

CONCRETE ROADS : A SMART AND SUSTAINABLE CHOICE

- ENVIRONMENTAL ASPECTS
- ECONOMIC ASPECTS
- SOCIAL BENEFITS
- OTHER DURABLE APPLICATIONS OF CEMENT AND CONCRETE



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INTRODUCTION

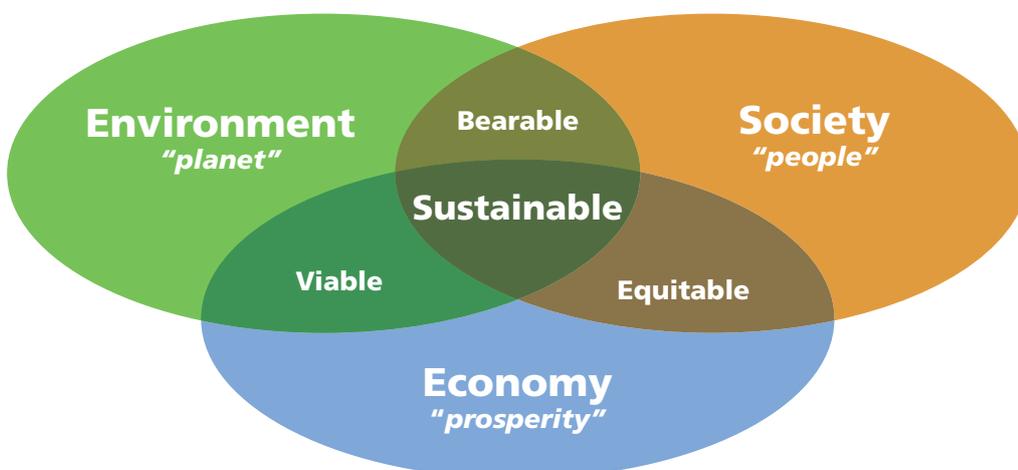
These days virtually everybody you talk to is aware of the universal challenge that we are faced with namely, how are we to adjust our lifestyles and what measures should we take in order to counter global warming and to ensure that the following generations can lead decent lives. This is precisely the implication of sustainable development, i.e. finding an answer to existing needs, while taking account of the economic, ecological and social factors in every decision-making process, so that it will be possible to meet the needs of tomorrow. In our sector we talk about "sustainable construction".

Concrete structures and concrete roads are commonly described as durable. In the past this was largely an acknowledgement of their robustness and the fact that these structures would last a very long time. These days however, there are many other aspects which are equally relevant. How the raw materials are obtained, the production of the elements, the whole construction process, the entire usage phase of the structure and its reuse or recycling are examined in detail in order to arrive at a global assessment. Consequently we do not simply mean materials that are durable in terms of how they are obtained or produced, but try to look at the bigger picture. After all in the final analysis it comes down to finding sustainable solutions for the transportation of people and goods.

The following definition of sustainable could be used for transport infrastructure and roads in particular:

"Sustainable roads make efficient use of natural resources and respect the environment during their entire life cycle; they improve transport facilities for the entire community, they provide services to society in terms of mobility, safety and comfort by means of judicious choices regarding design, construction, maintenance and demolition".

This publication draws on international experience to show that the modern concrete road can be a sustainable solution for our society and that it satisfies the basic criteria for sustainable construction in respect of the environment, economy and society.



In the context of sustainable development there is no doubt that it is the environmental aspect that receives the most attention and that often – although unjustifiably – economic and social considerations are largely ignored. The greenhouse effect, the resulting global warming and the role that humanity plays in this imply that this aspect is further accentuated. However, we must ask what is “green” and what is not? Numerous assessment systems are used to answer this question, and some are more complete than others. For example when a new motorway is to be constructed the tendering procedure may make use of the principles of “Green Public Procurement” to assess the environmental impact of several alternative solutions. In the following a series of factors are discussed that could influence the decision for a concrete road or otherwise. Some factors may be decisive, while other factors may have a lesser influence but can nonetheless not be ignored.

CARBON FOOTPRINT & LCA

Durability of concrete structures, namely the extremely long lifetime, also plays a crucial role in the three aspects of sustainable construction. For the environment this is expressed by the notion of the Carbon Footprint or an even broader evaluation method known as LCA or Life Cycle Assessment.

The Carbon Footprint is the overall amount of carbon dioxide (CO₂) and other greenhouse gas (GHG) emissions (methane, nitrous oxide, fluorinated gases) associated with a product along its supply chain including use and end-of-life recovery and disposal. CO₂ is used as the reference gas and the other gases are expressed in terms of their CO₂ equivalence in terms of “global warming potential”.

This Carbon Footprint, which only takes account of the impact on climate change, is only part of the full LCA approach, which assesses in a more complete way environmental impact over the entire life cycle,

i.e. from cradle to grave, using a standardized method (ISO 14040, ISO 14044). If only greenhouse gases were to be considered, this could have a negative impact on other environmental aspects. Environmental impact assessment and evaluation systems must therefore always be carried out with reference to a fair and holistic approach to all the phases of a structure, in this case the pavement.

It will be immediately clear that for concrete roads the environmental balance is favourably impacted by their extremely long service life of 30, 40 and more years. Furthermore concrete roads require little attention for maintenance and repair, not to mention the long-term savings in raw materials, transport and energy. We may also take account of the reduction in traffic delays caused by road works, which in turn cuts back on fuel consumption and exhaust gas emissions.

In order to determine where concrete roads stand in respect to flexible asphalt pavements, CIMbéton, France’s Centre for Information about Cement and its Applications, requested the Centre d’Énergétique de l’Ecole des Mines de Paris to carry out an LCA study to look into the question. Using objective data supplied by a Swiss and a German university the impact of six different road structures were compared with reference to twelve different environmental indicators. These indicators may be of global significance, such as energy and greenhouse gases or be of local or regional importance such as smog, odour, acidification, etc.

TABLE 1 – GLOBAL WARMING POTENTIAL OF VARIOUS GREENHOUSE GASES

Name - description	Chemical formula	Global warming potential over a reference period of 100 years
Carbon dioxide	CO ₂	1
Methane	CH ₄	25
Nitrous oxide (laughing gas)	N ₂ O	298
Fluorinated hydrocarbons CFCs, HCFCs, HFCs, PFCs	-	124 – 14.800
Sulphur hexafluoride	SF ₆	22800

TABLE 2 : ENVIRONMENTAL INDICATORS IN THE CIMBÉTON LCA STUDY

Indicator	Unit
Primary energy	MJ
Water Consumption	kg
Natural Resources	10 ⁻⁹ (consumption compared to world reserves)
Wastes	t eq
Radioactive wastes	dm ³
GWP ₁₀₀ (greenhouse gases)	kg CO ₂
Acidification	kg SO ₂
Eutrophication	kg PO ₄ ³⁻
Ecotoxicity	m ³ eq. polluted water
Toxicity to humans	kg eq. contaminated flesh
O ₃ smog	kg eq. C ₂ H ₂
Odour	m ³ eq. air pollution due to ammonia

The study prepared LCAs for four types of concrete pavement and one type of composite pavement, and one type of asphalt pavement used on a twin lane dual carriageway motorway with a length of one kilometre and a service life of 30 years. The traffic volume during the usage phase came to roughly 100 million cars and 25 million goods vehicles.

The structures examined were constituted as follows:

1. 21 cm dowelled plain concrete on 15 cm lean concrete;
2. 19 cm continuously reinforced concrete on 15 cm lean concrete;
3. 22 cm continuously reinforced concrete on 5 cm asphalt;
4. 37 cm undowelled concrete slabs on a 10 cm unbound granular base;
5. 2,5 cm bituminous wearing course on 17 cm continuously reinforced concrete (CRC) on a 9 cm asphalt-bound granular base;
6. 8 cm asphalt on a 26 cm asphalt-bound granular base.

These structures are based on French practice and do not necessarily correspond to practice in other countries. Other assumptions regarding the materials, construction, maintenance and recycling are also similarly open to discussion and adjustment. Even so this study does make it possible to obtain a generalized picture of the matter.



Dowelled plain concrete

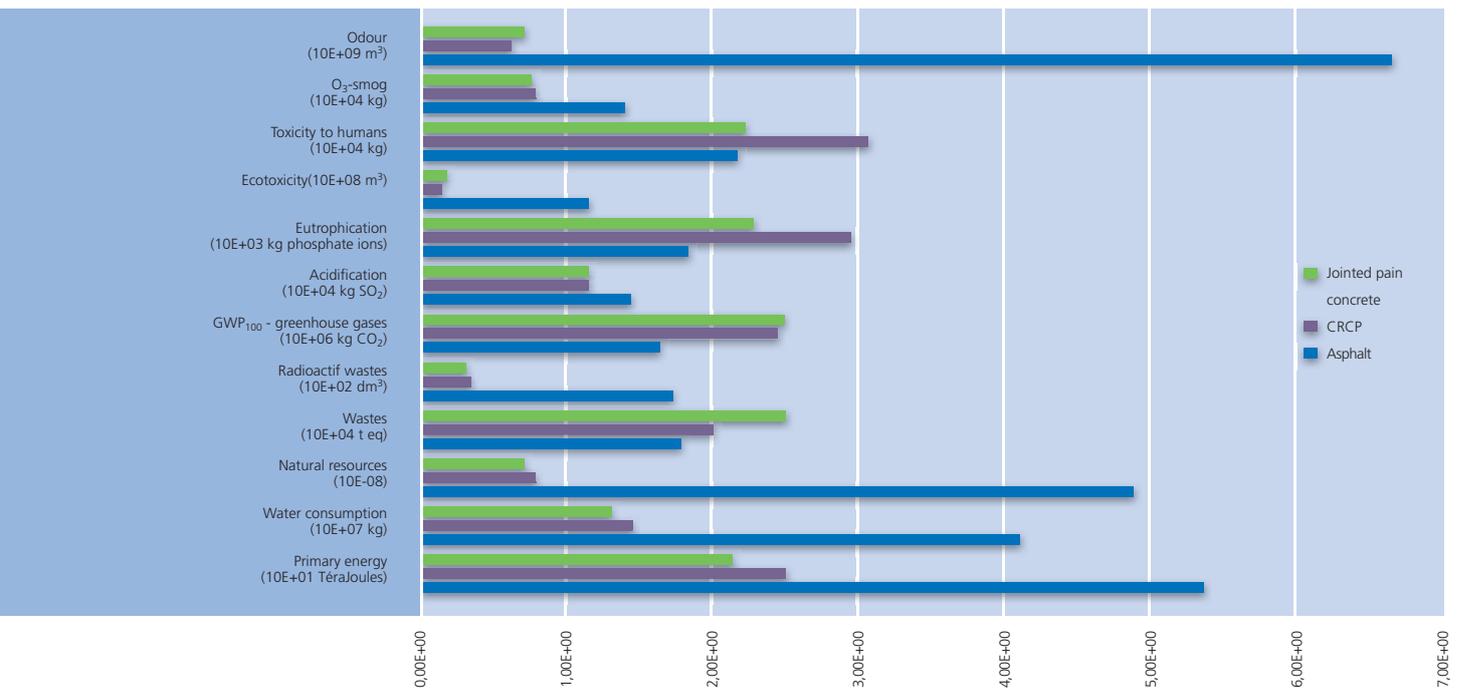


Continuously reinforced concrete

The results are presented in the form of a bar chart, in which the performance of the structures for each of the twelve chosen environmental indicators is compared. Each bar uses a scale that reflects the specific unit of measurement of the indicator concerned, so that the relative differences between the various structures can be compared visually. The shorter the bar, the lower the environmental impact of the structure is for this indicator. The bar lengths for the different indicators cannot be compared with one another because they each refer to totally different units of measurement. The study does not attribute any weighting to the environmental indicators.

The chart reproduced below compares concrete structure no. 1 (dowelled plain concrete), concrete structure no. 3 (CRC on a layer of asphalt) and asphalt structure no. 6 for the phases of obtaining and producing the raw materials, preparing and transporting the mixes, constructing the road structure, maintenance and decommissioning at end of life. The actual usage phase or, expressed otherwise, the impact of traffic is not included. The bituminous structure is more favourable than the concrete one for Wastes, Greenhouse Gases, Eutrophication and Toxicity to Humans. The concrete structure on the other hand is more favourable for the remaining indicators, namely Energy, Water, Natural Resources, Radioactive Wastes, Acidification, Ecotoxicity, Smog and Odour.

Figure 1 : Lifetime (30 years) impact of a road not including traffic for various environmental indicators – comparison of jointed plain concrete, continuously reinforced concrete and asphalt



However, when the usage phase, i.e. the traffic, is taken into consideration an entirely different picture emerges. This is clearly seen in the following bar diagram, which is applicable to the slab concrete structure. Here it is clear that the short yellow pieces of the bars due to the construction, maintenance and decommissioning of the road are notably short compared to the green parts of the bars that represents the contribution due to traffic. With the sole exception of the “solid waste” indicator the impact of the traffic is at least ten times greater than all the other phases of the lifetime of the road.

Measures that could reduce fuel consumption are therefore of very great importance. Such measures might lie in a variety of fields, such as:

- alternative fuels,
- automobile technology (motor, tyres,...),
- quality (evenness) and rigidity of the road pavement
- traffic measures
- fluid traffic movement, avoidance of tailbacks

From this we may conclude that the

comparison of various road structures and/or pavement types on the basis of an LCA results in a less black and white picture for the various environmental indicators. Whatever the case improvements and optimization must be pursued in the fields of design, construction, maintenance techniques, demolition and recycling. Other properties of concrete pavement such as greater reflectivity and reduced urban heat island effect are not considered in this study, but may nonetheless play a significant role in the whole climate change question, as will be seen below. Nonetheless the greatest potential for improvement lies in the area of vehicle fuel consumption.

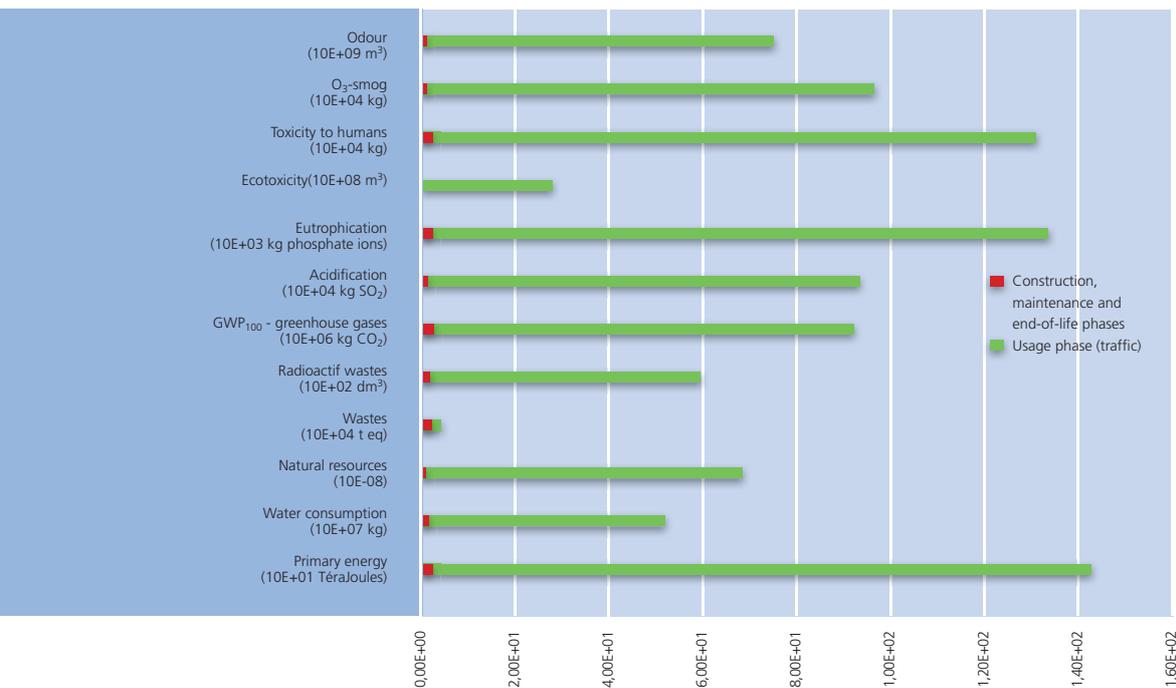


Figure 2 : Lifetime impact of a jointed plain concrete road including traffic for various environmental indicators

IMPACT OF THE TYPE OF PAVEMENT ON THE FUEL CONSUMPTION OF HEAVY GOODS VEHICLES

Precisely because of the social and ecological importance of reducing fossil fuel consumption a number of studies and research projects concerning the effect of the pavement type on the fuel consumption of cars and goods vehicles have already been carried out. The best known is the one made in Canada by the National Research Council. This was in fact a series of four investigations, which were progressively extended with additional tests on various types of roads and vehicles in different seasons and using a variety of statistical models. Reduced fuel consumption by heavy goods vehicles



WHAT DOES A FUEL SAVING OF 2,35% MEAN FOR GOODS TRAFFIC?

Let us suppose that we wish to change the heavily loaded traffic lane from asphalt to concrete. What impact would a fuel saving of 2.35% have on CO₂ emissions?

Imagine 1 km of carriageway with width of 4 m and a thickness of 23 cm. On working days it is used by 2000 trucks a day, with a fuel consumption of 35 l per 100 km. Let us assume that 1 litre of fuel corresponds to a CO₂ emission of 2.5 kg. The CO₂ emission is thus:

220 working days x 2000 trucks x 35 litres/100 km x 1 km x 2.5 kg CO₂/litre = 385 tons CO₂ per annum.
A fuel saving of 2.35% thus represents a reduction of 9.05 tons of CO₂ every year.

The CO₂ required for making the cement comes to:
1 km x 4 m x 0.23 m x 350 kg cement/m³ x 750 kg(*)
CO₂/1000 kg cement production = 241.5 tons CO₂

The CO₂ emission resulting from making the cement is thus fully compensated for after 241.5/9.05 = 27 years, or less than the anticipated 30 to 40 year lifetime of the concrete traffic lane.

(*) average value for Europe, see next paragraph.

was observed in all phases for concrete pavement compared to flexible bituminous pavement. The final phase, which was also the most complete and looked at a range of roads with various degrees of evenness and with observations made in all seasons did admittedly reveal the least large differences, but came nonetheless to the conclusion that the "fuel saving on concrete roads compared to asphalt roads, both for an empty and full tractor-trailer unit ranged from 0.8 to 3.9% in four out five periods in the year and that this was found with statistically significant results with a field of reliability of 95%." An average fuel saving of 2.35% is certainly not negligible and would over the lifetime of a busy motorway represent an immense difference in overall fuel consumption and emissions of polluting gases.

Laboratory research by the TRL (Transport Research Laboratories) in Great Britain commissioned by the Highways Agency was carried out to determine the effect of the rigidity of the pavement on fuel consumption. The reduced deflection of concrete pavement was found to lead to a 5.7% reduction in rolling resistance, which corresponds to a fuel saving of 1.14%. This difference proved, however, to be statistically insignificant, on the other hand the difference could have been greater because the concrete slab used in the tests was constructed in laboratory conditions.

Apart from the type of pavement, evenness and surface texture are important factors that have an influence on fuel consumption. The quality of the finished concrete surface plays a crucial role: a good quality and evenly laid concrete road retains these qualities for decades, a concrete pavement with undulations or uneven patches will require difficult and expensive treatment in order to obtain the desired ride quality while at the same time reducing fuel consumption to a minimum.

THE USE OF “LOW ENERGY CEMENT”

A common assertion is that the production of one tonne of cement results in the emissions equivalent to one ton of CO₂. Nonetheless this facile approximation is misleading. For cement made in the EU the average ratio is one ton of cement to emissions equivalent to 750 kg of CO₂. This is because apart from the primary product of clinker, widespread use is also made of secondary materials such as fly ash, blast furnace slag, and limestone filler in cement production.

For road building the situation is even more favourable because much use is made of blended cements such as Portland fly ash cement or blast furnace slag cement. In these cements part of the clinker is replaced by fly ash or blast furnace slag and it is precisely the production of clinker that is demanding in energy and which also releases even more CO₂ in the decarbonation process that takes place in the cement kiln.

Figure 3 gives a comparison of the energy content of various types and strength classes of cement. A comparison of CEM III/A blast furnace slag cement with CEM I Portland cement shows that the combustion and electrical energy requirement is reduced by about 40%.

The impact of using blended cements on CO₂ emissions during the production of cement can be read off figure 4, which is drawn from the “ECOserve” international cooperation project. The data takes account of the reductions due to reduced fuel consumption, reduced electricity consumption, lower CO₂ emissions during decarbonation as well as the increases caused by drying the replacement materials and the need to grind the cement finer. We see that the production of one ton of CEM III/A blast furnace cement corresponds to the emission of only 500 kg of CO₂. So it is in fact possible to achieve drastic reductions compared to the production of Portland cement.

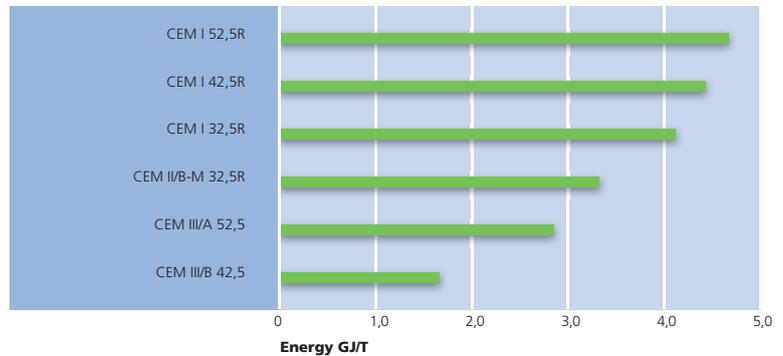


Figure 3 : Energy content of various types and strength classes of cement

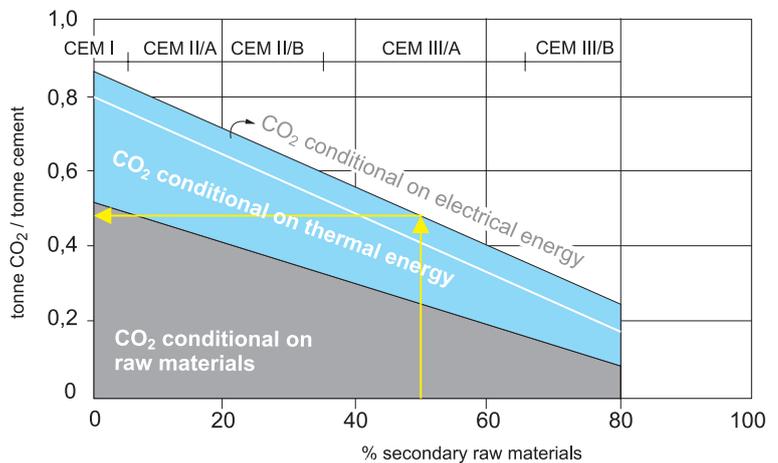


Figure 4 : CO₂-emissions from the production of blended cements

OVERALL CO₂ REDUCTION BY ENERGY RECOVERY FROM INDUSTRIAL WASTE

The use of industrial wastes such as tyres, solvents, waste oil, waste water treatment sludge, paint residues as alternative fuels in cement kilns can likewise make a valuable contribution to reducing overall CO₂ emissions. When such waste is not incinerated during cement production it has to be eliminated by means of traditional incineration.

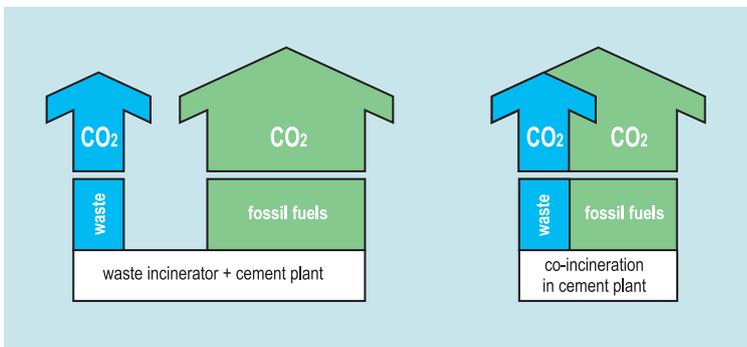
In the latter case the energy yield is much lower and the corresponding CO₂ emissions are additional to those from the cement industry. The remaining residues are then taken to a disposal site without being recovered in any way at all, and where they give rise to the formation of

methane, a gas that is 25 times more active as a greenhouse gas than CO₂. When such wastes are burnt in cement kilns at temperatures of up to 1450°C, all organic molecules are destroyed, so that there is no further danger of pollution. Moreover in such cases no residual wastes are left at all.

CO₂ UPTAKE BY THE CONCRETE

Just as CO₂ is released as a result of the decarbonation process during the production of cement, CO₂ is taken up by

Figure 5 : Reduction of CO₂ emissions by burning waste in cement kilns.



the concrete during the course of its lifetime as a result of the opposite reaction of recarbonation. This is known to be one of the possible causes of damage to reinforced concrete. However this is not a problem for concrete roads:



Concrete rubble stored in open air : increased CO₂ uptake

- jointed plain concrete is not reinforced and recarbonation is thus not regarded as harmful;
- in continuously reinforced concrete the reinforcement lies at a depth of 6 cm or more, depending on the design. This is more than enough to ensure to that the reinforcement zone remains untouched by the recarbonation front during the lifetime of the road.

Moreover road concrete is of an exceptionally high quality. It is compact and has few pores. The recarbonation depth, which is proportional to the square root of the duration of exposure, is only 5 to 10 mm after a period of 40 years. However, this also means that the uptake of CO₂ by the concrete is limited. Even so "limited" does not mean negligible. Studies show that the quantity of CO₂ taken up after 40 years, by a wall with a thickness of 20 cm and exposed to the atmosphere on both sides is about 20 kg per m³ of concrete. A road pavement is exposed only on one side and thus the CO₂ uptake comes out at 10 kg/m³ or 2 kg/m² for a similar thickness of 20 cm. This corresponds to 5% of the CO₂ needed for the corresponding production of blast furnace cement for the same area in m² of concrete pavement (1m² x 0,20 m x 400 kg cement/m³ x 0,5 kg CO₂/kg blast furnace cement = 40 kg/m²).

If at the end of the road's lifetime the concrete of the pavement is broken into concrete rubble there continues to be considerable potential for CO₂ uptake should the rubble be stored in open air. After all the specific area of concrete rubble is far greater and the recarbonation reaction proceeds much faster. Between 15 to 35 kg/m³ can be absorbed over a period of 2 to 3 years.

If we take the entire cycle into consideration, we then arrive at a figure for overall CO₂ uptake of between 25 and 45 kg/m³ for road concrete, which is roughly equivalent to 10 to 25% of the amount of CO₂ released during the production of the 400 kg of blast furnace cement needed to make the concrete.

ABSENCE OF HAZARDOUS LEACHING PRODUCTS

Objections are sometimes heard to the effect that the use of industrial by-products in the production of cement production (fly ash, blast furnace slag, etc.) could result to heavy metals being leached out and thus giving rise to soil pollution. Leaching is a technical term used to describe the process whereby chemical elements are lost from a solid material when it comes into contact with water (drinking water, rain water, seawater).

Belgium's National Centre for Scientific and Technical Research of the Cement Industry (O.C.C.N. – C.R.I.C.) has studied this problem. Using the "Tank Test" method as described in the NEN 7345 standard concrete samples were submerged in a leaching liquid, which after a predetermined period of time was subjected to ICP-MS analysis (plasma torch combined with mass spectrometry). The results showed that the leaching behaviour of road concrete, including both pavement quality concrete and lean concrete, is totally harmless to the environment. In fact the quantities of heavy metals leached out turned out to be lower than the quantities that occur naturally in the mineral water sold in stores!

RECYCLING

Concrete is an inert material that can be 100% recycled. The majority of concrete pavements that are demolished are sent to a crushing and screening installation. Afterwards the concrete rubble is recycled in road bases and sub-bases made from unbound or bound aggregate, lean concrete or roller compacted concrete.



Recycling concrete rubble in pavement quality concrete is perfectly feasible when used as twin course concrete and 60% or more of the coarse aggregate can be replaced by recycled road concrete. This is standard construction practice in Austria and is also applied in other countries (Germany, Poland, and others). Belgium has also followed this example: the first significant application in Belgium took place in 2007-2008 with the reconstruction of a 3 km long section of the N49/E34 between Zwijndrecht and Melsele. See box.

Recycling of demolished road concrete intended for use in a roller compacted concrete road base and as aggregate in new pavement quality concrete (A17-E403 Bruges-Kortrijk, 2007)

TABLE 3 : LEACHATE VALUES FOR ROAD CONCRETE AND PARAMETER VALUES OF THE EUROPEAN DIRECTIVE

"Tank test" - Demineralized water- Porphyry concrete, CEM I et CEM III/A 42,5
Values expressed in ppb (µg/l) (*) (**)

Element	Average levels ascertained after 24 hours of contact				European parametric values according to 98/83/CE (***)
	CEM I		CEM III/A		
	minimum	maximum	minimum	maximum	
Ba	6,4	22	8,0	8,8	none
Ni	0,19	0,45	0,096	0,28	20
Cr	0,31	0,71	0,13	0,29	50
Sb	0,011	0,028	0,010	0,068	5
Se	< 0,060	< 0,060	< 0,060	< 0,060	10
Mn	< 0,006	< 0,006	< 0,006	< 0,008	50
Hg	< 0,002	< 0,002	< 0,002	< 0,002	1
As	< 0,002	< 0,006	< 0,002	< 0,007	10
Ag	< 0,001	< 0,001	< 0,001	< 0,003	none
Zn	0,014	0,020	0,005	0,022	none
Pb	< 0,001	0,027	< 0,001	< 0,001	10
Cd	< 0,001	0,002	< 0,001	< 0,001	5
Cu	< 0,004	0,015	< 0,004	< 0,004	2000

(*) ppb = 'parts per billion' = e.g. micrograms per kilogram or liter water.

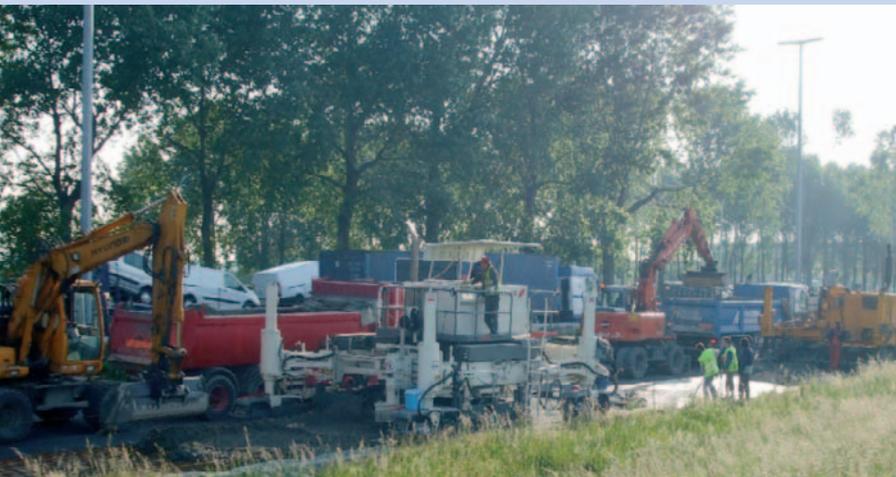
(**) Figures preceded by '<' refer to levels below the detection limit.

(***) The European parametric values are based on the maximum daily amount humans can take in without health side effects.

REHABILITATION OF THE N49/E34 AT ZWIJNDRECHT BY USING A TWIN LAYER CONTINUOUSLY REINFORCED CONCRETE PAVEMENT WITH RECYCLED CRUSHED AGGREGATE IN THE LOWER LAYER

The technique of twin layer concrete is used either to obtain a high quality upper course or to make it possible to use lower quality, i.e. cheaper, materials in the lower course, or for both reasons at once. In Europe this technique is widely applied in Austria where recycled concrete from the demolished pavement is used in the lower course. Growing environmental awareness and an innovative desire encouraged the Flemish Authorities to follow the Austrian example and it was decided to proceed with the construction of a 3 km pilot section in continuously reinforced concrete on the E34 express road at Zwijndrecht. The works were carried out in two phases, with the section in the direction of Gent being carried out in 2007 and the section in the direction of Antwerp in 2008.

This was a unique and international first, which admittedly drew on existing experience, namely the combination of twin course concrete pavement made from CRC and recycled concrete rubble. The design strives both for durability and sustainability, with CRC pavement being noted for its long lifetime combined with concern for the environment and the finite nature of natural resources. This project may therefore be most certainly regarded as an optimized sustainable road design and most definitely represents a contribution to the further development of this type of pavement.



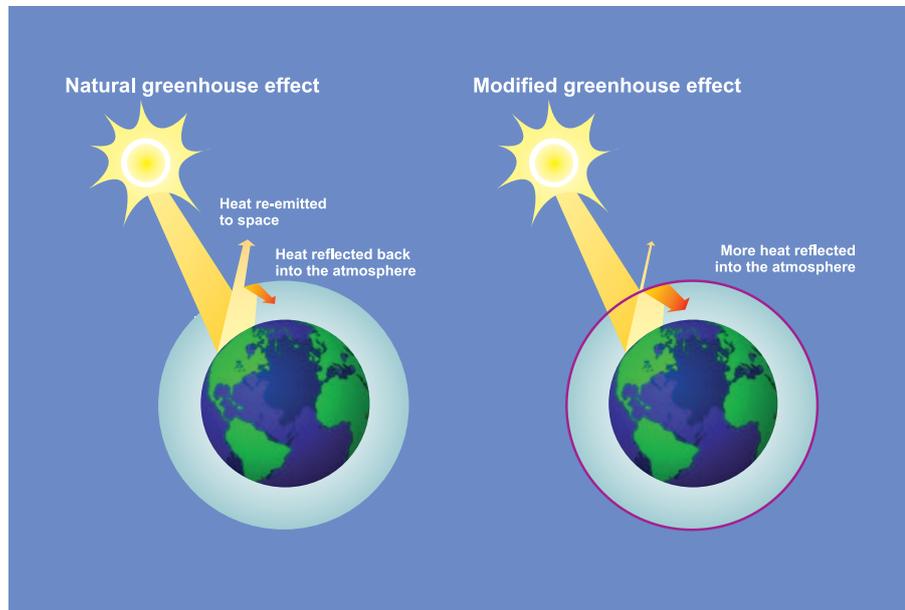
BETTER REFLECTION OF LIGHT AND REDUCED HEAT SINK EFFECTS IN URBAN AREAS

The ability to reflect light – or energy in other words – is determined by the albedo of a given surface. Albedo is expressed as the ratio of the reflected solar energy to the total solar energy received. The higher this percentage is, the more energy is reflected back into the atmosphere. On average the albedo of planet earth is 0.35. That is to say 35% of all the solar energy is reflected while 65% is absorbed. As a result the average temperature at the earth's surface is 15°C. Polar ice with its high albedo plays an important role in maintaining this temperature balance. Should the polar ice melt the average albedo of the earth will fall because the oceans will absorb more heat than the ice. The temperatures on earth will rise and global warming will accelerate.

TABLE 4: THE ALBEDO VALUES OF VARIOUS MATERIALS

	ALBEDO
Fresh snow	81 to 88%
Old snow	65 to 81%
Ice	30 to 50%
Rock	20 to 25%
Woodland	5 to 15%
Exposed soil	35%
Concrete	15 to 25%
Asphalt	5 to 10%

Nonetheless the global warming effect can also be slowed down by applying this knowledge, namely by providing more reflective surfaces such as white roofs and concrete pavements! This has been studied by a group of scientists from Berkeley (California, USA), who call themselves the Heat Island Group. They compared the albedo effect and the influence of the concentration of atmospheric CO₂ on the net radiation power responsible for global warming. They calculated that an increase by one percent of the albedo of a surface corresponds to a reduction in radiation of 1.27 W/m². This reduction in radiation has the effect of slowing global warming. Their calculations indicate that delay in warming is equivalent to a reduction in CO₂ emissions of 2.5 kg per m² of the earth's surface. Compared to a bituminous pavement a concrete pavement has an albedo of 10 to 15% and is thus equivalent to a reduction in CO₂ emissions of 25 to 38 kg per m² of area. Even the lowest value of 25 kg CO₂ per m² results in an enormous benefit, equivalent to 60% of the CO₂ required for the production of the cement needed for 1 m² of 20 cm concrete slab.



The lower heat absorption of light surfaces such as concrete also contributes to reducing the warming effect that occurs in large urban areas. Figure 5 shows a thermal image of a location where a concrete pavement abuts an asphalt pavement. The measurements were made in slightly cloudy conditions at about 17:00 hours in August 2007. The temperature difference between the two pavements is about 11°C.

Figure 6 : Heating of the Earth by the greenhouse effect.

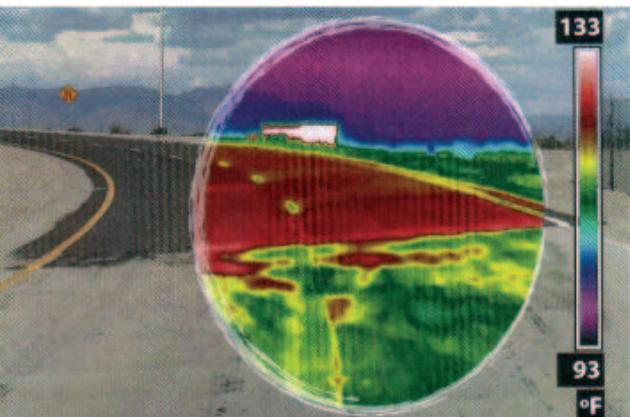
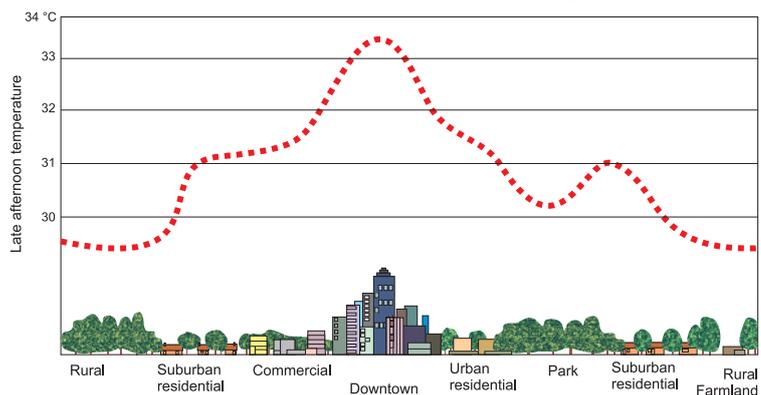


Figure 7 : Thermal image of a road pavement at Mesa, Arizona. The temperature difference between the asphalt pavement at rear and the concrete pavement in the foreground is striking

The urban heat-island effect is illustrated in figure 8 and leads to higher energy consumption by the air-conditioning systems of buildings and consequently has a high economic and environmental price. Higher temperatures also encourage the formation of smog. Light-coloured pavements can play a beneficial role by limiting warming and reducing the likelihood of smog.

Figure 8 : Illustration of the urban heat island effect



Every road manager or road authority wants to invest in sustainable structures that require only minimal maintenance and which offer a high level of availability over the longest possible lifetime. The technical parameters may be decisive when choosing for a particular structure, but the choice often depends on economic considerations as well. These can be categorized as follows:

- expenditure associated with the construction of the infrastructure or capital cost;
- the budget for subsequent maintenance and preservation works;
- the economic repercussions of maintenance operations, which by and large are the costs to society of things like the delays suffered by people and business resulting from traffic jams caused by road works and the reduced availability of infrastructure.

LIFETIME – MAINTENANCE – LIFE-CYCLE COST ANALYSIS

The initial investment cost is often and misguidedly used as the primary criterion. This approach can be mistaken even in solely economic terms when the costs of maintaining the new structure are excessive. The useful lifetime of the pavement clearly plays an important role here. There are mathematical – and even probabilistic – models that can provide support for the decision-maker when taking strategic long term decisions of this kind in the context of short term budgetary restrictions.

The “Life-Cycle Cost Analysis” or LCCA is an example of this kind of decision-supporting technique that helps assess the long term return of alternative investment options. In its completest form the LCCA takes account of the costs to the road manager/investor and to the user, and all other relevant costs throughout the structure’s lifetime for the various different options. A search is made for any given investment for the option that has the lowest long term cost but still achieves the desired performance.

The difficulty of using this technique lies in estimating or forecasting the required parameters of the model:

- useful lifetime of the various options,
- costs to the road manager,
- residual value of the pavement at the end of the analysis period,
- the costs to the road user (or costs to society) during the normal use of the road and during maintenance and renovation works, such as:
 - operating costs of the vehicle
 - costs due to delays
 - costs of accidents
- discount rate

In other words a whole range of parameters must be assessed, assumed or predicted with an acceptable degree of probability. To take account of this the LCCA model can be supplemented by a risk analysis. In this case use is generally made of probabilistic models such as the Monte Carlo simulation technique as well as specialized computer programs.

Because of the difficulty of quantifying the societal and social parameters, account is usually taken only of the construction and maintenance costs and perhaps the costs of demolition and reconstruction depending on what model is used.

de démantèlement et de renouvellement.

CLIMATIC AND METEOROLOGICAL PERFORMANCE

A concrete pavement can stand up to the worst that the seasons, weather and climate can throw at it. After a severe winter with repeated freeze/thaw cycles the road manager is not confronted with spalled surfaces, potholes in the road surface or dangerous crack formation.

It is admittedly not possible to lay concrete pavement in all weather conditions: at extreme temperatures the risks become higher and appropriate measures must be adopted regarding the formulation of the concrete mix, the procedures for use or both. However, once the concrete road has been properly laid, it is no longer subject to climatic influences. The various scenarios in connection with climate change therefore do not pose a problem for concrete roads.

LIGHTING COSTS

The superior reflectivity of concrete, due to its lighter surface, makes it possible to achieve savings in the costs of lighting streets and motorways. After all road lighting designers always base themselves on the reflected light as it is perceived by the driver of a vehicle. Economies can be achieved by placing fewer lighting columns or by using lamps of a lower luminance. In both cases costs can be reduced, primarily by being able to cut back on the number of lighting columns required and secondly in annual electricity consumption.

A Canadian study shows for example that whereas 14 lighting columns are required for a distance of one km of concrete carriageway, an asphalt road requires 20 lighting columns to achieve the same level of lighting.

PRICE STABILITY

If we examine the price evolution of the materials used in road construction, it is clear that imported materials such as heating oil and bitumen are entirely dependent on the international market price of crude oil and that this is subject to powerful fluctuations, particularly in periods of energy scarcity. Cement on the other hand is a locally produced construction material and in consequence its price is more stable, although of course it too is affected by energy prices. For example in periods of crisis characterized by oil shortages, we see the price of bitumen reaching unpredictably high prices, whereas cement reacts after a certain delay and displays fewer fluctuations.

In certain countries such as Turkey the market situation for cement and bitumen binders is different than in most other West European countries. There the initial investment cost for a concrete road is lower than for an equivalent bituminous road. Furthermore when the maintenance costs are added to the equation the differences become exceptionally high.



THE SIGNIFICANCE OF COMPETITION BETWEEN THE DIFFERENT TYPES OF PAVEMENT

In those countries where road construction is dominated by one or the other type of material – usually asphalt – there is the disadvantage that there is little or no competition on the market from other types of materials, resulting in higher prices for the basic materials. In countries where bituminous and cement pavements have developed in tandem, the road manager has the ability to select the most suitable option in function of the application, traffic volume, operating conditions, and there is no domination of one material over another, which in itself has a positive impact on the market situation.

Figure 9 : Bitumen, oil and cement price evolution in Belgium between 1969 and 2009

AN ECONOMIC COMPARISON BETWEEN BITUMINOUS AND CONCRETE PAVEMENTS FOR MOTORWAYS

In 2001 the Highway Administration of Belgium's Walloon region published a study that made an economic comparison between various pavements in continuously reinforced concrete and asphalt on the basis of a life-cycle cost analysis.

The great strength of this study is that it is based on more than 30 years of experience in the construction and maintenance of two 20 km sections of the E42 (Autoroute de Wallonie) over a period of 30 years.

Features of the study:

- conversion of all prices to 2001 values with reference to a discount rate;
- analysis for a period of 50 years;
- traffic estimates based on traffic censuses;
- accurate and up-to-date estimates of the costs of construction and maintaining various types of road;
- the maintenance scenarios were drawn up by local managers working as part of a workgroup that decided on a consensus basis;
- no indirect costs to the road user were included so that all the parameters were very well known and the study can be regarded as being extremely reliable in technical and economic terms.

Six different road structures were examined, two bituminous and four made from continuously reinforced concrete.

The total thickness of the two bituminous structures were different, namely 21 cm and 26 cm. In both cases the road base consisted of 20 cm lean concrete and the sub-base of respectively 35 cm and 30 cm of mixed sandstone aggregate. The first structure was a conventional for bituminous motorways; the second was found after the motorway had been given overlay without any milling of the underlying courses.

The four concrete structures differed only in the width of the carriageways:

- 7.20 m CRC with hard shoulder and central reservation in asphalt (road markings on the hard shoulder with the result that the CRC sustained loading damage on the edges);
- 8.00 m CRC with hard shoulder and central reservation in asphalt (road markings on the CRC to avoid edge effects);
- 10.30 m CRC with only the central reservation in asphalt;
- 11.05 m in CRC over the entire width.
- In all four cases the CRC was laid on with a thickness of 20 cm on an intermediate 6 cm bituminous course. The base was 20 cm of lean concrete and the sub-base was 30 cm of mixed sandstone aggregate.

The prices per m² were calculated on the basis of the average unit prices for the constituent courses of the motorway for CRC pavement, the asphalt hard shoulder and the two types of bituminous pavement. The initial investment cost for 1 km of motorway (in two driving directions) for each different structure is shown in the following table:

TABLE 5 : INITIAL INVESTMENT COSTS PER KM MOTORWAY FOR PAVEMENTS IN CONTINUOUSLY REINFORCED CONCRETE AND ASPHALT

Case No.	Description	Price per km motorway inc. VAT (€)
1	CRC – w = 7.20 m	1,080,215.30
2	CRC – w = 8.00 m	1,097,909.27
3	CRC – w = 10.30 m	1,148,779.42
4	CRC – w = 11.05 m	1,165,367.51
5	Asphalt thickness 21 cm	833,749.00
6	Asphalt thickness 26 cm	909,458.00

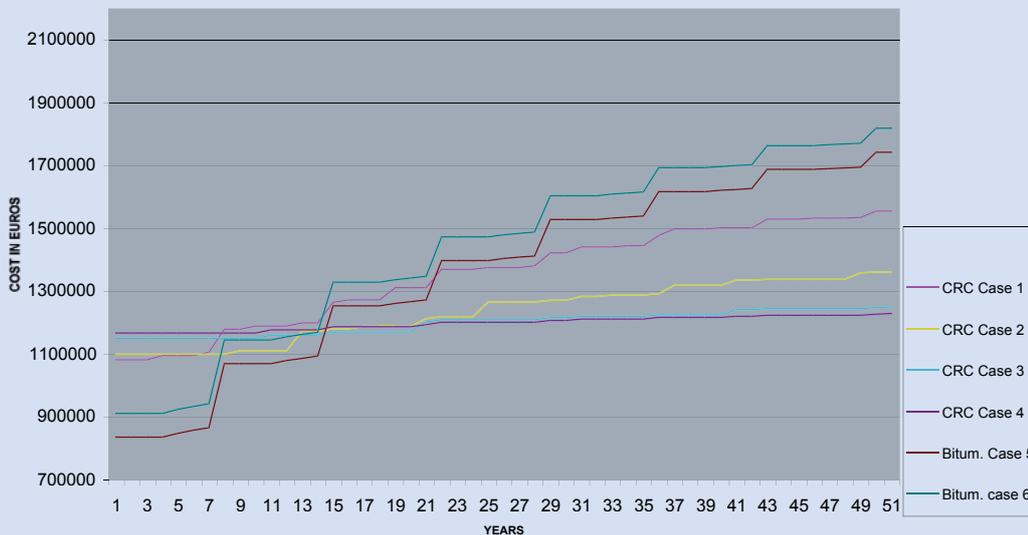


Figure 10 : Construction and maintenance costs of motorways in continuously reinforced concrete and asphalt

The construction cost of the road surface, base and sub-base of these sections of motorway therefore varied from about EUR 834,000 to about EUR 1,165,000. There is thus a significant difference. Here it should be pointed out that this study was carried out a time when oil prices were very low, a factor that works in favour of the bituminous structures.

The various maintenance scenarios were determined in mutual consultations between two motorway districts on the basis of their experience. Each scenario gives rise to a specific maintenance cost at a given frequency.

The results are presented in the chart in figure 10, which was calculated on the basis of a discount rate of 3.6%, the highest rate applicable during the period of the study.

The rising trend of the maintenance costs of flexible pavements is clearly evident from the chart. **The concrete structure starts to become more advantageous at the earliest in the 7th year and at the latest in the 14th year.** The lower initial investment cost of asphalt thus fails to outweigh the long term benefits of a road in CRC. This study thus confirms that the Belgian highway authorities were right to opt for continuously reinforced concrete for heavily trafficked motorways.

E42 "Autoroute de Wallonie"



SOCIETAL AND SOCIAL BENEFITS OF CONCRETE ROADS

In addition to the environment and the economy there is also a societal and social aspect to the sustainable development issue. In this context the well-being and safety of individuals is paramount. People do not want to be greatly delayed by road works during the construction, repair or maintenance of roads and expect the authorities to make good quality and sensible investments. Furthermore increasing importance is being attached to the quality of the road surface, particularly by those road users who wish to drive on safe and comfortable roads. Apart from the road itself, road equipment is also important, i.e. road markings, signing, lighting, safety equipment and similar.

FEWER ROADWORKS MEAN FEWER TAILBACKS

The low maintenance requirement of concrete pavements mean that fewer roadworks are needed during the lifetime of the pavement. This translates into fewer interventions and less nuisance to road users and neighbouring communities.

Moreover repairs to concrete pavement do not have to last long. The curing time of concrete is far from the 28 day period that is sometimes incorrectly suggested. A new concrete road made from conventional road concrete can be opened to traffic after 4 to 7 days of curing. Rapid hardening concrete mixes make it possible to reduce the curing time to 3 days and in certain cases to only 24 hours. Indeed this technique is currently used in several countries on busy traffic routes.

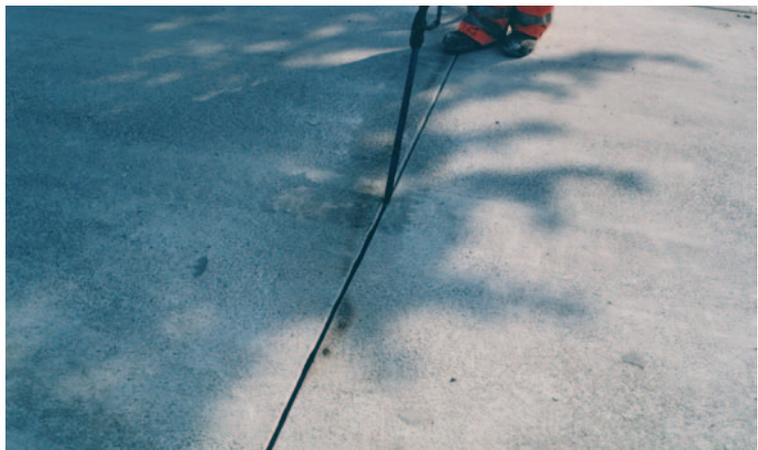
Improved surface characteristics throughout the lifetime of the road

Concrete pavements suffer from an image problem because there are many very old concrete roads still in existence which were designed long ago to very different design criteria than modern roads and were moreover laid using what are now regarded as obsolete techniques and equipment. Safety has always been a major concern but acoustic comfort and ride comfort were barely considered forty years ago. Modernized designs, new construction methods, better surface finishing and modern machines mean that it is nowadays perfectly possible to realize high quality road surfaces that do indeed satisfy the needs and objectives of road users, neighbouring communities and road managers.

RIDE COMFORT

Surface evenness, characterized by the longitudinal evenness and the megatexture, but also by rut formation and macrotexture, has a significant impact on ride comfort.

In the early period of concrete road construction non-reinforced concrete pavement was laid in the form of long slabs (8 to 15 m long). The slabs were separated by wide (25 to 50 mm) expansion joints. Such roads were perceived as offering poor ride comfort because of the width of the joints and step formation at the joints resulting from localized damage to a base that often consisted of compressible material or material susceptible to erosion.



Since the early seventies this problem has been dealt with by using designs that implement the following measures:

- shorter slabs (maximum 5 m long) make the pavement less susceptible to cracking;
- narrow bevelled and filled contraction joints limit the nuisance due to the joints to a minimum;
- dowels in the transverse joints and cement-bound bases ensure excellent load transfer and no longer allow any level differences at the joints.

Continuously reinforced concrete is often chosen for motorways and primary roads. This form of construction is characterized by the absence of transverse joints. The shrinkage of the concrete is absorbed by a pattern of fine microcracks that has no impact whatsoever on the road's evenness or ride comfort.

Smooth concrete roads can now be built thanks to:

- optimized concrete mixes offering constant workability and prepared in modern computer controlled mixing plants, which are often set up on the site itself;
- new generations of slipform pavers equipped with automatic vibrator control systems;
- properly installed guide wires for controlling the machine or wireless systems that make use of total stations;
- the use of a longitudinal levelling beam behind the finishing machine (super-smoother);
- new types of evenness measurement set up immediately behind the paver, thus allowing the correction of the construction process.

With the exception of those countries where studded tyres are allowed, concrete pavements are immune from rut formation. An important property of concrete roads is that the longitudinal and transverse evenness obtained after construction is retained for many years. Surface damage due to scaling is countered by using a good quality concrete mix (adequate cement content, low water to cement ratio and use of air entraining agents) Ravelling, i.e.

the phenomenon of the loss of aggregate from the surface is likewise not a problem for modern concrete surfaces.

SAFETY

Safety is still the most important consideration for a road surface. Ride comfort factors are equally relevant to safety. Nonetheless skid resistance, aquaplaning and visibility are even more important. Accidents can be prevented in both dry and wet weather by providing a good surface texture with sufficient surface friction.

In countries where a tradition of concrete roads exists, there is generally no problem with skid resistance. A few decades ago, transverse tining was often chosen as



surface finishing because of its excellent friction characteristics together with water drainage. These surfaces still have a good skid resistance today but are mostly very noisy. Other types of surface texture are transverse brushing or burlap drag. These have a good initial skid resistance but lower friction is observed over time, especially for the latter. The exposed aggregate surfaces seem to be the better compromise, as they do not show any significant decrease over time in skid resistance.

Since the mid-nineties numerous motorways and regional roads have been built with a fine exposed aggregate surface. Fine means that the maximum aggregate size is limited to 20 mm and that the finer aggregate (4 to 6 or 8 mm) constitute at least 20% of all the granular material (sand + aggregate). Although a decline in the initial values has been observed both the braking force and the sideways force coefficients on the wet road surface have held up over time. For the rest it may be recorded that the results vary greatly depending on the season in which the tests are carried out. Tables 6, 7 and 8 provide some of the results for the sideways force coefficient measured using the SCRIM



Transverse brushing



Motorway E40 in 1972

on Belgian roads with exposed aggregate surfaces.

Regardless of the type of surface of finish, the durability of the friction requires the use of the right aggregate on the upper surface of the pavement. They must satisfy all requirements with respect to polishability, hardness, and sensitivity to frost. An advantage of concrete pavements is that the required skid resistance is already present immediately after laying and that no fine aggregate is lost from the surface.

The texture of the pavement combined with the transverse profile has a major influence on the possible danger of aquaplaning, when the tyres of the vehicle lose all contact with the road surface. As concrete surfaces do not suffer from rut formation the likelihood of this is virtually non-existent as long as the transverse profile is given the correct superelevation.

Another cause of accidents in rainy weather is the reduced visibility due the splash and spray behind vehicles. Here non-porous concrete surfaces cannot compete with porous asphalt or with a porous topping layer in concrete. Nonetheless transverse textures or exposed aggregate surfaces with sufficient texture depth will certainly significantly limit any spray.

TABLE 6, 7, 8 : SKID RESISTANCE MEASUREMENTS WITH SCRIM ON HIGHWAYS A12, R3, A8 WITH SURFACES OF EXPOSED AGGREGATE CONCRETE

							2004 (3 years in use)	2008 (7 years in use)
A12 Brussels – Antwerp km 4,7 – km 6,5							0,59	0,51
A12 Antwerp – Brussels km 4,7 – km 6,5							0,62	0,51
	1997 (opened)	1998	1999	2000	2001	2002	2004	
R3 Charleroi Ring km 27,0 – km 24,0	0,56	0,57	0,58	0,59	0,55	0,53	0,58	
				2000 (1 st measurement)	2001	2002	2004	
E429-A8 Tournai - Brussels km 25,0 – km 30,0				0,55	0,52	0,55	0,54	

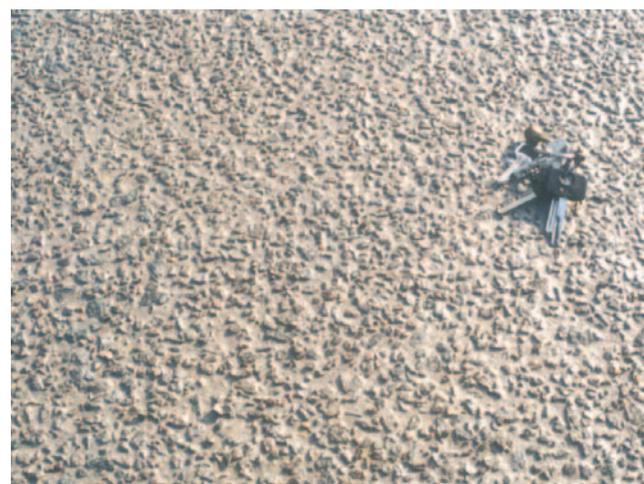
Finally a light coloured concrete surface will contribute to improving the night vision of vehicle drivers.

NOISE

Although traffic noise might be regarded as part of ride comfort, it is primarily of concern to residents of neighbouring communities, particularly in urban environments where the population density is high close to main traffic routes. The limitation of rolling noise at the source, i.e. at the road surface has

been shown by various studies to be the most cost effective solution. In recent years numerous noise-abating wearing courses have been developed and research and testing continues to go ahead.

Although it is true that the reductions available to the new porous surfaces or thin bituminous overlays cannot be obtained with conventional concrete pavements, the fine exposed aggregate techniques constitute a good alternative for a low noise yet safe road surface.



Fine exposed aggregate surface

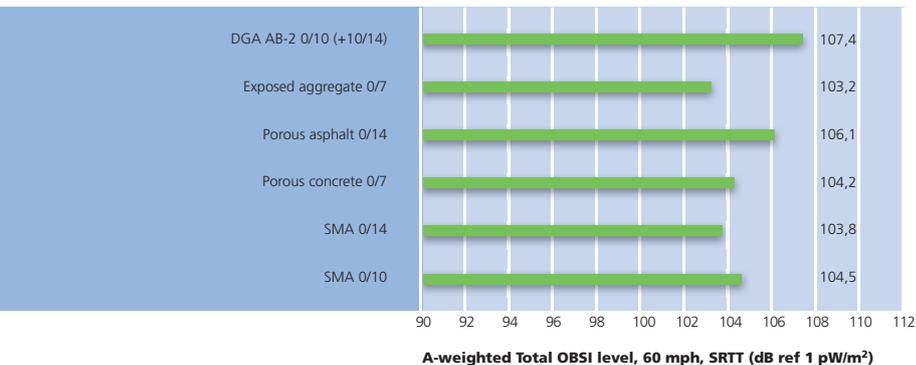


The rolling noise levels are comparable to those obtained for stone mastic asphalt and are achieved not just immediately after construction but throughout the entire lifetime of the pavement. Other effective techniques include creating fine longitudinal grooves (tining) and diamond grinding. Regardless of the type of noise-reducing surface is chosen it is firmly recommended not to make any concessions to safety.

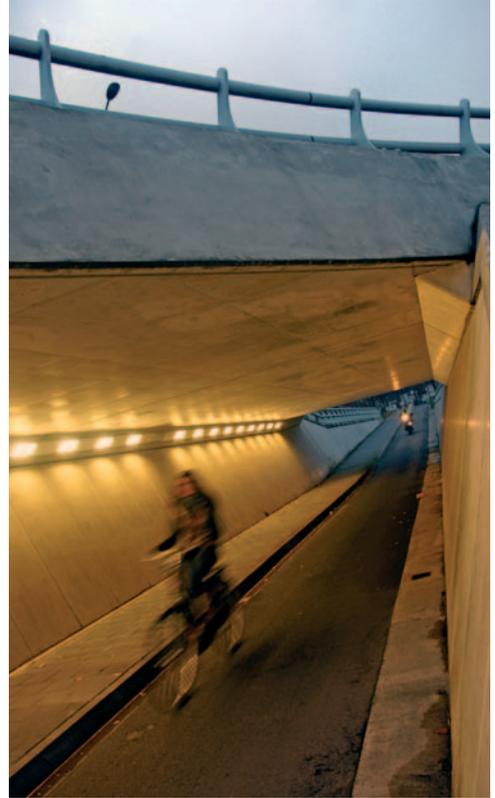
The best results are obtained by using twin layer concrete, in which the upper layer contains only fine aggregate, for example with a maximum aggregate size of 6 to 8 mm.

An experimental site on two-lift, continuously reinforced concrete (CRC) concerned low-noise pavement test sections in Herne, laid in 1996. An 18 cm CRC lower course was given different top lifts of fine exposed aggregate concrete, porous concrete, split mastic asphalt and porous asphalt. These test sections were subjected to various measurements and assessments. The general conclusion after 12 years of use is that a upper course in fine-grained, exposed aggregate concrete (0/7) performed best in the long term as regards noise production, while also being the most durable.

Figure 11 : Herne - OBSI (CPX) rolling noise on different road surfaces – Results by U.S. team – October 2007



Herne : low noise concrete



OTHER SUSTAINABLE APPLICATIONS OF CEMENT AND CONCRETE

A WIDE RANGE OF SOLUTIONS IN FAVOUR OF MOBILITY

The use of concrete is essential in numerous infrastructure projects for the achievement of sustainable mobility in all its forms.

Special applications in road constructions include the provision of roundabouts in plain concrete or continuously reinforced concrete.

With respect to road equipment concrete safety barriers, whether pre-cast or constructed in situ, represent a sound,

lasting and safe solution. These safety barriers comply with European standards (EN 1317), which specify the required performance on the basis of real-life tests with cars, buses and trucks.

In the urban environment, the visual appearance of through roads, streets and squares is an important consideration. Here use can be made of a wide range of concrete paving blocks or coloured exposed aggregate.

Concrete sidewalks and cycling paths meet the needs of the vulnerable road user.



Furthermore increasing use is being made of concrete as a sustainable solution for the infrastructure used by public transport systems, whether buses, trams or trains.

Concrete rural roads serve country communities well. Their rigidity meant that in the past they could be laid without any foundation. Even after many years of use and no maintenance whatsoever they continue to meet the needs of the increasingly heavy vehicles used in modern agriculture.



Finally there are the important links provided by tunnels and over viaducts, not to mention canals and waterways, airport runways and aprons, and port infrastructure.

FIRE SAFETY IN TUNNELS

The benefits of concrete pavement come to the fore when selecting pavement for use in road tunnels. Long service life, minimal maintenance and repair requirements, a safe road surface that does not suffer rutting, and the light colour of the surface, which ensures improved visibility for the driver and reduces the lighting requirement. A major additional advantage of concrete is that it is fireproof and releases no toxic gases when heated. A concrete pavement does not contribute to the calorific capacity available to the fire and therefore does not constitute an extra hazard to the evacuation of people or to emergency services. A choice for concrete therefore fits in well with a policy of risk prevention and limiting the consequences of fire in tunnels.



SOIL TREATMENT TECHNIQUES, IN SITU RECYCLING AND IMMOBILIZATION OF CONTAMINATED SOILS

The in situ treatment of soil consists of mixing the soil with a binder (cement, lime, or a hydraulic road construction binder) on the spot with the object of improving or stabilizing a layer of soil. The word stabilization is used when the layer thus created can withstand water and frost. Possible applications are sub-grades, sub-bases and even the road bases of less heavily loaded pavements.

The in situ pavement recycling technique consists of milling the existing aggregate base, which may or may not be covered with an asphalt pavement, and mixing it on site with cement and water if required. Where necessary granular material may be added in order to obtain a grain size distribution that ensure optimal binding with the cement. The result is a cement-bound foundation with a very good bearing capacity and excellent resistance to erosion due to water or frost. Covering with one or two layers of asphalt results in a road that has been renovated over its entire depth with virtually no material being brought in or removed. In other words this is an excellent technique for renovating secondary roads.

A third major application is the immobilization of wastes by bonding them with cement. The contamination of soils and ground water by heavy metals is one of

the great dangers to the environment and public health and often it is not possible to remove and treat polluted soils and materials for both practical and financial reasons.

The benefits of these different techniques can be summarized as follows:

- speed of execution,
- reduction or avoidance of disposal costs,
- elimination of the need for new granular materials,
- reduction in the demand for new aggregate and sand,
- reduction of local traffic around the site,
- an economic solution for the bearing layer in the structure,
- a way of dealing with contaminated soils.

PERMEABLE PAVEMENTS

Permeable pavements, usually made of permeable paving blocks, constitute an exceptional environmentally attractive application. They allow precipitation to pass through the surface into the structure, where it is temporarily contained and subsequently slowly released, either into the permeable soil or into nearby infiltration zone or drainage system. Permeable foundations combined with permeable pavement can thus help to avoid flooding by reducing the amount of water running into the drains. Moreover they can even improve the quality of the ground water by retaining polluting elements into the road base.



Soil treatment with cement



Parking pavement made with permeable paving blocks

Permeable pavements can be made either using porous pavers or paving blocks with enlarged joints or with drain holes. Lean draining concrete offers an ideal combination of stability and permeability for the material of the base.

AIR-PURIFYING CONCRETE PAVEMENT

Air pollution is a steadily increasing problem in densely populated areas and towns. The most significant pollutants due to traffic include fine particulate matter, volatile organic compounds (VOCs) and nitrous oxides. When the latter are present concurrently with VOCs they lead to ozone formation and thus amplify the impact of the fine particulate matter. It is thus of great importance to limit traffic emissions as much as possible. Of course this is achieved primarily by limiting the traffic emissions themselves, nonetheless the road and the immediate vicinity of the road can also make a contribution.

Indeed it is possible to achieve an air-purifying effect by using TiO_2 (titanium dioxide) on the pavement surface. When exposed to ultra-violet light, and increasingly visible light as well, titanium dioxide acts as a catalyst, resulting in the conversion of harmful compounds such as nitrogen monoxide and nitrogen dioxide (or NO_x) into nitrates (NO_3). These nitrates settle on the surface and are washed away by rainfall. This counters the action of the naturally arising vicious cycle and the NO_x , which can lead to ozone formation, acid rain and the formation of fine particulate matter, is captured from the air as quickly as possible. Such photocatalytic materials can also capture harmful organic compounds from the air by causing them to dissociate. The TiO_2 is added separately to the concrete mix, or alternatively specially formulated cements can be used that contain nano particles of TiO_2 .

Various research projects have demonstrated the photocatalytic effect in the laboratory. In these tests the conversion of NO_x as a result of a single contact between the air and the photocatalytic material was determined. Reductions of 30 to 95% were measured. Efficiency in real life applications will of course not be entirely dependent on the efficiency of the photocatalytic material itself, but also on the contact (quantity of air and contact time) between the air and the surface, the light intensity, relative humidity, and the pollution present in the air.

One of the first occasions on which this technology was applied to road construction was in 2004-2005, when the side roads flanking Antwerp's "Leien" – a tree-lined urban avenue forming a semi-circle around Antwerp's historic centre - were repaved with 10,000 m^2 of concrete paving stones with titanium dioxide in the upper layer of the stones. The durability of the photocatalytic action of the paving stones has been established in the laboratory.

Other applications of interest include the use of this photocatalytic material in the surface layer of a twin layer concrete pavement or in thin concrete overlays, such as tried at the Porte de Vanves in Paris. Two 300 m sections of a busy street used by 13,000 vehicles a day were repaved as follows:

- one section with conventional concrete paving;
- one section with an experimental thin concrete overlay using cement with photocatalytic action.

Measurements of the air quality and the surface water run-off were carried out over one year. It was found that NO_x contamination was cut by about 20% in unfavourable weather conditions.

Research also revealed that the photocatalytic reaction took place not only in UV light but also in ordinary visible light, opening the prospect of lining tunnels with air-cleaning tiles combined with conventional lighting.



Porous pavers



Streets flanking Antwerp's "Leien"



CONCLUSION

The majority of decision-makers are convinced that in the long term a concrete road offers a great many benefits and that it is in economic terms the most favourable solution when the whole life maintenance costs are taken into account. This is more true when the user costs are taken into account, if only because concrete requires minimal maintenance and that in consequence no disruption to road users is created.

Nowadays, however, it has become just as important to show that concrete roads are beneficial to the environment and that they can provide socially acceptable solutions with respect to the question of mobility.

The many strengths of concrete pavements have been illustrated from the perspective of the three mainstays of sustainable development, namely environment, economy, and societal and social importance. Performance in each of these three fields must be evaluated on the basis of the entire life cycle of the pavement. From this it is clear that even now these pavements are perfectly compatible with a sustainable construction philosophy, although there is still room for improvement in a number of areas. Research and study is therefore ongoing and form part of a process of technical development that is closely linked to the expectations of modern society.

In view of the great relevance of the service life to sustainability it is essential that the performance of concrete as a material and its application in road construction are not compromised by measures that hold out the prospect of apparent short term gains in respect of the environment, cost and society.

Choosing a concrete road demands the same courage, careful thinking through, and long term vision as the choice for sustainable construction.

Choosing a concrete road IS choosing a sustainable solution.



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Published by :

EUPAVE
European Concrete
Paving Association

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Agentschap Wegen en Verkeer,
photo-daylight.com, A. Nullens (cover)
Cement&BetonCentrum – W. Kramer
vwb foto
P. de Koning
R.W.S. – J. van Houdt

September 2009

