Bond Performance of FRP Bars in Low-Carbon Geopolymer Concrete

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Keywords: Geopolymer; Concrete; Bridges; Research; Fibre Reinforced Polymer (FRP).

1. Introduction

In response to climate change mitigation and sustainable development goals, there is increasing demand for low-carbon binders and innovative construction technologies that reduce the significant carbon footprint of the concrete industry. One promising approach is the integration of fibre-reinforced polymer (FRP) reinforcement in Ground Granulated Blast Furnace Slag (GGBS)-based geopolymer concrete (GPC) to enhance the durability and structural performance of concrete, particularly in aggressive environments where reinforcement corrosion is a major concern. Unlike conventional Portland cement concrete, whose production generates high CO_2 emissions, GGBS-based geopolymer binders utilise industrial by-products and can reduce embodied carbon by up to 80% while achieving comparable strength and durability. However, despite these benefits, the bond behaviour and performance between FRP reinforcement and GGBS-based geopolymer concrete remain insufficiently understood, highlighting a critical research gap that this study aimed to address.

2. Research project details

For the first time at the Civil Engineering Laboratory of the University of Bristol, an extensive experimental programme of pull-out tests was conducted to investigate the bond behaviour of glass-FRP and basalt-FRP reinforcement bars embedded in both low-carbon geopolymer concrete and conventional Portland cement (PC) concrete. Pull-out loads were applied to the reinforcement bars to establish the pull-out force-slip relationships at the loaded ends, in accordance with ACI 440.3R-06 (2006) guidelines. The experimental parameters included concrete type, reinforcement, and embedment length.

Fig. 1: Pull-out test setup

Results demonstrated that basalt-FRP bars exhibited higher pull-out capacities, lower slip values, and superior bond performance compared with glass-FRP reinforcement. Geopolymer concrete specimens also showed enhanced bond strength due to their denser matrix in comparison to PC specimens. Pull-out capacity increased while bond stress decreased with greater embedment length. Importantly, this study pioneers the development of novel analytical and finite element models to predict bond strength of FRP bars, providing new insights and practical design tools for FRP reinforcement in geopolymer concrete structures.

3. Conclusions

The findings provide contractors and designers with new knowledge supporting the use of embedded FRP reinforcement in low-carbon geopolymer concrete as a sustainable alternative to conventional concrete, enabling more resilient structures, reduced carbon emissions, shorter construction programmes, and enhanced long-term value for concrete infrastructure assets.

References

ACI, Guide for the design and construction of structural concrete reinforced with FRP Bars. ACI, Farmington Hills, MI, USA, Report No. ACI 440 1R-06, 2006.