GEOPOLYMER CONCRETE TO REDUCE THE ANTHROPOGENIC GREENHOUSE GAS EMISSIONS ASSOCIATED WITH THE CONCRETE AND CONSTRUCTION INDUSTRY

Ali Amin *University of New South Wales*

INTRODUCTION AND RESEARCH SIGNIFICANCE:

The binding agent of concrete, Ordinary Portland Cement (OPC), accounts for approximately 5% of global industrial energy consumption, with water consumption the only resource used more than concrete. The global OPC industry consumes an estimated 2.9 billion tonnes of natural resources each year and contributes to approximately 7% of all anthropogenic CO_2 emissions. Australian production processes release about 800 kg of CO_2 per 1 tonne of cementious material produced. Utilisation of industry waste products, such as fly ash and slag, in place of cement is a potential alternative to reduce the carbon footprint of the concrete industry without compromising performance. Geopolymers utilise such waste products; they contain no OPC and behave in a similar quasi-brittle fashion to that of concrete – thus proving to be an emerging sustainable material.

As the demand to construct structures of greater complexity increases, so too does the requirement for superior materials in terms of robustness and durability. The use of discrete ductile fibres to reinforce concrete members has been examined over the last five decades to try and meet this demand. In addition to increasing the shear and tensile capacity of a cementious mix (which were the main findings of this research), the inclusion of fibres to a concrete matrix has been shown to enhance a number of other material properties such as fatigue resistance, energy absorption and toughness, ductility, durability and improves the service life of the material. By adding fibres to a concrete mix the objective is to bridge discrete cracks providing for some control in the fracture process.

MAJOR FINDINGS AND OUTCOMES:

Ten large scale fibre reinforced geopolymer concrete beams of varying fibre content (ranging from 0-1.5% by volume) and fibre type (end-hooked or straight) were constructed and tested to failure (refer to Figure 1). It was found that an increase in fibre content resulted in a linear increase in the ultimate shear capacity of the fibre reinforced geopolymer concrete beams. Furthermore, an increase in fibre content also saw an increase in the deformability behaviour of the fibre reinforced geopolymer concrete beams. These ductile responses are much more desirable than brittle or sudden failures for all reinforced concrete structures.

Cracking of the beams under load was investigated. It was shown that the quantity of fibres and type of fibres used in the geopolymer concrete mixture did not significantly affect the cracking load but had a significant influence on the rate of crack propagation and reduction in crack widths.

An experimental investigation was also carried out to investigate some common short term mechanical properties which included the Fracture Energy, Modulus of Rupture, Indirect Tensile Strength, and Stress-Strain response. It was found that an increase in fibre content improved each of these properties.

Following the experimental works of this project, a numerical study was conducted which focussed on modelling and verifying those results. A commercially available finite element package, ATENA 2D, was used in conjunction with material parameters derived from the Unified Variable Engagement Model, after Htut and Foster (2010) to describe the shear versus deflection response, principal strain distributions and crack patterns. A very reasonable correlation between the experimental test data and computer output was attained for all properties considered.

Furthermore, a sub study was conducted to examine the accuracy of available design models to describe the capacity of fibre reinforced concrete beams in shear. A predictive model described in Foster (2010) provided the best approximation to quantify the fibre contribution to the shear resistance of fibre reinforced geopolymer concrete beams. The correlation between the ratio of the model and the experimental results was excellent, with a mean value of 0.99 and a coefficient of variation of 12% attained. Minimum shear reinforcement was also explored to some extent and it was concluded that a fibre volumetric ratio of 0.75% of 35mm long end-hooked fibres was sufficient to replace minimum conventional reinforcing steel (stirrups) requirements for shear under AS3600 (2009).

FURTHER RESEARCH SUGGESTIONS:

Geopolymer concrete is relatively young in its development and much research on the behaviour of the material is still required. Over the conduct of the experiments and subsequent analyses, which were performed as part of this research, a number of aspects surfaced which are considered worthy of further investigation:

- The development and verification of a comprehensive mix design for a range of strengths and grades of workability for geopolymer concrete
- An in-depth analysis into the durability of geopolymer concrete, which may include examining the integrity of:
  - attacks by external chemical agents, such as sulphates, sea water & acid media
  - corrosion of reinforcement, longitudinal or fibre, embedded in geopolymer concrete
  - potential issues regarding expansion due to alkali-aggregate reaction
- A thorough assessment into the time dependent effects, such as creep, of fibre reinforced geopolymer concrete
- An examination into use of different fibre types, and/or the use of a 'cocktail' of fibre types into the shear response of fibre reinforced geopolymer concrete beams. An investigation into the bond strength of each of the fibre types is necessary prior to considering the response of large scale beams
- An examination of the combined effect of conventional shear reinforcement, such as stirrups, with fibre reinforcement, into the shear capacity of geopolymer concrete members

CONCLUSIONS:

Overall, it can be summarised and concluded that geopolymer concretes have several beneficial properties. The introduction of fibres into a geopolymer matrix promotes many of the short term engineering properties of this material. Geopolymer concrete presents as an economically viable structural alternative to OPC concrete products. A comprehensive mix design procedure, however, is paramount in order to promote this material for use in infrastructure.

It is clear that many efforts are required to expand the understanding of the structural responses of this material. Once these behavioural characteristics are understood, and 'whole of life costs' are considered, it is hypothesized that the favourable properties of geopolymer concrete will be endorsed as a socially and environmentally acceptable product.

REFERENCES:

HTUT, T.N.S., & FOSTER, S.J. (2010), Unified model for mixed mode fracture of steel fibre reinforced concrete. *Fracture Mechanics of Concrete and Concrete Structures- High Performance, Fiber Reinforced Concrete, Special Loadings and Structural Applications*- B. H. Oh, et al. (eds)

FOSTER, S.J. (2010), Design of FRC Beams for Shear using the VEM and the Draft Model Code Approach, fib shear workshop, Salo, Italy, 15-16 October, 2010 (in-press).

AS3600 (2009), Concrete Structures. Standards Association of Australia.

NCCARF
National
Climate Change Adaptation
Research Facility
Adaptation Research Network
SETTLEMENTS AND INFRASTRUCTURE

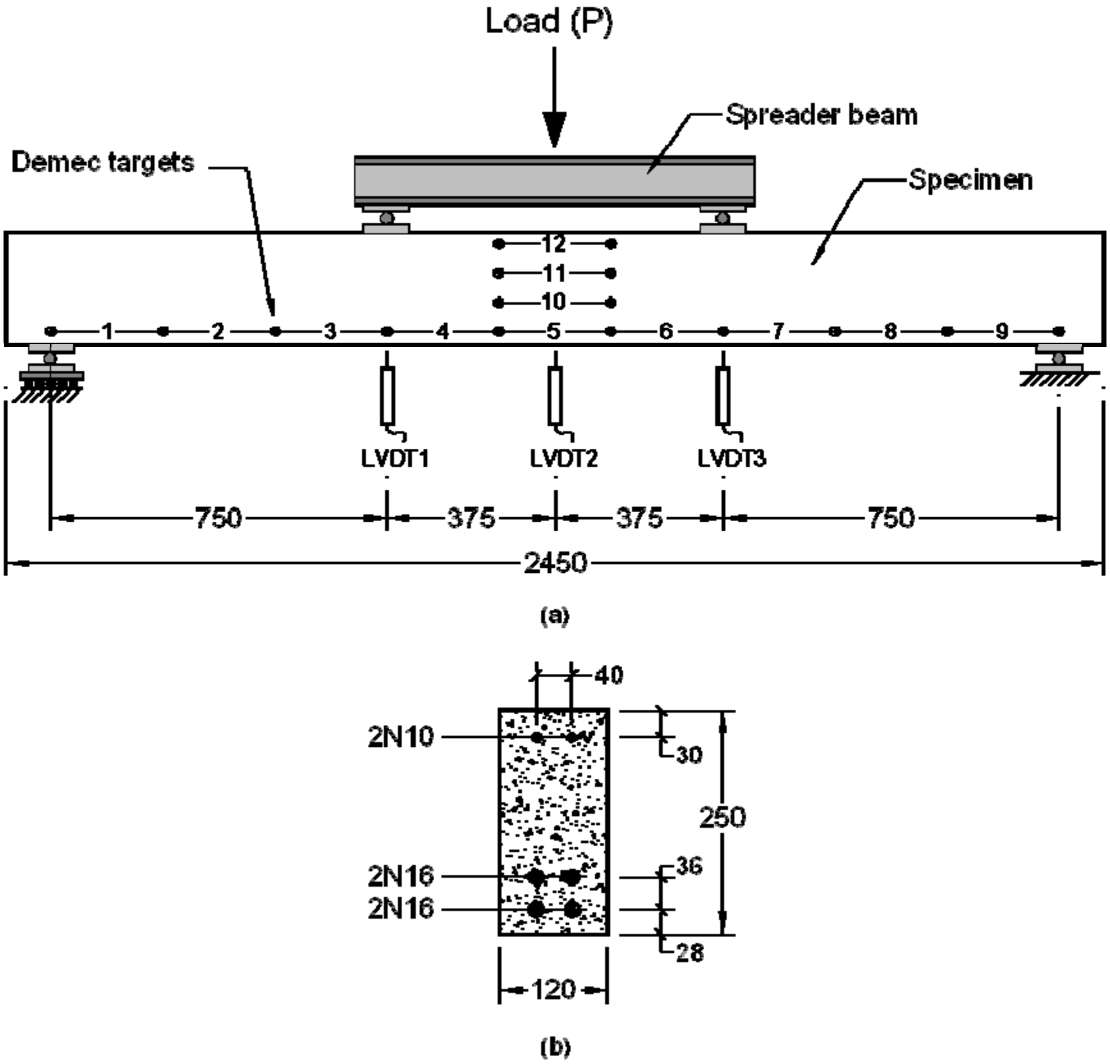

Figure 1: Details of (a) Test Arrangement, (b) Cross Section.

Grant Holder: Ali Amin, School of Civil and Environmental Engineering, University of New South Wales
Honours Thesis Supervisor: Professor Stephen Foster