Reducing spalling in tunnel fires

Micro-polypropylene fibres can be used to reduce the potential for explosive spalling of reinforced concrete in fires.

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When concrete is rapidly heated in a fire, explosive spalling can occur. Typically, this is in dense, high-strength concrete which, when subjected to a high-temperature fire, will shatter violently, with pieces of concrete being projected several metres from the heated concrete face. This process will repeat until the temperature subsides or all the concrete has, to all intents and purposes, been removed.

This has been a cause for concern for many years, especially in tunnel construction where the risk of explosive spalling of concrete is increased with a fire occurring in a relatively confined space. The resulting damage can be significant, such that the structural integrity of a tunnel can be put at risk.

The causes and extent of explosive spalling are complex, involving many factors such as concrete mix design, aggregate type, permeability, presence of reinforcement, moisture content and external loadings. Inherent in all of this is the pore pressure that builds within a concrete element, which induces the shattering effect. It is understood that residual moisture in the concrete when heated changes to steam vapour and without a mechanism to release this vapour, the subsequent internal pressure it induces exceeds the tensile capacity of the concrete, causing the concrete to spall.

Precast segmental tunnel lining with micro-polypropylene fibre reinforcement.

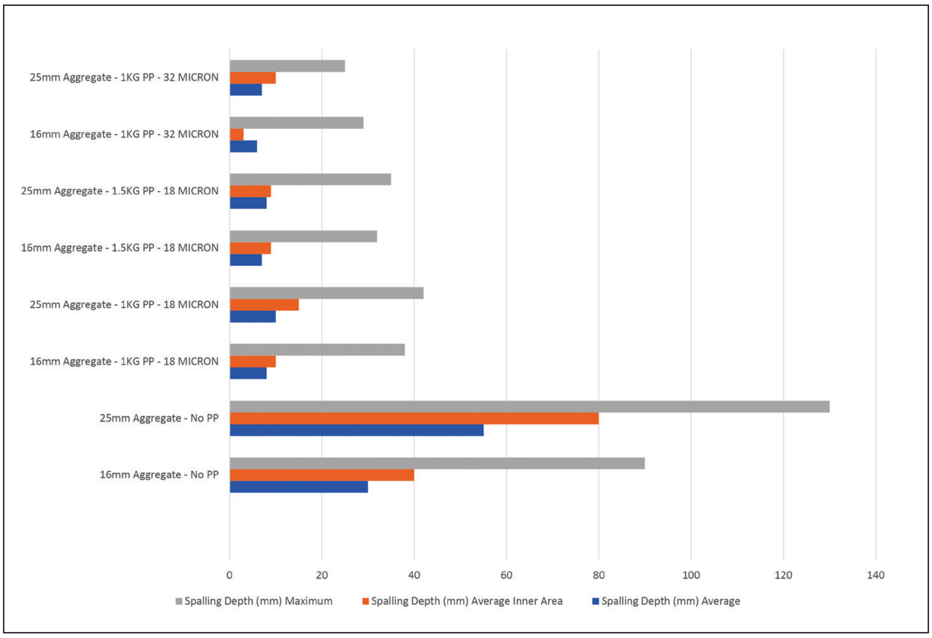
Studies by Kodur[1] and those presented at Leipzig[2] considered the mechanism of explosive spalling and subsequent solutions that could be adopted to mitigate its effects. Further work by Sullivan[3] and Liu *et al*[4] added to the concept and validation of using micro-polypropylene fibres to reduce and prevent the occurrence of explosive spalling.

The coefficient of expansion of concrete is almost identical to steel reinforcement, whereas polypropylene is much higher. The studies witnessed the effects of differential expansion of the polypropylene fibres dispersed throughout the concrete prior to melting. This typically occurs at temperatures less than 140°C, the softening point of polypropylene, and leads to micro-cracking in the concrete surrounding the fibres. This micro-cracking eventually leads to networks of cracks that allow the release of the vapour at the concrete surface caused by the heating and consequent reduction of the internal pressure to levels below the concrete's tensile capacity, substantially reducing the spalling.

However, this is not as simple as adding just any micro-polypropylene fibre.

For optimum performance, consideration is required of the stresses that the thermal expansion of the fibre can induce, together with the effects the fibre dosage and fibre count may have on the concrete to which they are added. A large-diameter fibre may cause greater expansion than a smaller-diameter fibre, but for a given dosage there may be insufficient fibres to create the network of cracks so vital for releasing internal vapour pressure. Similarly, smaller-diameter fibres may not expand sufficiently to cause micro-cracking, despite very high numbers of fibres to create the potential and necessary network for pressure release. Also, very-small-diameter fibres will be more difficult to disperse evenly throughout the concrete, imperative for consistent protection measures, and may also have a negative effect on the rheology or consistence of the concrete.

Studies completed by Jansson and Boström[5] considered the effect of the fibre size (diameter) when tested in large-size panels and the onerous Rijkswaerstatt (RWS) fire curve – so providing a more representative test of explosive spalling resistance. This demonstrated that an optimum diameter of 32μm gave the overall best performance in comparison with finer or higher fibre count solutions, for a given dosage.



SP Sweden research results[5]: Spalling depths after 30 minutes RWS fire – large slabs.

The selection of the fibre type should also consider its practical use. The incorrect choice of fibre may have a detrimental effect on the fresh state properties of the concrete in terms consistence, air content and strength. This is because a very fine fibre, for example 18μm diameter, would have a surface area some 77% greater than a 32μm-diameter fibre and a threefold effect on the fibre count. Depending on the dosage required to achieve the spalling resistance for a specified fire curve, this increase in surface area may require the specific concrete to be adjusted to compensate for the demand of additional cement paste, in order to maintain the desired consistence. The addition of three times the number of fibres per kilogram dosed also risks an increased air content, which will have a negative effect on the compressive strength of the concrete, as typically a concrete would experience a 6% reduction in compressive strength for an increase of air content of 1%.

EN 1992-1-2[6] 6.2 (2) Method D states that a dosage of more than 2kg/m^3 polypropylene micro-fibres will mitigate the effects of explosive spalling. This guidance does not reveal the dimensions of the polypropylene fibres required to provide this protection.

However, empirical research and testing has concluded that typically 1–2kg/m^3 fine monofilament polypropylene fibres with diameter 15–32μm is the most effective fibre dimension for control of explosive spalling, and the dosage rate will depend on: a) the concrete constituents; b) the fire curve to which the concrete is to be subjected; and c) the degree of spalling (loss of surface depth or area) acceptable to the application's design parameters.

FCS has considered all the test and practical evidence presented to the construction industry over 25 years, and concluded that 32μm-diameter Vertex polypropylene fibres offer the optimum balance of resisting explosive spalling, while causing the least effect to the rheology of the concrete into which they are added.

The dosage rate will either be 2kg/m^3, complying with EN 1992-1-2 6.2 (2) Method D, or determined by testing to the specified fire curve adopted for the application, with the minimum dosage being 1kg/m^3.

All fibres used for the reinforcement of concrete should be CE marked and comply with the Standard EN 14889[7] Part 2 Class Ia.

The acceptance of the role played by micro-polypropylene fibres in resisting explosive spalling is such that it is unlikely a major transportation tunnel would go ahead without their inclusion in the concrete mix design. ■

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Vertex micro-polypropylene fibres.