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A Cementitious Long-Life Wearing Course to Reduce Frequency of Maintenance Works on High-Traffic Roads

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Abstract

Under the framework of OECD/CEMT JTRC, an international team of road research laboratories worked together in order to evaluate technical solutions for long-life pavement. As a matter of fact, there are in many countries highly trafficked road sections where any traffic disruption brings high external costs. For such a case, the aim was to study wearing courses that could last several decades with no maintenance. The paper briefly presents an innovative technical solution, called HPCM (High-Performance Cementitious Material), consisting of a thin layer of ultra-high performance fibre-reinforced mortar with calcined bauxite aggregate embedded in the surface when in a fresh state. Many laboratory and two full-scale tests were carried out, dealing with surface resistance (abrasion, wear, shocks, freeze-and-thaw, acid attacks), cracking under restrained shrinkage and fatigue resistance due to heavy traffic loading. Although this material still requires some additional research to be implemented on scale-1 road sites, there are good expectations of its potential durability.

1. Introduction

Under the framework of OECD (Organisation for Economic Cooperation and Development), ECMT (European Conference of Ministers of Transport) and their Joint Transport Research Centre (JTRC), a number of road laboratories have worked together to develop the concept of a

long-life wearing course for highly trafficked pavements. The first phase of the JTRC-IM3 project indicated through an economic analysis, that, for some specific applications, it was worth studying technical solutions that could extend the service life for up to 20, 30 or 40 years, with no maintenance nor traffic disruption during this period [1]. In Phase II of the project, two technical families were evaluated; a bituminous and a cementitious surfacing. The innovative High-Performance Cementitious Material (HPCM) solution consists of applying an 8-mm layer of ultra-high performance, fibre reinforced fine mortar, in which hard, polish-resistant aggregate particles are embedded [2-4]. The paper gives the results of the HPCM material development. In conclusion, the perspectives opened by this new technology are briefly presented.

2. Design of the HPCM complex

One of the most important requirements of a wearing course is the need for good skid resistance, which is dependent upon the aggregate in the surfacing. For a long-life top layer, it is thus necessary to choose an aggregate with a superior polishing resistance. According to general experience, calcined bauxite, an artificial aggregate obtained by subjecting a natural mineral to a thermal treatment, is recognised as one of the best solutions. However, it is an expensive material, with limited suppliers: its unit cost may range from 30 to 40 times that of ordinary aggregates. Therefore, a *surface dressing* which only comprises a single layer of particles is relevant. Among available aggregate fractions, the 3-7 mm size has been chosen, because a maximum size of aggregate of around 6 mm tends to be the optimum size when a combination of adequate skid resistance and limited noise emission is required.

The next requirement is the design of the binder, the key function of which is to stick the calcined bauxite chippings to the pavement. When the option of using a hydraulic binder is taken, one must develop a fine material with the maximum tensile strength obtainable on site. From the experience gained with the ultra-high performance concretes [5-6], a design mix of sand, Portland cement, silica fume, superplasticizer and water, with a low water/binder ratio is suitable. As in the ultra-thin white topping technology [7], a good bond is expected between the cementitious mortar and the bituminous substrate. However, due to the shrinkage of the mortar which will be restrained by the pavement structure, cracking is likely to occur. To limit the crack opening, some sort of reinforcement is needed, but, given the thinness of the mortar layer, only fibres added to the mix are appropriate. The thickness of this fibre-reinforced mortar should be minimal for economic reasons. However, it should prevent the chippings from coming into direct contact with the asphalt layer. Moreover, the chippings/mortar composite should form a strong protecting layer for the lower pavement layers. Thus a thickness of 8 mm is selected for the mortar.

The following constituents were taken for the original mixture designs, based on previous experience of the participating laboratories:

- a 3/7 mm calcined bauxite from China
- an aeolian siliceous fine sand
- a Portland cement CEM I
- a light grey silica fume from Norway
- a polycarboxylate-type superplasticizer in powder form
- steel fibres with a length of 13 mm and a diameter of 0.2 mm
- alternatively, PVA (polyvinyl alcohol) fibres with a length of 15 mm and a diameter of 0.33 mm.

As for the mixture proportions, three ratios were fixed arbitrarily: the water/cement ratio (0.2), the silica-fume/cement ratio (0.2) and the dry superplasticizer/cement ratio (0.003), based on

previous experience. As for the fibrous reinforcement, both the type and dosage rate of the fibres had to be determined later, after the results of some specific tests.

A first mortar recipe was developed and tested among the different participants. Later, it was adjusted in order to get a more stable rheological behavior at the fresh state and a better bond, thanks to a softer consistency. Table 1 displays the optimised recipe used in most of the tests performed during the project. This mortar had to incorporate fibres in order to resist to the shrinkage-induced tensile stresses.

Table 1. Mixture-proportions of the plain mortar C.

Components	Kg/m^3
Siliceous coarse sand 0.2/1	429
Siliceous fine sand 0.08/0.315	429
CEM I Portland cement	985
Silica fume	197
Superplasticizer (dry powder)	4.40
Retarder	4.95
Water	207
w/c	0.21
Slump (cm)	21

3. Plain mortar tests

Table 2 displays the main mechanical properties of the mortar, with 4% PVA fibres. The shrinkage of plain mortar was measured on 7x7x28 cm specimens, from 1 day up to 250 days. The final autogenous shrinkage was about 650 microstrains, and total shrinkage at 50 % R.H. attained a value of 800 microstrains. Also, the coefficient of thermal expansion was found to be equal to 17.6×10^{-6}. Therefore, it was verified that this material has the ability to crack in restrained conditions, whatever the outer humidity; fibres are definitely required if cracking is to be avoided.

Table 2. Properties of the hardened mortar C with 4% of PVA fibres (fresh state properties: slump 23 cm, air content 4.5 %), after a 28-day curing at 100 % R.H.

Dimensions of specimens (cm)	Type of test	Mean value (MPa)
Prisms 4x4x16	Flexural	28.5
Prisms 4x4x16	Compressive	164
Cubes 10x10x10	Compressive	148
Cylinders Ø11x22	E-modulus	43 000
Cylinders Ø11x22	Compressive	129

The fiber reinforced mortar was also subjected to up to 25-million of flexural fatigue cycles. With at least 2 % of fibres, it was found that the material could resist, only showing a decrease and a stabilisation of the apparent E-modulus, whatever the nature of the fibres.

4. Cracking tests

The cracking tests were decisive in selecting the type and dosage of fibres. Two campaigns of in-situ cracking tests were carried out, where 6-m long, 14-cm wide strips were laid in parallel on an old asphalt pavement (see Fig. 1). After some months, it was tentatively concluded that either 3 % of steel fibres or 4 % of PVA fibres could equally well prevent cracking. The latter solution was preferred, owing to better workability and lower cost induced by these synthetic fibres. A large, 20x2 m test pad was cast, in order to check that no cracking would appear at full scale. Unfortunately, after a hot early summer, it was found that PVA fibres tended to soften; this reinforcement was then no longer able to overcome the crack development in the strips, unlike steel fibres. Consequently, the final solution recommended by the authors is to use at least 3% of steel fibres to eliminate any visible cracking. This finding is also confirmed by a series of laboratory cracking tests performed on the mortar phase.

Figure 1. Testing site for the cracking strips.

5. Surface resistance tests

Various tests were applied on laboratory specimens, in order to investigate the likelihood of surface distress under traffic. Rutting testers, with a cornering angle, resulted in a chipping loss of about 7.5 % in a HPCM specimen, a value that can be compared to 4.5 % obtained with a typical epoxy-asphalt surface dressing. ASTM abrasion tests showed the importance of the embedment process for limiting the amount of chipping loss. A more specific test using a tribometer (see Fig. 2) was then carried out on a series of wearing course materials. At 20°C, the performance of HPCM was intermediate between conventional bituminous materials and epoxy-asphalt materials (concrete or surface dressing). This result is quite satisfactory, given the fact that the temperature should not affect the HPCM behaviour in the 20-50° range, unlike bituminous materials, whose resistance rapidly drops when the temperature increases.

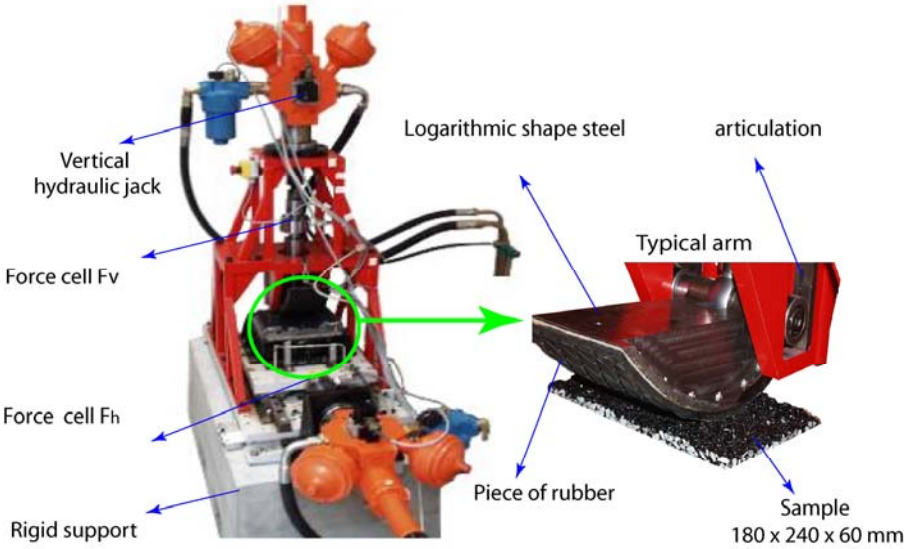

Figure 2. The 'Tribometer' test, recently developed at LCPC (France)

Climatic aggressions were simulated through conventional freeze-and-thaw scaling tests, normally devoted to conventional cement concrete. The results obtained led to classify HPCM behavior in the 'very good' category. Then, a more aggressive test called 'total test', encompassing acid attack, freeze-thaw and shocks was carried out. In the absence of a control material, no HPCM classification can be deduced from this last tests. However, it was found that with up to 20 % of chipping loss, the texture characteristics and skid resistance of HPCM are hardly affected, showing the level of safety that can be attained with such a wearing course material.

6. Miscellaneous

The original texture of a cracking strip was acquired and processed through software aiming at simulating the noise generation likely to occur under traffic. It was found that HPCM should behave as an exposed-aggregate cement concrete of similar texture.

Finally, a key performance test was carried out with the TRL Pavement Testing Facility (TRL, see Fig. 3) including an equivalent of 1.0 M standard axles at 20°C, followed by 0.5 M standard axles at 35°C. This structural test could help in evaluating a pavement structure with various wearing courses, even if the number of loading cycles remained small with regard to the expected traffic for a long-life pavement.

Figure 3. The TRL Pavement Testing Facility (Crowthorne, UK)

Three test pads were tested, covered with HPCM, SMA (stone-mastic asphalt) and EA (epoxy-asphalt) concrete, respectively. The loading programme at ambient temperature only provoked a slight level of rutting, which greatly amplified when temperature was raised. The HPCM succeeded in limiting the rutting level to 1.5 mm, although much higher values were attained with the epoxy asphalt (6 mm) and the SMA (8 mm). The HPCM surface remained sound, with a high skid resistance resistance (SRT value of 92). Thin cracking was observed in the two long-life pavement candidate materials, and some delamination happened at the edges of the HPCM pad in the bituminous base course. This distress was due to the rutting of the base course and the lack of tensile strength at 35°C. It was therefore concluded that HPCM had to be applied on a quite stiff asphalt concrete, with a low rutting and a low sensitivity to temperature. These requirements are a direct consequence of the search for a long-life pavement, whatever the wearing course could be.

7. Conclusion

A new material for a long-life wearing course was developed through a large, collaborative scientific project involving 13 countries, of which 7 were active participants. The main idea for the design of HPCM is the use of best quality materials in minimal quantity. The data acquired in the phase II program are globally encouraging, and one may expect a much longer lifespan, as compared to current asphalt wearing courses (which last generally between 7 and 15 years). The authors are now looking forward to participating in phase III, where practical implementations on trafficked test sections will be carried out. Further research will be necessary during this next phase to develop a suitable construction facility, and to investigate the sensitivity to water dosage and two-dimensional cracking behavior.

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