Using fibres in concrete for fire resistance

The use of polypropylene fibres in concrete subjected to fire can reduce the risk of explosive spalling.

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For the past 16 years, ADFIL has been promoting the use of its patented fibres (see Figure 1) for use in concrete to reduce explosive spalling. While initially supplying relatively small quantities, mainly for refractory products, this changed exponentially after the Channel Tunnel fire in 1996 (see Figure 2). Other tunnel fires (see Table 1) have also motivated engineers and specifiers to find a relatively low-cost solution to reducing the loss of life and the economic cost associated with the closure of these key transport routes.

While much research has been conducted on a project-by-project basis there is nevertheless a consensus that the use of polypropylene fibres in concrete subjected to fire significantly reduces the risk of explosive spalling. The following information briefly summarises the types of fire curves used, the mechanism of spalling and the current understanding of how the fibres work.

Types of fire curves

Several fire curves are commonly used across Europe and relate to the potential fire load that could realistically be attributed to that tunnel (see Figure 3). They vary significantly from the ISO 834 curve up to the Riijkswaterstaat (RWS) curve. The severity of the test often relates not only to the fire load but to other factors such as:

- Location of the tunnel – is it under a river or the sea?
- Does the tunnel run through stable or unstable rock?
- If the tunnel collapses will it make escape bays or chambers inaccessible?
- Economic impact of total collapse of the tunnel.
- Design life of the tunnel.

Spalling mechanism

There are three main mechanisms that cause explosive spalling in concrete subjected to fire and these are as follows:

Water vapour formation

The transition of water from a liquid to a gas under identical pressure conditions means that the vapour occupies a volume approximately 1100 times greater than for the same mass of water. Since the volume may not be present in the concrete, the pressure will build up until the tensile strength of the concrete is attained and then this pressure is released abruptly and fragments of the concrete structure explode away from the main body.

Chemical processes

During a fire the raw materials from which the concrete is made begin to alter chemically. For instance, at 200°C some flint aggregates start to dehydrate. At 300°C the siliceous materials contained in the concrete exhibit a loss in strength. At 400°C, dehydration of the calcium hydroxide present in the cement paste commences and the strength of the concrete deteriorates. For concrete containing quartz, the mineral starts to expand at 575°C, causing the concrete structure to exhibit signs of bursting. At about 800°C, concrete containing limestone starts to deteriorate rapidly as decarbonisation of the limestone leads to CO_2 exiting the concrete as a gas; if its route is blocked it can cause further damage to the structure.

Thermal

Due to the high temperatures present in such fires, the concrete will expand and this should be taken into account when designing a tunnel. In addition, the concrete can experience onion skin peeling, which is caused by internal stresses within the concrete due to temperature variations between the surface exposed to the heat and the cooler zones within the concrete.

As a consequence of the above mechanisms, any structural steel in the concrete must be carefully positioned so as to avoid exposure to high temperatures, as at 700°C the load-carrying capacity of steel is reduced to approximately 20% of its value at normal temperatures.

(Photos and illustrations: ADFIL.)

Figure 1: ADFIL polypropylene fibres.

Figure 2: Damage in the Channel Tunnel, 1996.

> *Polypropylene fibres are now used in every continent for their ability to reduce explosive spalling in concrete, mainly in tunnels.*

Year	Tunnel	Length	Deaths	Dangerous goods
1978	Velsen, Netherlands	770m	5	
1979	Nihonzaka, Japan	2045m	7	Ether
1980	Kajiwara, Japan	740m	1	Paint
1982	Caldecott, Oakland, USA	1028m	7	Benzine
1983	Pecorile, Savone, Italy	600m	8	
1986	L'Arme, Nice, France	1105m	3	
1987	Gumefens, Bern, Switzerland	340m	2	
1993	Serra a Ripoli, Italy	442m	4	
1994	Huguenot, South Africa	3914m	1	
1995	Pfander, Austria	6719m	3	
1996	Isola delle Femmine, Italy	148m	5	LPG
1999	Mont Blanc, France/Italy	11600m	39	
1999	Tauern, Austria	6400m	12	Paint/lacquer
		Total deaths	97	
2000	Kaprun, Austria		155	
2001	Gotthard, Italy-Switzereland		11	

Table 1: Tunnel fires.

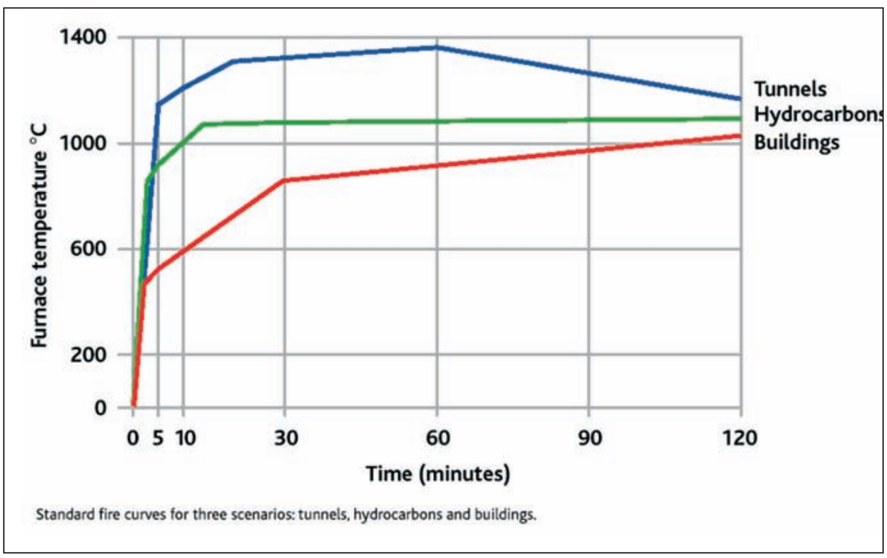

Figure 3: Standard fire curves for three scenarios: tunnels, hydrocarbons and buildings.

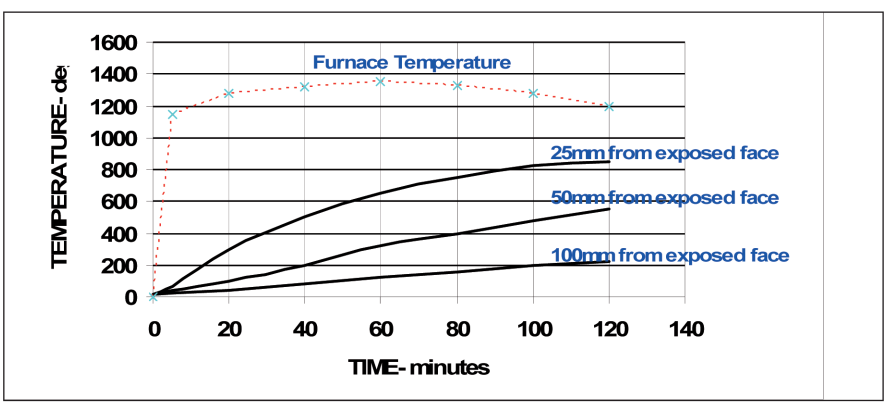

Figure 4: Typical temperature profile within concrete during test.

How do the fibres help to reduce explosive spalling?

In order for the polypropylene fibres to work effectively, it is important to source the correct concrete ingredients to minimise the risks described above.

Research into the reasons why the inclusion of polypropylene fibres works so effectively is moving apace, especially through academic studies led by experts in many European countries. In essence, the polypropylene fibres work by allowing moisture and water vapour to escape as the temperature of concrete exposed to a fire increases. As can be seen in Figure 4, the temperature of the concrete heats gradually from the surface inwards. In the first instance, due to a polarity mismatch there is poor adhesion between the concrete and the polypropylene fibres and this allows the transfer of moisture under pressure through the channel between the concrete and the fibre. In addition, as the fibre starts to heat up during a fire it will contract in length and expand in width.

This is a reversal of the effect of the manufacturing process that actually stretches and orientates the fibres. This contraction will then create cavities in the concrete that could lead to gas transfer within the concrete matrix. It has been suggested that this expansion of the polypropylene could cause micro-cracks in the matrix that will also allow the movement of moisture away from the fire.

Fibres at the surface would almost certainly be vaporised immediately, creating a channel through which the moisture can escape. As the concrete continues to heat, the internal fibres would experience a cycle of melting, then pyrolsis and finally combustion. This would then form a chain of interconnecting channels that would reduce explosive spalling caused by the expansion of water.

Conclusion

Polypropylene fibres are now used worlwide for their ability to reduce explosive spalling in concrete, mainly in tunnels. It is now time for the engineering community to seriously consider using polypropylene fibres more widely in concrete structures above ground. ■

Further reading:

1: KHOURY, G. NewCon project. *Concrete Engineering International,* Vol.10, No.1, Spring 2006, pp.6–11.
2: KHOURY, G. Tunnel concretes under fire: Part 1 – explosive spalling. *CONCRETE*, Vol.40, No.10, November 2006, pp.62–64.
3: WETZIG, V. *Fire protection in tunnels.* EFNARC technical committee draft.