Centre for Cement and Concrete

Bond Behaviour of Reinforcing Bars in GRC

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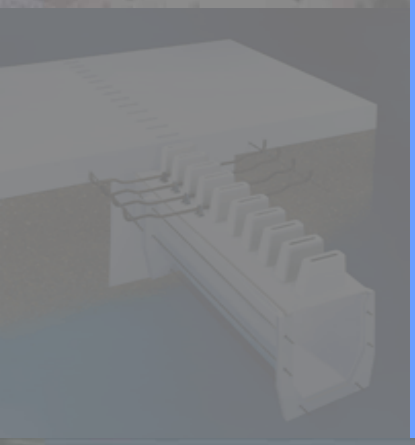
BACKGROUND

- ✓ Easy to create complicated shapes
- ✓ Light self-weight
- ✓ Good Durability of the cover
- ➢ High Strength & Stiffness
- ➢ Superior corrosion resistance
- ➢ Require minimum cover



⇨ **FRP reinforced GRC Structures**

- Thin structural elements or permanent formwork
  -- GRC containing FRP reinforcement >> conventional steel rc
- GRC elements need reinforcement to increase their effective spans

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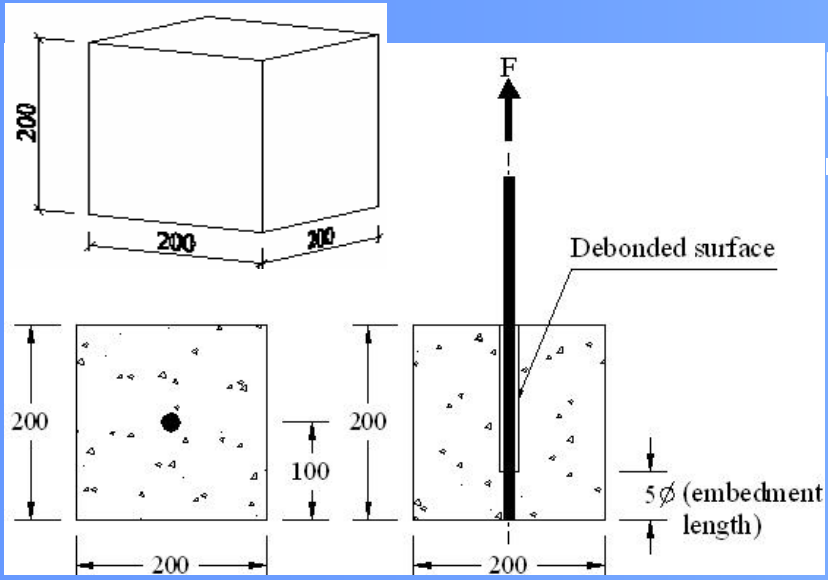
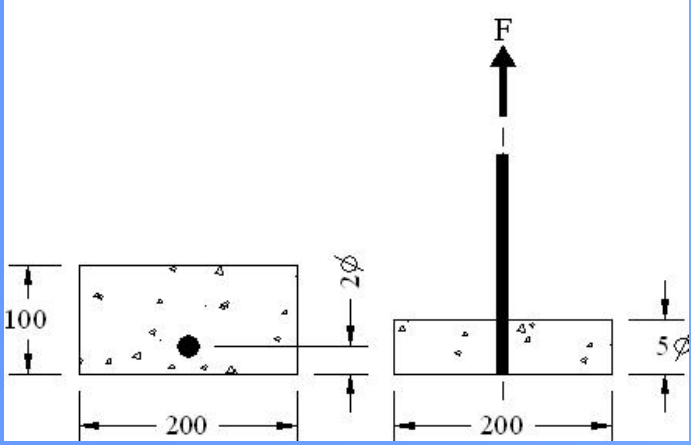
OUTLINE

- A preliminary experimental study (Pullout & Splitting)
- Bond behaviour of GRC containing embedded reinforcing bars
- Bond Strength is quantified
- Effect of using FRP in GRC sections
- Cost effective
- Tension stiffening contribution

EXPERIMENTAL SET-UP



<Concrete cubes for Pullout test>



<Concrete cubes for Splitting test>

❑ METERIALS

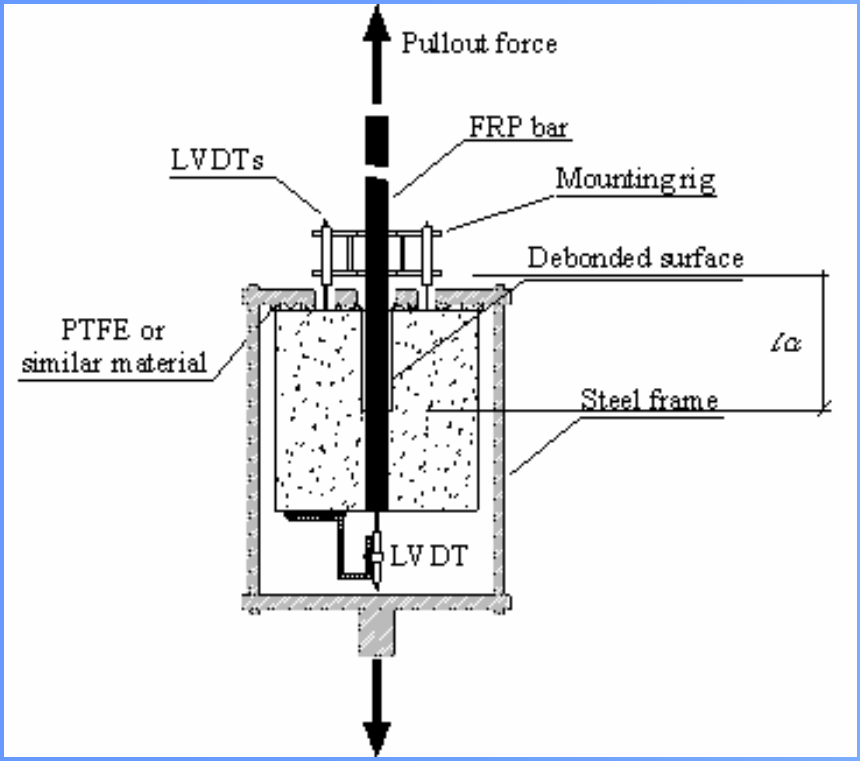
- Mechanical properties of GRC
  - W/C = 0.35, S/C = 1.0, Mix 1 = 2%, Mix 2 = 3%
  - f_c = 54 and 66 MPa
    (6 controlled cylinder cubes per mix)
  - f_{ct} = 6 and 7MPa (by Brazilian Test)
    (3 controlled cylinder cubes per mix)

- Mechanical properties of rebars
  - f_{t_steel} = 500 MPa, f_{t_GFRP} = 900 MPa
  - E_{GFRP} = 45 GPa, E_{steel} = 205 GPa

EXPERIMENTAL SET-UP (Cont.)

❑ EXPERIMENTAL SET-UP

✓ Four / Five LVDT have been used



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❑ Test systems

❑ EXPERIMENTAL PROGRAM

	Standard Pull-out Tests		Splitting Pull-out Tests	
	8mm FRP	6mm steel	8mm FRP	6mm steel
Mix 1	3	3	3	3
Mix 2	3	3	3	3
Total	24			

EXPERIMENTAL ANALYSIS

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SLIP

Actual slip of the bar with respect to the concrete, δ_{le}

Average slip measurements of three LVDTs, δ_{av}

Elastic elongation of the unbonded portion of the bar, Δl

$$\delta_{le} = \delta_{av} - \Delta l = \left(\delta_1 + \delta_2 + \delta_3\right)/3 - Fl_a/(EA)$$

where, δ1 , δ2 , δ3 = slip measurements of the three LVDTs

la = unloaded length

F = applied pullout load

E = elastic modulus of the bar

A = cross-sectional area of the bar

BOND STRESS

$$\tau = \frac{F}{\pi dL}$$

where, F = applied pullout load

d = diameter

L = bond length of the bar

TEST RESULTS

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- Mix Design 1 (glassfibre = 2%)

	$P_{max\_average}$	$\tau_{max\_average}$	$\delta_{peak\_average}$
Pullout Test 6mm	15.938 36.800*	28.183 16.300*	2.988 1.440*
Pullout Test 8mm	18.175 10.800*	14.199 8.490*	1.404 0.820*
Splitting Test 6mm	4.330 8.100*	7.657 3.600*	0.413 0.080*
Splitting Test 8mm	5.002 4.000*	3.907 3.100*	0.877 0.027*

* Mischopoulos, N., "Bond of FRP reinforcing bars in concrete"
University of Sheffield

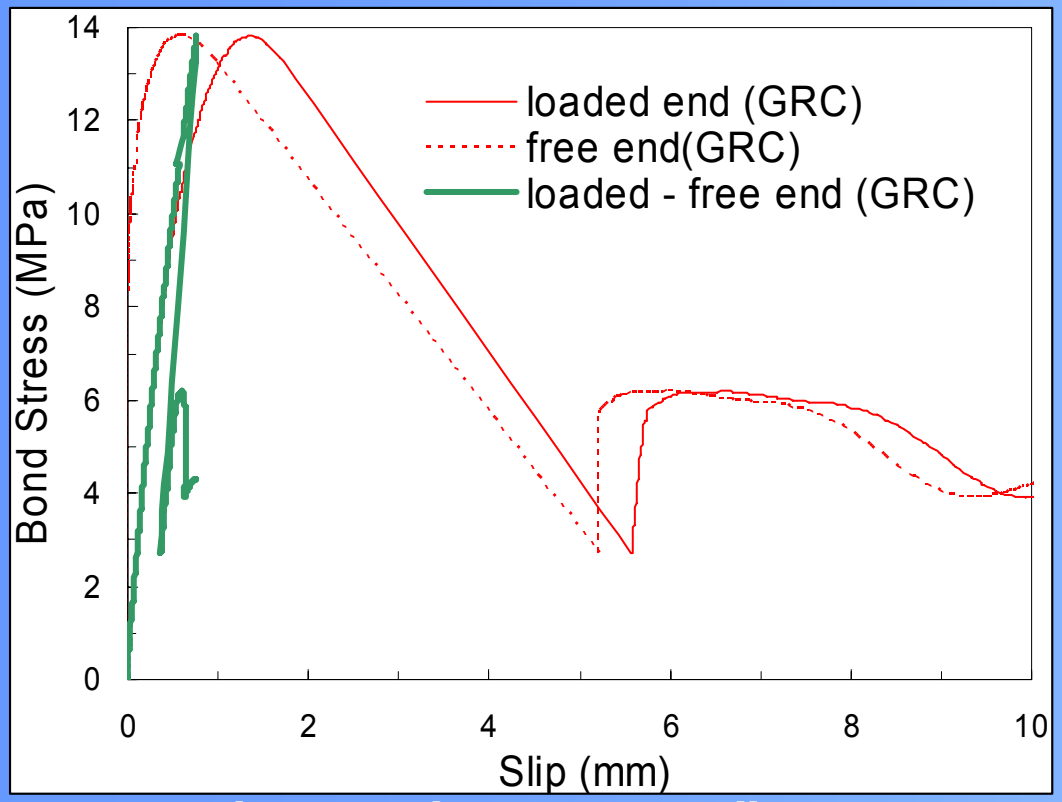
TEST RESULTS (Cont.)

- Mix Design 2 (glassfibre = 3%)

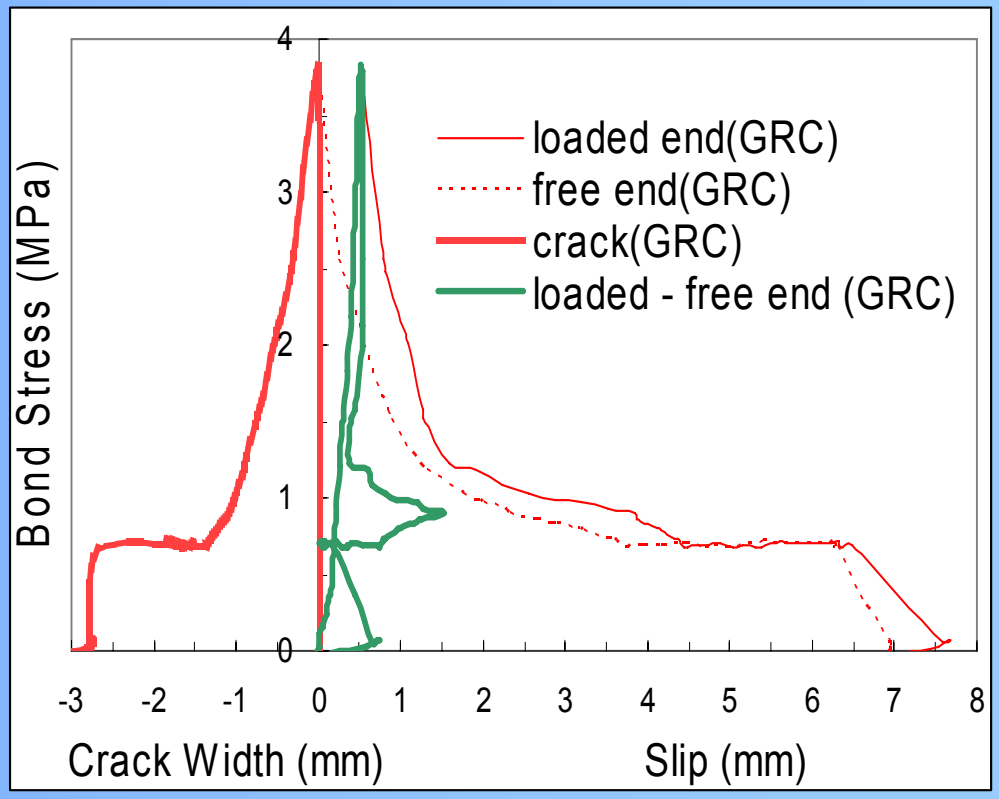
	$P_{max\_average}$	$\tau_{max\_average}$	$\delta_{peak\_average}$
Pullout Test 6mm	14.036	24.821	2.225
Pullout Test 8mm	14.091	11.009	0.721
Splitting Test 6mm	2.752	4.866	0.477
Splitting Test 8mm	4.868	3.803	0.247

Slip characteristics

- Debonding process ; loaded end → free end
- Failure of the resin rich layer of the surface → the bar pull-out by several mm
- Bond failure ; concrete splitting (by crack width measurements in splitting test)



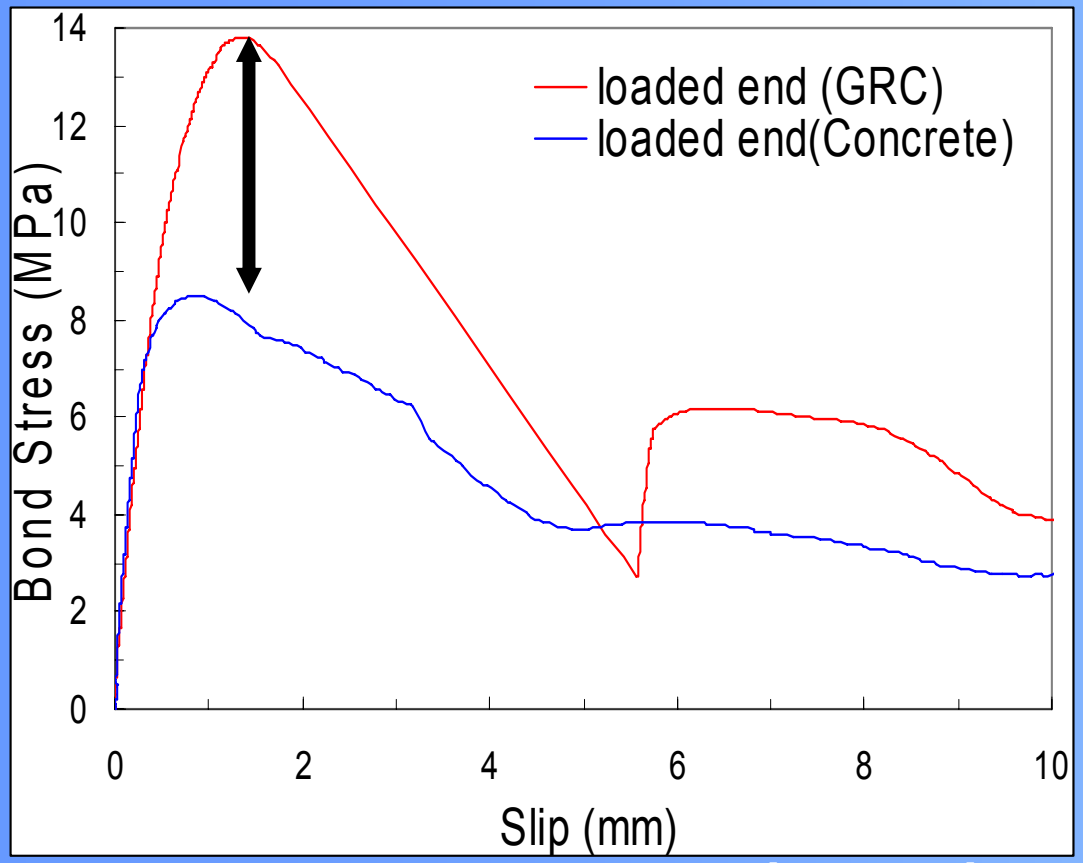
<Bond Stress - Slip response ; pullout test>

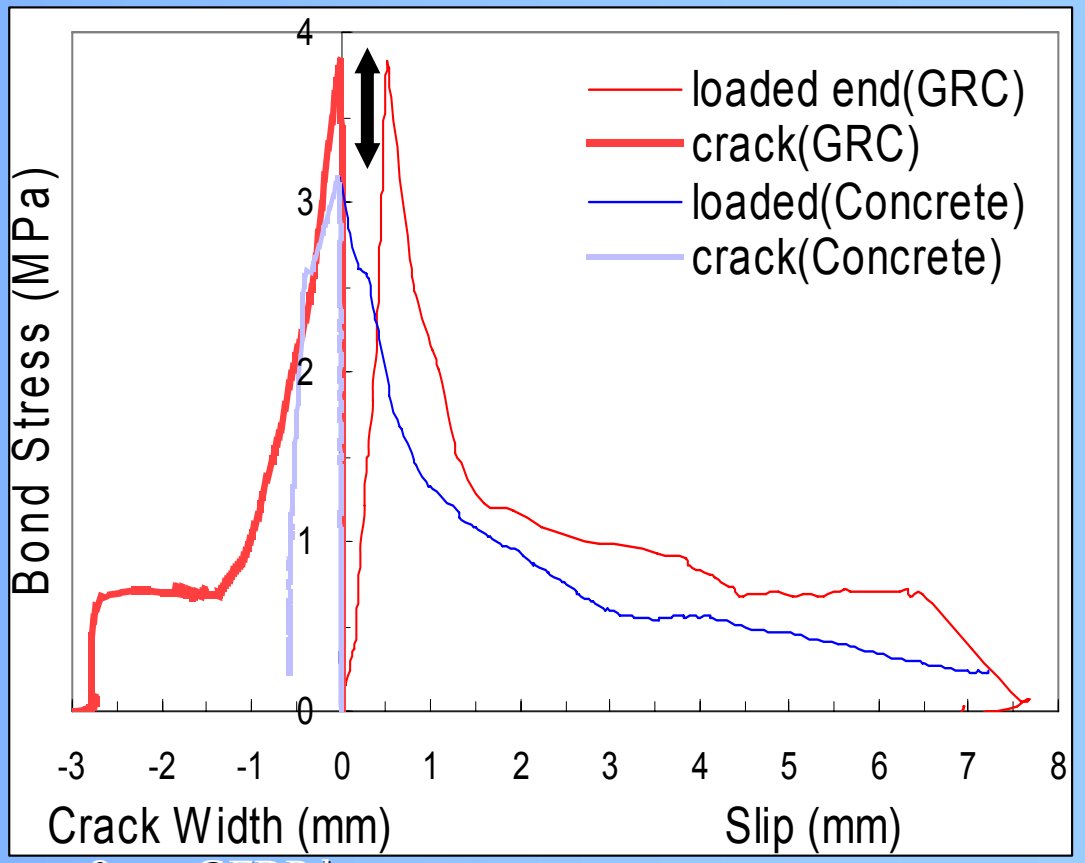


<Bond Stress - Slip response ; splitting test>

GRC & Concrete

- Similar failure mechanism
- GRC provides higher initial and residual strength than Concrete
- Bond stress in GRC ; 60% (pullout) & 26% (splitting) higher than in Concrete

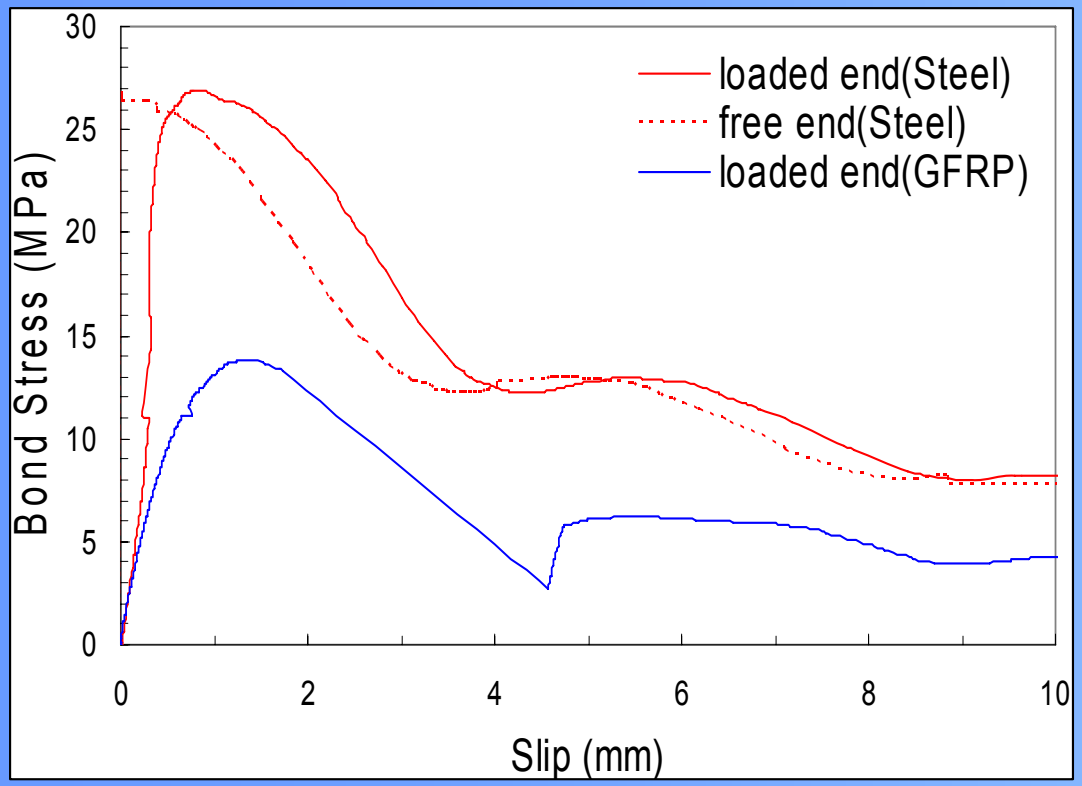


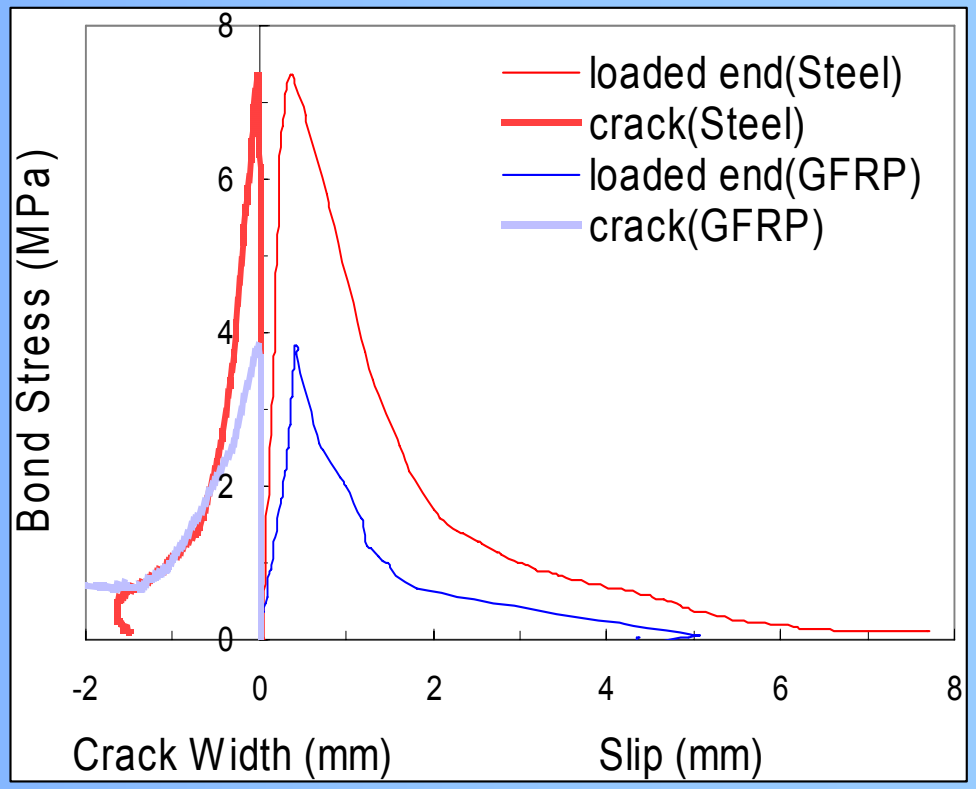


<Bond Stress - Slip curves ; 8mm GFRP bars>

Steel & GFRP bar

- Slightly different failure mode ; initial slippage in the steel bar occurs suddenly and without any damage to the steel bar surface
- Pullout & splitting strength ; Steel reinforcement >> GFRP bar (small bar diameter)

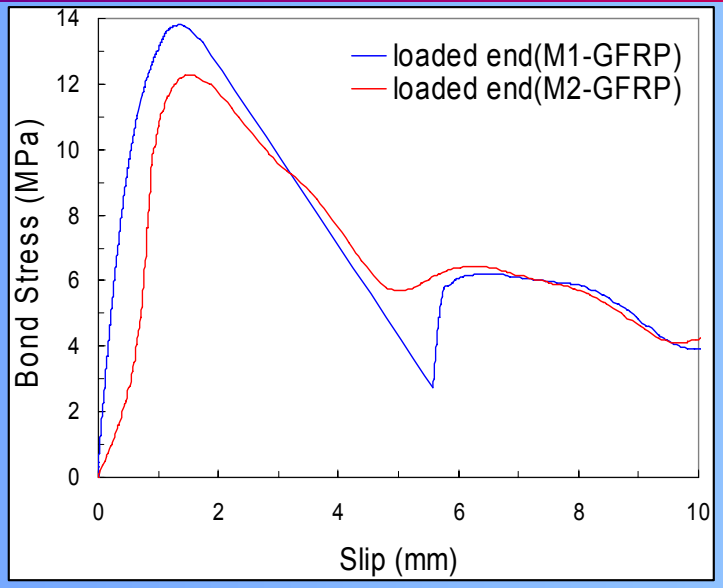


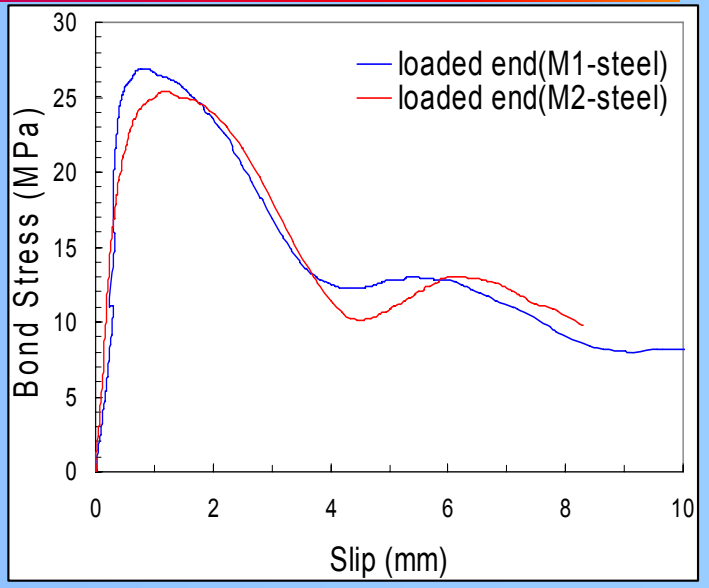


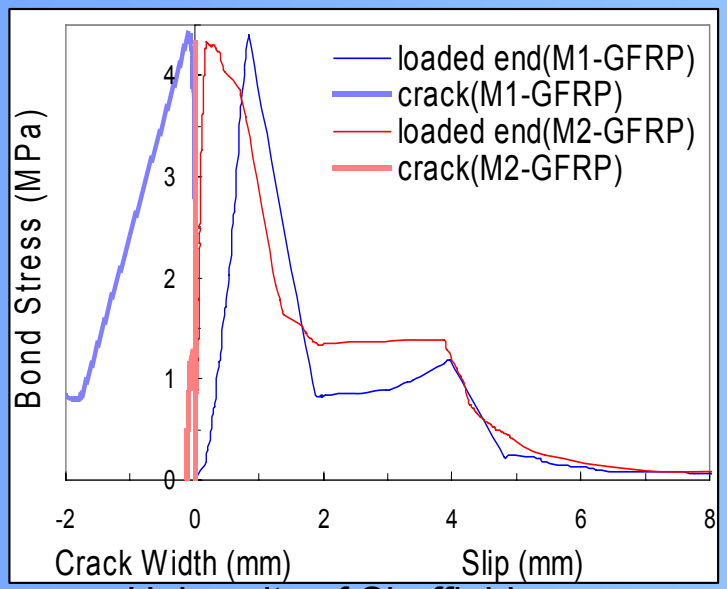
<Bond Stress - Slip curves ; Steel & GFRP bar>

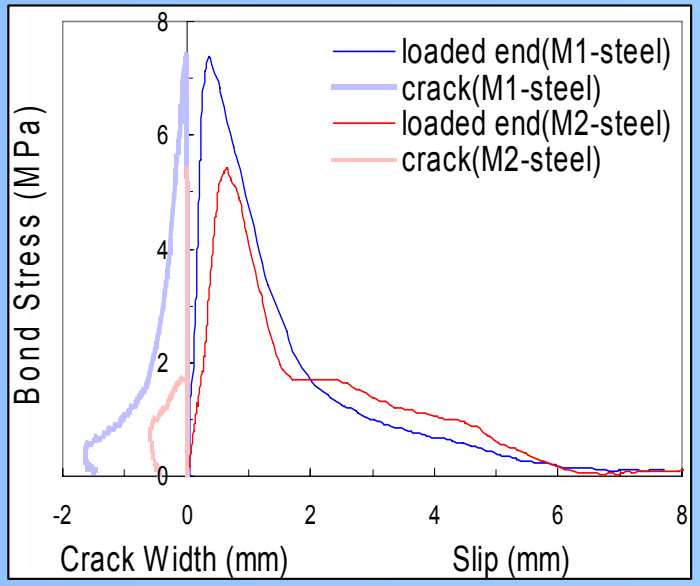
Mix 1 & Mix 2

- Two different type of rebar & two different mixes of GRC
- fibre reinforcement in GRC → high tensile resistance to the splitting crack (expected)
- Benefit for resisting splitting is not as much as for pull out
- Bond strength for Mix 1 > Mix 2 (Unexpected)









CONCLUSIONS

- $\tau_{\text{GFRP rebars and GRC}} \approx 1.6 \times \tau_{\text{GFRP rebars and Concrete}}$
- Local bond stress – slip relationships predicted bond failure by pullout
- The volume of fibres have no effect on the maximum bond strength
- GFRP reinforcement in GRC
- Further experimental investigation, Proper anchorage of bars