Tunnel concretes under fire:  
Part 2 – toxicity

Polypropylene fibres are being used in concrete to combat explosive spalling in fire. However, there remain a number of issues that require further investigation and clarification. For example, how toxic are the combustion products of polypropylene (pp) fibre constituents in concrete when exposed to fire? This is one of the important issues being investigated by the international research project NewCon(1,2) and is discussed in this paper.

GABRIEL ALEXANDER KHOURY, LEADER OF NEWCON EUROPA INTERNATIONAL, PROJECT IMPERIAL COLLEGE LONDON; PRODA UNIVERSITY ITALY, DIRECTOR FIRE SAFETY DESIGN, SCIENTIFIC MANAGER OF UPTUN AND SAIN EUROPEAN PROJECTS; CHAIRMAN 80 INTERNATIONAL COMMITTEE 43.1

Toxicity analysis

The properties of polypropylene fibres are dependent upon temperature and time. As the temperature rises, the fibres undergo the following phase changes:
- softening at approximately 20°C
- melting at approximately 165°C
- pyrolysis at approximately 469°C
- combustion at approximately 550°C.

The pyrolysis and combustion temperatures are approximate and somewhat variable depending upon the conditions. In practice, thermal decomposition can occur at somewhat lower temperatures in air and significant decomposition occurs at a temperature of 450°C.

The main products from the decomposition of pp fibres presenting an acute hazard to occupants of contaminated enclosures are:
- carbon monoxide
- smoke
- mixed organic irritants.

The thermal decomposition and combustion products of pp fibres are similar to those of hydrocarbon products such as petrol. So, 1kg of pp fibres will produce, upon burning, similar quantities of combustion products to those produced by 1kg of petrol (or 2kg of wood).

Tunnel example

Calculations were carried out(1) for a typical tunnel of internal diameter 5.8m with a 275mm-thick concrete lining. The fire scenario is assumed to be in accordance with Table 1 and Figure 1, which is more severe than a hydrocarbon fire (in terms of temperature-time at the concrete surface), with a rapid increase in temperature of the concrete surface to 1020°C in just four minutes. This type of fire normally occurs when a large vehicle containing combustion materials is set on fire. It is described as a large fire in excess of 20–50MW. If the tunnel is a railway tunnel, the fire load may not be so high as to produce such a scenario, so the assumptions made here may be quite conservative.

The calculations were made for a fire duration of 120 minutes. The temperatures were calculated for depths of 40mm and 90mm into the concrete during the fire. Based on this thermal analysis, it is assumed that all the pp fibres up to a depth of 90mm are melted and released into the tunnel (a conservative assumption) and combusted during the severe fire for a period of 120 minutes.

The annular 90mm concrete area affected is approximately 1.5m² for a fully circular cross-section and the internal tunnel circular area is 21.65m². Assuming that the tunnel wall is in fact only 75% of these dimensions, then the affected annular area will be 1.13m² and the internal area 16.24m². For a metre length of tunnel, the corresponding volumes of affected 90mm concrete and tunnel interior are then 1.13m³ and 16.24m³ respectively.

If the concrete contains 2kg/m³ of fibres, then the amount of fibres combusted over a period of 120 minutes from the concrete up to a depth of 90mm is 2.26kg per metre length of tunnel. Assuming that this material is combusted in a linear fashion over a period of 120 minutes, then the release of toxins is equivalent to the burning of 19 grams of pp fibres (or petrol) per minute per metre length of tunnel.

Assuming that a 50MW fire is required to produce the temperatures given in Table 1 and Figure 1, then the fire would need to be caused by the equivalent of 80–100kg of petrol combusted per minute (petrol combustion releases

![Image](https://example.com/image.png)

Table 1: Severe fire scenario assumed for tunnel example.

<table>
<thead>
<tr>
<th>Time period in minutes</th>
<th>Concrete surface temperature (°C)</th>
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<tbody>
<tr>
<td>4</td>
<td>1020</td>
</tr>
<tr>
<td>10</td>
<td>1130</td>
</tr>
<tr>
<td>15</td>
<td>1170</td>
</tr>
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<td>1190</td>
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<tr>
<td>30</td>
<td>1200</td>
</tr>
<tr>
<td>60</td>
<td>1200</td>
</tr>
<tr>
<td>120</td>
<td>1200</td>
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</tbody>
</table>

Figure 1: Severe fire scenario assumed for the toxicity analysis in the example tunnel, showing temperature distributions at three depths and for three polypropylene fibre thermal processes.
44.5kJ per gram burnt). In this case, the combustion products per minute of the fire would be approximately those relating to 90,000 grams of petrol burnt compared with 19 grams of pp fibres (or petrol), a ratio of 4700 to 1. Even if it is assumed that the fire is 20MW and not 50MW, then the ratio is reduced to approximately 2000 to 1. If we further assume that the pp fibres are released at twice the rate assumed above, then the ratio is reduced to 1000 to 1.

Assuming further that 10m of tunnel length is affected and not 1m, then the ratio reduces to 100 to 1. Such release of pp fibre toxins can only take place in the locality of the fire when the concrete temperatures are high. The temperatures reduce at distances away from the fire but the smoke and other toxins spread away from the fire. In the vicinity of the fire itself, people would not only be fatally exposed to the toxins from the fire itself but also from its very high temperatures.

Concluding remarks

In conclusion, a large primary fire would be necessary to raise the concrete to temperatures at which the polypropylene might melt and decompose. It would be unrealistic to assume that the fibres are combusted in the absence of a primary fire with its own significant toxic combustion products. Under such conditions, the yields of carbon monoxide, smoke and irritants per gram of material decomposed from the primary fire are likely to be similar in nature to those from polypropylene. The contribution of the pp fibres to the toxicity of the environment in the example tunnel during a fire is likely to be well below 1% of the total toxicity from the fire itself. Under those conditions, the role of the pp fibres would be insignificant.

References: