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Accelerated pavement testing for the evaluations of structural design and safety performance of an innovative road coating

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Abstract: Pervious concrete use has increased since more than a decade thanks to its main feature of high water permeability. However the use of this material is still limited to light traffic areas, like car parks or walkways in urban areas. Recently LafargeHolcim Research Center has developed an innovative concept of concrete pavement structure using this type of material for heavy traffic highways. An ultra-thin innovative pervious concrete layer is laid directly (wet on wet) on top of an optimized concrete layer just after its placement. This innovative solution allows ensuring both structural performance and surface characteristics for road users in terms of safety, riding comfort and aesthetic. In order to evaluate the actual performance of this innovative pavement structure, an accelerated pavement test (APT) was carried out using the FABAC heavy traffic simulator of IFSTTAR in Nantes. A total of five million cycles of 6.5 tons half-axle load were applied. Structural performance and lifetime of the pavement were evaluated by comparison with a design process using the French-standard-design-software called Alizé-LCPC. The evaluation of the bonding strength at the interface between the pervious wearing course and the structural concrete bottom layer showed good durability throughout the entire test, which could allow possible consideration of the surface layer in the whole pavement design process. Finally, dynamic friction tests conducted on the innovative wearing course during the APT allowed to evaluate and predict the evolution of its skid resistance throughout the pavement lifetime.

Keywords Pervious concrete, APT, Pavement design, Interface bonding, Dynamic friction test, Innovative Road Coating.

1 Introduction

Road maintenance budgets have a strong economic impact. In general, developed countries are spending in maintenance yearly amounts between 0.2 % and 0.4 % of their GDP. With bitumen price rising, concrete pavements become competitive with asphalt pavements, with lower maintenance costs during their service life. Indeed, maintenance cost, including the economic loss caused by traffic disruption due to maintenance works, represent an important budget (FEHRL, 2008).

However, the riding comfort (evenness, noise) of concrete pavements is still a big issue. Many studies were carried out to improve the riding comfort of rigid pavements but the results are still far from expectations. Recently, LafargeHolcim Research Center (LRC) has developed an innovative coating as wearing course for concrete pavements, to offer: a durable solution with concrete structural capacity; expected standards in terms of comfort and safety; technical innovations such as color choices and easy placing.

This new wearing course with a thickness of 3-4 cm, which is placed "fresh on fresh" on conventional concrete, aims to offer an interface between the structural function and the user perception. It is designed to have equivalent costs at construction level as classical concrete pavements, and no structural maintenance over the lifetime, (only surface maintenance, to be assessed). To validate this innovative concept, a full-scale accelerated test was carried out, with the FABAC traffic simulator of IFSTTAR.

2 Material properties

The properties of the ultra-thin pervious concrete, based on polymer modified cement, were studied in the first stage by laboratory mechanical tests, including 3-point flexural strength, compressive strength and durability (scaling resistance).

The strength of concrete containing different types of polymers was measured by 3-point flexural tests and compressive tests on 4 cm x 4 cm x 16 cm size prisms. Figure 1 shows that the mechanical strength of concretes, at a constant rheology, is significantly different, depending on the type and dosage of polymer. In general, polymer improves the flexural strength of concrete (up to 40 % compared to the control concrete without polymer). The influence of polymer on the compressive strength needs to be studied further, as it can enhance or reduce the latter.

The influence of polymer on the resistance to scaling of concrete was also studied with 2 different families: an acrylic acid ester copolymer which proved very efficient to improve the flexural strength and classically recommended polymer for concrete, Styrene Butadiene emulsion. The scaling test used the most severe method, developed by LRC, in which the pervious concrete is submerged in salty water containing 3% of NaCl and is submitted to freeze-thaw cycles (cf. figure 2) until complete failure.

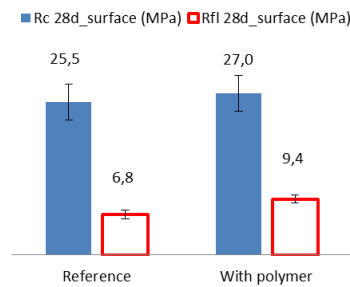


Fig. 1 Influence of polymer type on the mechanical strength of concrete

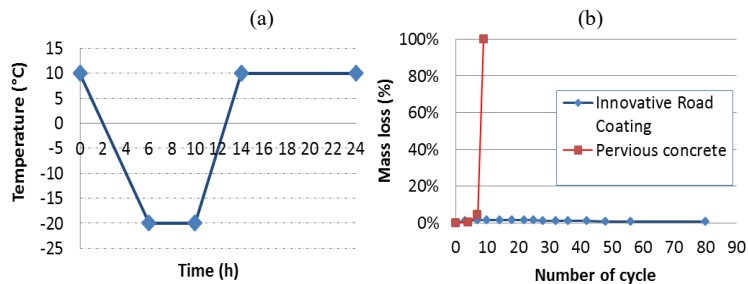


Fig. 2 a) 24 hour freeze-thaw cycle used for scaling testing b) Scaling results and comparison with a classical pervious concrete

The polymer pervious concrete performance was compared to that of classical pervious concrete tested simultaneously. The classical pervious concrete used a 6/10 mm crushed aggregate within cement paste volume of 160 liters for a Water/Cement ratio of 0.34. The results, presented on figure 2 show that polymer can improve significantly the scaling resistance of pervious concrete.

3 FABAC traffic simulator and APT pavement structure

The FABAC machine is a small linear traffic simulator, capable of applying heavy vehicle loads on small pavement sections. The machine has a total length of 10m, and is equipped with four wheel modules, driven by a chain and electric motor (see figures 3 and 4). Each wheel module can be equipped with single or dual wheels, and apply loads varying between 30 and 75 kN. The length of the loaded section is 2 m. The loading speed can vary between 1 and 5 km/h.

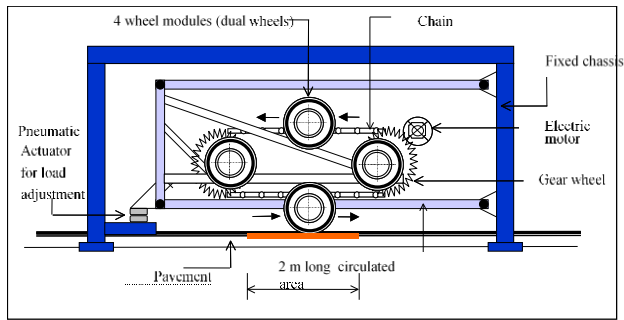


Fig. 3 Principle of the FABAC machine



Fig. 4 View of the FABAC machine

The experimental pavement was built in September 2016. It consisted of a 3 cm thick porous concrete surface course, a 25 cm thick concrete base, and a 10 cm thick unbound granular subbase. It was built on a 70 MPa subgrade.

A classical road concrete, of class BC5, was used for the base course. A wooden formwork was installed on the granular subbase, for the construction of the concrete structure (figure 5).



Fig. 5 Compaction of the porous concrete layer with a striker roller, and then a vibrating plate

The BC5 concrete was placed in the formwork, leveled and vibrated. Then, the pervious concrete was laid on top of the base layer immediately (fresh on fresh). A 4 cm thick layer was put in place. The concrete was first vibrated with a striker roller (figure 5), but the compaction was not very efficient. Therefore, it was decided to modify the compaction method: a wooden board was placed on the porous concrete, and the compaction was carried out using a vibrating plate, placed on the board (figure 5).

24 hours after the construction, two joints were created, by sawing the pavement structure up to a depth of 9 cm. One joint was created in the middle of the structure, and the second one 50 cm apart. The surface texture of the porous concrete and the joint are shown on figure 7. The experimental pavement was also instrumented with 8 temperature probes, measuring the air temperature, and the temperatures at different depths in the structure.



Fig. 6 Surface texture of the porous concrete, sawed joint, and sealing of the joint (Sikaflex resin)

4 Test program

The experimental pavement section was subjected to 5 million load cycles with the FABAC machine, using dual wheels, loaded at 65 kN (French standard equivalent axle load), and a loading speed of 3,6 km/h. The test was performed between November 2016 and June 2017. The monitoring of the pavement included:

- Visual inspections, to assess pavement deterioration;
- Transverse profile measurements, carried out with a profilometer equipped with a laser displacement sensor, with a vertical resolution of 1 mm;
- Air temperature and pavement temperature measurements (8 sensors).
- Mean texture depth measurements, using the sand patch method;
- Skid resistance measurements, using the Skid Resistance Tester (SRT) and the Dynamic Friction Tester (DFT);
- Coring, outside the loaded area, to perform pull-off tests, to evaluate the bonding strength between the porous concrete and the base layer.

Commenté [NM1]: Car l'équipe de construction ne savait pas comment utiliser ce striker roller compactor. Maintenant, seul ce mode de compactage suffira.
Tung, pourrais-tu confirmer cela ?
Pour l'article, est-ce tu d'accord de laisser cette description ?

5 Results

5.1 Bonding strength

To verify the bonding strength at 28 days of the 2 layers, pull off tests (NF EN 1542 standard) were carried out on the slab at different positions. The results are shown in table 1. The National Concrete Pavement Technology Center (USA) recommends a bonding strength from 0.5 MPa to 2.5 MPa for a durable two-lift concrete pavement.

Table 1 Bonding strength of porous concrete versus base course concrete

	Mean	Standard deviation	Coeff of variation	Min. value	Max. value
Direct tensile strength	2.00 MPa	0.49 MPa	24.5 %	1.09 MPa	2.82 MPa

5.2 APT structure analysis

5.2.1 Temperature measurements and visual inspections

Figure 7 presents the surface temperature variations recorded during the whole test period. On the surface, the temperatures varied between 0°C in the winter and 40°C in the summer. These conditions are representative of the Nantes climate.

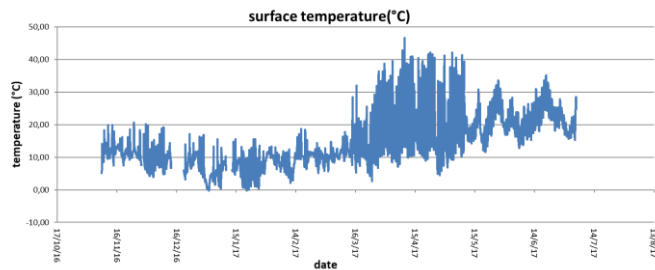


Fig. 7 Temperature variations at the surface of the pavement structure

Visual inspections were performed at different stages of the test, to detect surface damage (cracking, surface wear). As practically no evolution was observed, only the results obtained at the end of the test are presented. Figure 9 shows the aspect of the surface of the porous concrete, and of the joints, after 5 million load cycles. The marks on the surface correspond to rubber deposited by the tyres, and to grease

coming from the FABAC machine. No cracking or deterioration of the surface was detected at the end of the test. The joints also presented no significant damage (no wear or breaking of the edges of the joints - figure 8).



Fig. 8 View of the porous concrete surface, and of one transverse joint at the end of the test

5.2.2 Transverse profile measurements

Transverse profile measurements were made at 4 different positions on the experimental pavement, at different stages of the test, using a profilometer with a non contact laser displacement transducer. An example of transverse profiles measured after construction and at the end of the test, near the center of the test section is shown on figure 9. The measurements indicate absolutely no permanent deformation of the concrete. The same results were obtained for the other transverse profiles.

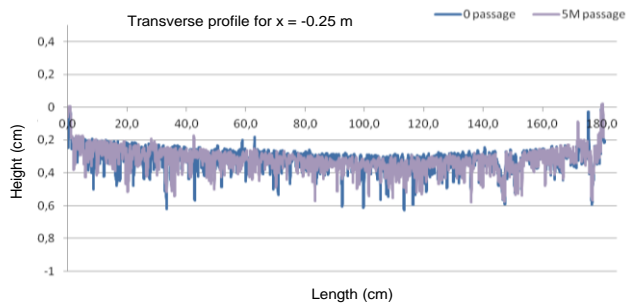


Fig. 9 Transverse profiles in the center of the experimental section, after construction and after 5 million load cycles

5.2.3 Service life of the evaluated structure

Calculations were performed with the French pavement design method, to evaluate the design life of the tested structure. These calculations were performed considering different traffic classes, (and design hypotheses for structuring road networks (VRS)). The results are summarized on Figure 10: for each traffic class, the figure indicates the design life (in number of years), and compares it with the applied traffic (also converted to number of years). The tested structure has a design life of 23 years, for a traffic class T1 (500 heavy vehicles/day), which is validated by the results of the FABAC test (no significant deterioration after this level of traffic). Naturally, this type of structure could be designed for a heavier traffic, by increasing its thickness.

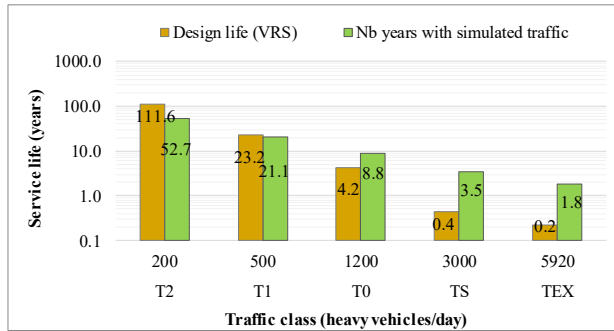


Fig. 10 Comparison of design life and observed service life (in years) for different levels of traffic.

5.3 Skid resistance evolution

To evaluate the evolution of the surface characteristics of the porous concrete, three types of tests were performed:

- Mean texture depth measurements (MTD), by the volumetric patch test (standard NF EN 13036-1);
- Skid resistance measurements, using the Skid Resistance Tester (SRT, standard NF EN 13036-4) and the Dynamic Friction Tester (DFT, ASTM E 1911 standard). The DFT measures the friction force between the surface and three rubber pads attached to a rotating disc. A water supply unit provides a water depth of 1 mm on the surface. A friction-speed curve is recorded from 80 km/h to complete stop. Generally, values of friction coefficient, at 20, 40 and 60 km/h (DFT20, DFT40 and DFT60) respectively, are extracted for analyses.

The mean texture depth and friction measurements were performed before loading, and after 1, 3 and 5 million load cycles at 4 different points on the pavement. The results (mean values) of the different tests are summarized in table 2. The mean texture depth of the porous concrete is relatively high, and remained practically constant throughout the test. The lower value obtained at 1 million loads is probably due to the particular test conditions (humid weather and wet pavement).

Table 2 Mean texture depth and friction coefficient measurements

Number of cycles	Initial (0 loads)	1 million load cycles	3 million load cycles	5 million load cycles
MTD (mm)	0.85	0.75	0.85	0.91
SRT (friction coefficient μ)	0.74	0.75	0.52	0.54
DFT20 (μ)	0.60	0.55	0.46	0.41
DFT40 (μ)	0.59	0.52	0.45	0.41
DFT60 (μ)	0.55	0.48	0.43	0.40

Figure 11 presents the evolution of the SRT and DFT measurements with the number of load applications. The SRT tests indicated a high initial friction coefficient (0.74), followed by a decrease after 3 million loads, and then a stabilization. After 5 million loads, (which represents a high level of traffic), the friction coefficient is equal to 0.54, which remains satisfactory, according to French practice.

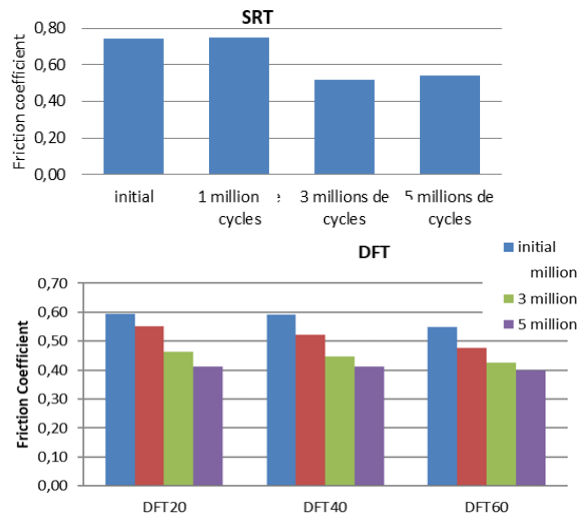


Fig. 11 Evolution of the SRT and DFT friction coefficients during the experiment

The DFT tests show a similar trend to the SRT, with a decrease of the friction coefficient in the first part of the experiment, followed by a stabilization. For this test developed in the USA, there are no specified values in France. However, the final value of DFT20 of 0.41 meets the requirements of the state of Louisiana for a conventional mix with a life of 15 years.

6 Conclusions

In the APT test, the Innovative Road Coating was submitted to 5 million loads, without presenting significant damage. The macrotexture did not evolve after 5 million cycles. The microtexture has decreased as expected, but still presented a satisfactory level after 5 million cycles. The SRT test gave relatively stable results between 3 and 5 million cycles, while the DFT friction test showed a continuous wear of the microtexture, with still acceptable values at the end of the test.

Measurements of cross-sectional profiles showed no significant deformation after 5 million passages, and no evolution of the joints.

The design calculations confirmed the durability of the structure tested here, which can support 20 years of traffic, with 500 trucks per day per lane, without any maintenance due to safety or structural requirements. The new material could then represent an excellent alternative as wearing course for concrete pavements for upcoming projects.

7 References

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