IMPROVING FIRE SAFETY IN TUNNELS:
The concrete pavement solution

CONCRETE ROAD PAVEMENT IMPROVES TUNNEL SAFETY

Cointe tunnel (link E25-E40) in Liege, Belgium: use of concrete road pavement for improved tunnel safety

The total length of tunnels used for transport in Europe is in excess of 15,000 km. Tunnels are vital to maintain the transport infrastructure. For example, in Switzerland, around 50% of the highways proposed to be built for the completion of the road network by 2015 would run through tunnels. However, tunnels are not just used to cross mountains. Increasingly, they are being built under cities, e.g., Stockholm and Paris, to relieve surface congestion. Tunnels are also being built under waterways, e.g., the Oresund and Great Belt tunnels in Scandinavia.

Road and railway tunnels as well as underpasses can pose risk to the public. Appropriate choice of materials and design help to minimise the risk.

Recent high-profile tunnel fires in Europe (see table below) have demonstrated the need for appropriate choice of materials for tunnel construction to ensure high safety and reliable availability to traffic. These fires are inevitably of great intensity leading to structural damage and even loss of life. Temperatures reached in these tunnel fires are estimated to be very high (greater than 1000 °C). The fires developed quickly and burned for a long time (up to 53 hours).

RECENT FIRES DISASTERS IN TUNNELS IN EUROPE

Fire	Tunnel Type	Year	Duration & Temperature	Victims	Vehicles damaged
St Gotthard Switzerland	Road (1 tube) 16.3 km	2001	24 hrs 1200°C	11 deaths	10 cars 23 lorries
Gleinalm Austria	Road (1 tube) 8.3 km	2001	37 minutes	5 deaths	2 cars
Kitzsteinhorn Austria	Funicular rail 3.2 km	2000	Not known	155 deaths	1 shuttle train
Tauern Austria	Road (1 tube) 6.4 km	1999	14 hrs 1200°C	12 deaths	26 cars 14 lorries
Mont-Blanc France-Italy	Road (1 tube) 11.6 km	1999	53 hrs 1000°C	39 deaths	10 cars 23 lorries
Palermo Italy	Road	1999	Not known	5 deaths	19 cars 1 coach
Eurotunnel Channel	Rail 52 km	1996	10 hrs 1100°C	2 injured	1 shuttle train

Source: various publications

These disasters have turned this type of works into a real challenge as far as safety and environment are concerned. The closing and repair of such works bring about major economic and environmental consequences.

Public opinion and the media highlight these story and force regulators to take hasty alternative measures and some important features have not received proper attention. The regulators' main concern is to improve the conditions of rescue and self rescue for persons involved in accidents in road tunnels, focusing on road users' self-evacuation and rescue response time.

However, so far, little attention has been paid to the material used for road construction. Specifiers are almost always focusing on tunnel structural safety, robustness and stability but do not consider the road surface, which is sometimes of traditional asphalt construction.

With these concerns in mind, it is also important to take into account the quality of the road pavement. In case of fire in traffic tunnels, an incombustible and non-toxic road pavement contributes to the safety of persons (users and rescue teams), protects the tunnel equipment and structure and helps preserve the environment.

There are significant benefits in constructing the road pavement with concrete. Concrete is incombustible and does not emit harmful emissions in a fire providing maximum safety in a severe fire. Additionally, concrete mix design has evolved to provide structural stability and robustness for the construction of the tunnel itself.

Tunnel operators and regulatory authorities are urged to take measures to specify concrete pavements in all new tunnel construction. The Austrian Decree of September 2001 requiring concrete road pavement for new tunnels longer than one kilometre can be used as a reference basis. *(See Current national regulations box)*

Fire fighting authorities recommend that *"road pavement should be incombustible, emit no toxic smoke and be of clear colour which improves visibility. Concrete should therefore be preferred as material to the traditionally used asphalt pavement which ignites and emits toxic gases"*.

A quotation from CTIF (International Committee of Fire Prevention & Extinction) Congress "Are tunnels safe enough", Regensdorf, Switzerland, 8 November 2002.

CONCRETE PAVEMENT IN ROAD TUNNELS & UNDERPASSES

Improving overall safety in road tunnels requires *incombustible and non-toxic road pavements* that ensure maximum safety for people, facilities and the environment.

Kinkempois Tunnel (link E25-E40) in Liege, Belgium, using concrete pavement

The benefits of concrete pavements in tunnels and underpasses are:

- **Improved safety for people and structure**
- **Improved durability of the road pavement, facilities and structure**
- **Reduced maintenance**
- **Contribution to environmental protection & sustainable development**

These key factors should be taken into account from the design stage of the tunnel through a global approach in order to maximise safety for people and goods, increase environmental protection and optimise performance.

- ***Improved safety for people and structure***

  Incombustible and non-toxic concrete road pavement contributes to safety in tunnels.

Active measures (ventilation, smoke extraction, alarms, detection) are contributing factors to fire safety in tunnels. However, the best passive measures should also be considered such as the use of totally incombustible materials like concrete pavement.

In case of fire, concrete pavement has good performance characteristics facilitating road users' self-evacuation and rescue team's arrival (fire crews and emergency services).

- **Concrete road pavement is incombustible and non-toxic**

  Thanks to its purely mineral composition, concrete is an inert, stable and non-flammable material.

  Concrete is therefore classified as a material with a high fire safety factor and in no way contributes to the fire load.

  In case of fire, concrete road pavement will ensure good conditions for people's evacuation and rescue team and firemen's intervention, as concrete pavement does not burn.

Asphalt road pavement burns at a temperature of around 500°C (well below the temperature observed in tunnel fires) and adds to the fire load. In case of fire, the increase in temperature caused by the burning asphalt pavement can damage the tunnel equipment and security systems, which jeopardises both people's evacuation and rescue intervention.

The Laboratory at Cergy Pontoise University (France) has carried out comparative fire tests on the behaviour at high temperature (according to ISO 834 fire curve) of samples in asphalt and concrete materials used for road pavement. *(See figures 1 & 2)*

The results of this study[1] on the thermal behaviour and toxicity (chemical analysis of smokes and gas emitted during the combustion of the asphalt) shows that **asphalt has a high calorific value**.

- Asphalt surface ignites between 428°C and 530°C, after 8 minutes of heating.
- The first vapours emitted are felt 5 minutes after the beginning of the heating. Gases emitted are toxic of which some are suffocating (CO_2) and carcinogenic.
- Asphalt loses its mechanical characteristics (only aggregates are still present but not bound anymore by asphalt) and can no longer fulfil its main purpose.

In comparison,

- Concrete is incombustible and does not emit fumes.
- Concrete does not change shape when submitted to high temperature and keeps a large part of its mechanical characteristics.

Sources: *Characterisation of asphalt exposed to high temperature: Application to fire case of asphalt pavement*, Albert Noumowe, Cergy Pontoise University, 2003. (English version)

Revêtement de chaussée en enrobé hydrocarboné ou en béton en situation d'incendie, Albert Nouwome, EPU Editions Publibook Université, Paris, 2003. (French version)

[1] *Characterisation of asphalt exposed to high temperature: Application to fire case of asphalt pavement*, Albert Noumowe, Cergy Pontoise University, 2003. (English version)

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Figures 1 & 2 shows the results of the test consisting in heating in an oven during one hour prismatic specimens of asphalt (left) and concrete (right) to a temperature of 750°C according to the ISO curve.

Figure 1 Comparison of specimens of asphalt (left) and concrete (right) after heating to 750°C

Source: Characterisation of asphalt exposed to high temperature: Application to fire case of asphalt pavement, Albert Noumowe, Cergy Pontoise University, 2003.

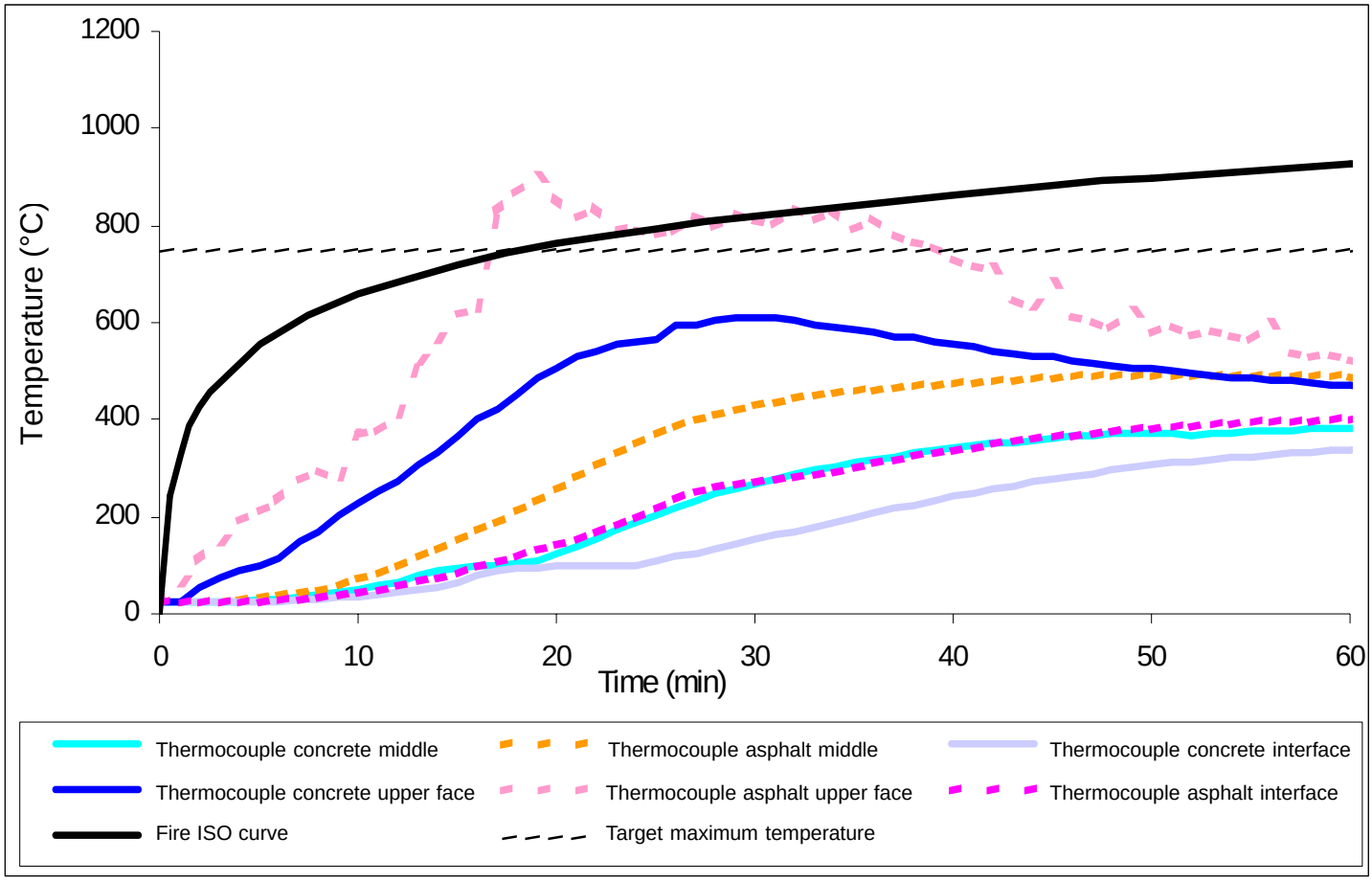

Figure. 2 Comparison of temperature charts for concrete and asphalt over a 1-hour period.

Source: Characterisation of asphalt exposed to high temperature: Application to fire case of asphalt pavement, Albert Noumowe, Cergy Pontoise University, 2003.

As an example, a road pavement made of a 25 cm graded aggregate-bitumen layer covered by a 5 cm asphalt wearing course has a calorific potential of approximately 1,600 MJoules per m^2. In comparison, a light vehicle (i.e. an average car) produces during its complete combustion 18,000 MJoules. (See table below)

Type	**Calorific potential in MJ** Energy released while burning
1 m^2 of asphalt road pavement	1,600
1 average car	18,000
1 average truck (including combustible load)	125,000

In the Mont-Blanc fire in March 1999, the asphalt road pavement was damaged for a length of 1,200 m. The combustion of this asphalt pavement released an additional calorific energy equivalent to the burning of 85 cars or 12 trucks.

Sources: *Rapport du 30 juin 1999 de la mission administrative d'enquête technique sur l'incendie survenu le 24 mars 1999 au tunnel routier du Mont Blanc, Ministère de l'Intérieur - Ministère de l'Equipement, des Transports et du Logement.*

Tunnel du Mont Blanc - Températures atteintes dans la chaussée et comportement au feu de la chaussée, Document interne, Laboratoire Central des Ponts & Chaussées, France, Décembre 2000.

Rapport d'activité 2001 du LCPC, Laboratoire Central des Ponts & Chaussées, France, 2002.

Etudes spécifiques des dangers, Guide méthodologique du CETU, Centre d'Etudes des Tunnels, Dossier Pilote des Tunnels, Edition 2002.

- **Concrete road pavement does not emit harmful emissions**

  Whereas:
  Asphalt road pavement emits smoke, pollutants and toxic gases (carbon dioxide and monoxide, etc.) and harmful substances.

  Asphalt road pavement releases soot that reduces visibility through windscreens and clogs the filters of rescue vehicles.

  Consequences:

  - People's evacuation is slowed down and/or jeopardised.
  - The rescue team and firemen's intervention is slowed down and/or jeopardised.

- **Concrete road pavement does not change shape with high temperature and keeps a large part of its mechanical characteristics**

  Whereas:
  Asphalt road pavement loses its mechanical properties.

  Further to the asphalt burning, only aggregates are still present but are not bound together anymore by the binder. Because of this, the material can no longer fulfil its main purpose and even hinders the rescue services.

- **Concrete road pavement contributes to road user's safety through increased visibility, vigilance of drivers and shorter braking distance**

  Any underground works should be considered by road users as potentially risky. In order to ensure increased road safety, some discontinuity should be created between the inside and the outside of the tunnel.

  Clarity and brightness are intrinsic properties of concrete:

  - Concrete road pavement brightness ensures better visibility for road users.
  - Concrete road pavement brightness requires less electric lighting, thus reducing the energy consumption as well as initial investment and maintenance costs.

  Modulating the road plain aspect by choosing appropriate surface prompts the driver to keep on being vigilant through sound perception.

  Braking distance with concrete surfaces is less than asphalt due to better grip on the road.

In conclusion, combating fires in tunnels is made considerably more difficult by restricted accessibility, the amount of smoke and the enormous heat radiation.
Firemen are therefore recommending the use of fire-resistant materials interiors to improve fire protection in tunnels. *(See quotation from CTIF on page 2)*

➢ *Improved durability of the road pavement, facilities and structures*

Concrete incombustible road pavement gives the tunnel owners the guarantee that their works will be safeguarded.

The limited damage with concrete pavement reduces the duration of the repair and facilitate therefore a quick return into operation of the tunnel.

Damage to property is due to high fire load. Any addition of combustible material contributing to the fire load leads to a further damage of the tunnel control units and facilities. Closure of tunnels for long periods can inevitably lead to considerable disturbance to traffic and increase accident risk.

➢ *Reduced maintenance*

Concrete road pavement guarantees the durability of the mechanical characteristics of the pavement (no rutting), uniformity of surface and grip on the road.

The use of concrete road pavement leads therefore to the following advantages:

- Reduction of maintenance/repair cycles and thus fewer road works, less tunnel closing with diversion itineraries causing environmental nuisance.
- Restriction of road works in the presence of road users and therefore less workers on the site which represents a source of accidents.

With Concrete pavement:
⇨ Reduction of accident risk.
⇨ Decrease in maintenance costs.
⇨ Protection of the environment.

➢ *Contribution to environmental protection and sustainable development*

Concrete road pavement has a long service life, which saves raw materials and therefore contributes to sustainable development.

During the operational phase, the concrete road pavement in a tunnel requires less maintenance and repair and reduces energy consumption (electricity lighting). The result is to limit pollution in the tunnel and reduce environmental nuisances caused by diversion itineraries, in case of tunnel closure.

Concrete is resistant to car fuel: an accidental spillage of fuel does not damage the pavement and the dangerous products can be directly drained into gutters built for that purpose.

At the ultimate life stage, concrete pavement could be recycled into aggregates to be used for road layers or new concrete.

Concrete durability ensures the uniformity of pavement surface and grip on the road resulting in a better environmental performance (respect for air purity, soils, persons, etc.) through

⇨ *Low use of fossil materials and reduced energy consumption.*
⇨ *Better air quality.*
⇨ *Reduced pollution.*

Incombustible concrete road pavement does not emit soot that sticks to the walls and needs to be cleaned up, which is an environmental burden.

RAILWAY TUNNELS

Within the framework of the intermodal transport policy (trucks on train), developing railways is a priority of the Trans-European Transport Networks (TENs-T) promoted by the EU Commission.

A simple solution is to lay down the railways on a incombustible and non-toxic concrete pavement, which allows a quicker access for rescue teams and even closer to the disaster than on aggregate ballasts, as it is difficult for very long or very deeply buried tunnels to benefit from preventive measures.

CONCRETE ROAD PAVEMENTS CONTRIBUTE TO HIGHER SAFETY IN TUNNELS

The safety of a tunnel depends on a series of measures.

Preventive infrastructural as well as operational fire protection measures together with fire combating measures embrace the choice of suitable (fire-resistant) materials to be used.

We should give as many guarantees as possible to ensure safety and thus avoid any materials (for structure or equipment) likely to be dangerous because of their combustion and production of fumes and aggressive fire gases.

The concrete solution for tunnel pavement improves safety and reduces overall cost.

Concrete is a material, which is inherently safe in a fire and in no way contributes to the fire load.

BIBM, CEMBUREAU and ERMCO

- **Call for regulatory measures to be taken in order to ensure safety in tunnels.**
- **Recommend the specification of incombustible and non-toxic concrete road pavements** as the most appropriate techniques and materials for guaranteeing security of people and facilities while protecting the environment and offering an economic solution.

The Austrian Decree (see Current national regulations box) can be used as a reference basis.

Current national regulations

The *Austrian Decree* of September 2001 relating to tunnel projects directives “Projektierungsrichtlinien RVS 9.234” requires concrete road pavement in new tunnels longer than one kilometre.

In Slovakia, the Ministry of transport and the Slovak road administration are requiring, from 2001, concrete road pavements in new tunnels.

In Spain, public authorities recommend the use of concrete road pavement in tunnels.

The objectives to be reached by a regulation on fire safety in tunnels (as defined by PIARC[1]) are:

- Saving lives by enabling evacuation.
- Facilitating rescue and fire-fighting operations.
- Preventing explosions.
- Limiting damage in the tunnel, (equipment, neighbouring buildings, civil engineering).

Through (as defined by TRANS/AC Group of Experts on Safety in Roads Tunnels[2]):

- Risk prevention.
- Reduction in consequences.

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1 PIARC Committee on Road Tunnels (C5) Report on *“Fire and smoke control in road tunnels”* 05.05.B published in 1999.

2 *Recommendations of the Group of Experts on Safety in Roads Tunnels* – Final Report, TRANS/AC.7/9, United Nations Economic and Social Council, 10 December 2001.

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