Shear Strength of Concrete at Elevated Temperature

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INTRODUCTION

Performance based methods for designing concrete structures in fire have, to date, focused upon the flexural performance of beam and slab elements and large displacement mechanisms for sustained load capacity at high temperature. Shear failure has received little attention, but there is a growing awareness that shear can govern the failure of concrete structures in fire, for example in punching shear or as a consequence of restrained thermal expansion.

The mechanisms through which shear is transferred in reinforced concrete include (Figure 1):

1. compressive force paths within the concrete;
2. tensile crack bridging by the reinforcing steel (relying upon concrete-steel bond);
3. dowel action in the reinforcing steel; and
4. friction across cracked surfaces due to aggregate interlock

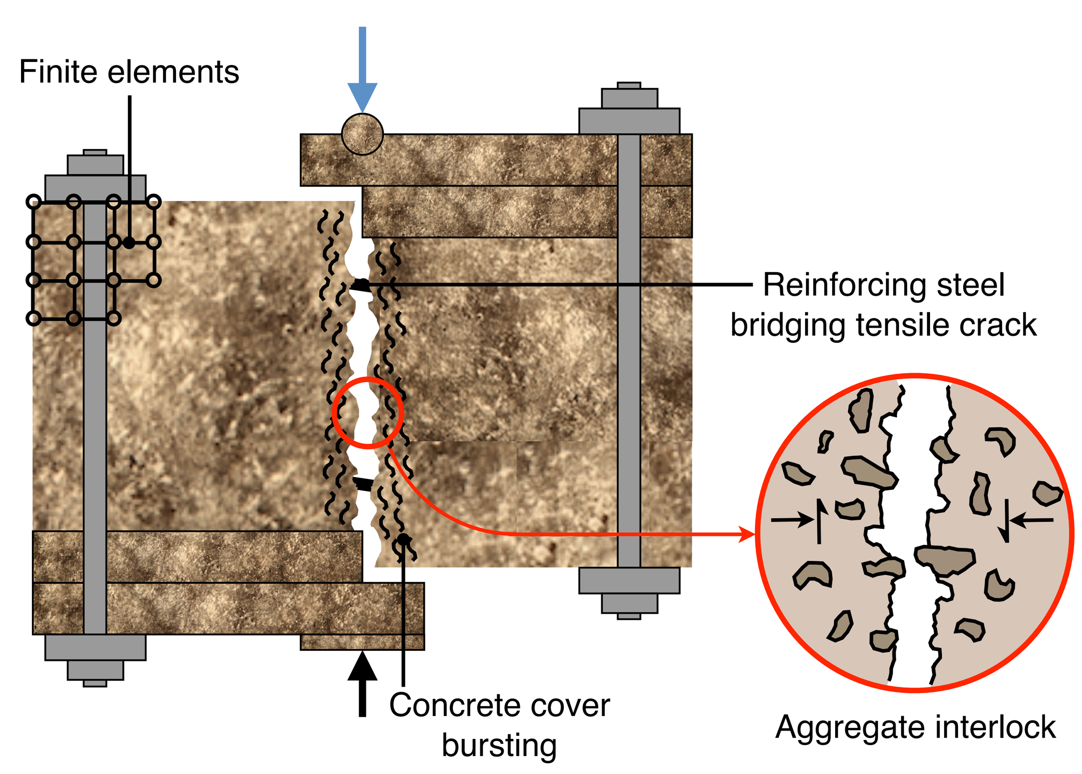

Fig. 1: Shear Mechanisms

RESEARCH OBJECTIVES

- Study the effect of elevated temperature upon the shear mechanisms and their interactions.
- Establish constitutive shear information that can be used in modelling and design.

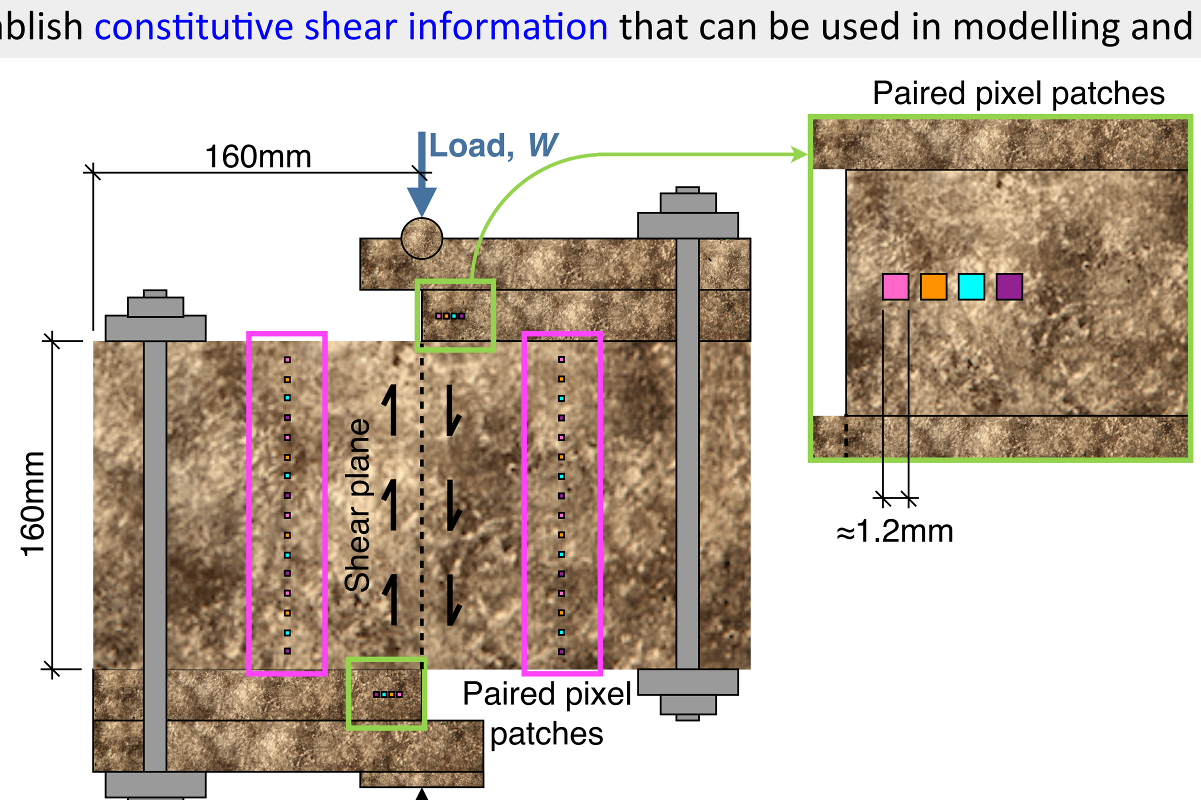

Fig. 2: Test Arrangement & Measurement of Shear and Crack Opening Displacement by Digital Image Analysis

EXPERIMENTS

Sixteen shear block specimens (100×160×320mm) were cast with a readymix concrete (ambient f_c=29MPa, ambient f_t=1.8MPa) reinforced with ⌀6mm smooth steel bars (ambient f_y=415MPa). Four shear stirrups crossed the shear failure plane. The specimens were heated in an electric furnace to temperatures of 112°C, 188°C, 390°C, 475°C, and 622°C. A reference specimen set was unheated (17°C).

Seven days after heating, steel loading plates were used to force shear failure. A thermocouple at the centre of the shear block was used to record the internal temperature, and a second thermocouple was used to record the furnace temperature.

High resolution digital images were recorded at 5 second intervals during the tests, focusing upon the shear failure plane (Figure 2). These images were analysed (using geoPIV software) (Bisby & Take, 2009) to track the motion of selected patches of the speckle pattern from image to image.

Relative vertical displacement of paired pixel patches → shear displacement

Relative horizontal displacement of paired pixel patches → crack opening displacement

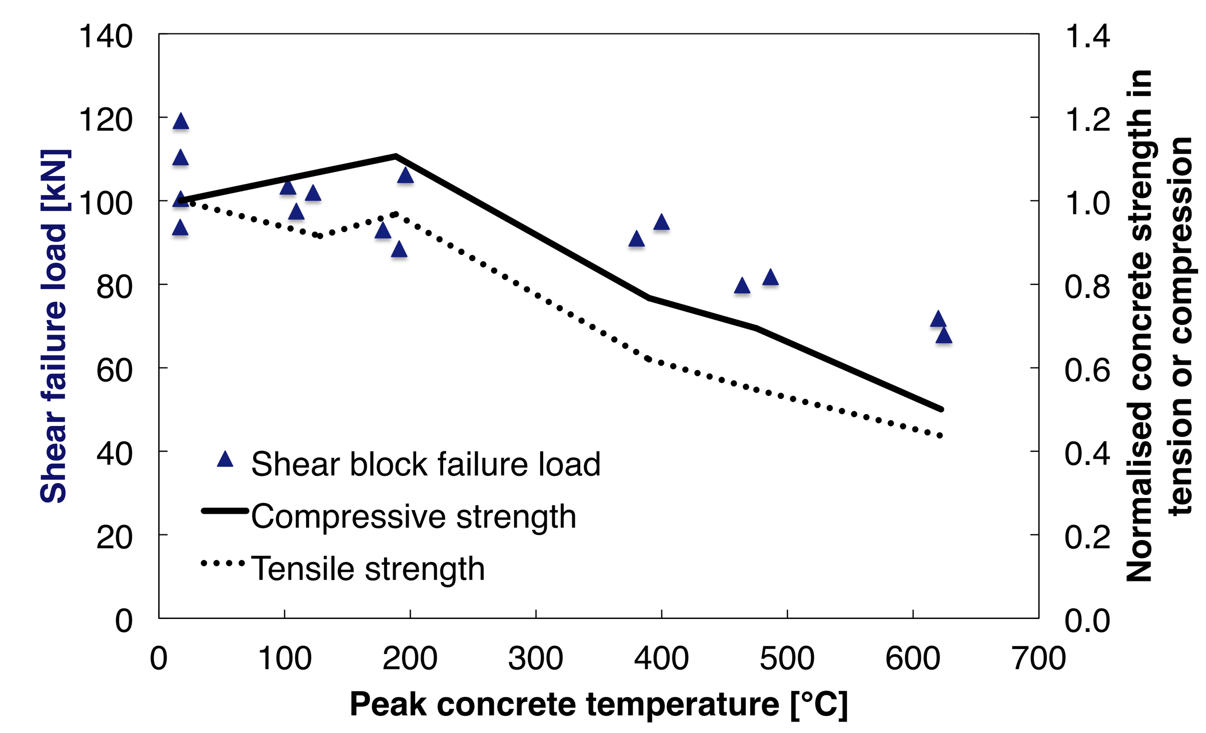

Fig. 3: Temperature Impact on Residual Strength of Shear Block and Normalised Residual Compressive and Tensile Strengths

RESULTS

Figure 3 shows the normalised variation in compressive and tensile strengths of the concrete cylinders with temperature and the variation in shear block strength with temperature. The shear strength reduction at high temperature is less pronounced than that shown by the concrete strength, as it depends on both the concrete and steel.

The load-displacement response of the shear blocks (Figure 4) shows the initial stiffness and peak strength to reduce with temperature, whereas the displacement at peak strength increases with temperature. The strength post-peak drops to a frictional value that is governed by the mechanisms: 2,3 and 4. Post-peak there are two clear groups: lower temperatures sustaining a frictional shear of 50kN and the higher temperatures sustaining a frictional shear of 25kN. The concrete cover loss was extensive at high temperature, leading to a decrease in mechanism 2 transfer (Figure 4).

The crack opening width development with temperature again highlighted two clear groups: lower temperatures produced low crack displacements and high temperatures caused large crack opening displacements.

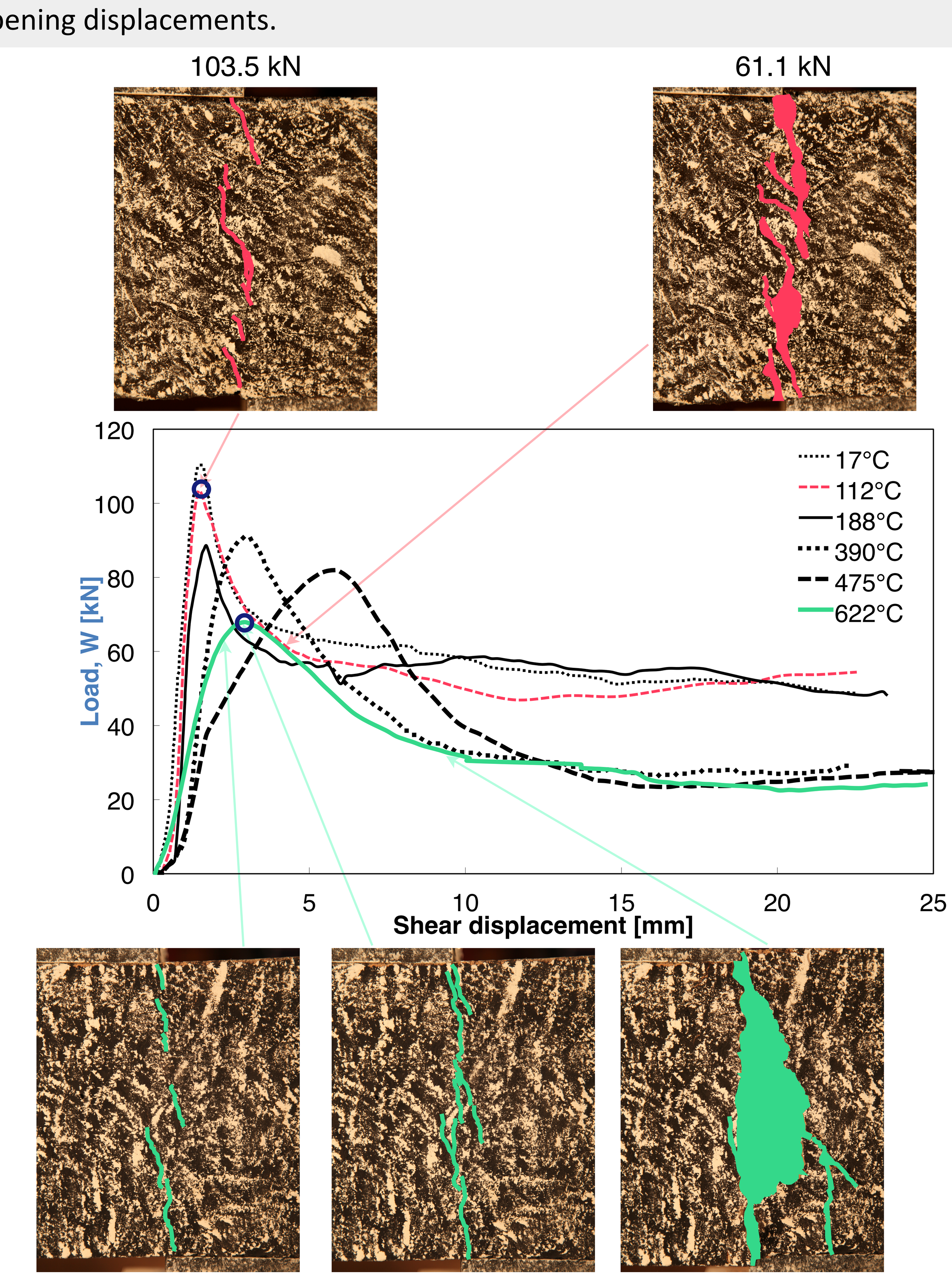

Fig. 4: Shear Block Residual Load-Displacement Response with Temperature

CONCLUSION

The tests demonstrate that the residual shear strength of reinforced concrete is affected by high temperatures. The decrease in strength can be attributed to a complex interaction of concrete and steel through shear transfer mechanisms.

Bisby, L. A., Take, W. A. (2009). Strain Localizations in FRP Confined Concrete: New Insights. Proceedings of the ICE - Structures and Buildings, 162(5):301-309.

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