FIBRES FOR USE IN CONCRETE FOR FIRE RESISTANCE

POUŽITIE VLÁKIEN DO BETÓNU NA POŽIARNU ODOLNOSŤ

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ABSTRACT
Following a succession of major tunnel fires across Europe, the need for effective fire protection for the structural concrete lining has become a matter of priority for both new and existing tunnels. Some European countries have issued guidance and/or regulate or standardize fibre concrete with national guidelines. Later on Directive 2004/54 EC laid down a set of harmonised minimum safety standards dealing with the various organisational, structural, technical and operational aspects. Passive fire protection, where construction fibres fall, forms a permanent part of the tunnel and does not require external activation in the event of a fire. It applies to both, the safety of people and the safety of the structures.

1 Introduction

For the last 16 year ADFIL has been promoting the use of its patented fibres for use in concrete to reduce explosive spalling in concrete. Whilst initially supplying relatively small quantities mainly for refractory products this changed exponentially after the Channel tunnel fire in 1996 (Fig. 1).

Fig. 1 Damage in the channel tunnel 1996

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Other tunnel fires (see Table A) have also helped to focus engineers and specifier´s minds on finding a relatively low cost solution to reducing the loss of life and the economic cost associated with the closure of these key transport routes. Whilst a lot of research has been conducted on mainly a project by project basis there is one conclusion and this is the use of polypropylene fibres in concrete subjected to fire which significantly reduces the risk of explosive spalling. The following information is aimed to briefly summarise the types of fire curves used, the mechanism of spalling and the theory behind why the fibres work.

Table A Tunnel Fires

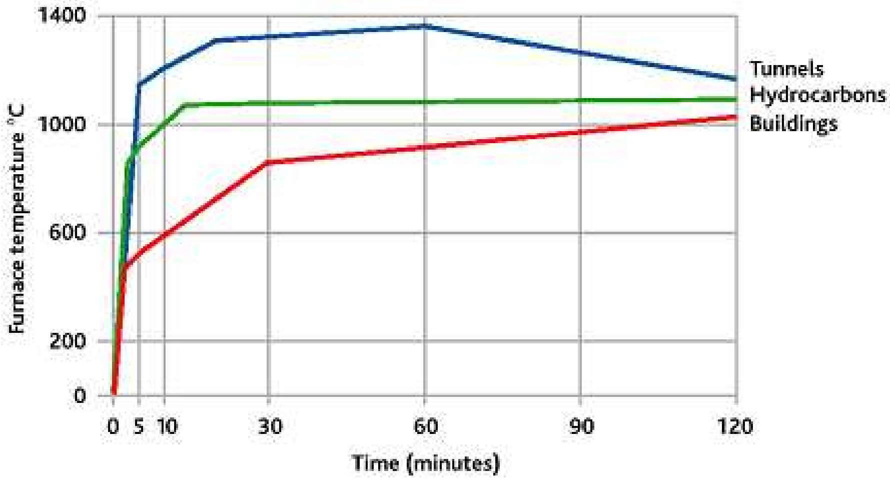
Year	Tunnel	Length	Deaths	Dangerous goods
1978	Velsen, Netherlands	770m	5	
1979	Nihonzaka, Japan	2045m	7	Ether
1980	Kajiwara, Japan	740m	1	Paint
1982	Caldecott, Oakland, USA	1028m	7	Benzine
1983	Pecorile, Savone, Italy	600m	8	
1986	L´Arme, Nice, France	1105m	3	
1987	Gumefens, Bern, Switzerland	340m	2	
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
2000	Kaprun, Austria	3300m	155	
2001	Gotthard, Italy-Switzerland	16900m	11	

2 Types of fire curves

Several fire curves are commonly used across Europe and the curve used usually relates to the potential fire load that could realistically be attributed to that tunnel. As seen in the Table B, the fire curves vary significantly from the ISO 834 curve up to the Riijkswaterstaat (RWS). The severity of the test often relates to not only fire load but other factors such as.

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

Table B Standard fire curves for three scenarios: tunnels, hydrocarbons and buildings



3 Spalling mechanism

There are three main mechanisms which cause explosive spalling to occur in concrete subjected to fire and these are:

- 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 are 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 starts to occur and this decomposition starts to cause the strength of the concrete to deteriorate. For concrete containing Quartz then at 575 °C the mineral starts to expand and as a consequence of this increase in volume the concrete structure will exhibit signs of bursting.

At about 800 °C concrete containing limestone will start to deteriorate rapidly as decarbonisation of the limestone will lead to the CO 2 exiting the concrete as a gas and if its route is blocked it can cause further damage to the structure.

- Thermal

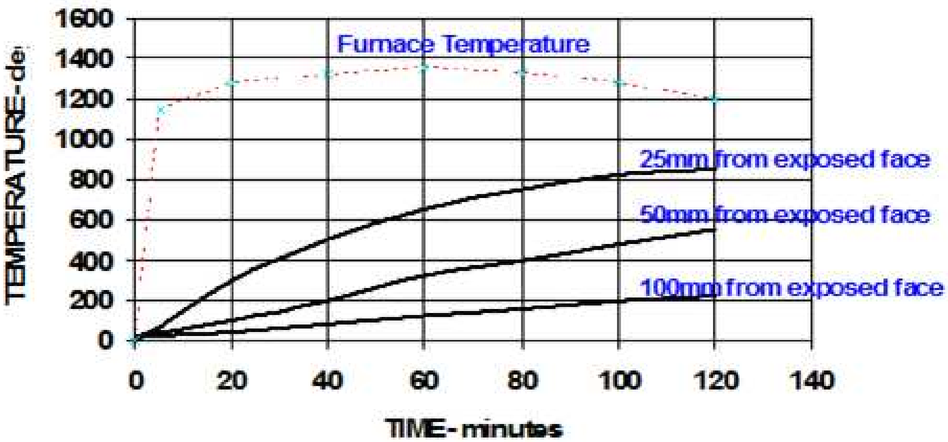
Due to the high temperatures present in such fires the concrete will experience changes in length and therefore in designing a tunnel this should be taken into account. In addition to the changes in length the concrete can experience onion skin peeling which is caused by internal stresses within the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

As a consequence of the above mechanisms the placement of any structural steel in the concrete has to be carefully positioned so as not to become exposed to high temperatures as at 700 °C the load carrying capacity of the steel is reduced to approximately 20 % of its value at normal temperatures.

4 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 in order to minimise the risks seen above.
Research into the reasons why the inclusion of polypropylene fibres works so effectively are moving apace especially through academic studies lead by experts in many European countries.
In essence the polypropylene fibres work by allowing moisture and water vapour to escape away as the temperature of the concrete exposed to a fire increases. As can be seen in the table C, 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 will allow the transfer of moisture under pressure through the channel between the concrete and the fibre. In addition to this 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 actual manufacturing process which actually stretches and orientates the fibres. This contraction will then create cavities in the concrete which could lead to gas transfer within the concrete matrix.
It has been theorised that this expansion of the polypropylene could cause micro cracks in the matrix which will also allow the movement of moisture away from the fire.
For fibre at the surface they would almost certainly be vaporized immediately creating a channel through which the moisture can escape. As the concrete continues to heat, the fibres contained in the concrete would be gradually going through a cycle of melting then pyrolsis and finally combusting which would then form a chain of interconnecting channels which therefore helps to reduce explosive spalling caused by the expansion of water.

Table C Typical temperature profile within concrete during test



5 Conclusion

The use of polypropylene fibres is now used in every continent for its ability to reduce explosive spalling in concrete mainly in tunnels .It is now time for the engineering community to look seriously at using polypropylene fibres more widely in concrete structures above ground.

6 References

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