

Evaluation of the Positive Impact on CO₂ Emission and Safety Using Concrete Pavements in Italian Tunnels

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Abstract

The paper estimates the total energy savings (MW/year) and the corresponding reduction of CO₂ emissions, in tons of oil equivalent (toe), obtainable in the Italian tunnels, replacing asphalt pavements with concrete ones, highlighting how concrete can contribute in:

- reaching the 2020 EU target of cutting emissions by 20% from 1990 levels
- supporting climate change mitigation and safety in road tunnels.

Introduction

Nowadays everyone in Europe is aware of the worldwide challenge of adjusting our lifestyles in order to limit global warming. It is clear that the main goal we have to reach, in order to mitigate the causes of climate change, is to reduce greenhouse gas emissions.

Italy has about 1230 km of tunnels, half of the total mileage in Europe. Most of the tunnels will require retrofitting by 2019, to upgrade their safety standard according to the European Directive requirements (EU Directive 2004/54/EC).

Recent fires in European tunnels have demonstrated the need to adopt some measures in order to minimize risks for both people and infrastructure, such as:

- Escape for occupants and access for emergency workers
- Fire suppression systems
- Fire detection systems
- Smoke hazard management
- Emergency lighting
- Exit signs
- Emergency phones
- Emergency service radio system
- CCTV
- Traffic flow monitoring
- Fire hydrants and boosters
- Fire extinguishers and hose reels
- Flame traps for flammable liquid spills and fire water (sprinkler and drencher systems), even if there are critics on the use of these systems in road tunnels:
 - Smoke layers lose their buoyancy on operation of the system
 - Steam is produced placing occupants at risk
 - Flammable liquids are spread

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- o Because the fires are generally internal drenchers are ineffectual (Bryant K. 2002)

In any case, an appropriate choice of materials for tunnel construction to ensure high safety and reliable availability to traffic is mandatory.

Road tunnels concrete pavement advantages Concrete, due to its specific characteristics, could be a good solution to face some safety problem of tunnel pavements, with special regards to the following issues:

- The light color improves visibility: the road user can be more constantly aware.
- The greater reflecting capacity of concrete (0.10 against 0.07 of asphalt) calls for less lighting. This reduces the energy consumption and the costs for installing and maintaining the lighting installation (approximately 30% (Gajda et al. 1997) compared to asphalt pavements that are not brightened).
- Concrete provides excellent fire resistance and does not issue any harmful gases. It therefore ensures maximum safety in the event of a fire because it does not contribute to additional fire load (Cembureau 2004; EUPAVE 2009).
- In the event of a fire, concrete pavement provides good conditions for evacuation and firefighting by the rescue team and fire brigade.
- Concrete does not deform when it is exposed to high temperatures and, for the most part, retains its mechanical characteristics. Asphalt, on the contrary, is combustible and loses its mechanical properties under the effect of temperature because the mineral aggregate is no longer bound by the bitumen.
- Concrete is a sustainable construction material as highlighted in Life Cycle Assessment studies. It can endure for many years (at least 30 years expected) with limited costs for maintenance and repair (less work in tunnel and fewer tunnel closures) (CAC, 2010).
- Concrete pavement ensures a good level of smoothness and grip due to the slow decay of skid resistance (Haider et al. 2009).

Environmental concrete pavement advantages All the above advantages of concrete enhance environmental protection and support the sustainable development of concrete roads: less maintenance and repairs save raw materials. In addition, there are others important environmental advantages (CAC, 2010):

- reduction in fuel consumption;
- pollution reduction with the use of smog eating cement;
- at the end of its life cycle, concrete can be easily used as an aggregate in road courses or new concrete;
- the potential energy saving contributes to decrease CO₂ emission.

The positive impact on CO₂ emission The light color of concrete pavements in tunnel offers obvious advantages for both drivers and infrastructure managers (Domenichini et al. 2006, Routes 2006).

The 1,230 km of tunnels of the Italian infrastructure network are managed by Highway Concessionaire Companies and by ANAS and they all have asphalt pavement.

The energy savings (kW/km/year) has been estimated assuming the replacement of asphalt pavement with concrete pavement inside tunnels.

Results have been estimated using data calculated by Tecno Engineering 2C s.r.l. with one of the existing tunnels' software lighting systems design, applied to some Italian standard tunnels "cross-sections".

To simplify calculation, illumination has been considered uniform along tunnels without the starting reinforcement.

Depending on the carriageway dimensions, the results change from 17,520 kW/km/year for a 10.50 m carriageway (2 lanes/shoulders), to approximately 117,000 kW/km/year for a 14.95 m carriageway (3 lanes/emergency).

A standard lighting system has been considered to estimate power consumption, considering length and width of the existing and planned Italian tunnels carriageway until 2020, according with INTERTUNNEL 2010 publication.

Two scenarios have been considered:

- Business As Usual scenario (BAU): asphalt pavements.
- Best Available Technologies scenario (BAT): concrete pavements.

The results are summarized in Table 1:

Table 1. Estimated power consumption for tunnel lighting replacing asphalt with concrete pavements.

Years				
2010	2016		2020	
Total kilometers of road in the Italian tunnels				
1,230	1,389		1,587	
Estimated power consumption for tunnels lighting				
BAU MW/year	BAU MW/year	BAT MW/year (694 km) 50% km converted	BAU MW/year	BAT MW/year 100% km converted
101.2	131.7	113.2	150.7	108.2

This has led to estimate a possible scenario of total savings achievable in MW/year, depending on replacement rate, as summarized in Table 2.

Table 2: Estimated power consumption reduction due to concrete pavements

Year 2016	Year 2020
Assumptions: pavements conversion 50%	Assumptions: pavements conversion 100%
18.5 MW/year	42.5 MW/year

We have assumed the conversion factor of 0.5 kg of CO₂ per kWh, as suggested by "Confindustria", the Italian organization representing manufacturing and services companies, for the Italian market (see Table 3). The factor takes into account the mix of the Italian power plants.

Table 3. Estimated savings in CO₂ emissions due to power consumption reduction.

Year 2016	Year 2020
Assumptions 50% of conversion	Assumptions 100% of conversion
9283 tons CO ₂ /year	21268 tons CO ₂ /year

According to the scenario defined above, we have estimated the benefit obtainable in tons of oil equivalent (toe), due to the reduction of CO₂ emissions, as summarized in Table 4 (1 Mtoe = 3 Mton CO₂).

Table 4. Estimated savings of tons of oil equivalent due to the reduction of CO₂ emission.

Year 2016	Year 2020
Assumptions 50% of conversion	Assumptions 100% of conversion
0.003 Mtoe/year	0.007 Mtoe/year

This is only an estimate based on averages, but can be very useful to highlight the attention of the Italian stakeholders towards the possible goal of the road sector to contribute to the global warming potential reductions.

The positive impact on safety

Recent fires in European tunnels have demonstrated the need for an appropriate choice of materials for tunnel construction, in order to ensure higher safety and reliable availability to traffic.

Fire. In case of fire, an incombustible and non-toxic road pavement material, such as concrete, contributes to people's safety (users and rescue teams) and protects both the tunnel equipment and its structure (Cembureau 2004; De Lathauwer 2007; BIBM – BFT 2007; Strade & Autostrade 2006, Jofré et al. 2010).

Materials. Even if the EU Directive 2004/54/EC on the minimum safety requirements for tunnels in the trans-European road network contains no reference regarding the type of road pavement to be used, in Germany, the supplementary technical conditions of contract and guidelines for civil engineering structures (Zusätzliche Technische Vertragsbedingungen und Richtlinien für Ingenieurbauten - ZTV-ING), Part 5, Tunnel construction) (ZTV-ING Teil 5, 2007) contains the following recommendation regarding road construction:

Section 11.2 Road structure and sealing of the base (Fischnaller and Wunderer 2011): "Generally the road is constructed in the same way and with the same construction class as the adjoining open sections. The guidelines for the standardization of the surfacing of traffic areas (FGSV 499 (2001) Richtlinien für die Standardisierung des Oberbaues von Verkehrsflächen (RstO -01) apply".

This requirement first of all indicates that the structure of the open section of road should be continued in the tunnel. However, in Section 10.4 –“Fire safety measures for the inside extension” goes on defining: "Only materials of construction class A to DIN 4102 should be used for the interior structure. The construction class should be verified by a test certificate from a recognized material testing agency ...

Materials that release substances that are harmful to the construction or to personnel under the effect of fire may not be used".

ZTV-ING therefore clearly stipulates that bituminous pavements are not permitted in tunnel because, firstly, they do not correspond to Construction class A in accordance with DIN 4102 Fire behavior of construction materials and components (bituminous pavement => construction class B2) and, secondly, they release gases under the effects of fire which are toxic and have an asphyxiating effect.

Maintenance. Concrete pavements present another advantage for tunnel safety: a decrease of possible accidents during maintenance operations, since those are not frequent. It is well known that concrete road pavements guarantee the durability of mechanical characteristics, surface evenness and grip on the road. The use of concrete therefore leads to a reduction of maintenance/repair cycles, thus fewer road works. It means less tunnel closure with diversion itineraries and less restriction of road, resulting in the presence of road maintenance workers on site, with an increased potential for accidents.

Skid Resistance. The exposed aggregates surface (EAS) texture maintains high values of the coefficient of transverse grip over time, because of the high quality of the topmost parts, as shown in Figure 1 (Haider et al. 2006).

Generally, the skid resistance provided by grooving decreases over time, due to the traffic wear so, in the long term, only the crushed aggregate class sizes between 10 and 20 mm contribute to skid resistance (Routes 2006).

Since the mid 1990's pavement surfaces are very often treated with exposed aggregate technique.

The graph in Figure 1 shows the skid resistance surveys for two different EAS pavement sections, in the same motorway: it can be seen how the skid resistance level is similar for the two sections although they have different service life (lane 1: seven years old; lane 2: five years old). This reduces, as compared to asphalt paving, the maintenance operations of the surface of the pavement.

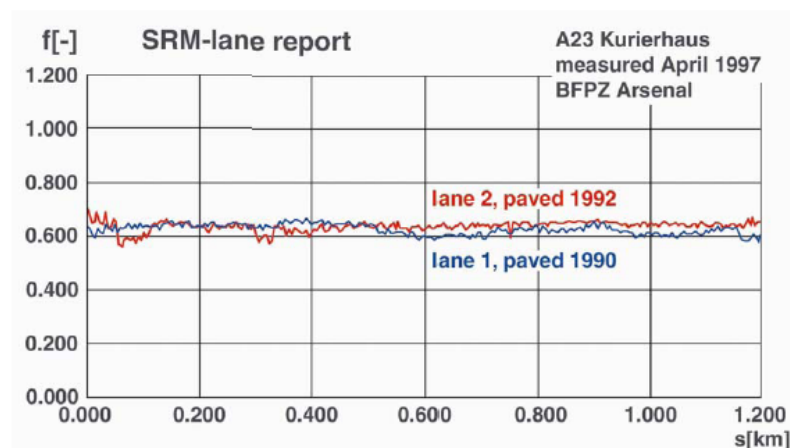


Figure1. Skid resistance EAS pavements 5 and 7 years after construction (Haider et al. 2006).

In Tables 5 and 6 other SCRIM (*Sideway-force Coefficient Routine Investigation Machines*) test results are pointed out for motorways and regional exposed aggregate concrete (EAC) roads with an aggregate size limited to 20 mm,

where smaller stones (2 to 6 mm) constitute at least 20 % of the aggregates (sand + stones).

Although a decrease of the initial values, there is a good performance of characteristics over time (Briessinck and Rens 2010).

Table 5. Mean sideway friction coefficient measured with SCRIM on EAC on a Belgian motorway.

Skid resistance x 100: E429-A8 Tournai – Brussels (km 25.0 – km 30.0)		
2000 (1st measurements)	2002	2004
54.8	54.7	54.2

Table 6. Mean sideway friction coefficient measured with SCRIM on fine EAC on a Belgian road.

Skid resistance x 100: R3 Ring Charleroi (km 27.0 – km 24.0)			
1997 (in service)	1998	2001	2002
56.1	56.5	54.9	52.7

Conclusion

The paper highlights how the use of concrete pavement ensures advantages in road tunnels:

- it has a positive impact on the Italian CO₂ emission due to the lighting of tunnels because the replacement of asphalt with concrete pavements can contribute to reach the EU 2020 target of cutting emissions by 20% from 1990 levels;
- it is the appropriate material for road pavement in tunnel because it contributes to increased safety (fire protection, maintenance reduction and skid resistance values over time) and reliable availability to traffic;
- it has further environmental advantages such as the reduction in fuel consumption and pollution with the use of smog eating cement.

Many decision makers are convinced that a concrete road offers economic benefits when the whole life cycle (maintenance costs) are taken into account. This is even more real when the user costs are taken into account (no user disruption due to less maintenance activities). Consequently concrete roads provide socially acceptable solutions with respect to the matter of mobility.

References

BIBM – BFT International (2007) “Comprehensive fire protection with concrete (part 1)”, n. 10.

Briessinck M., Rens L. (2010) “Characteristics of today’s concrete surfaces”, 11th *Interantional Symposium on Concrete Roads*, Sevilla Spain.

Bryant K. (2002) “Who are you designing your tunnel for?”, *Tunneling and Underground Space Technology*, Volume 17, Issue 2.

CAC Cement Association of Canada (2010) “Sustainability Report 2010”.

Cembureau, BIBM, ERMCO (2004) "Improving fire safety in tunnels: the concrete pavement solution".

De Lathauwer W. (2007) "Effects of pavement on fires in road tunnels", *Routes Roads*, n.334.

Domenichini L., La Torre F., Caputo F.J. (2006) "Impiego delle pavimentazioni in calcestruzzo nelle gallerie stradali", *Strade e Autostrade* (I), N. 6.

EUPAVE (2009) "Concrete roads: a smart and sustainable choice", *EUPAVE publication*.

European Parliament (2004): "Directive 2004/54/EC of the European Parliament and of the Council of 29 April 2004 on minimum safety requirements for tunnels in the Trans-European Road Net".

FGSV 499 (2001): "Richtlinien für die Standardisierung des Oberbaues von Verkehrsflächen – (RStO 01)".

Fischnaller G., Wunderer R. (2011) "Road Pavements in Tunnel Construction" - *Brenner Congress*.

Gajda J.W., Van Geem M.G. (1997) "A comparison of six environmental impacts of Portland cement concrete and asphalt cement concrete pavement", PCA R&D serial N° 2068, Portland Cement Association.

Haider M., Steigenberger J., Piber H. (2006) "Long-term performance of low-noise concrete pavements", *10th International Symposium on Concrete Roads*.

INTERTUNNEL (2010) "Turin Italy: European Tunnel".

Jofré C., Romero J., Rueda R. (2010) "Contribution of concrete pavements to safety of tunnels in case of fire", *EUPAVE Publication*.

Routes (2006) "Tunnel de Sinard: les atouts majeurs de la chaussée béton" N.98.

Strade & Autostrade (2006) "Galleria di gallerie", n.55, pp.60-63.

ZTV-ING Teil 5 (2007) "Tunnelbau, Zusätzliche technische Vertragsbestimmung und Richtlinien für Ingenieurbauten", Bundesanstalt für Straßenwesen 12.