Bond performance of glass-FRP, basalt-FRP and stainless steel bars embedded into low-carbon geopolymer concrete

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Introduction

In the context of climate change mitigation, there is a growing demand for low-carbon building materials to reduce the construction sector's significant carbon footprint. Fibre reinforced polymer (FRP) materials have emerged as a sustainable alternative in concrete structures due to their high strength-to-weight ratio, corrosion resistance, and shear strength enhancement. Similarly, stainless steel bars offer superior mechanical performance and corrosion resistance compared to conventional carbon steel reinforcement.

This research project examined the bond behaviour of glass-FRP (GFRP), basalt-FRP (BFRP) and stainless steel bars bonded into high strength, low-carbon geopolymer (GPC) concrete. The GPC mixture was primarily composed of Ground Granulated Blast Furnace Slag (GGBS), offering an 80% reduction in embodied carbon compared to normal Portland cement (NC) concrete without compromising the durability and shear strength. Experimental variables included concrete type, bar type and embedment length. The findings contribute to advancing low-carbon, high-performance materials for sustainable infrastructure.

Methodology

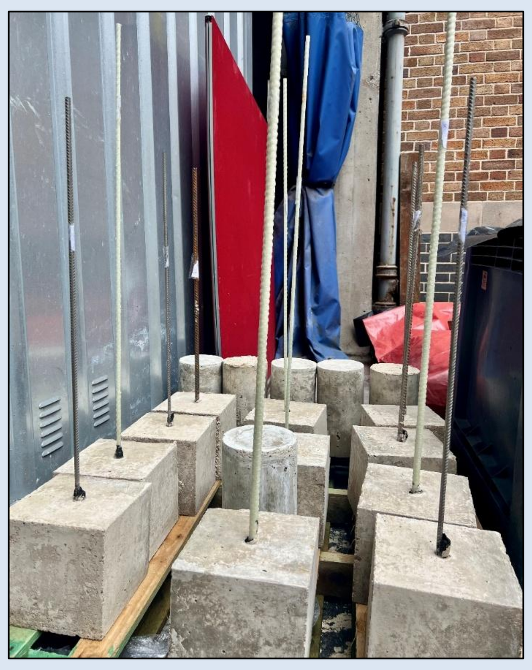
A total of twenty-seven concrete cube specimens (200 x 200 x 200 mm) with embedded GFRP, BFRP and stainless steel bars were tested. A pull-out load was applied on these bars to obtain the pull-out force-slip relationship at the loaded ends of the tested bars in accordance with ACI 440.3R-06 (2006) guidelines. Standard bar diameter (d_b) of 10 mm with embedded lengths of $5d_b$, $10d_b$ and $15d_b$ were used to assess bond performance and failure modes. Figures below illustrate the types of bars used, methods of preparation for test specimens and setup arrangement.

Glass-FRP

Basalt-FRP

Stainless steel

Moulds preparation



Specimens

Curing

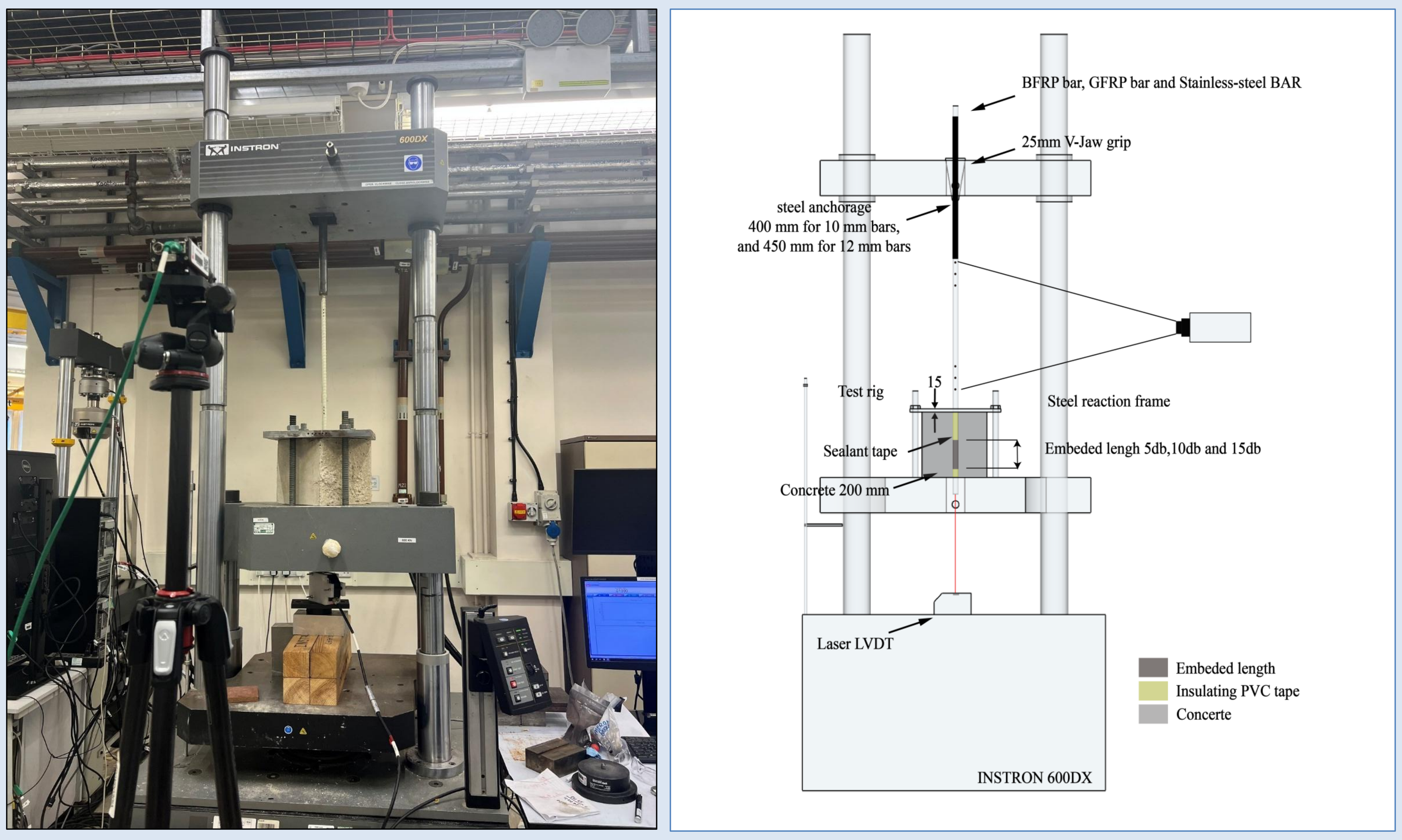
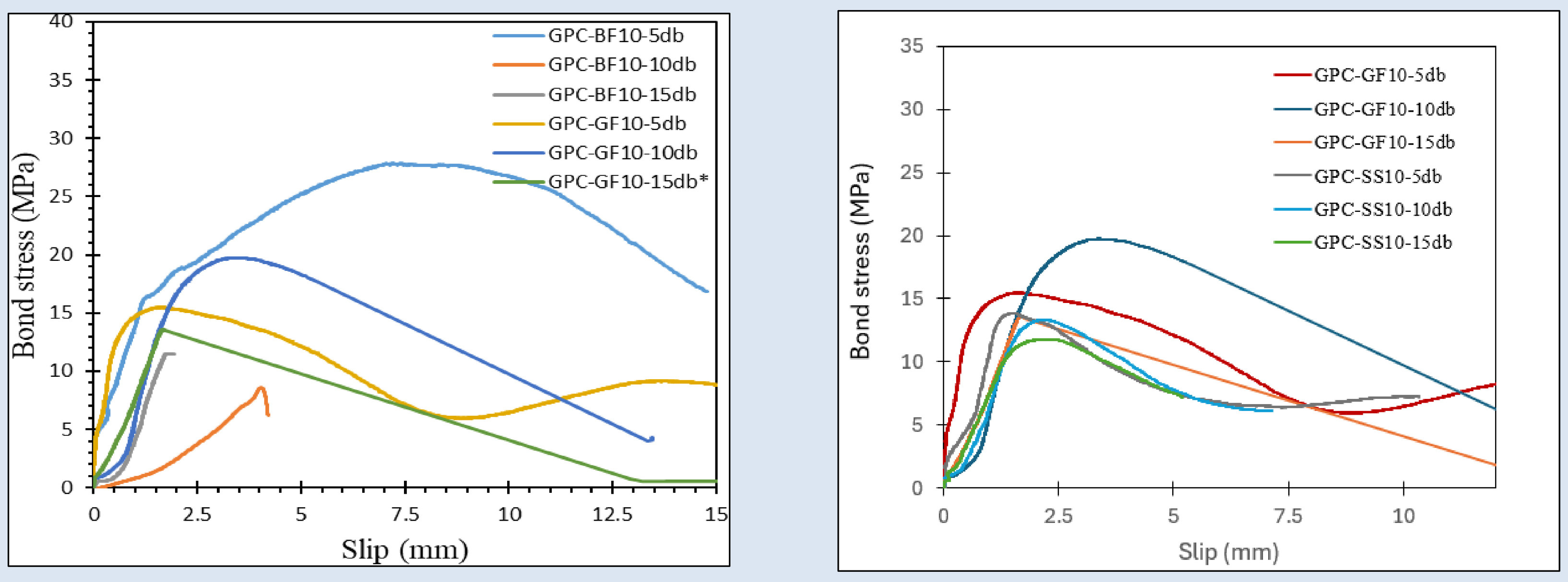


Figure 1. Test specimens and setup

Key findings and discussion

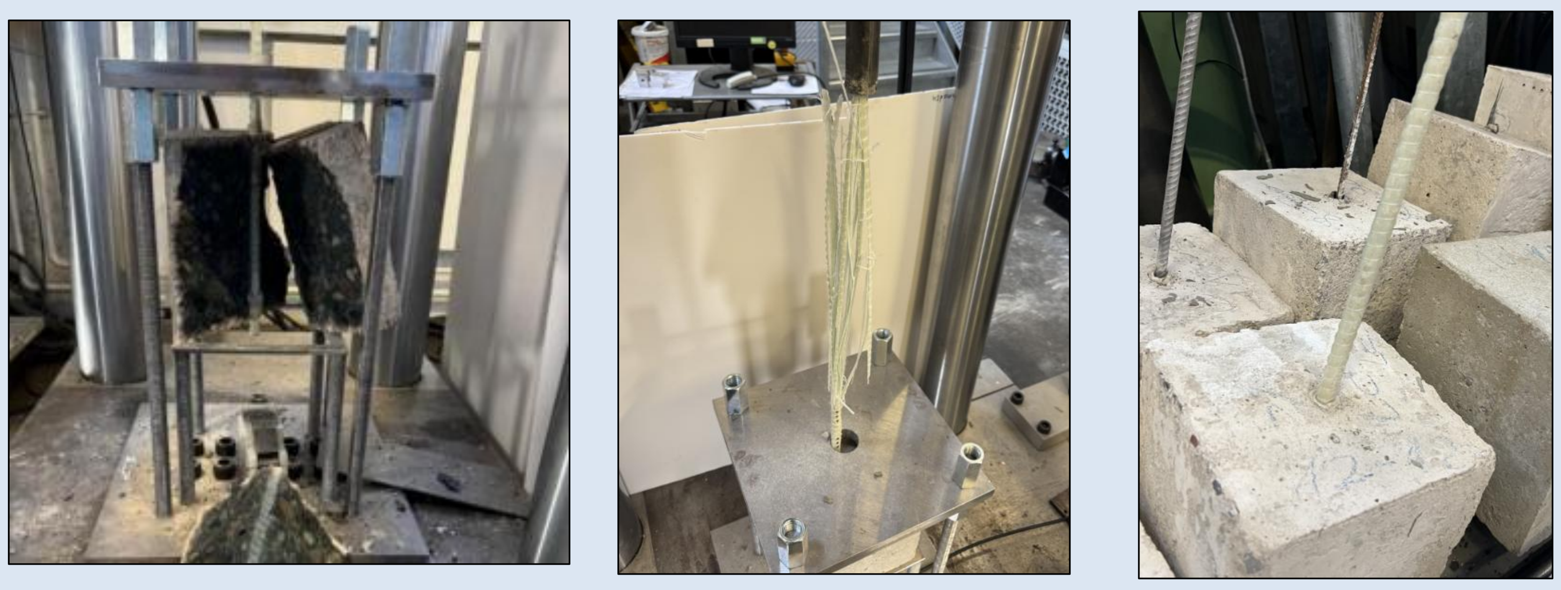
Bond-slip behaviour and failure modes

Figures 2a and 2b illustrate the bond stress-slip curves for the tested specimens with 10 mm FRP and stainless steel bars, respectively. The overall behaviour of these curves is characterised by an initial, almost linear, increase in the pull-out force with slip (ascending branch), followed by a gradually descending branch once the maximum pull-out force is achieved. Specimens with basalt-FRP bars (BFRP) exhibited higher initial stiffness and maximum bond stress than the corresponding specimens with glass-FRP (GFRP) and stainless-steel bars. The failure modes are also displayed in Figure 3.



(a) (b)

Figure 2. Bond stress-slip curves for the specimens with: (a) basalt & glass-FRP bars and (b) glass-FRP & stainless steel bars

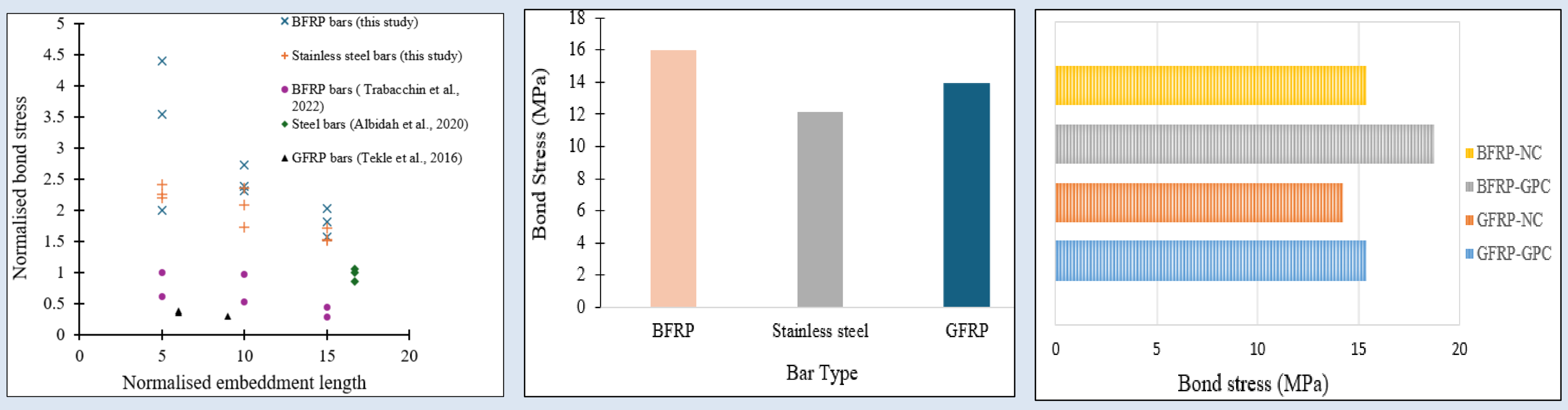


(a) (b) (c)

Figure 3. Failure modes: (a) concrete splitting, (b) bar rupture and (c) bar pull-out

Impact of parameters

Figures 4a, 4b, and 4c display the impact of embedment length, bar type and concrete type on the bond stress, respectively.



(a) (b) (c)

Figure 4. Effect of: (a) embedment length, (b) bar type and (c) concrete type

Conclusions

- For all bar types, the pull-out capacity increased whereas the bond stress decreased with the increase in embedded length.
- The specimens with basalt-FRP bars achieved higher pull-out capacities and better bond performance than those with glass-FRP bars.
- Specimens with geopolymer concrete (GPC) achieved a superior bond performance and higher bond stress than specimens with normal Portland cement.
- Results support the feasibility of adopting GPC-FRP systems for sustainable structural applications.

References

- ACI (American Concrete Institute). (2006). ACI 440.1R-06: Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars, Farmington Hills, MI: American Concrete Institute.
- Albidah, A., Altheed, A., Alrshoudi, F., Abadel, A., Abbas, H. & Al-Salloum, Y. (2020). Bond performance of GFRP and steel rebars embedded in metakaolin based geopolymer concrete. Structures, 27:1582-1593..
- Trabacchin, G., Sebastian, W. & Zhang, M. (2021). Experimental and Analytical Study of Bond between Basalt FRP Bars and Geopolymer Concrete. Construction and Building Materials, 315:125461.