The Evaluation of Bond-Slip Behavior of GFRP Bars in Conventional and Sustainable Concrete

ACIC

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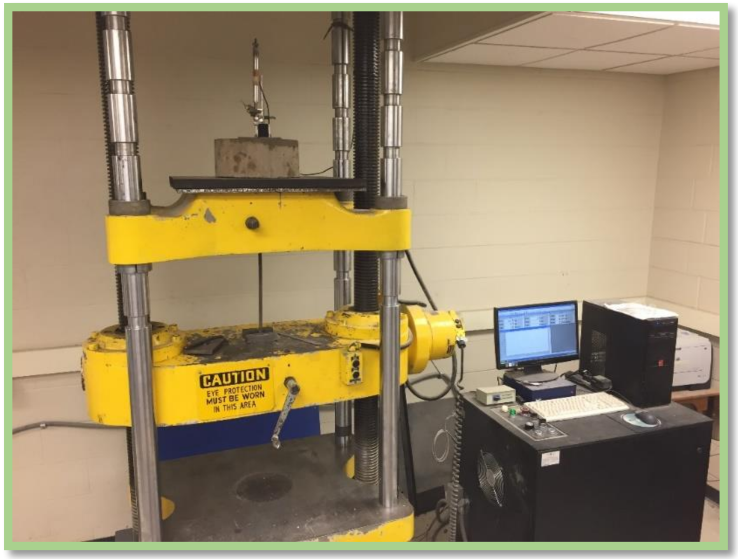
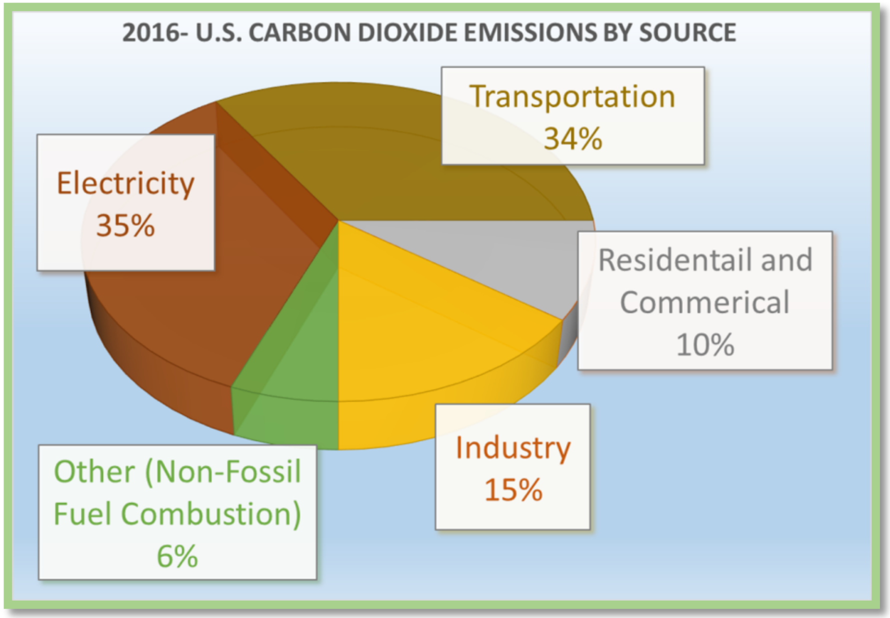
Outline

- Introduction
- Research Objective
- Materials
- Mixture Design
- Specimen Preparations
- Test Setup
- Test Results
- Statistical Analysis and Results
- Conclusions



Introduction

- Issue I: Excessive CO_2 emissions from Conventional Concrete
- Issue II: Corrosion of steel reinforcement
- Alternative I: High-volume fly ash concrete
- Alternative II: Glass fiber (GFRP) reinforcement



https://www.americanfiberglassrebar.com
http://www.materialsperformance.com/articles/material-selection-design
https://theconstructor.org/building/fly-ash-properties-types-mechanism/26654/

Introduction

- Pullout test used to conduct the bond study.
- Naik. et al. conducted pullout using 15% - 25% fly ash.
- Gopalakrishnan et al. conducted pullout using 50% fly ash.
- Zenon A., and Kypros P. conducted pullout cube specimens using , mild steel, CFRP, and GFRP rebars.
- Ginghis M. et al. conducted pullout using GFRP rebars with geopolymer concrete.
- In this study, GFRP rebars used in CC and 70% HVFAC compared to those with mild steel.

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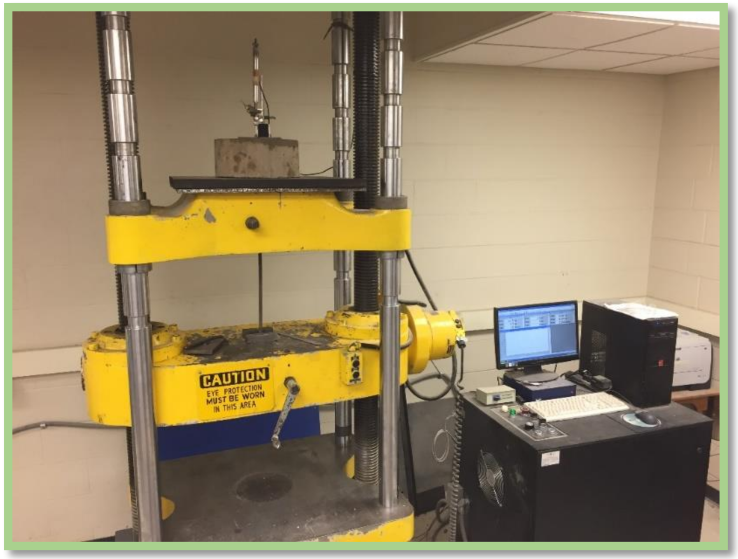

Research Objectives

- Study the bond performance of GFRP rebars in conventional and high-volume fly ash concrete.
- Compare the results to control specimens made using mild steel reinforcement.
- Statistically, evaluate the significance between GFRP and mild steel.
- Create a mathematical model to predict the bond stress.

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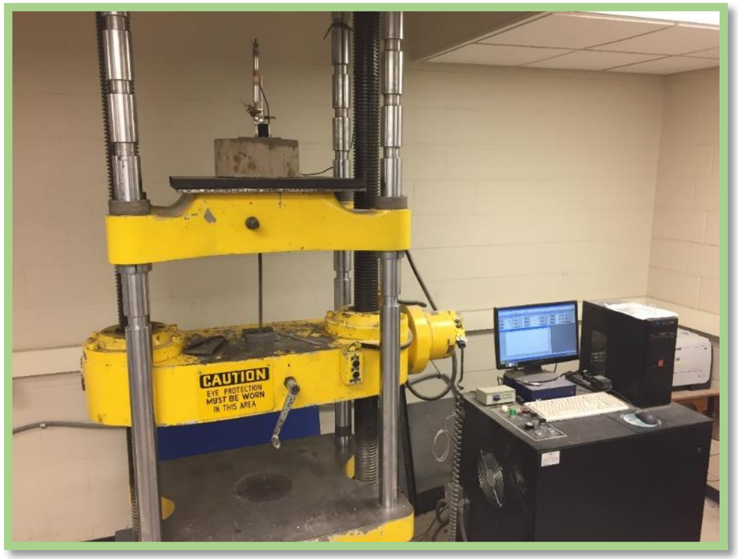

Materials

- ASTM Type C – Fly Ash
- ASTM Type I/II – Portland Cement
- 19 mm Max Size Coarse Aggregate
- Natural sand used as a source of Fine Aggregate
- Glass Fiber Rebars (13 and 19 mm) – Owens Corning
- Mild Steel Rebars (13 and 19 mm)
- Sonotube (concrete form) – 300 mm diameter
- Design compressive strength 35 MPa

https://www.pinterest.com/pin/350577152214559645/
https://www.brockaggregates.com/blog/the-basics-of-sand
https://civilengineersforum.com/fly-ash-in-concrete-advantages-disadvantages/
https://www.alibaba.com/product-detail/Granite-Aggregate-20mm-Construction-Sand-Concrete_142482556.html

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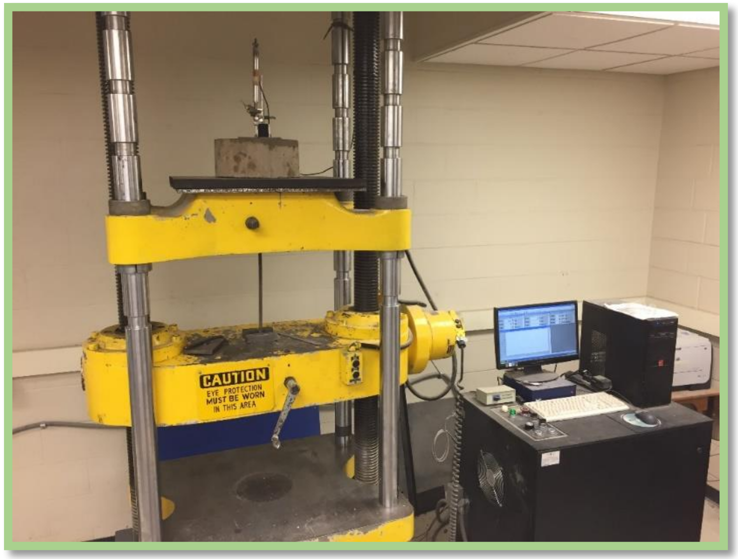

Mixture Design

- Design compressive strength: 35 MPa
- Two types of concrete made: CC and HVFAC
- w/c ratio: 0.4
- Air-Entraining Additive: 161 g/m
- Quality control cylinders: Compressive and Split Cylinder tests
- Cylinder testing age: 28 and 56 days
- Unit weight: 2390 kg/m for CC, 2340 kg/m for HVFAC
- Slump: 114 mm for CC, 127 mm for HVFAC
- Air content: 4% for CC, 4.5% for HVFAC

Fresh and Hardened Properties of Concrete

Property	Specification	Test Age, Days	CC	70% HVFAC
Slump, mm (in)	ASTM C143	-	114 (4.5)	127 (5.0)
Air Content, %	ASTM C231	-	4	4.5
Unit Weight, kg/m^3 (lb/ft^3)	ASTM C138	-	2390 (149)	2340 (146)
Splitting Tensile Strength, Mpa (psi)	ASTM C496	28	1.59 (231)	1.41 (205)
		56	1.72 (249)	1.42 (206)
Compressive Strength, MPa (psi)	ASTM C39	28	36.5 (5290)	29.6 (4300)
		56	40 (5755)	33.2 (4821)

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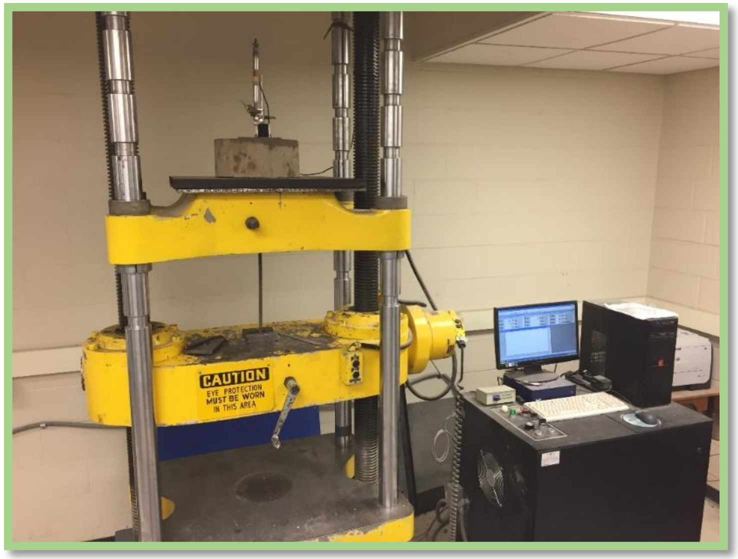

Specimen Preparations

- Silicon caulk used to attach the sonotube to the base
- Form diameter 300 mm
- Form depth 127 mm for 13 mm Rebars
- Form depth 190 mm for 19 mm Rebars
- Embedment length is half the form depth
- Testing age: 56 days

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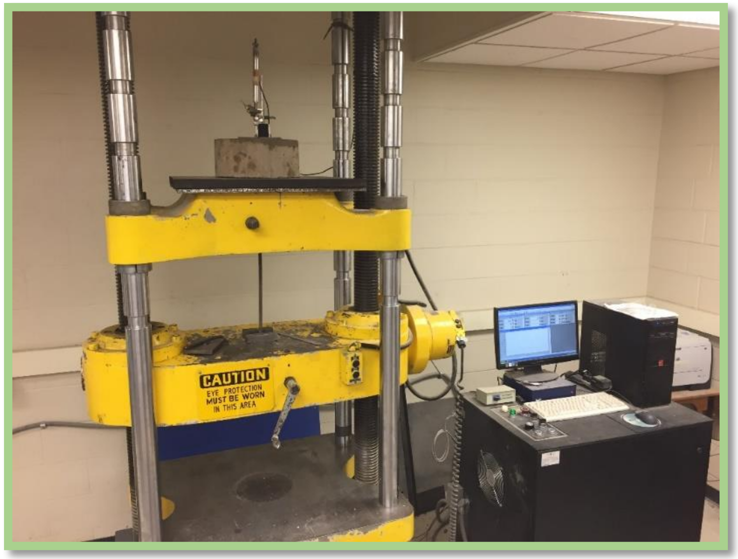
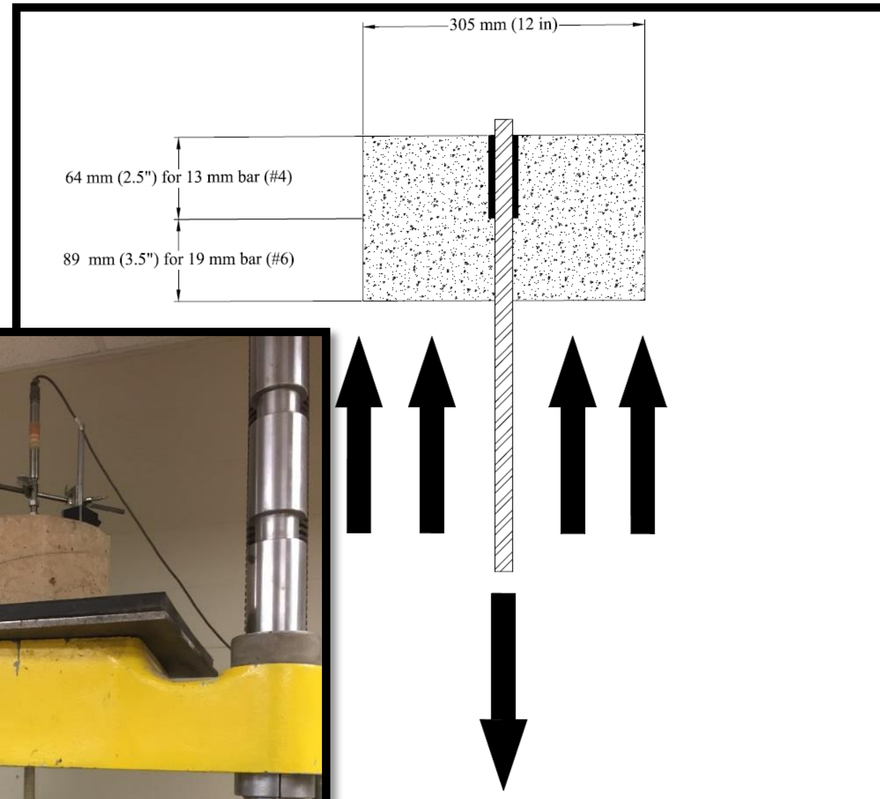
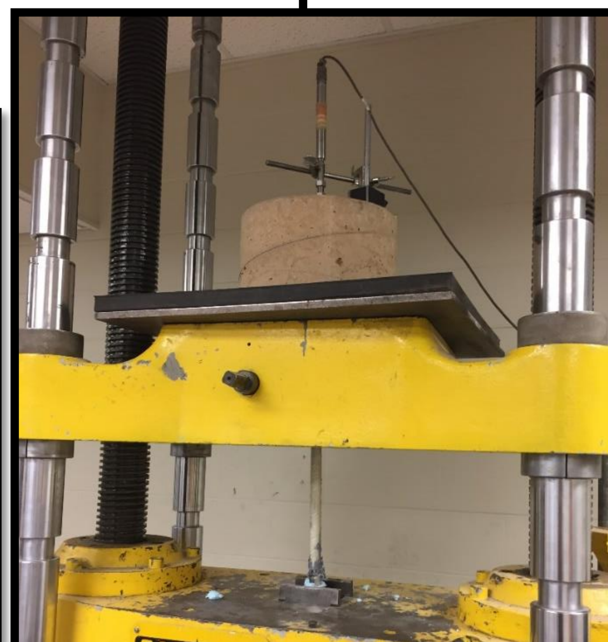


Test Setup

- 890 kN Tinius Olsen – Universal machine
- Pullout test
- LVDT used
- Load rate 2.5 mm/min.





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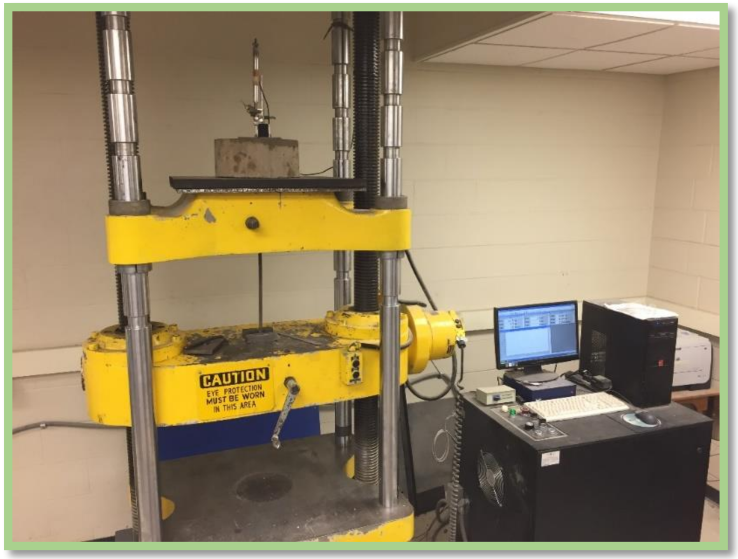
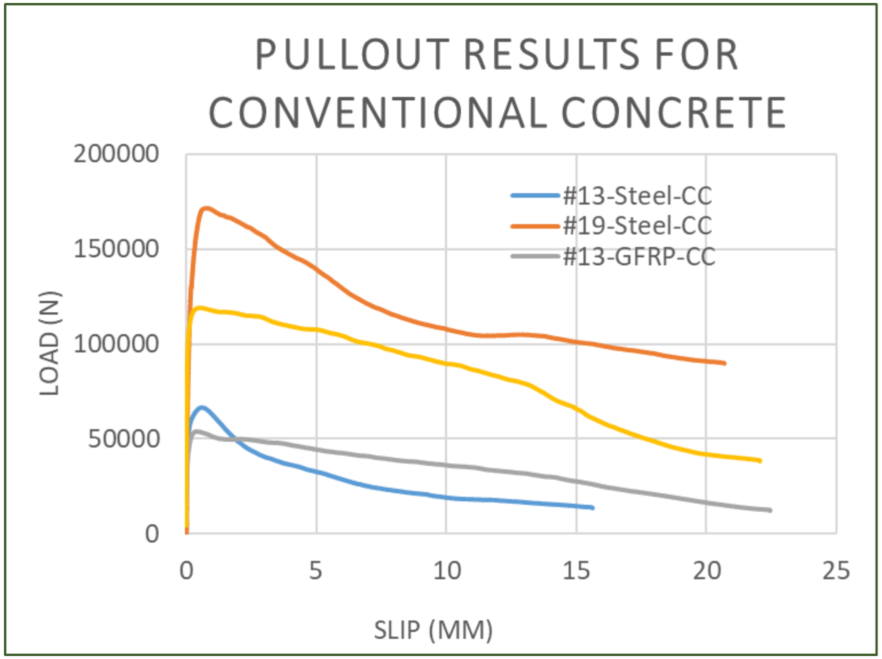
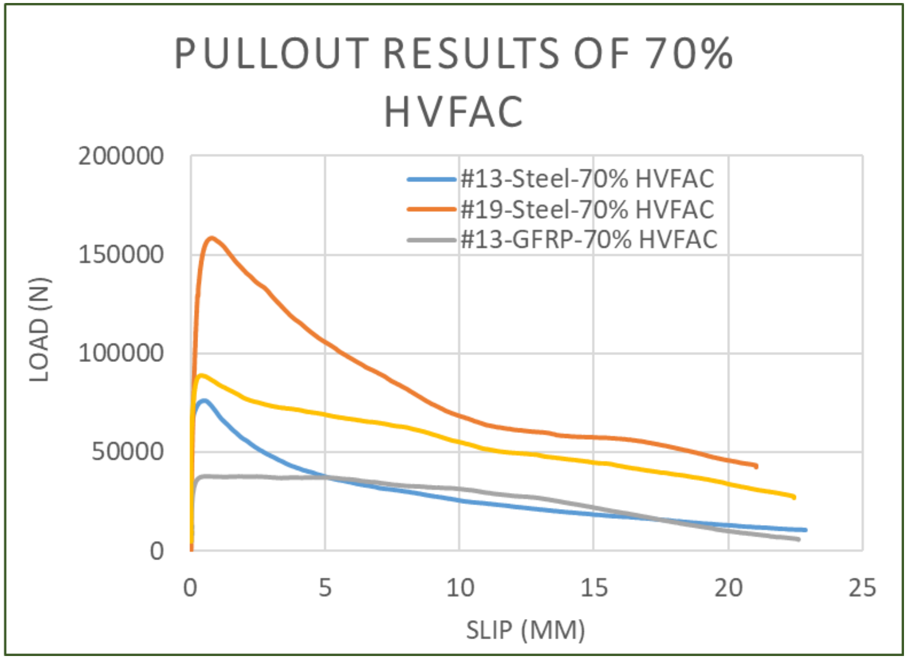


Test Results

- Bond Strength of GFRP rebar is less than that resulted from mild steel by:
  - 25% when CC used
  - 50% when HVFAC used
  - GFRP slippage failure is less steep than that of mild steel





Test Results

Concrete Type	Rebar Size (mm)	Rebar Type	P (kN)	f'c test (MPa)	P/(f’c design/f’c test)^0.5 (MPa)	P avg. (kN)	COV. (%)
CC	#13	Steel	66	37	69	65	8
			59		61		
		GFRP	54	37	56	50	14
			44		45		
	#19	Steel	171	37	177	165	11
			148		153		
		GFRP	119	37	123	118	6
			103		103		
70% HVFAC	#13	Steel	71	30	66	68	5
			76		71		
		GFRP	34	30	31	33	8
			38		35		
	#19	Steel	158	30	146	146	0
			159		147		
		GFRP	79	30	73	78	8
			89		82		

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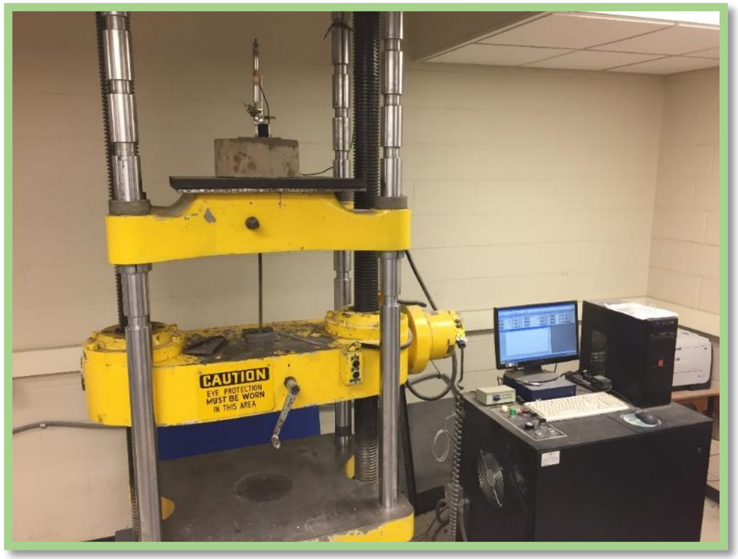
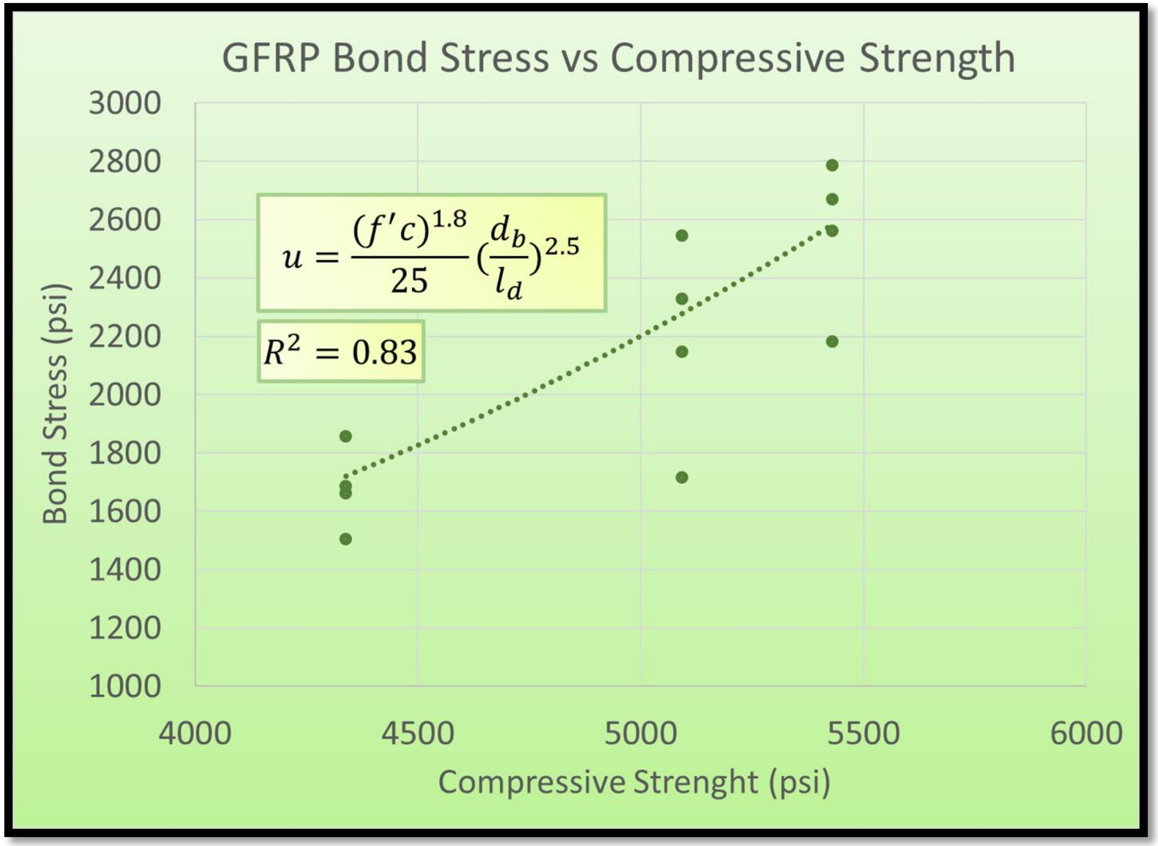


Statistical Analysis and Results

- Anderson-Darling showed: normal distribution of the data
- Two sample t-Test: investigate the statistical significance between GFRP and mild steel's bond strength
- t-Test results showed: for 13 and 19 mm rebars: null hypothesis was confirmed in CC and rejected in HVFAC
- t-Test example: Ho = null hypothesis, Ha = alternative hypothesis
- Ho = the mean of the normalized bond strength of steel rebars is equal to that of GFRP rebar
- Ha = Not Ho

Statistical Analysis and Results

- Multiple regression analysis used to predict the bond strength
- Mathematical model based on:
- Concrete compressive strength, f'c
- Rebar diameter to embedment length ratio, d_b/l_d
- R-squared = 0.83



Conclusions

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- Bond strength of **GFRP** was less than that of **mild steel**.
- All specimens failed in slippage.
- The higher the rebar dimeter was, the higher the bond strength.
- Chemical adhesion of **CC** was higher than that of **HVFAC**.
- Two sample t-Test showed significance when CC was used and no significance when HVFAC was used.
- Mathematical model was built to predict the bond strength with R-squared of 0.83.