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To cite this version:

Francois de Larrard, Armelle Chabot, Thierry Sedran, Bertrand Pouteau, Mathias Vincent. Recent developments in French concrete pavement technology. Global Construction: Ultimate concrete opportunities - http://www.icevirtuallibrary.com/doi/abs/10.1680/cfti.34020.0002, Jul 2005, Dundee, Scotland, United Kingdom. hal-01677026

HAL Id: hal-01677026

https://hal.science/hal-01677026v1

Submitted on 16 Jul 2023

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RECENT DEVELOPMENTS IN FRENCH CONCRETE PAVEMENT TECHNOLOGY

François de Larrard, Armelle Chabot, Thierry Sedran, Bertrand Pouteau, Vincent Mathias

ABSTRACT : The paper gives an overview of three recent research projects carried out at LCPC (Central Laboratory for Roads and Bridges, Nantes, France), dealing with concrete pavement. In the first one, a laboratory fatigue test was developed in order to measure the toughness of interface in composite pavement structures, having a Portland cement concrete base course cast over an asphalt subbase course. In the second project, a new structure was developed where a thin, unbonded and reinforced wearing course in high-performance concrete was supported by an hydraulic, cracked base course. The third project dealt with the recycling of reclaimed asphalt pavement in cement concrete; a new, hybrid material was examined, and showed interesting properties for pavement applications. It was concluded that a part of the future of PC concrete in pavement lies in the association with asphalt materials.

Keywords : Bond, Composite Structures, CRCP (Continuously Reinforced Concrete Pavement), Delamination, Experimental Site, Fatigue, High-Performance Concrete, Mechanical Properties, Reclaimed Asphalt Pavement, Recycling, White-Topping

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Dr. Bertrand Pouteau is a research engineer at Eurovia group, Mérignac, France. Formerly, he prepared a PhD thesis at LCPC (defended in December, 2004) on adhesion between cement and asphalt concrete in composite pavements.

Dr. Vincent Mathias is a research engineer at CTG (ItalCementi group), Guerville, France. Formerly, he prepared a PhD thesis at LCPC (also defended in December, 2004) on the recycling of reclaimed asphalt pavement in cement concrete.

INTRODUCTION

In France, bituminous materials are by far dominant in the pavement landscape, whatever the traffic. Cultural reasons, as much as excellence in asphalt technology and cement cost (compared to that of other European countries) may explain this situation. Moreover, the mild climate with moderate differences between winter and summer temperatures tends to limit the effect of corresponding pathologies in asphalt pavement (cracking and rutting, respectively). This is why it can be stated that French pavement are typically both good, and black! However, the French road directorate still maintains a certain level of research effort towards 'white" materials, in order to keep competition between techniques, while considering the possible long-term shortage of some material resource, such as bitumen. With the support of cement and concrete pavement industries, LCPC (Central Laboratory for Roads and Bridges) recently carried out three projects aiming to push the concrete pavement technology ahead, which are summarized in this paper.

COMPOSITE CONCRETE PAVEMENT

Existing Techniques

The term 'composite concrete pavement' means a pavement made up with a cement concrete base course, cast over an asphalt concrete subbase. Two types of such structures can be currently found:

(i) in the white-topping technique, a thin plain concrete slab (with a 5-10 cm thickness) is cast over an existing asphalt layer, for rehabilitation purpose. The top slab is sawn up to one third of the depth, with a distance between joints close to 1 metre. To obtain a durable repair, the asphalt layer needs to be in good shape, i.e. undamaged by fatigue; only a certain level of surface deterioration or rutting is acceptable, corrected by a milling stage before concrete casting;

(ii) in the late '90, the French pavement community developed a composite structure made up with a continuously reinforced concrete course over a relatively thin asphalt layer. This technique is devoted to new, high traffic (highway type) roads. Thanks to the (presumably) good bond between the two materials, the overall thickness of the structure is quite low, producing a competitive structure as compared to full asphalt solutions.

The success of these two composite techniques greatly depends on the bond quality between the two layers. There is a general consensus on the fact that bond takes place when concrete sets. The question addressed in the related research is to know to what extent this bond remains in the long run (up to 30 years and more).

A Fatigue Test to Evaluate the Interface Bond Durability

A literature survey shown that all laboratory tests developed to measure the interface bond were of static nature, while it is well known that most degradations in pavement come from the fatigue phenomenon. Therefore, a special, laboratory fatigue test was developed at LCPC [1], the principle of which is given in Fig. 1. On the left-hand part, a triangular stiff console supports an oil jack which applies a horizontal force on a composite specimen. A more

detailed view of this specimen is provided on the right-hand part of the figure, where the beginning of a delamination process between the asphalt- and cement-concrete parts can be observed.

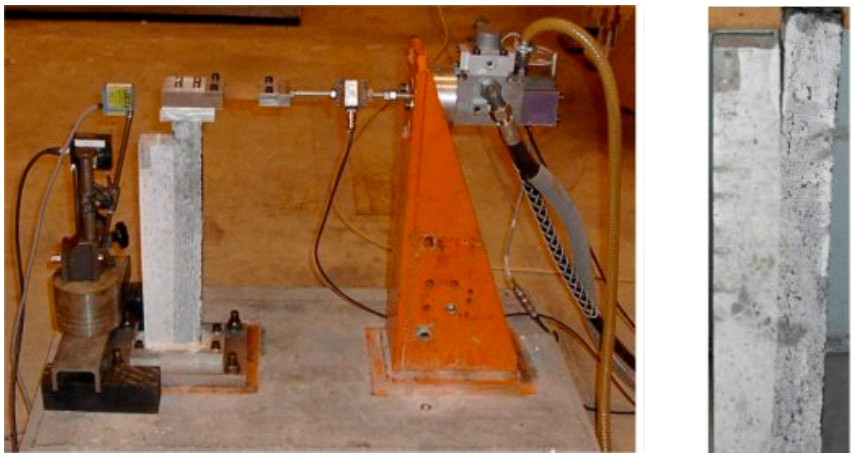

Figure 1. A laboratory fatigue test to evaluate the interface bond in a composite pavement.

With this new test, it was possible to generate delamination, at low temperature (0 °C) and for composite beams where no treatment was applied on the asphalt layer prior to the concrete casting. The quantitative analysis of this test is still in progress.

Full-Scale Testing of a Composite Pavement in Fatigue

By changing the scale of the study, an intermediate size model was built at LCPC, to be tested with the FABAC machine [2]. This linear fatigue machine is a portable device, which can be put over a pavement structure, to apply a rolling load equal to a typical lorry load, with a 65-KN single axle twinned wheel system. The model was a reduction of a real CRCP composite structure: a 10-cm cement concrete layer cast over a 8-cm asphalt concrete subbase. In the vicinity of sawcuts made up in the concrete layer to simulate classical, shrinkage induced transverse cracks, the delamination process could be reproduced after one million cycles.

Instrumentation of Composite CRCP

To complement small- and medium-scale investigations, the opportunity of an experimental site near Strasbourg (eastern France) was taken to monitor the durability of a composite CRCP structure interface [2]. On a 4-m section of this pavement, a plastic panel was put over the asphalt layer prior to cast cement concrete, in order to simulate a large interface crack. The aim of this experiment was to see to what extent this crack would propagate under the action of traffic and weather conditions. An original NDT method based upon analysis of acoustic waves was developed to detect an evolution of interface bond conditions without taking cores. Thanks to this method (tests performed with the COLIBRI device), it could be shown that no propagation took place after two years of heavy traffic, although this road section suffers from a heavy traffic between France and Germany.

Tentative Conclusion

Through this research, it was demonstrated that delamination in composite pavement submitted to fatigue loading may happen, even if both materials (cement- and asphalt-concrete) do not fail under flexural stresses. However, in a full scale structure representative of a real composite CRCP (according to current French design), such a degradation is unlikely to appear, as long as boundary conditions are kept constant. More research is needed to further develop the fatigue laboratory test together with a suitable mechanical analysis; this would allow to provide engineers with an operational method aiming to measure bond toughness and to prevent this type of failure in composite pavements.

HIGH-PERFORMANCE CONCRETE CARPET

The Concept of HPC Carpet

The HPC carpet is a new cementitious material pavement structure, where the cement phase is concentrated in the wearing course [3, 4]. Instead of building two concrete layers of similar thickness, the idea is to have a thin top layer in reinforced high-performance concrete (HPC), cast over a thicker, structural layer (see Fig. 2). The latter can be built either in lean concrete or cement-treated base materials. Contrarily to the case of composite structures (see previous section), no bond is desired at the interface, in order to avoid reflexive cracking. The HPC layer is reinforced in both directions with a welded-wire mesh, to control the appearance of possible fatigue cracks. Hence, this thin layer is allowed to crack in all directions, the microcracking giving flexibility to the wearing course, justifying the 'carpet' term.

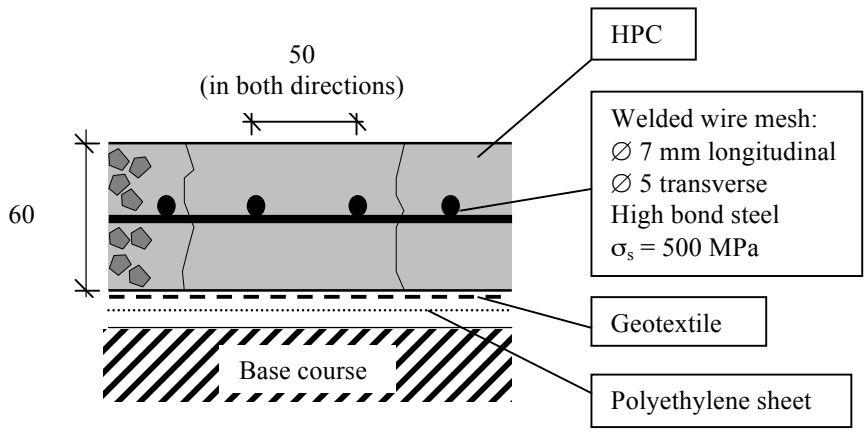

Figure 2. Design of the HPC carpet.

The mixture used is a special concrete with a compressive strength of 80 MPa at 28 days, and a small maximum size of aggregate (6 mm). It incorporates silica fume and limestone filler, plus an amount of superplasticizer and retarder.

As compared to traditional CRCP design, the HPC carpet design is expected to give lower initial costs, providing competitiveness to concrete pavement in the present high-traffic pavement market. The trend is also favourable in terms of sustainable development: less non-renewable material resource consumption, and a reduced noise emission due to the small maximum size of aggregate (6 mm).

Design Calculations for the Prevention of Buckling and Control of Cracking

Such an innovative concept quickly rises the question of behaviour under extreme temperatures. In the case of hot weather, one may wonder whether such a thin, unstuck and flexible top layer may buckle, owing to compressive stresses appearing by restrained swelling. To avoid such a catastrophic phenomenon, the HPC is specified with a minimum shrinkage of 700/750 10^{-6} at 50 % R.H.. In normal conditions, the pavement will crack after some days due to this restrained shrinkage. In the case of high-temperature, a limited amount of compressive stress will take place in the wearing course. It can be then demonstrated that this compressive stress (maximum value closed to 3 MPa) is unlikely to provoke instability, provided that the radius of the longitudinal profile is large enough [4].

On the 'cold side', the use of small diameter rebars, with a higher percentage of longitudinal steel (about 1.1 %) and a high tensile strength concrete is supposed to lead to very thin cracks close to each other. Although the specified concrete cover is less than in ordinary CRCP, no corrosion risk is anticipated, at least in the first decades, owing to the low transport properties of HPC.

Full-scale Testing in Fatigue

A 10 m-long, typical section of HPC carpet was tested with the FABAC machine already described in the previous section dealing with composite structures (see Fig. 3). After one million cycles, only three thin and stable cracks were observed. No wear nor punch-outs were recorded.

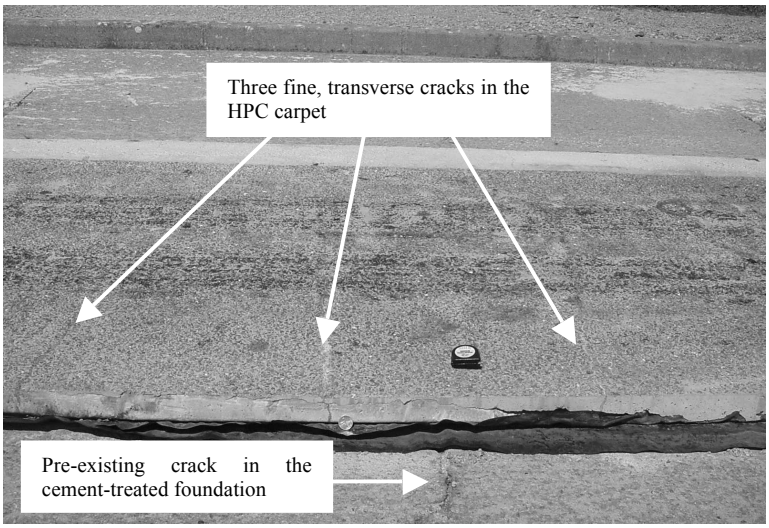

Figure 3. The HPC carpet model, after one million cycles in fatigue loading.

Experimental Site in Villeurbanne, France

An experimental 100-m long lane was built in 2003 and has supported a heavy lorry traffic since its construction [5]. Thanks to this site, where the HPC carpet was cast with a slipform machine (see Fig. 4), the industrial feasibility could be demonstrated. Although the cracking process appeared quite random, as usual in CRCP, the mean distance between cracks and crack openings were found to be similar to the design calculations. After one year of utilization, this pavement does not display any deterioration. The monitoring will continue in the coming years, but LCPC is now looking for a longer test section to further develop this promising concept.

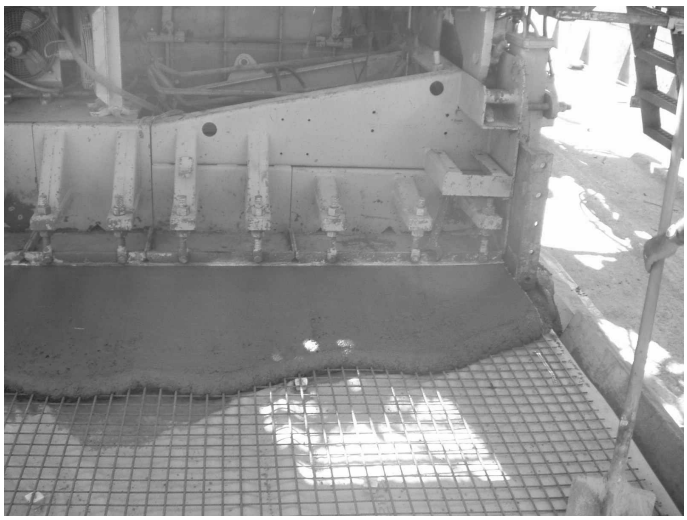

Figure 4. Casting of the HPC carpet with a slipform machine.

RECYCLING RECLAIMED ASPHALT PAVEMENT IN CEMENT CONCRETE

Why Thinking about RAP in Concrete ?

Reclaimed asphalt pavement (RAP) is one of the main waste materials generated by the road industry. In France, about 5 Mt are produced annually, but less than 10 % of this resource is recycled in hot-mixed asphalt. The remaining materials are then available to replace ordinary aggregates in all types of road granular materials, including PC concrete. Moreover, the construction of certain types of cement concrete pavement is preceded by the milling of existing asphalt pavement producing a certain amount of RAP which may not be landfilled, according to European regulations. This is why LCPC has carried out a specific research on the effect of RAP incorporation on the properties of concrete.

Effect of RAP Incorporation on Concrete Mechanical Properties

RAP is essentially a wide grading range aggregate, containing some percents of old bitumen. This soft inclusion acts as a supplementary porosity in hardened concrete, decreasing the level of compressive strength and tensile strength and E-modulus (see Fig. 5 & 6, [6]).

LCPC developed during the nineties a comprehensive and scientific mix-design method for structural concrete, where the main material mechanical properties are linked with the mixture-composition, thanks to a set of semi-empirical models, extensively validated on several series of independent data [7]. The present research shows that the effect of RAP incorporation can be simply predicted considering that bitumen acts as a water addition in concrete, with an 'efficiency' coefficient depending on the temperature: the higher the temperature, the more detrimental the bitumen for the mechanical properties [8]. This coefficient ranges from 0.69 to 1.87 (at 0 and 40 °C, respectively). The dependency of the efficiency coefficient with temperature makes 'RAP concrete' a slightly thermosensitive material. However, in terms of global mechanical properties, this hybrid material is closer to cement concrete than to asphalt concrete.

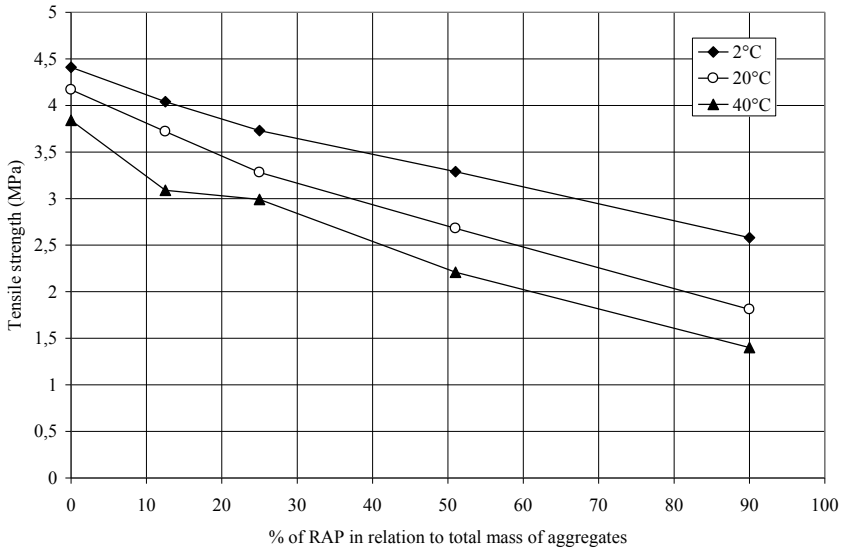

Figure 5. Effect of RAP incorporation on the tensile strength of plain concrete.

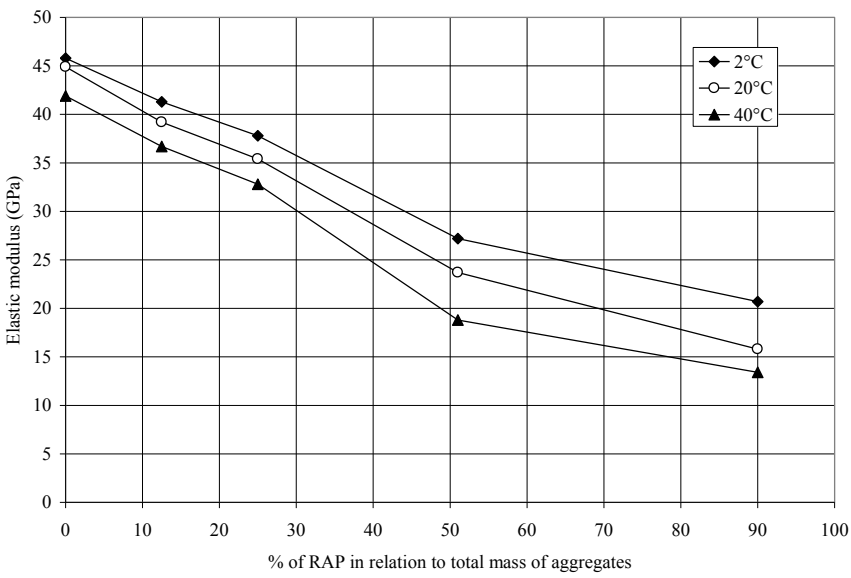

Figure 6. Effect of RAP incorporation on the elastic modulus of plain concrete.

Cracking Behaviour of RAP-CRCP

Tests shown that the use of RAP tends to increase the drying shrinkage of concrete. On the other hand, it is likely that this new material will exhibit a higher level of creep and relaxation, owing to the viscoelastic nature of bitumen. Therefore, the question of cracking of CRCP in presence of RAP is open.

Restrained shrinkage tests were carried out with a 3.5 m cracking bench. Reinforced concrete beams were cast and monitored during several months, with a control of overall length; winter conditions were simulated through an imposed elongation of the cracking bench. An ordinary reference concrete and a RAP concrete were tested in parallel. The cracking pattern (number of cracks, distance between cracks and crack openings) was similar in both concretes. Therefore, it seems that usual CRCP design would be applicable to RAP concrete, provided that the correct levels of tensile strength, E-modulus and fatigue behavior are accounted for.

Global Approach of Recycling

Fatigue tests on the material were then carried out, in order to be able to design a pavement structure made up with two layers of concrete with various levels of RAP incorporation. As compared to current CRCP designs, it turns out that the use of such a recycled material appears to be economically sustainable, provided that the RAP aggregate has a nil cost. Hence, it is necessary on one hand to increase the cement content, in order to counteract the 'softening' effect of bitumen. On the other hand, there is a cost saving when e.g. a proportion of 50 % of the normal aggregate is replaced by recycled one. Finally, this research has opened a new avenue for the application of sustainable development issues in material engineering. Furthermore, a bridge was established between two separate worlds (the 'black' and the 'white' one).

CONCLUDING REMARKS

Through his short survey on three recent projects dealing with concrete pavements, it is suggested that the future of pavement material technology could be, at least partly, grey:

- the research on white/black bond was launched after having realized the mechanical and economical efficiency of these composite structures. Here, advantage is taken from the strength, stiffness and durability of cement concrete, combined with the flexibility and adhesion of asphalt concrete;

- incorporation of RAP in cement concrete leads to an hybrid material which seems to work well in a pavement structure, giving an interesting recycling opportunity while matching the demand for a strong, durable, economical and environment-friendly material;

- even HPC carpet, which is more a 'purely white solution', is partly inspired by asphalt technology through the specialization of pavement layers (a thin wearing course with little structural role, cast over a thick base course).

As usual in material engineering, many advances can come from crossover between different families and traditions.

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