Cold bituminous mixtures for wearing courses

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Abstract

The potential benefits related to a reduction in energy costs, of risks to the environment as well as to improved safety for workers lead to an increasing interest for the use of paving materials bound with bituminous emulsions. Up to now, the mechanical properties achieved with this kind of technology remain however lower than those reached by hot mixes. This has restricted its use to roadbase materials (gravel-emulsion) or to maintenance works (micro-surfacing) on light or medium traffic roads. The design of true cold bituminous concrete wearing course mixes, which may be laid in lifts of several centimetres, is confronted to rather challenging technical issues, especially with regard to the manufacturing and laying conditions allowing to reach sufficiently high mechanical properties. This communication presents the systematic approach which has been undertaken by the EUROVIA company so as to develop cold bituminous concrete. This effort has particularly benefited from the outcome of the European OPTEL project. This project, which has been run with several industrial partners and research organisations, has especially contributed to a better fundamental understanding of the product. Our practical experience as a road building contractor further leads us to the statement that the optimisation of cold mixes call for a change in our traditional way of thinking, stemming from the formulation methods for hot mixes. These thoughts have allowed us :

- to develop specific laboratory tools for a better appraisal of the behaviour of these materials at the different manufacturing and laying stages,
- to elaborate the general frame of a mix design method suitable for cold mixtures,
- to adapt our manufacturing (mixing plant) and laying equipment.

The paper also presents the state of the validation studies which have been conducted so far in the frame of various full-scale experiments.

KEYWORDS : Cold mix, Emulsion, Formulation, Workability, Equipment

1. INTRODUCTION

For various technical and economical reasons the technology of dense cold mixes, more precisely of cold bituminous mixtures for wearing courses, has not yet achieved any real breakthrough. From a strictly technical point of view, it is true that this technology has to overcome rather difficult specific problems. To be successful, it will probably not be enough to look for new products and processes but it will also be necessary to "free" ourselves from the thinking patterns and the design methodologies stemming from many years of hot mix formulation practices. This is what we will try to illustrate in this communication.

2. COLD BITUMINOUS MIXTURES : PROBLEM STATEMENT

The performance of bituminous mixtures in general is basically conditioned by their formulation (choice and dosage of constituents) and the conditions under which they are mixed, laid and compacted. In the case of hot mixes, the manufacturing and laying processes are essentially dependent on the temperature of the binder and the "final" product is obtained as soon as the mixture has cooled down to ambient. Since temperature can be easily controlled in the laboratory, it is quite easy to manufacture realistic test samples, i.e. with a compacity close to the one expected in-situ.

Things are completely different for cold bituminous mixtures which incorporate a bituminous emulsion, i.e. a binder which is highly evolutionary over time. Indeed, emulsion breaking and coalescence phenomena are initiated as soon as this binder comes into contact with the mineral aggregates. These processes must be mastered all along the successive mixing, transportation, laying, compacting and in-place curing stages. Final compacity and, hence, the final mechanical performance of a cold mix will be very heavily conditioned by the way the water resulting from the breaking of the emulsion will drain out of the mixture. We are no longer dealing with a unique binder but rather with a bitumen + water composite which must be optimised (choice and dosage of emulsifiers and bitumen) with regard to these different phases.

To be realistic, laboratory formulation studies can no longer be as simple as for hot mixes. They must indeed reproduce the emulsion breaking and water drainage processes which occur at the various stages of manufacturing and laying. Moreover, the final mechanical properties have to be measured on samples from which the water has been drained out through an accelerated procedure without altering its structure and properties.

Under such premises, the procedures and criteria used for the design of hot mixes can obviously not be applied as such to cold mixes. The problematic of designing cold mixes raises a number of specific needs, ranging from a better fundamental understanding of the underlying phenomena to the design of ad-hoc laboratory tools. In this respect, we have been able to benefit from and sometimes to further develop the findings from the European OPTEL project (Potti, 2002).

3. CONTRIBUTIONS AND FURTHER DEVELOPMENTS TO THE OPTEL PROJECT

3.1 Intrinsic constituent properties

OPTEL has more particularly shown the importance of aggregate reactivity as well as of specific emulsion properties.

3.1.1 Aggregate reactivity.

To quantify the reactivity of a given aggregate, OPTEL has more particularly shown the interest of a rather simple procedure which can be easily used in the frame of a mix design methodology. The so-called "rise in pH" test simply measures, as a function of time, the change in pH of an acidic water solution containing a certain amount of filler of the considered aggregate (10g for 200 ml of water at pH = 2). Such tests have allowed to clearly differentiate aggregates with a basic or acidic behaviour. In the case of aggregates which are only weakly or moderately reactive, our studies have however shown that one should get as close as possible to real conditions by increasing the exposed surface area of the filler (Delfosse, 2002).

The curve giving the evolution of pH with time is thus a criterion for aggregate reactivity from which we may derive guidelines for the choice of an adequate emulsifier/acid combination. This information needs however to be coupled with the value of their specific surface. Indeed, both it are these two values which will allow to optimise both the specific surface of the emulsion and its residual emulsifier content.

3.1.2 The key characteristics of the emulsion.

As far as the emulsion is concerned, it is the particle size distribution, rather than just the binder content, which is linked to the specific surface and, consequently, to the coating ability of the emulsion. Similarly, whereas the breaking index only gives a rough overall information depending on several factors (amount of residual emulsifier but also binder content and particle size distribution), it is the effective amount of residual emulsifier which needs to be adjusted in relation to the reactivity and the exposed specific surface of the aggregates !

Particle size distribution together with the viscosity and the chemical nature of the bitumen do also play a major part in the breaking and coalescence phenomena which control the rise in cohesion of cold mixes. OPTEL has thoroughly investigated these processes (Leal Calderon, 2000, 2001). According to a classical scheme, the different steps are as follows : close-up of two bitumen droplets, drainage of the film of water separating them and, finally, merging of the two droplets (coalescence). OPTEL has shown that small particles should allow to retard the onset of coalescence (breaking of the emulsion) but then lead to a fast evolution (contraction).of the system of interconnected droplets. The contraction process is heavily dependent on bitumen viscosity. For droplets of 10 microns, the characteristic relaxation time is about several hours for a 70/100 bitumen grade whereas it is only a few minutes for a 160/220 bitumen grade. The speed of the contraction phase is also related to the chemical nature of the bitumen and its interfacial tension. This explains why naphtenic type bitumens are given the preference in micro-surfacing applications.

3.2 Formulation tools

As it has been stated earlier, the laboratory optimisation of cold mixes requires specific tools for a correct appraisal of the complex aggregate-emulsion interactions occuring at the different stages of manufacturing and laying. OPTEL has more particularly worked on following items :

- The measure of the workability of cold mixes immediately after mixing
- Water drainage during compaction
- A procedure for accelerated curing

3.2.1 Workability tests

To assess the workability of cold mixes, NYNAS has developed a specific equipment and procedure. The test consists in measuring the resistance to shear of a sample of the loose mixture moulded into a shear box just after mixing. One records the maximum force, called “cohesive strength”, which is developed by the material when sheared at a given speed (Figure 1). The evolution of cohesive strength in relation to curing time is a measure for the workability of the mix. The test being destructive, it is necessary to prepare a sufficient number of shear boxes to determine the evolution of cohesive strength in relation to curing time.

Various tests performed with this equipment have shown that workability is heavily conditioned by a large number of factors pertaining as well to mix formulation (contents in bitumen, emulsifier, water, …) as to environmental conditions (temperature, hygrometry). As an example, we show hereafter the incidence of the amount of residual emulsifier. The low values of cohesive strength obtained at a level of 0.3% have been ascribed to an heterogeneous coating resulting from the premature breaking of the emulsion. A higher amount of residual emulsifier (0.6%) leads to a better coating and a deferred breaking which explains the observed increases in cohesive strength (Figure 1).

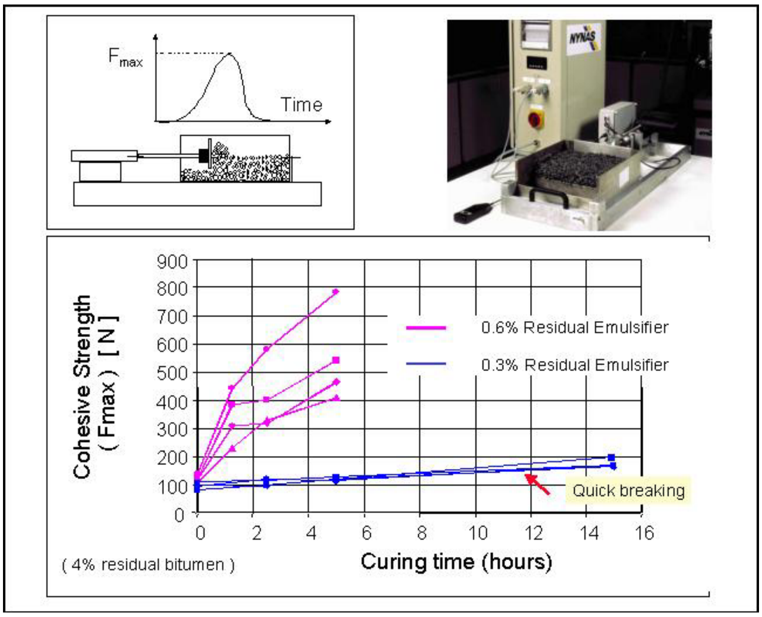

Figure 1 – OPTEL : Workability tests

When confronting these results to in-situ experience, we have however often observed that the material delivered by the mixing plant or at the job site is often more cohesive (less workable) and more evolutionary than suggested by the workability test. These observations have led us to question the standard sample preparation procedure (Delfosse, 2002). Indeed, in the method used so far, the material is manipulated several times from the mixing stage to the final moulding of the test sample which, by destroying a certain amount of the early connections, may prevent the build-up of initial cohesion and lead to "flat" workability curves which do not correspond to the reality as seen on job site. We have thus replaced the standard procedure with a modified method in which the workability test sample is moulded immediately after mixing, without any intermediate handling, thanks to a laboratory mixer with two parallel horizontal mixing shafts equipped with an emptying trap at the bottom of the mixing vessel (Figure 2).

If one admits that the early cohesion of the material may be destroyed by the sample preparation procedure, this may also be the result of an extended mixing time, especially for emulsions which break quickly in the presence of aggregates. We have tried to back-up these assumptions through a small experimental program on the impact of mixing time (10s to 60s of mixing with the emulsion after 10s of aggregate mixing) and sample moulding procedure ("standard" versus modified method).

The results we obtained (Figure 2) show that the cohesion values measured with the workability tester are indeed dependent on the degree of breaking of the emulsion which in turn depends, for fast breaking emulsions, on the mixing time. For short mixing times, breaking is incomplete and continues after the moulding of the test sample. Although the quality of aggregate coating may be average, bitumen "bridges" are then formed between the particles, which explains why high cohesion values after 2 hours are high and continue to grow between 2 and 4 hours. Extended mixing ensures a more complete breaking of the emulsion but does probably also destroy the early "bridges", leading to a more "dry" material which opposes less resistance and does not evolve anymore in time. The additional manipulations of the material generated by the "standard" specimen moulding procedure further amplify these phenomena. Both procedures lead to similar results for extended mixing times (60s).

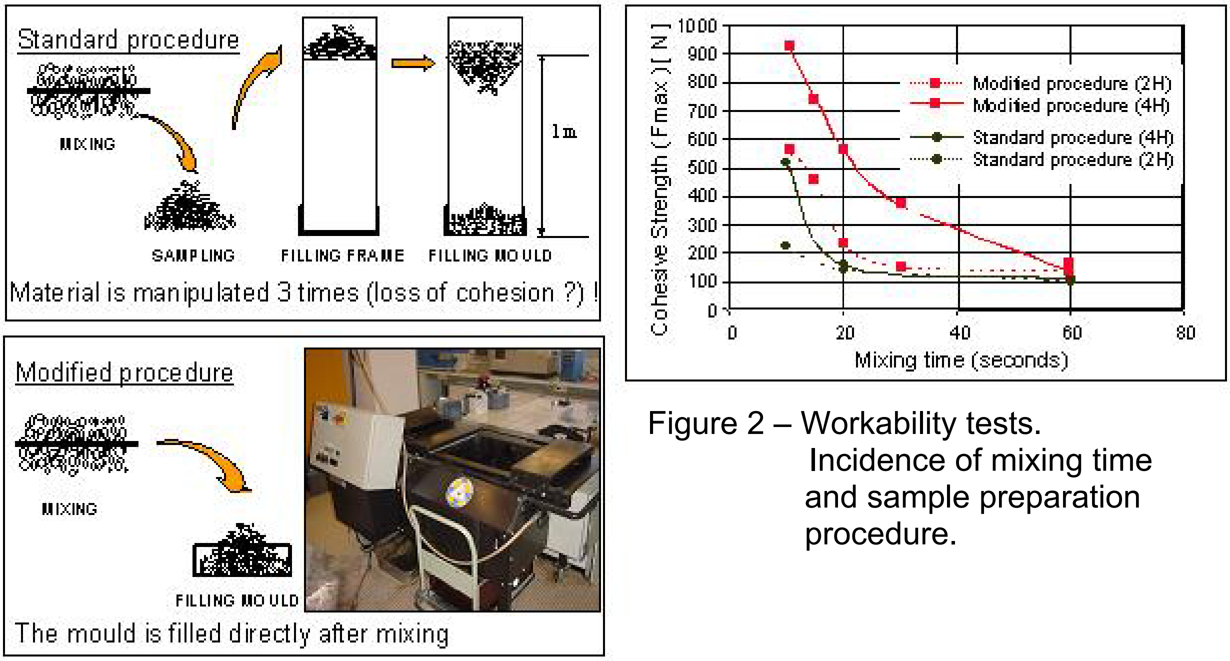

Figure 2 – Workability tests. Incidence of mixing time and sample preparation procedure.

3.2.2 Compacting ability

OPTEL has investigated the behaviour during compaction by the means of a gyratory compactor equipped with a water sucking device (Lesueur, 2000). The recording the evolution of "voids filled with air" and "voids filled with water" in relation to the number of gyrations (under a vertical pressure of 600 kPa, an angle of 1° and a speed of 6 rpm) evidences a particular point (Ne, Ce) which corresponds to the onset of water drainage Theoretically, one may think that the in-situ compacity should stay constant once the Ce value has been reached. Indeed, real life compaction should then move the water inside the mix without drainage. This theory could be checked in the laboratory by a comparison to results obtained with the slab compactor. Since the later is less effective than real compactors, one may think that the final in-situ density should be at least equal or slightly higher than the Ce value from the PCG. On-site density measurements did however not show a good agreement with the Ce values from the PCG test. Different factors can be called upon to explain these divergences, such as the difficulty of measurements of in-situ density in the presence of a barely known quantity of water or the fact that the compacting schemes of the various sections were not identical.

3.2.3 Accelerated curing procedure

Laboratory formulation requests a means for evaluating the final mix properties. To that end, OPTEL has worked on a sample curing procedure allowing to accelerate the drainage of residual water by adjusting temperature and hygrometry (Le Bec, 2000). For that purpose, we have simultaneously monitored the evolution of residual water content and of the compressive strength of DURIEZ samples compacted at only 30 kN so as to obtain void contents similar to those usually observed on site (~ 14%). It has been found that increasing the temperature while maintaining hygrometry (50% relative humidity) does not allow to significantly accelerate the departure of the water. It is much more efficient to reduce hygrometry. For instance, at 50°C and only 10% of relative humidity, the water content stabilises after only 3 days of curing. Under these conditions, 5 days are enough to reach a compressive strength which is only obtained after 30 days under the reference conditions (18°C – 50% Hum.) ! But one does always get a final stage during which strength continues to grow while the amount of residual water drops only very slowly to an apparently ultimate limit of about 1% (in this example) (Figure 4). In comparison to the in-situ behaviour, some questions remain however unanswered :

- Is the residual water trapped in the same way ?
- Is the increase in cohesion occurring after the stabilisation of the water content really representative ?

One may guess that, for both questions, temperature and the impact of bitumen rheology on coalescence, are of importance. This suggests that it is probably a better choice to accelerate the drainage of the water by reducing relative humidity rather than by increasing the temperature ! In this respect, we believe that the conditions (35°C – 20% of relative humidity) suggested by some of our colleagues (Serfass, 2003) may be a good compromise.

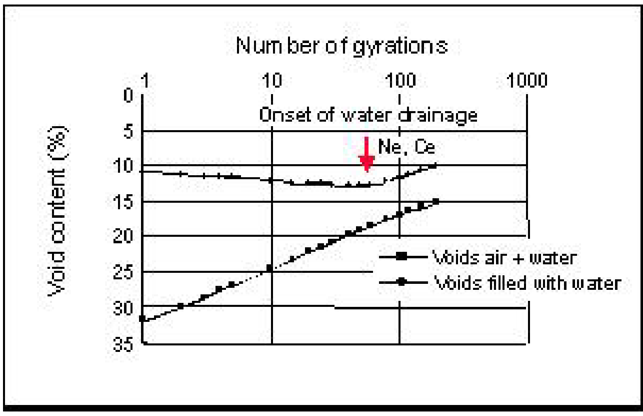

Figure 3 – OPTEL. Gyratory compaction with water sucking device.

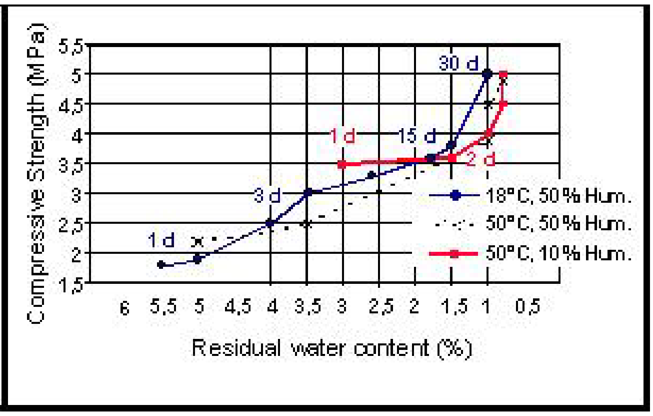

Figure 4 – OPTEL. Accelerated curing procedures.

4 HOW TO DESIGN COLD MIXES ?

4.1 New targets for the laboratory studies.

From what has been stated so far, a methodology for the laboratory formulation of cold mixes must include test methods allowing to quantify :

- The reactivity and the specific surface of the aggregate, i.e. its impact on the stability of the emulsion.
- The behaviour of the mix during each of the successive mixing, laying and compacting stages, as well as during curing.

Even if, as it has been illustrated for the workability test, we may continuously improve the presently available test methods, we must however admit that an accurate reproduction at laboratory scale of the conditions prevailing during mixing, laying and compacting remains largely out of reach. This is however not a reason to give them up ! Rather than expecting these tests to deliver absolute values, it is enough if they are sufficiently "sensitive" to the different involved parameters to correctly guide the designer in its choices. Considering the experiments conducted within the OPTEL project as well as our own work, we believe that this is perfectly possible.

The limitations of laboratory tools as well as the important variability of manufacturing and laying conditions do also lead us to assign specific objectives to the formulation study as such. Rather than to strive for an "optimal" solution, i.e. a precise formulation leading to a maximal performance, we believe it to be more judicious to look for solutions which are :

- "Robust", that is to say little sensitive to the fluctuations of the various parameters such as water and filler contents, temperature, ….

- "Flexible", that is to stay allowing rapid adjustments, at manufacturing and laying stage, to unexpected variations of the above mentioned parameters. Such a flexibility may for instance be obtained by the use of additives to be incorporated into the water added at mixing stage.

4.2 The industrial tool must evolve as well ….

Also the industrial equipment must adapt itself to the specificity of cold mixes.

The quite different workability of cold mixes, which have higher internal friction and are more sticky than hot mixes, calls for some modifications on the conventional paving machines. For instance, laying can be made easier by limiting the amount of mix fed into the paver and placing less weight onto the paver screed.

At compacting stage, the need for ensuring a maximum of water drainage should lead to a re-thinking of parameters such as the frequency and amplitude of roller vibrations, the applied load and the compacting scheme.

But it is essentially for the mixing equipment that the major improvements are likely to be achieved. It is indeed at this stage that coating should be optimised since it provides an essential contribution to the workability and to most of the future performance properties of the product. It is also at mixing stage that a maximum of flexibility is required so as to allow to compensate the fluctuations in materials and climatic conditions. The mixing plant must thus offer a maximum of possibilities, more particularly with regard to :

- the energy and duration of the mixing,
- the feeding of the different component materials to the mixing shaft,
- the dosage and the repartition of the emulsion during mixing,
- the introduction of the added water,
- the incorporation of additives into the added water.

5 FIRST TRIALS

Already in 2000, EUROVIA had experimented, on three job sites in Maine-et-Loire, the application of fluxant free cold wearing course mixtures conforming to the French NF P98-139 standard “ Couches de roulement : bétons bitumineux à froid “. These jobs have namely allowed to significantly improve the design of the cold mixing plant (Figure 5).

Following the Maine-et-Loire trials, which had been performed with aggregates of low reactivity, a number of small « feasibility » trials performed in 2000 and 2001 have allowed to apply the findings from OPTEL and to better tailor the formulation of the emulsion in relation to the aggregates. They also helped in adjusting the operating conditions for laboratory tests, especially with regard to workability.

In 2002, these efforts did materialise in the form of an “Innovation Chart” signed with the General Council of the Côtes d’Armor Department and the SETRA (Technical consultancy body for Roads and Motorways). More than 450 tons of a 0/10 mix, at an average application rate of 80 kg/m², have been applied on the RD28, close to Kerpert (Figure 6). The objective assigned to this trial, i.e. the mastering of a reactive local aggregate with a non-fluxed 65% emulsion of pure bitumen (70/100) has been perfectly reached. Despite poor meteorological conditions (cool weather and fine drizzle), the mix placed itself very well and did not lead to significant losses of aggregates.

Much remains however to be done. Although the mix could be effectively mastered with regard to workability, the void contents after compaction remain however too high and the mechanical properties too low to allow this product to be exposed to high traffic or excessive shear stresses. Improving the built-up of cohesion has now the priority in our research program.

Figure 5 – Mixing plant.

Figure 6 – Experimental stretch.
CD28 – Kerpert.

6 CONCLUSION - THE REQUIREMENTS OF A NEW TECHNOLOGY

The outcome of the above mentioned works and thoughts lead us to following summary on the new specific requirements for the development of dense cold mixes :

- A better fundamental understanding of the way such materials behave.
- Laboratory tools allowing to evaluate the behaviour of these materials during the different stages of manufacturing and laying. It is more particularly necessary to assess their sensitivity to fluctuations of the various involved parameters.
- The search for "robust" and "adjustable" rather than for "optimal" solutions.
- The modification of manufacturing and laying equipment, more particularly in such a way that they can easily accommodate fluctuations in material characteristics and climatic conditions.

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