BOND OF REINFORCEMENT IN CONCRETE UNDER ELEVATED TEMPERATURES AND THERMAL CYCLING

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ABSTRACT

Reinforced concrete structures used in specialized industrial applications may be subjected to elevated temperatures and repeated thermal cycling during normal operation. These structures may be required to maintain their functional and structural performance at moderately elevated temperatures, potentially ranging between 200°C to 300°C. Such exposure can deteriorate concrete properties and degrade the bond between concrete and reinforcing steel. In regions containing lap-spliced reinforcement, adequate bond is critical for developing the yield strength of the spliced bars and ensuring the intended ductile failure through yielding. However, temperature-induced bond degradation increases the risk of premature bond-splitting failure. Existing development-length provisions in ACI 349-23, ACI 318-25 and guidance in ACI 408-03 primarily address ambient-temperature conditions, while the fire-resistance provisions of ACI 216.14 primarily address accidental fire exposure rather than sustained operational temperatures and repeated thermal cycling. This highlights the need for systematic investigation of bond deterioration and the development length provisions for operational elevated temperature environment.

The primary objective of this research was to investigate bond degradation between concrete and steel reinforcement following repeated thermal cycling, with particular emphasis on bond-splitting failure in critical lap-spliced regions. Key factors affecting bond performance such as development length, clear concrete cover, bar diameter, transverse reinforcement, maximum exposure temperature and thermal cyclic loading are integrated into this study. The research methodology involved experimental and numerical investigations at both local and global levels. Modified beam-end specimens were used to investigate local bond behavior, while full-scale reinforced concrete slabs containing critical lap splices were tested to evaluate bond development and structural performance following elevated-temperature exposure. Three-dimensional finite

element, coupled thermo-mechanical non-linear microplane model was used to extend experimental dataset through numerical parametric studies.

The findings indicate that bond deterioration increases with maximum exposure temperature and is significantly influenced by clear concrete cover. Increasing the clear cover results in more concrete volume over the reinforcement which provides two-fold benefits: (1) higher confinement to the test bar, (2) reduced temperature penetration into the concrete core. The first thermal cycle causes the most damage to the bond. Although bond degradation continues, it appears to stabilize after three thermal cycles, with negligible reductions in bond strength occurring beyond this point. Staggering the lap splices did not improve flexural capacity but resulted in a more ductile post-peak response. Sustained loading during thermal cycling caused marginal reduction in flexural capacity. Numerical investigations further demonstrated that increasing splice length improved flexural capacity and stiffness retention following elevated-temperature exposure. Based on the combined experimental and numerical findings, a temperature-dependent analytical model was developed to predict bond-strength reduction under elevated-temperature exposure. An elevated temperature modification factor was proposed for incorporation into the existing ACI 349-14 development-length provisions for deformed bar in tension. The proposed elevated-temperature modification factor provides a practical approach for adjusting reinforcement development lengths to account for thermal deterioration of bond strength.