GROOVED FIBRE-REINFORCED ULTRA-HIGH PERFORMANCE CONCRETE: A NEW MATERIAL FOR PAVEMENT LONG-LASTING WEARING COURSE

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Abstract

An innovative material, called Grooved Fibre-Reinforced Ultra-High Performance Concrete (GFRUHPC) is presented in this paper. In the framework of an international OECD project, supported by a French ANR project, the aim was to develop an hydraulic material for long-lasting wearing courses, devoted to highly trafficked road sections. The current solution is a fibre-reinforced UHPC, longitudinally textured for the sake of surface drainability. Titanium dioxide can be also incorporated in order to provide an additional air-depolluting capacity. An experimental construction site was carried out in 2011 in Loire-Atlantique (western France). Measured performance in terms of skid resistance, noise generation and depolluting capacity are encouraging. Necessary technological improvements are given in conclusion, for the sake of industrial maturity and dissemination of a globally sustainable material.

Résumé

On présente dans cet article un matériau innovant, l'Enduit Hydraulique Fibré Rainuré (EHFR). Dans le cadre d'un projet international mené par l'OCDE, et d'un projet français financé par l'ANR, il s'agissait de mettre au point un matériau hydraulique pour couches de roulement à longue durée de vie, pouvant être appliqué sur des sections à très fort trafic. La solution actuelle est constituée d'un mortier fibré à ultra-hautes performances, rainuré longitudinalement afin de lui procurer une drainabilité de surface. On peut également incorporer dans le matériau du dioxyde de titane afin de lui conférer une fonction supplémentaire dépolluante. Un chantier expérimental a été réalisé au printemps 2011 en Loire-Atlantique. Les performances en adhérence, en génération de bruit et en capacité dépolluante sont très encourageantes. L'article conclut sur les améliorations technologiques nécessaires pour permettre un développement industriel de ce nouveau matériau, dont le bilan global en termes de développement durable apparaît positif.

[1] Now at Lafarge LCR

1. INTRODUCTION

In France high-traffic road bases are designed for 30 years, and frequently last longer. Besides, wearing courses display much shorter lifespans (typically 7-10 years). They are replaced either because of their degradation or their polishing, which eventually causes an excessive decrease of skid resistance. Therefore maintenance works take place periodically, with a strong disruptive effect for some critical sections of highway networks. For these particular pavement sections, it would be desirable to have materials as durable as the ones used in the lower layers. Based on this assumption, a working group was created, called Long-Life Pavement (LLP), under the framework of JTRC (Joint Transport Research Council), a common body of OECD (Organisation of Economical Cooperation and Development) and ITF (International Transport Forum). This paper presents an innovative technical solution, developed within the CLEAN French project (*Chaussée à Longévité Environnementale Adhérente et Nettoyante*). The genesis of the material is recalled, then its main properties are presented, as measured in the laboratory or on a construction site carried out in 2011, in the Loire-Atlantique department (western France). The depolluting properties of the photocatalytic version are also displayed. Finally, expectations brought by this new concept are presented, followed by the remaining technical questions that must be solved to reach a full industrial development.

2. "HIGH-PERFORMANCE CEMENTITIOUS MATERIAL", OR HPCM (LLP OECD PROJECT)

During the phase 1 of the LLP project, it was shown that such a high durability material could find a market, provided that the unit cost per square meter would remain under the triple of the one of current solutions [1]. During the phase 2 [2-6], two solutions were studied in the laboratory: epoxy-asphalt concrete and a new hydraulic solution called High-Performance Cementitious Material (HPCM).

Fig. 1 displays the principle of HPCM, which is basically a surface-dressing, where the binder is a fibre-reinforced, ultra-high performance fine mortar, and the aggregate among the hardest and most polishing resistant ones, namely calcinated bauxite. The aspect of the material appears in Fig. 2, and its mix-composition is given in Table 1.

Deep investigations were carried out in order to chose the right nature and amount of fibres. Only steel and aramid fibres were found capable of preventing cracking in restrained conditions. However the latter was either too weak to resist to a long mixing/pumping process or lacked of bond with the cement paste.

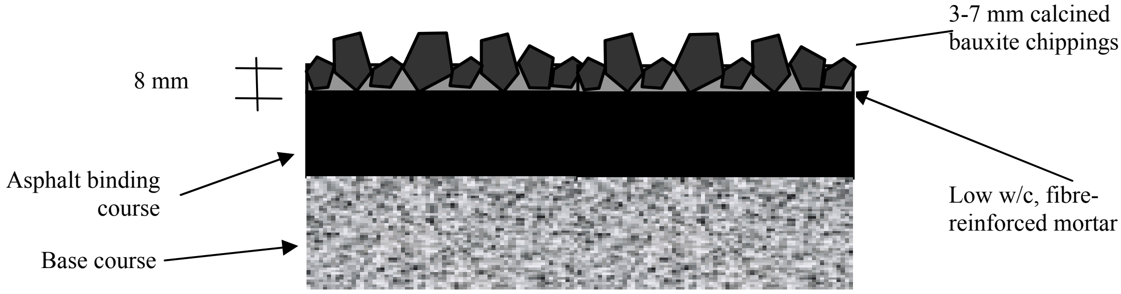

Figure 1: principle of the High-Performance Cementitious Material (HPCM) [2].

Table 1 : HPCM mix-composition
A: recipe used by the various partners of LLP phase 2 working group.
B: recipe as used on Loire-Atlantique construction site.

Constituents (in kg/m³\ of the Mixtures	**A**	**B**
0.2/1 mm rounded siliceous sand	429	-
0.08-0.315 mm rounded siliceous sand	429	-
0/1 crushed quartz sand	-	883
CEM I Portland cement	985	982
Silica fume	197	-
Superplasticizer (dry powder)	4.4	2.21
Retarder (in liquid form)	4.95	2.65
13x0.2 mm steel fibres (3% in volume)	235	226
Water	207	294
w/c	0.21	0.30
Slump [cm]	21	20-26
Chippings	4.5 kg/m² (4/6 calcined bauxite)	3 kg/m² (4/6 porphyric)

Figure 2: aspect of HPCM

The properties of HPCM, as measured in the laboratory, were very attractive: a compressive strength of about 180 MPa, as measured on 4x4x16 cm prisms; a flexural strength of 40 MPa; an excellent resistance to wear and shear surface stresses, with no loss of material in the IFSTTAR Triboroute test (see Fig. 3) and a superior resistance to freeze-and-thaw, chocks and acids in the German "Total test" [3]. Also, the skid-resistance was assessed through the Wehner & Shulze test [7]. The results were much better than those of current asphalt wearing courses, and the "polishing durability" appeared as at least three times the one of the control material, even when the costly calcinated bauxite was replaced by a much cheaper natural aggregate (see Fig. 4).

Based upon these positive results, the phase 3 LLP project was launched in 2009. The aim was to organise full-scale test sections, either with HPCM or with the competing asphalt solution (epoxy-asphalt). Regarding HPCM, the CLEAN project, funded by ANR (Agence

Nationale de la Recherche) was launched, since further research was necessary to optimise the material and to develop suitable site machines. All the results of this project are available on a dedicated Internet site (http://clean.ifsttar.fr). The first CLEAN construction site took place in the Sarthe department (central France) in 2010. Two major issues were identified regarding the HPCM technology: a difficulty to control the embedment of chippings in the fresh mortar; and a rough texture, generating a high level of rolling noise under traffic.

These findings led to the re-conception of this hydraulic solution, avoiding the incorporation of chippings and creating a mortar macrotexture.

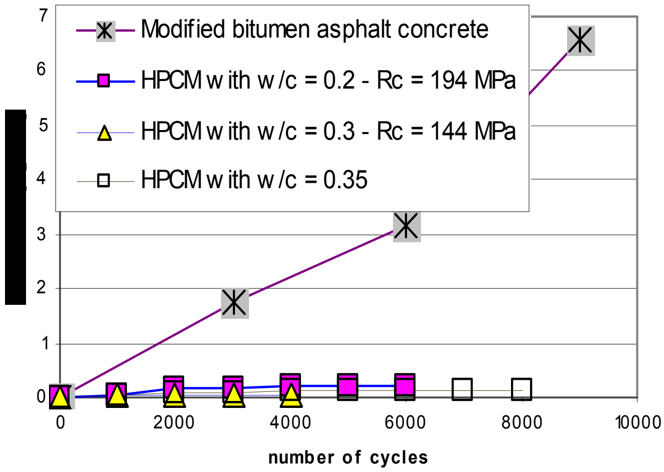

Figure 3: resistance to wear of HPCM, compared to that of modified bitumen asphalt, as measured with the Triboroute™ apparatus.
No loss of material is found for hydraulic solutions.

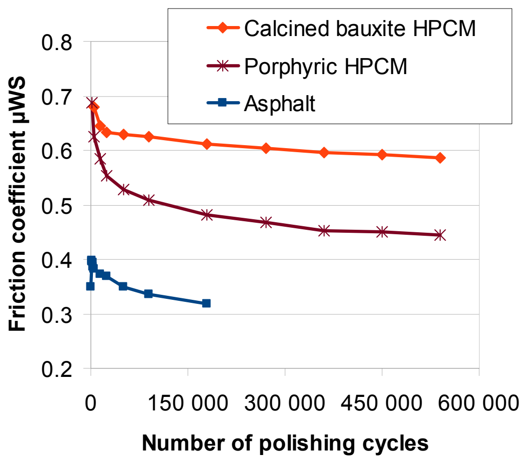

Figure 4: skid-resistance of HPCM, as measured with the Shulze machine [7].

3. GROOVES RATHER THAN CHIPPINGS

The first idea was to reproduce the texture of the best current asphalt wearing courses, e.g. the BBTM 0/6 (very thin asphalt concrete with 6 mm maximum size of aggregate). Tests were carried out with polymeric matrix, but this process was found difficult to mechanise on site. It was finally preferred to use a known technique, which is well mastered in the USA [8], consisting in sawing narrow longitudinal groves in the hardened mortar (see Fig. 5).

(a) (b)

Figure 5: Grooved Fibre-Reinforced Ultra-High Performance Concrete,
as applied on the second CLEAN construction site.
(a) : grooving with a diamond saw. (b) : final aspect.
Grooving specification: inter-axle distance 10 mm, width 4.5 mm, depth 3 mm.

3.1 Risk assessment

With such a technique, three types of risks had to be assessed prior to proceed with a full-scale application:

- the shimmy phenomenon for two-wheel vehicles. This problem is well-known in the motorcyclist community, and made in the past some concrete pavements very unpopular. However, according to recent American experience, it seems that shimmy only appears above a certain critical dimension of the groves. With the ones specified for GFRUHPC, this risk seems to be overcome;

- tyre puncture. Hence, since steel fibres are used in the mortar, one could expect that some fibres would come out of the top surface, and could hurt the vehicle tyres. Tests were carried out on a 25-m long test section at IFSTTAR, Nantes [9]. The risk was confirmed for bicycles, but not for motorcycles, cars or trucks. Since the GFRUHPC technology is dedicated to highways, the choice of steel fibre was confirmed;

- hydroplaning. Any wearing course must pass requirements dealing with water drainage under tyres. Based on a recent study published at TRB [10], confirmed by theoretical calculations [11], this risk could be eliminated, provided that the grooving specifications are matched.

3.2 Skid-resistance

As for HPCM, the Wehner & Shulze machine was used to assess the potential skid resistance of a GFRUHPC layer (see Fig.6). The smooth material, in the absence of surface texturing, has shown a rapid decrease of its friction coefficient. However, the use of a crushed, angular quartz sand, together with the application of groves in the fresh mortar, led to a large improvement of the skid resistance. After the rapid wear of the superficial cement paste, there seems to be a surface regeneration which creates an increase of friction coefficient. The remaining level of friction after 500,000 cycles is even higher than the best one achieved by the control asphalt material after only some thousands of cycles.

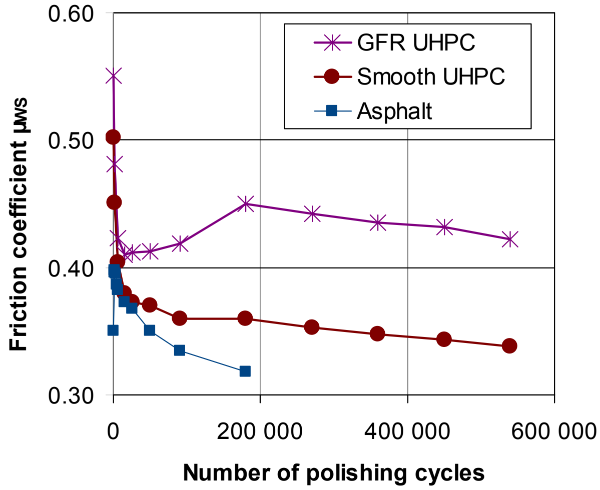

Figure 6: skid-resistance of GFR UHPC, as measured with the Wehner & Shulze machine

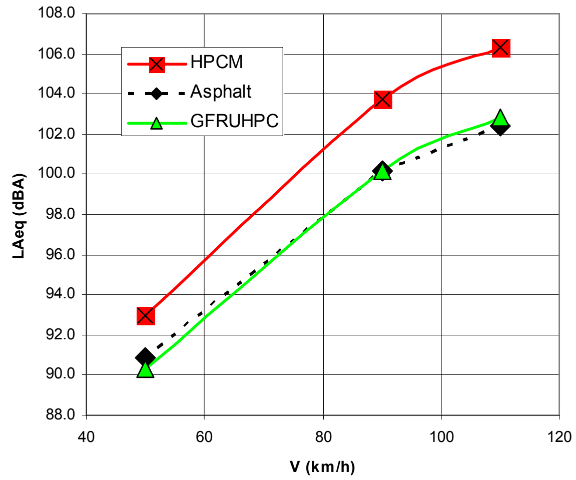

Figure 7: noise generation as measured by the CPX method on the Loire-Atlantique test section (3rd track), after 2 weeks of traffic

3.3 Noise generation

This parameter cannot be measured in the laboratory within the current pavement material technology. The second CLEAN construction site offered two 75-m long test sections in HPCM and GFRUHPC, respectively. The noise generation was assessed through the CPX technique [12], which consists in measuring the noise level with microphones fixed near the tyres of a reference car. The results are displayed in Fig. 7. HPCM confirms its noisy character, with an increase of 3-4 dBA as compared to the BBTM 0/10 control asphalt material. However, the GFRUHPC displays the same type of noise generation as the one of asphalt, as well in terms of total energy as of frequency range.

4. PHOTOCATALYTIC OPTION

For several years now, titanium dioxide ($Ti0_2$) has been incorporated in cementitious materials in order to foster the photocatalysis of NOx (nitrogen oxides) degradation caused by the sun UV radiancy. Hence NOx are among the most harmful pollutants found in urban air, and the level of NOx concentration is a major issue during pollution peaks. During the

CLEAN project, an option was studied consisting in the use of a special $Ti0_2$ cement in the mix-design of HPCM/GFRUHPC. Laboratory results of NO_x drop are displayed in Tab.2, dealing with the innovative materials, as compared to a conventional concrete pavement. HPCM performance is lower than that of the control, due to the hiding effect of incorporated chippings. Besides, the GFRUHPC displays the best results. After the construction site completion, cores were periodically taken, in order to monitor the evolution of depolluting capability of the material. As for conventional concrete, it appears that a periodical cleaning process is necessary to maintain a certain level of this function. Specifications remain to be developed in this matter.

Table 2: photocatalytic performance of the hydraulic materials, as measured with the ItalCementi procedure

Material	**Photo-catalytic cement**	Relative drop (%)		
		NO	NO_2	NO_x
Vanves pavement concrete [13]	No	0	9	2
Vanves pavement concrete [13]	<u>Yes</u>	38	45	41
HPCM (lab mixture with silica fume and PVA fibres)	No	-2	11	5
HPCM mixture as used on CG 44 test section (w/c = 0.23)	Yes	30	28	29
GFRUHPC mixture as used on CG 44 test section (w/c = 0.23)	<u>Yes</u>	55	43	50

5. CONCLUSION

A comprehensive review of the GFRUHPC, encompassing technical, economical and environmental aspects, can be found on the CLEAN internet site. The main points are summarized hereafter:

- the material requires a long mixing time, unless special mixers, as the ones used for more conventional UHPC are used;
- attention must be paid to the risk of fibre clusters formation;
- in case of conveying the fresh material with a pump, piston pumps should be preferred;
- a consistent application of the material cannot be carried out in less than 19 mm, given the precision of application techniques and the evenness of the base courses;
- a thorough curing process should be applied just after casting in order to avoid the appearance of cracks;
- GFRUHPC sections should commence and terminate with an overthickness, and measures must be taken to ensure the good bond with the base course;
- the material should be applied in full lane width (3.50 m according to the French standard), avoiding inlay application;
- the typical material specifications could be as follows: use of angular, hard sand with a maximum size of 1 mm, amount of steel fibre of 2.5-3 % in volume, slump of [20-24 cm], compressive strength of 40 MPa at traffic opening, to reach 120 MPa at 28 days, total shrinkage less than 0.5 ‰.

In terms of sustainability, the GFRUHPC technique, as compared to current asphalt solutions, appears as equivalent in terms of CO_2 emission, lifecycle cost and noise generation, and better in terms of energy and non-renewable resource consumption, traffic disruption and safety. Therefore, it is the authors' belief that the development of GFRUHPC is worth continuing.

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