Polypropylene fibres reduce explosive spalling in fire

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The addition of fine monofilament polypropylene fibres to concrete reduces plastic cracking and plastic settlement, and improves resistance to impact and abrasion. The fibres also reduce freeze/thaw damage and penetration from water and chemicals due to the three-dimensional effect of the fibres within the concrete matrix. These characteristics also help reduce the dangers of explosive spalling, as found during fire tests on tunnel linings at the British Research Establishment.

Polypropylene fibres have been included in such projects as the Heidrun oil platform project in the early 1990s, where 23,000m^3 concrete containing polypropylene fibres was used, and currently in the North Downs Tunnel, which forms part of the Channel Tunnel Rail Link between Folkestone, Kent and St Pancras in London. The Channel Tunnel fire, other similar fires and the resultant damage caused to the conventional reinforced concrete tunnel lining have focussed attention on the mechanisms that cause extensive spalling. To prevent such spalling, it is important to understand the mechanisms by which it occurs.

Mechanism of concrete spalling

When concrete is heated, desorption of moisture in the outer layer occurs. Most of the water vapour flows into the interior void structure of the concrete, away from the heat source. Once the interior voids become saturated, they are overtaken by the advancing heat front and water evaporates at the interface. Owing to the rapid rise in temperature and restrained expansion in the voids, the vapour pressure rapidly rises. The tensile strength of the concrete perpendicular to the heat front will initially resist this pressure. When a plain concrete slab is heated from one side, the concrete close to that surface is put into tension. This can create cracks in the plane parallel to the heated surface. If the tensile strength of the cracked concrete at the temperature attained is not sufficient to resist the forces produced by vapour pressure within the concrete, a shallow layer will suddenly be dislodged in the form of explosive spalling of the surface layer. The sequence can then repeat itself, leading to progressive loss of surface.

Figure 1: Monofilament polypropylene fibres.

How do polypropylene fibres reduce explosive spalling?

At 160°C, polypropylene fibres start to melt, leading to a reduction in volume of the individual fibres. As the heat increases, the fibres will degrade, and start to ignite at 360°C. They regress to their constituent materials, and all that remains of the individual fibre is soot, which occupies approximately 5% of the void. The gases given off will simply be burnt away by the fire or dissipate into the atmosphere. The voids that remain create routes that let the water vapour escape. In this way, vapour pressure is released and explosive spalling is avoided for a while.

Fire test programmes

A test programme was carried out at T.N.O. (The Netherlands Organisation for Applied Scientific Research), Utrecht during 1999. The purpose of these tests was to establish if there was a marked difference in reduced explosive spalling when either monofilament or fibrillated fibres were used. Both types of fibre were used at a dosage of 2kg/m^3, and the concrete sections were heated to temperatures up to 1300°C within the furnaces. Results showed that concrete test panels containing monofilament fibres gave greater explosive spalling resistance over the concrete containing fibrillated fibres. These findings were taken into consideration when Rail Link Engineering started its own test programme.

Channel Tunnel Rail Link, North Downs Tunnel, Kent

As a result of the Channel Tunnel fire, Rail Link Engineering commissioned a series of tests to evaluate how different materials performed in fire, determining the circumstances

under which spalling occurs and how to improve the integrity of linings in similar conditions.

- Specimens were loaded to pre-determined load levels of 2.5N/mm^2 in equal increments of 100kN
- The samples were heated to temperatures ranging from 1100° to 1200°C
- Fibre dosages were 1kg/m^3 and 2kg/m^3
- Tests followed the ISO 834 Standard Heat Curve
- Materials tested included monofilament polypropylene fibres and steel fibres.

Summary of RLE tests

The test results stated that adding polypropylene resulted in a significant increase in fire resistance. In particular, the monofilament fibre mixes did not spall. Over 40,000kg of fibres have been supplied to this project and used at a dosage rate of 1kg/m^3 of concrete. The site batching plant mixed the concrete, and fibres were added to the aggregate weigh hopper by a fibre-dispensing unit. Concrete was then mixed in a conventional truck mixer and the fibre-entrained concrete taken to site, where it was poured behind the shutters onto the sprayed concrete sections. This fibre-enhanced concrete is known as a sacrificial layer.

Conclusions of the CTRL fire tests

There are a number of recommendations to be made:

- Lightweight aggregates should not be used in the high-strength impermeable concrete specified for tunnel linings.
- Monofilament polypropylene fibres must be incorporated in the concrete.

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Figure 2: The interior of the North Down's Tunnel, which is coated in fibre-enhanced concrete.

- Further testing is required to optimise the concrete mixes for each contract. These tests will include a simple system for placing the test pieces into compression to simulate loading conditions in a tunnel.

It is important to remember that the proportion of fibres required to reduce explosive spalling purposes can vary because of load level, compressive strength and quantity of steel reinforcement required for each project.

Sprayed concrete containing polypropylene fibres

Fibre-enhanced concrete can also be sprayed in tunnel applications, as was the case in the much-publicised Humbercare Flow Transfer Project in Hull, where a section of tunnel collapsed. After the ground was frozen with liquid nitrogen, a primary lining was applied against the frozen ground. The lining was then reinforced with mesh, lattice arches and a mixture of steel and polypropylene fibres.

Benefits of using polypropylene fibres in a sprayed concrete application include:

- Less rebound
- Steelwork within concrete is protected
- Reduced leakage
- Good adhesion
- Increased strength and toughness
- Improved concrete workability
- Low-permeability construction
- More constant concrete mix.

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