



High and ultra-High performance concrete in pavement : tools for the road eternity

François de Larrard, Thierry Sedran

► To cite this version:

François de Larrard, Thierry Sedran. High and ultra-High performance concrete in pavement : tools for the road eternity. 9th international symposium on high performance concrete : design, verification and utilization, Aug 2011, France. 18p. hal-00877025

HAL Id: hal-00877025

<https://hal.science/hal-00877025>

Submitted on 25 Oct 2013

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

HIGH AND ULTRA-HIGH PERFORMANCE CONCRETE IN PAVEMENT: TOOLS FOR THE ROAD ETERNITY?

François de Larrard, Thierry Sedran

LUNAM Université,
IFSTTAR Centre de Nantes (formerly LCPC),
France

Abstract

The paper presents a review of recent works dealing with application of high-performance (HPC) or ultra-high-performance concrete (UHPC) in pavement technology. It is first shown that these materials exhibit a number of attractive properties for this type of applications, which must be balanced by difficulties encountered on site. Then, the state-of-the-art quotes a number of attempts to use HPC/UHPC in real projects: fast-track repairs, thinner conventional pavements or continuously-reinforced thin concrete slab with a bi-dimensional reinforcement. The ultimate application lies in the development of a 1-cm thick surface-dressing of ultra-high-performance, steel-fibre mortar where aggregate particles are embedded. This innovative solution, called High-Performance Cementitious Material (HPCM) is currently developed within an international program supported by OECD/ITF. Real test sections are being built in several countries, and shall be monitored in the coming years. It is expected that a long-life (30, 40 years or more) can be obtained with this new wearing course, while current asphalt materials must be replaced every 7 to 15 years, depending on the climate and supported traffic.

1 INTRODUCTION

In many countries, cement concrete is a popular material to build high-traffic roads. As a matter of fact, this material exhibits some unique properties as strength, stiffness, and durability under all climates. It can suffer extreme temperatures without losing its resistance to traffic loads, which is a great advantage under continental climates. This is why many critical road sections, as interurban or peri-urban highways are made up with concrete. In terms of structural concept, the top layer may be divided into successive slabs, sometimes with dowels at the joints, or can be continuous, with longitudinal reinforcement.

Low water-binder, high-performance concrete has been disseminated for about 30 years in most construction sectors, as bridges, off-shore constructions, or prefabrication industry because of its superior mechanical and chemical resistance. Strangely, there are still little reported applications in the pavement area. Why? Should this situation evolve in the future? In the present paper, the material properties are first reviewed with regard to pavement technology. Then, a survey of the recent international literature is carried out, which shows a growing interest for HPC in horizontal infrastructures. Finally, some prospects are provided about what could be the optimal use of HPC/UHPC pavement, for the sake of very long-life and economical roads.

2. POSITIVE AND NEGATIVE ASPECTS OF HPC/UHPC FOR PAVEMENT APPLICATIONS

High-Performance and Ultra-High-Performance Concrete have been deeply studied for the early '80 [1-2]. Their properties, as compared to those of normal-strength concrete (NSC), are well known. Some of them should help in designing thinner and/or more durable pavement. Others can lead to difficulties in the design and/or practical implementation of this material in the pavement area.

2.1 What makes these materials attractive for building roads?

The concrete hardening time has long been considered as a weakness as compared to asphalt. Indeed, while an asphalt pavement can be trafficked as soon as the asphalt temperature has fallen down to a value close to the ambient one, it is necessary to wait for several days, sometimes several weeks, before to ride a concrete pavement. However, a *high early strength* (e.g. at one day) is a feature of all HPC/UHPCs. Therefore the use of HPC in pavement can lead to rapid works with a minimal traffic interruption.

The next interesting range of properties deals with the *tensile and flexural strength of the mature concrete*. Even if these properties do not grow as quickly as compressive strength when the water-binder ratio decreases, the tensile strength can be easily doubled when going from normal to high-strength concrete. Thus the thickness of concrete slabs can be reduced,

although the reduction is limited by the increase in E-modulus, which creates a higher tensile stress for a given deflection.

As compared to asphalt, even ordinary concrete shows a superior *abrasion resistance*. This property continues to grow in the HPC/UHPC domain (see Fig. 1). This feature can be profitable to very long life pavement, or when the traffic includes vehicles equipped with studded tyres.

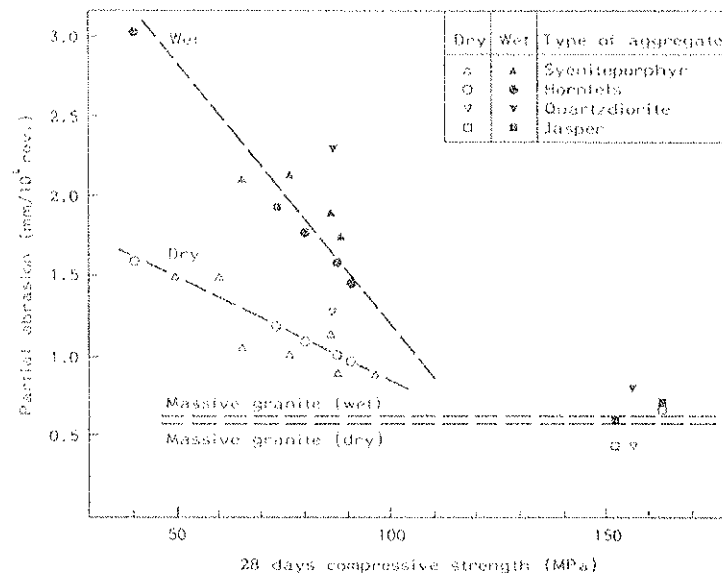


Figure 1. Effect of compressive strength on the abrasion resistance [3].

Although concrete slabs are generally designed on the basis of fatigue calculations, the contact conditions with the base course play a decisive role in the occurrence of cracking in the long run. These contact conditions are controlled by the concrete shrinkage, which provokes the well-known *curling* phenomenon. With a HPC/UHPC, the *drying shrinkage* is generally reduced, as compared to ordinary concrete. Everything being equal, a reduction of drying-induced curvature is favourable to a longer life.

Regarding the material durability, it is well known that most concrete properties evolve in a positive direction when the water-binder of the material is reduced. For instance the *carbonation depth* becomes insignificant, the *electrical resistivity* increases and the *chloride permeability* decreases. This is of course favourable with regard to the risk of steel corrosion in Continuously Reinforced Concrete Pavement (CRCP). Also, the *resistance to freeze-and-thaw* is enhanced, to the point that entrained air may become superfluous.

2.2 Difficulties in the practical use of HPC/ FRUHPC in pavement

In theory, HPC/UHPCs are extremely suitable to build durable and thin roads. However, the practical implementation on site reveals a number of difficulties.

At the production state, the preparation of these 'high-tech concretes' requires *more constituents* than ordinary mixes, as superplasticizer, silica fume or fibres. The local aggregate sometimes has to be substituted by another one of better quality. Therefore, new silos and production equipments may be needed. Also HPC/UHPCs require systematically longer mixing duration than ordinary concretes [4]. This phenomenon substantially impairs the production rate of a concrete plant. If the choice of HPC is not accompanied with a reduction of pavement thickness, there may be a need for supplementary production facilities, with a negative cost effect for the overall project.

The use of superplasticizer used as a high-range water reducer leads to mixtures which display a *higher plastic viscosity* and *more thixotropy*, for a given slump. Also, this slump becomes much more sensitive to changes in the water content. As a result, most industrial HPCs are produced with high slump values. On the other hand, usual pavement concretes display quite stiff consistencies, owing to the laying technique (slipform machines, vibrating screeds...). The same tools applied to a fluid HPC sometimes lead to difficulties in controlling the surface evenness (see Fig. 2).

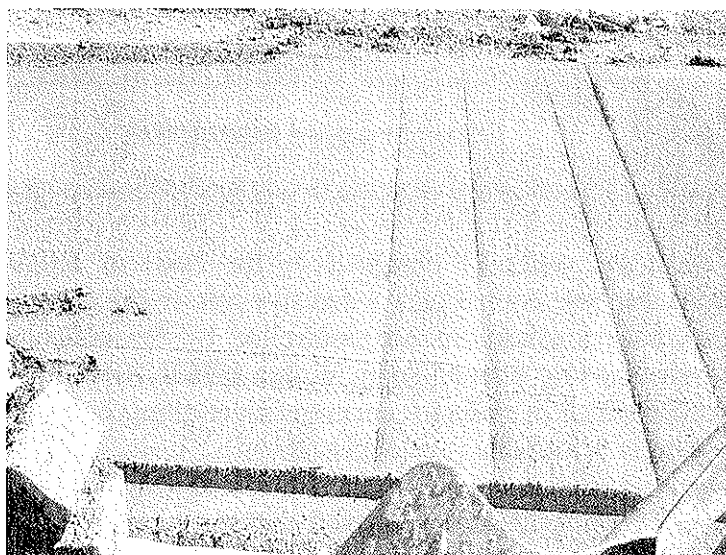


Figure 2. Effect of excessive concrete fluidity and irregular machine speed on the evenness of a HPC thin slab [5].

Another well-known peculiarity of low water-binder ratio concretes is their high sensitivity to *plastic shrinkage*. While a NSC bleeds after casting, which lets a certain delay to cure the concrete surface, HPC does not exhibit any bleeding. Therefore, if an efficient curing is not

applied within some tenths of minutes, a wide cracking pattern appears which is very difficult to repair.

Due to the retarding effect of superplasticizers, the dormant period of HPC is generally longer than the one of normal-strength mixtures. However, after setting the hardening of concrete develops quite rapidly. When a surface treatment is scheduled, as the one consisting in brushing or cleaning the superficial cement layer to increase the surface macrotexture ('exposed aggregate' concrete), the cleaning window is both quite narrow, and strongly depends on atmospheric conditions. This may create a difficulty in obtaining a consistent texture depth, important property to control the pavement skid-resistance and the rolling noise generation.

Autogenous shrinkage is another peculiarity of HPC. This shrinkage develops at early age, and its effects are superimposed to those of thermal shrinkage, which is also higher in HPC owing to their high binder dosage. As a result, a HPC concrete slab will tend to shrink quite rapidly in the first day after laying. In CRCP technology, this phenomenon is problematic regarding the management of end-of-day joints. Measures must be taken to avoid the horizontal displacement of these joints.

A last trap lies in the type of crack propagation in HPC. While tensile cracks generally propagate at the aggregate-matrix interface in NSC, they tend to break aggregate particles in HPC. The *fracture surfaces are then smoother* and the aggregate interlock phenomenon, which is searched in jointed, undowelled concrete slab pavement, does not play its role. The transfer coefficients used in the design of these pavements certainly needs adaptation when HPC is used instead of ordinary pavement concrete.

3. RECENT DEVELOPMENTS IN VARIOUS CONTINENTS: A REVIEW

3.1 Developments in America

Balbo [6] emphasized the choice of concrete strength with regard to application in Ultra-Thin White Topping (UWT), a technique where a 50-100 mm concrete slab is cast over an existing asphalt pavement. According to a finite-elements design model, the prevention of corner cracking leads to the requirement of flexural strength that may attain 8 or 9 MPa, when the thickness is limited to 100 mm and the cumulated traffic is in the high range. A collection of projects built in the USA in the early '90 show that a high early-strength (as 20 MPa at 24 d. or more) is frequently specified in UTW, for fast-track purpose. This may lead to mixtures with a water-cement ratio less than 0.35, which can be considered as HPC.

3.2 Developments in South Africa

Burger et al. [7] reported on the use of UHPC in Ultra-Thin Continuously Reinforced Concrete Pavement (UTCRCRCP). A HPC mixture containing cement, fly ash, silica fume, polypropylene and steel fibres was developed, with a compressive strength at 28 d. of 90 to

120 MPa, and a flexural strength higher than 10 MPa. The 50-mm thick layer was reinforced by a 50x100 mm, 5.6 mm dia. welded wire mesh, and placed over a 30 mm asphalt layer. The cementitious wearing course was also subject to a specification of energy absorption, through a circular panel test. The paper gives a number of interesting, practical details dealing with site implementation. The constituents were pre-bagged, with a premix of cementitious materials and polypropylene fibres, and the use of dry aggregate fractions. Emphasis is put on the choice and specification of the sand fraction. The 150-200 mm slump mixture was produced with two 0.33 m³ site mixers, with a production rate of 10-20 m³ per day. Then the placement was carried out manually, with the help of rotating, oscillating roller screeds for compaction and bull floats for finishing. Finally, the fresh concrete surface was tined grooved with a rake, at an angle of 60° with the road axis. Obtained mean texture depth (sandpatch method) ranged from 1 to 2 mm. Two applications of wax-based curing compound terminated the construction process. Details are also provided about lateral form of the slab, fixing of the reinforcement over the base course and end-of-day joint construction.

Perie et al. [8] provided complementary information about the same technology. They mentioned a trial program where 8 short test sections were submitted to fatigue testing through a Heavy Vehicle Simulator (HVS). Then, three scale-1 trial sections were built, the performance of which is reported. A crawler lane was built on the N3 road, with site-mixed HPC. An upward curling was encountered at a free edge thickening of the section, the concrete part having lifted from the asphalt base on a length of several tenths of centimetres. On the N12 fast lane section, some parts of the UTCRCP exhibited a clustered, transverse cracking, and a failure of longitudinal steel reinforcement was observed at a joint location. The joint was opened by 4 mm, and the adjacent slab was curled. The third trial section, on N3, was a screener lane. Here, two major defects were noted: a blow-up (see Fig. 3), due to built-in compression in the thin slab, and some punch-outs appeared in heavily cracked zones. Although these pavements displayed quite serious degradations, the authors seem to believe in the technology, provided that all procedures are more strictly observed, including precision in batching concrete. However, the design of this UTCRCP needs apparently to be reconsidered.

3.3 Developments in Asia

Hachiya et al. [9] have investigated the use of HPC in airport pavement, with the view of reducing slab thickness, with a minimal change in the industrial process. A comprehensive mix-design study was carried out, aiming at developing a suitable concrete with a higher flexural strength. By increasing the cement content from 340 to 450 kg/m³, the water-cement ratio went down from 0.40 to 0.30; the design flexural strength increased from 5.0 to 6.5 MPa, which allowed a reduction of slab thickness from 420 to 340 mm. The laying of concrete could be simulated in laboratory with a mini-finisher. Also, atmospheric conditions (wind, sun) were reproduced to avoid the risk of plastic shrinkage cracking. Finally, experimental slabs were built and monitored. It was concluded that thinner, HPC airport slabs are feasible with conventional methods of production and placement. However, economical aspects are not documented in this paper. It seems that the use of HPC according to this approach leads to reduce the aggregate consumption per unit surface, but not the cement one.



Figure 3. Blow-up in UTCRCRP [8].

Tsai et al. [10] proposed to replace asphalt pavement by jointed reinforced HPC pavement for the exclusive bus lanes of Taipei (Taiwan), in order to avoid rutting and other type of degradation. In this special pavement design, the slabs were reinforced with two layers of wire mesh, and cast in two layers ('fresh on fresh'), with 275 mm of plain HPC, and a 75 mm top layer of steel fibre HPC. The slab corners were protected with steel angles, to avoid traffic-induced spalling. Two bus stops were reconstructed with this technique. The sites had to be carried out within three days. For this reason, a compressive strength at 3 days of 35 MPa was specified. An optimised mixture with a water/binder ratio of 0.29 was developed, and exhibited a compressive and flexural strength at 28 days of 60-80 and 8-10 MPa, respectively. Superior durability properties such as electrical resistivity and chloride penetration were measured. According to the authors, durability and volume stability provided by HPC, together with a high early strength, were the main arguments justifying the use of this kind of concrete for this application. After one year, the behaviour of the two bus stops was considered satisfactory.

3.4 Developments in Northern Europe

Alte-Teigeler [11] reported about the use of HPC for quick renewal of isolated, damaged slabs in highways or airfields. A premix of dry sand, cement and (probably) admixtures was provided on site, and mixed with aggregate and water in a mobile mixing plant. The special mixture developed very early strength, with values of 20, 50 and 80 MPa at 4 hours, 24 hours and 28 days, respectively. The mixture displays a workability window of about 40 min., and the total renewal operation took 5 to 7 hours. More than 1,000 slabs had been treated in Germany with this technology, when this paper was written.

Riffel & Hanke [12] presented similar applications of high-early strength concrete, for the quick repair of a bus lane and an airfield pavement. These peculiar properties were obtained

through the use of a special, finely ground cement. With a Blaine specific surface of about $800 \text{ cm}^2/\text{g}$, a cement strength of 1.8 MPa at 5 hours was obtained. A HPC was designed using 450 kg/m^3 of this cement, with a superplasticizer, achieving a water-cement ratio of 0.35/0.38, and a workability window of 60 minutes, which allowed the production in a ready-mix concrete plant. While the cube compressive strength at 28 days reached 91.5 MPa, a value of 68 MPa was already obtained after 4 hours, according to a non-destructive site test. The airport traffic could be released after only 4 hours of interruption.

Other sophisticated mixtures were developed and used by Buitelaar et al. [13] for special horizontal concrete works, namely bridge deck reinforcement or rehabilitation. The HPC/UHPCs contained silica fume, acrylic and steel fibres, and exhibited high compressive (120/180 MPa) and flexural strength. They were used in combination with heavy welded wire mesh reinforcement, sometimes in several layers. In a number of projects, the material was placed with a slipform machine, and was subject of later, supplementary compaction. Although these developments are out of the pavement area, they have the interest to show that casting ultra-high performance material with a traditional concrete pavement machine is feasible.

An attempt to transfer the previous concepts to highly trafficked pavement was undergone by Schmidt et al. [14], who investigated the use of steel fibre HPC and UHPC in UTCRCP. A deep mix-design study was carried out, and two mixtures were produced. The HPC contained 400 kg/m^3 of cement, 80 kg of silica fume, a basalt aggregate having a maximum size of 8 mm, with a water-binder ratio of 0.30. Obtained cubic compressive and flexural strength at 28 days were 133 and 14 MPa, respectively. In the UHPC, the cement dosage was increased up to 725 kg/m^3 , the silica-fume content was 100 kg/m^3 , a quartz filler in several fractions was added, and the water-binder ratio was about 0.22. The cubic compressive strength reached 175 MPa, while the increase in flexural strength was minor (15 MPa). Both mixtures had a DIN table spread value of 35 cm, which is a typical target value for slipformed pavement concrete. All durability measurements (porosity, resistance to freeze/thaw, carbonation) displayed very good results. Two models (in HPC and UHPC, respectively) of reinforced, thin slabs were built over a concrete base course, and subject to a series of punching fatigue loadings. The behaviour was very encouraging, with no visible distress after 1 million of cycles. However, since the base layer was divided in individual slabs, it was found that a lack of direct contact could appear between the two layers. Therefore, a decision was taken to ensure a mechanical connection between UTCRCP and its base course with a system of steel bolts. This provision was observed on a 250-m trial section, built over a German highway truck parking lane. A HPC slab with a thickness of 6 to 8 cm was built, anchored with bolts on the surrounding concrete base course. The pavement was cast with a slipform machine, then the material was cured and brushed (exposed aggregate technology). The obtained mean texture depth was around 0.7/0.9 mm. No data are given in the paper about the performance of this lane, built in 2008, but a monitoring was set after construction.

3.5 Developments in Southern Europe

Diaz Minguela [15] reported about the repairs carried out on a 43 km-long CRCP section in the north of Spain. Fast-track concretes were needed either to rebuild broken slabs or local punch-outs. A series of high-early strength mixtures were cast, in order to re-open traffic after 24-30 hours, 6 or even 3 hours, respectively, with a minimum compressive strength of 15 MPa. Low water-binder cement concretes were developed, (probably) with chemical accelerators. In the last case, the site-mixed concrete exhibited a cylinder compressive strength of 14 MPa at 2 hours.

The High-Performance Carpet

In France, the HPC carpet is developed since the end of the '90 par de Larrard et al. [16-19]. This innovative concept resembles those of Buitelaar [13], Perie et al. [8] or Schmidt et al. [14], although it has been proposed previously and independently. Here the idea is to separate the functions of the various layers. The pavement structure is made up with one or two layers of medium-to-low quality cementitious materials, as cement-treated materials, roller-compacted concrete or lean vibrated concrete, with possible incorporation of local or recycled aggregates. Then, a thin layer of small aggregate, 80 MPa HPC is used as a wearing course, matching all requirements in terms of skid resistance, evenness, low noise generation and protection of the base course (see Fig. 4). The HPC layer is laid over a geotextile and a polyethylene sheet, to drain the water coming through the top layer cracks.

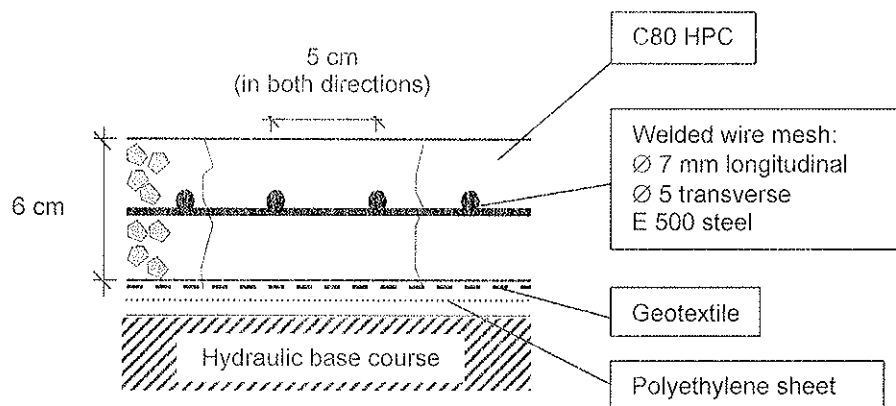


Figure 4. The HPC carpet [18].

There are two important differences between the HPC carpet and the previously presented concepts: first, the wearing course is not bonded to the base course, in order to avoid reflective cracking from the foundation; second, a thin cracking is allowed in both transverse and longitudinal directions, induced by restrained shrinkage and traffic. It is thought that, thanks to the wire mesh and the water tightness of the multilayer system, there shall be no erosion in the base course, so that, once cracked after some weeks of service, the top concrete layer shall become flexible and shall not degrade, just as a coat of mail. In particular, no punch-out should appear. Among other aspects, the design of HPC carpet deals with the

prevention of buckling by hot weather. HPC carpet road sections should begin and end on a transverse beam, anchored in the hydraulic base course. A *minimal* level of shrinkage is specified for the concrete, so that the HPC slab is constantly in tension owing to the restrained free deformation. Finally, the thickness is not determined through fatigue calculations, but from the prevention of steel corrosion, which requires a minimum concrete cover of 20 mm in presence of chloride ions.

As far as sustainability is concerned, the HPC carpet is an attractive solution since it leads to save scarce resource. The gains per unit surface of pavement are about 30 % on the cement and steel, and 70 % on high quality aggregates, as compared to conventional CRCP [18]. The use of exposed aggregate, with a 6 mm maximum size of particles provides a very good skid resistance, together with a limited noise generation (see Fig. 5). The thinness of the top layer favours a good evenness, and the intrinsic qualities of HPC should lead to a high durability (several tenths of years without maintenance). Finally, the high early strength of HPC can lead to resume the traffic 24 hours or less after concrete laying.

After a scale-1 fatigue test carried out at LCPC in 2001/2002, a first experimental test section was built in 2003 near Lyon, France [19]. The feasibility was demonstrated, and a number of practical issues were identified, as the difficulty of controlling evenness with a slipformed fluid mixture. In 2006/2007, the concept development went ahead with two site trials, followed by a 300 m-long test section built on a trafficked highway near St Quentin, France. Most of the previously identified problems were fixed. However, due to a change in the slipform machine design, voids under the wire mesh were created in the pavement, so that punch-outs appeared under traffic. More recently, the fresh concrete flow in the slipform machine was simulated, which allowed to understand the origin of observed defects [5]. New projects are now being launched to finalise the HPC carpet development. It is thought that this material could be a sound solution to cover high-traffic roads built over hydraulic base courses, in the future context of post-oil pavement.



Figure 5. Aspect of the HPC carpet. Note the thin, closely-spaced transverse cracking.

3.6 Summary

After this review of the use of HPC in pavement, it appears that three main options are encountered:

- in the first one, the design of concrete pavement is unchanged (plain concrete slabs with or without dowels). The high early strength of HPC is the only specific property which is used for quick traffic resuming after completion of the maintenance works;
- in the second one, the thickness of the concrete layer is slightly reduced, by specifying a higher flexural strength at 28 days. With regard to sustainability, there is a saving in aggregate consumption, but the gain in terms of cement expense per unit surface is not significant;
- in the third one, a new design is adopted, that could be called "Bi-dimensional thin CRCP". The top layer is reinforced in both longitudinal and transverse directions (with a welded wire mesh), which means that the risk of cracking is anticipated, and the thickness is dramatically reduced (to 50-70 mm). Steel fibres are sometimes added to the mix.

In this last case, which makes a better use of the unique HPC properties, there are again three options concerning the base course:

- in the first option, the thin HPC slab is stuck over an asphalt layer. Here, the problem may happen at the joints level: the concrete slab is subject to free movements that cannot be overcome by the soft base course;
- in the second option, the HPC top layer is cast on a concrete layer and fastened with vertical bolts. This option may be quite labour-consuming. Moreover, in case of cracking of the base course, there is a risk of propagation of the cracks in the top layer;
- in the third option, the HPC layer is cast over an hydraulic base course, with a sliding interface. The HPC slab is tensioned between two transverse beams, anchored in the concrete base. In such a case, the risks of joints movements and reflexive cracking are overcome. In the author's opinion, it is the best solution. However, the long term durability of such an innovative design under an aggressive traffic, typical of an interurban highway, remains to be demonstrated.

4. HIGH-PERFORMANCE CEMENTITIOUS MATERIAL (HPCM): A NEW MATERIAL DEVELOPED WITHIN AN INTERNATIONAL, COLLABORATIVE EFFORT

In all previously mentioned applications, the thickness of the top concrete layer is at least 50 mm. This layer participates to the pavement structural bearing capacity. In this section, a new, radical concept is presented, where the best possible cementitious material is used in minimal quantity. Here, the developed technology is closer to the one of *surface-dressing*, that is an extremely thin, sticking layer of mortar in which a single layer of aggregate particles is embedded.

4.1 LLP phase 1 and 2

JTRC (Joint Transport Research Committee) is a common institution of OECD (Organisation for Economical Cooperation and Development) and ECMT (European Council of Transport Ministries), the latter recently transformed into ITF (International Transport Forum). In this framework, about twenty public road research laboratories from Europe, America and Oceania have worked together since 2002 in the Long-Life Pavement working group. The common objective was to investigate the feasibility and development of road wearing courses lasting 30 or 40 years. In many developed countries, the traffic is supported by asphalt wearing courses, which are replaced every 7 to 15 years, depending on traffic and climate aggressiveness. However, on the most trafficked sections of the road network, such as peri-urban boulevards or main highways, maintenance works are strongly disruptive for the road users and for the neighbourhood. In such a context road owners would accept increased costs for these top layers provided that a much longer life would be guaranteed. The works of LLP phase 1 shown that a threefold cost could be envisaged depending on traffic and updating rate [20]. Based on this economical projection, the phase 2 of the project was carried out from 2005 to 2007 [21, 22].

Two technological solutions were examined, namely the epoxy asphalt and the HPCM (High Performance Cementitious Material). The latter is an innovative solution, consisting of a 8-mm thick steel fibre ultra-high performance mortar, in which a single layer of strong, polishing resistant aggregates is embedded (see Fig. 6-7).

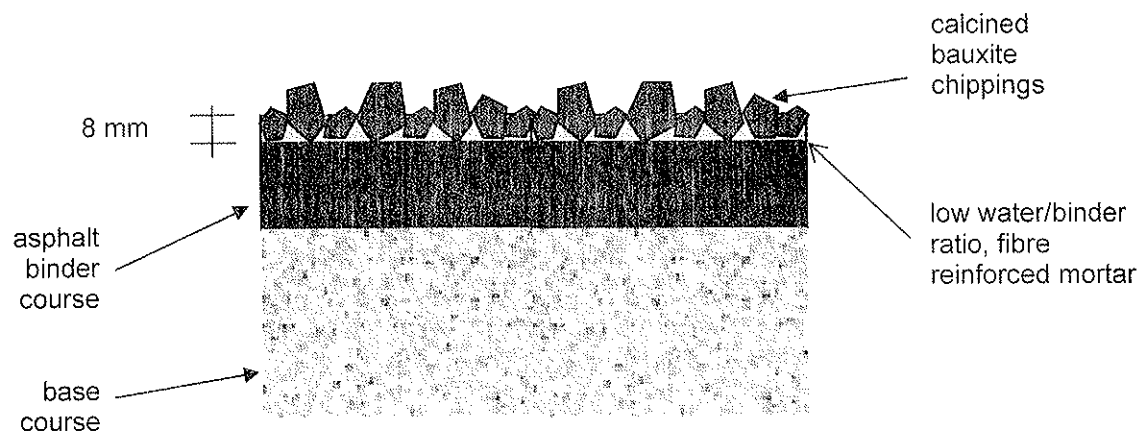


Figure 6. Principle of the HPCM solution

The mortar contains about 1000 kg/m^3 of cement, 200 kg/m^3 of silica fume, a fine siliceous sand with a 1-mm maximum size, and a 3 % steel fibre reinforcement (in volume). With a water-cement ratio near 0.20, this ultra high-performance steel-fibre reinforced concrete exhibits a fluid consistency at the fresh state, and a compressive strength at 28 days near 180 MPa (as measured on $4 \times 4 \times 16 \text{ cm}$ prisms).

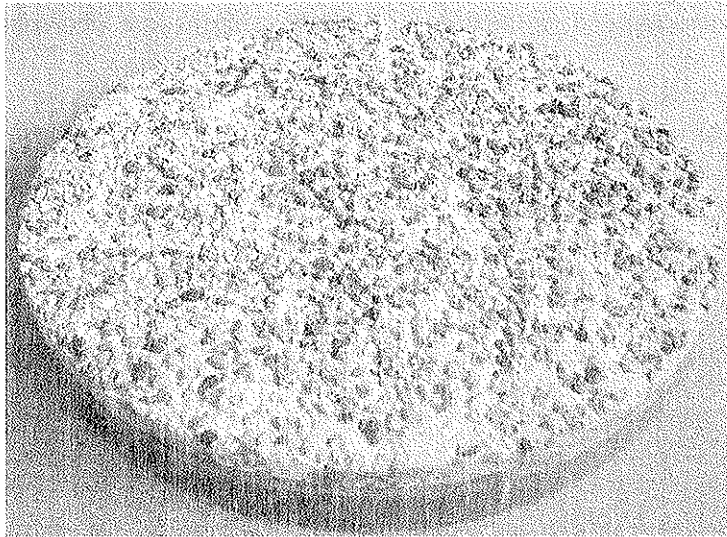


Figure 7. Aspect of HPCM. The 13 mm-long steel fibre are laid horizontally, which make them efficient to prevent horizontal cracking.

During the LLP phase 2 project, the HPCM was intensively studied by seven national laboratories [22]. Most intrinsic and functional properties were investigated, such as compressive and flexural strength, E-modulus, coefficient of thermal expansion, shrinkage, skid-resistance, cracking resistance under restrained shrinkage, behaviour under freeze-and-thaw, acid attack, abrasion, rutting, wear and fatigue. One of the most significant trials dealt with the construction of a 20-m pad, which was submitted to fatigue loadings simulating 1.5 M of ESALs, at various temperatures. The results were sufficiently encouraging to justify the pursuit of this international study, in a phase 3 devoted to site implementation.

4.2 LLPS 3

The LLPS 3 (Long-Life Pavement Surfacing phase 3) project started in 2009 [23]. As for the previous phase, epoxy asphalt and HPCM are developed in parallel, within two subgroups. In the HPCM sub-group, six countries are working together. To date the main active contributions have been provided by UK and France. They are reported hereafter.

4.2.1 The British contribution

The British partners carried out a series of laboratory and small scale tests (see Fig. 8-9). The original design developed during phase 2 was first experienced, through the production of small batches and manual laying of some square meters pads. A number of issues were identified, such as a long required mixing time, a difficulty to pump the original mixture, the need of a higher thickness to cope with the base unevenness, and a high thixotropy of the fresh mortar, making difficult to incorporate the aggregate chippings after more than 10 minutes. Finally, several options were taken that should ease the future construction of a significant, circulated test section (even if the material cost will be twofold):

- the mix-design was changed, increasing the water content and decreasing the silica fume content;
- a Baron pan mixer was adopted;
- the screw pump was adapted, with a different rotor-stator system;
- the amount of laid mortar was substantially increased (up to 15-20 mm);
- the maximum size of aggregate was increased up to 10 mm;
- the amount of chippings was raised up to 6 kg/m³; and
- a vibratory screed was adopted to embed the chippings in the fresh mortar.

A 50-100 m test section was searched for an experimental site to be carried out in '2011.



Figure 8. Laying of the mortar

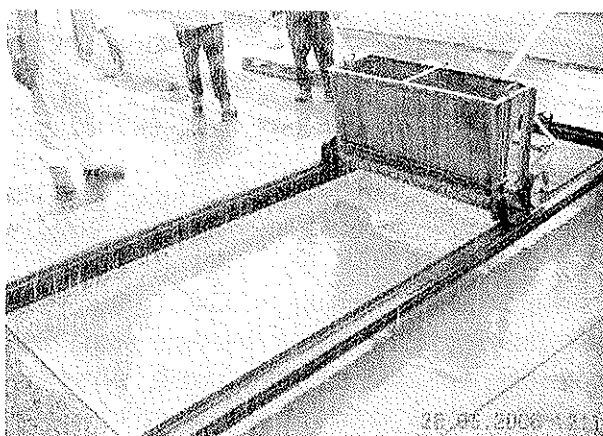


Figure 9. Spreading of chippings

4.2.2 The French contribution (CLEAN project)

The French partners decided to develop a mechanised technology in order to apply the HPCM at a semi-industrial level. A substantial research effort was necessary to match this objective. This is why a 8-partner, 3-year project was proposed to ANR (*Agence Nationale de la Recherche*), who decided to support it. The 'CLEAN' project (*Chaussée à Longévité Environnementale Adhérente et Nettoyante, ie: environmentally durable, skid resistant and cleaning pavement*) was therefore launched in early 2009.

The first block of the project is devoted to the material development. The selection of all constituents was reconsidered. In order to decrease the level of thixotropy of the fresh mortar, and given a certain overdesign of the original recipe, it was decided to use Portland cement as the only binder. Various alternative fibres were deeply tested, namely PVA, glass or aramid fibres, but steel fibres appeared as the only ones allowing at the same time a safe pumping placement and efficient crack prevention at the hardened state. Also, the incorporation of titanium dioxide in the mixture was investigated, in order to foster the urban air NOx photocatalysis [24], so that a depolluting function could be added to the material. Finally, an alternative to the surface dressing option was studied, where no coarse aggregate were embedded in the fresh mortar. Rather a texture was provided to this material, with the idea of controlling both the skid resistance and the noise generation.

different key properties (a superior skid resistance for the surface-dressing – see Fig. 15, a low noise generation for the textured mortar).

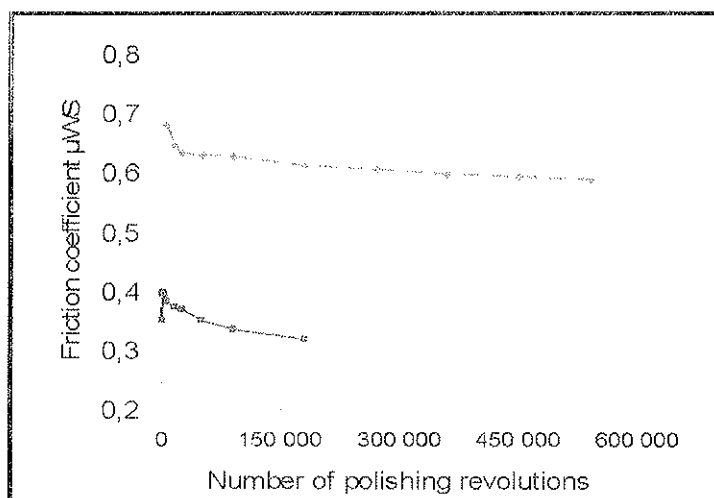


Figure 15. Friction coefficient against wear, as obtained by the Wehner & Schulze machine. Bottom curve: typical asphalt concrete. Top curve: HPCM with calcined bauxite chippings.

4. CONCLUSION – THE FUTURE OF THE CONCRETE ROAD

After this review of recent developments in the field of HPC/UHPC applications to pavement, the following conclusions can be drawn:

- 1) HPC and UHPC exhibit superior properties which make them quite attractive for concrete pavement. The most important ones deal with their high early strength, their high flexural strength at 28 days, their improved abrasion resistance and their high durability in harsh conditions;
- 2) However, these positive aspects are accompanied by less tempting ones. On site highly superplasticised mixtures exhibit peculiar behaviours as longer mixing time, high viscosity and thixotropy, risk of plastic shrinkage, high autogenous and thermal shrinkage etc., that must be taken into account for a successful placement and a good in-service performance;
- 3) Traditional concrete pavement designs can be kept when using HPC/UHPC, but the advantage of using such expensive materials will remain limited. However in the case of fast-track repair the high-early strength can be a sufficient justification;
- 4) Specific designs are currently developed in various parts of the world, aiming at drastically reducing the thickness of the HPC/UHPC top layer. Here the idea of designing a thin CRCP reinforced in both directions comes naturally. Differences are found in the choice of surrounding material, interface and end conditions. Potential

The second block of the project deals with the development of site facilities, in order to lay the fresh mortar, to spread the chippings and to embed them in their matrix. Fig. 10-12 show the equipments built for the first experimental site.

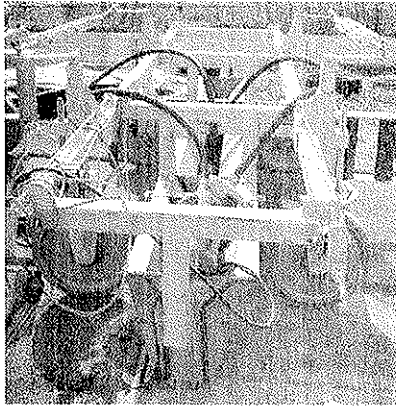


Figure 10. Mortar spreader

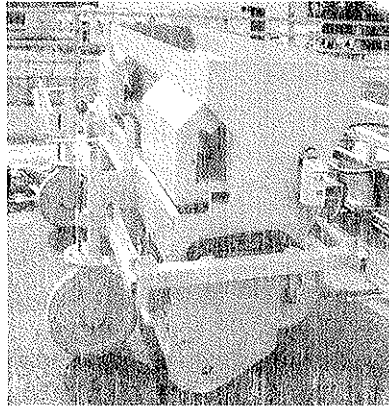


Figure 11. Chippings spreader

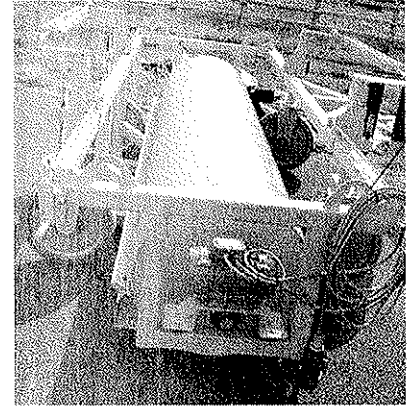


Figure 12. Roller

In April, 2010, a first experimental site was carried out, near Le Mans (Sarthe district, France, see Fig.13-14). This roundabout was built within a week. Three concentric, 2-m wide rings were laid successively with the machines displayed in Fig. 10-11. However, the roller did not prove its suitability, so that the compaction was performed manually with the help of wooden boards. After the site completion, a new machine was designed and built. Preliminary tests performed in January, 2011, gave much better results, so that the semi-industrial application technology of HPCM is now quite well mastered.



Figure 13. Application of HPCM.



Figure 14. Aspect of HPCM after laying.

A second experimental site is scheduled in May-June, 2011, dealing with a straight, interurban, 200-m long road section, near the city of Nantes (France). A part will be constructed with the near-to-original HPCM concept, while no chippings will be used in the second part. Hence the idea is to experience two solutions, both highly durable but with

problems as shrinkage-induced or reflective cracking, end horizontal movements, punch-out or buckling by hot weather must be carefully addressed;

- 5) It appears that conventional concrete pavement, the thickness of which is classically between 10 and 40 cm, may evolve towards a 1-cm thick long-life surface dressing over an asphalt base course. Such a solution called High-Performance Cementitious Material, is currently developed within an international program supported by OECD/ITF JTRC. Several test sections are being built and will be monitored in order to ensure the soundness of this innovative and sustainable concept.

ACKNOWLEDGEMENTS

The authors gratefully thank their colleagues from the international OECD/ITF LLPS 3 project and French CLEAN project for their involvement in the reported research. Also, the financial support from ANR (Agence Nationale de la Recherche, France) is deeply appreciated.

REFERENCES

- [1] Malier Y., ed., "High-Performance Concrete. From Material to Structure", E & FN Spoon, Chapman et Hall, London, 1992.
- [2] Aitein P.C., "High-Performance Concrete", Modern Concrete Technology Series No. 5, E & FN Spoon, London, 1998.
- [3] Gjrv O.E., Baerland T., Ronning H.R., "High-Strength Concrete for Highway Pavements and Bridge Decks", Proceedings of "Utilization of High Strength Concrete", pp. 111-112, Tapir Ed. (Trondheim), June, 1987.
- [4] Chopin D., de Larrard F., Cazacliu B., "Why do SCC and HPC require a longer mixing time?" Cement and Concrete Research, Vol. 34, pp. 2237-2243, 2004.
- [5] de Larrard F., Roussel N., "Flow simulation of fresh concrete under a slipform machine", Road Materials and Pavement Design, accepted, October, 2010.
- [6] Balbo J.T., "Applications of High-Performance Concrete for Ultra-Thin Pavement Overlays (Whitetopping)", Second CANMET/ACI International Conference on HPC, Gramado, Brasil, 1999.
- [7] Burger A.F., Ebels L-J., Brink A-C., "Experience with the construction of an ultra-thin continuously reinforced concrete pavement", 11th International Symposium on Concrete Roads, Svilla, October, 2010.
- [8] Perrie B., Kannemeyer L., Strauss P.J., "Ultra-thin CRCP – From research into practice", 7th International DTU-Workshop on Design and Performance of Sustainable and Durable Concrete Pavements, Carmona (Spain), October, 2010.
- [9] Hachiya Y., Noda J., Kameta S., Tochigi T., Tsubokawa Y., "Applicability of concrete with high flexural strength to airport pavements", 10th International Symposium on Concrete Roads, Brussels, September, 2006.
- [10] Tsai C.T., Tung-Chin Kung G., Hwang C.L., "Use of high performance concrete on rigid pavement construction for exclusive bus lanes", Construction and Building Materials, Vol. 24, p. 732–740, 2010.
- [11] Alte-Teigeler R., "Renewal of concrete slabs using high performance concrete", 9th International Symposium on Concrete Roads, Istanbul, April, 2004.

- [12] Riffel S., Hanke V., "Modern SFHC – Super Fast Hardening Concrete repair system for airfields and roads, based on special cement for infrastructure projects", 11th International Symposium on Concrete Roads, Sévillla, October, 2010.
- [13] Buitelaar P., Braam R., de Wit M., "Heavily reinforced ultra thin white topping to re-strengthen infrastructural structures", 10th International Symposium on Concrete Roads, Brussels, September, 2006.
- [14] Schmidt M., Freisinger-Schadow S., Stöckert U., "Whitetopping with ultra-thin layers of high and ultra-high performance concrete", 11th International Symposium on Concrete Roads, Sévillla, October, 2010.
- [15] Díaz Minguela J., "Fast – track concrete for repairs in a continuously reinforced concrete pavement in Spain", 11th International Symposium on Concrete Roads, Sévillla, October, 2010.
- [16] de Larrard F., "La moquette en BHP - Un nouveau concept de couche de roulement" (The HPC carpet – A new concept of wearing course), Technical Note, Bulletin des Laboratoires des Ponts et Chaussées, No. 223, pp. 105-110, September-October, 1999 (in French).
- [17] de Larrard F., « The High-Performance Concrete Carpet – A New Type of Concrete Course Layer », 9th International Conference on Concrete Roads, Istanbul, April, 2004.
- [18] de Larrard F., « High-Performance Concrete Carpet : a hydraulic flexible wearing course. Part I : design », Scientific note, International Journal of Road Materials and Pavement Design, Vol. 6, Issue 4, pp. 533-548, 2005.
- [19] de Larrard F., Kerzreho J.-P., Potier J.-M., Baroin L., Abdo J., « High-Performance Concrete Carpet : a hydraulic flexible wearing course. Part II : full-scale testing », Scientific note, International Journal of Road Materials and Pavement Design, Vol. 6, Issue 4, pp. 549-564, 2005.
- [20] OECD/ECMT, « Economic evaluation of long-life pavements. Phase I », ISBN 92-64-00856-X@OECD, 2005.
- [21] de Larrard F., Garcin O., Hammoum F., Travers F., « Preliminary tests on a hydraulic surface dressing for wearing courses with a long life », Technical note, Bulletin des Laboratoires des Ponts et Chaussées, No. 258-259, pp. 121-128, October-December, 2005. Freely downloadable on <http://www.lcpc.fr>
- [22] OECD/ECMT, « Long-Life Surfaces for Busy Roads - Economic evaluation of long-life pavements. Phase II », OECD 77 2007 031 P1 / ISBN: 978-92-821-0158-2, April, 2008.
- [23] de Larrard F., Chandler J., Thøgersen F., "High Performance Cementitious Material (HPCM): a long-life wearing course for heavy duty pavement", 11th International Symposium on Concrete Roads, Seville, October, 2010.
- [24] Murata, Y., Tawara, H., Obata, H.O. and Hiroshi, T., 'Air purifying pavement: development of photocatalytic concrete blocks', Journal of Advanced Oxidation Technology 4 (2) 227– 230, 1999.

* * *