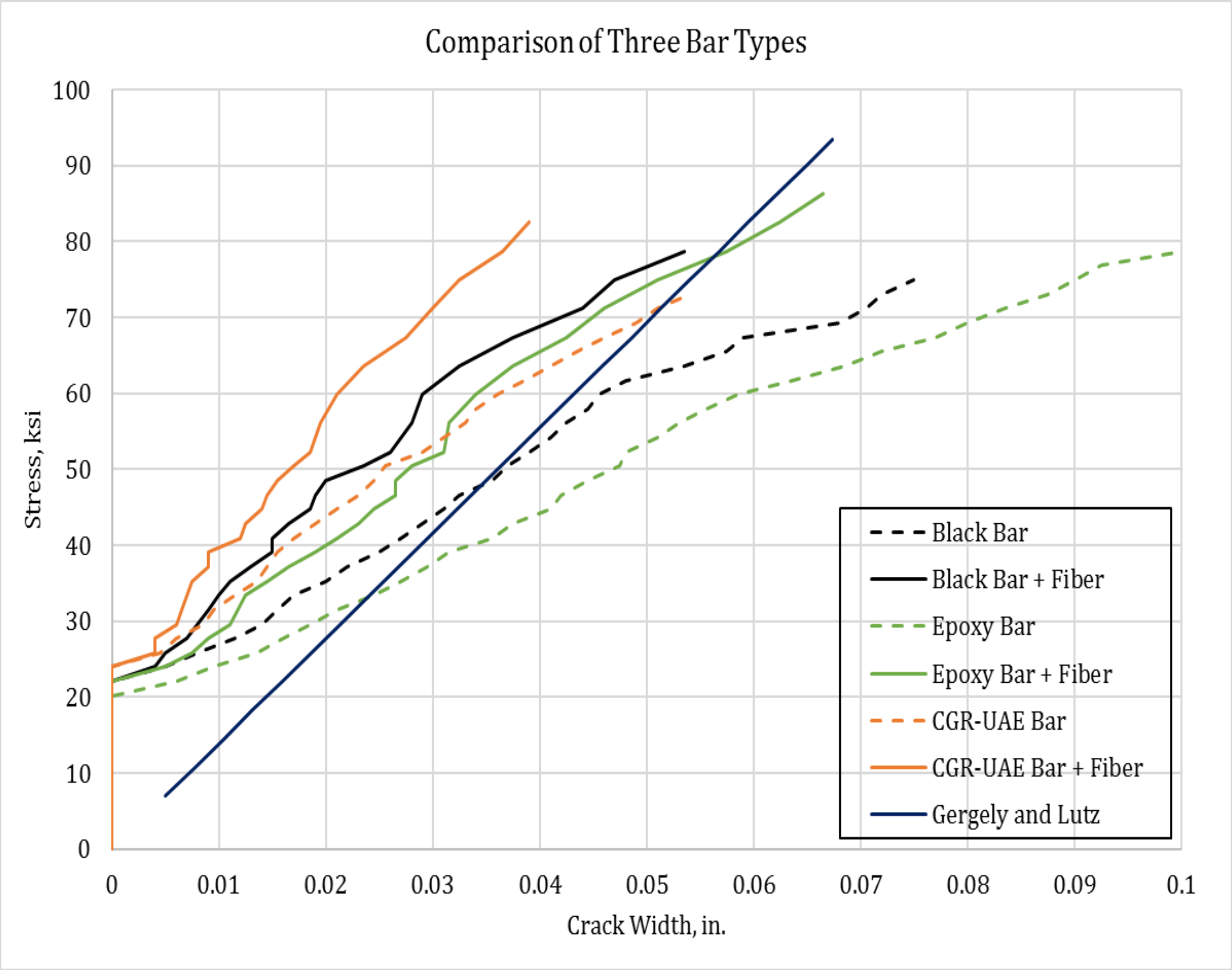
Load Vs. Crack Width Plots for Common Bars



Load Vs. Crack Width Plots for Common Bars



Load Vs. Crack Width Plots for Common Bars



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End

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