OUTLINING SPECIFICATIONS FOR COLD MIXES IN ROAD CONSTRUCTION AND MAINTENANCE

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Cold mixes, more precisely those made with emulsion, have several specific features (presence of water, aggregate-emulsion, reactivity, properties evolving with time). Their behaviour, in many respects, different from that of hot mixes. Diverse types of cold mix have now reached a considerable level of development: grave-emulsion, open-graded cold mix asphalt concrete, stockpile mixtures. Others, like dense cold mix asphalt concrete, have not been extensively developed yet; some are still at research stage. The various types of cold mix are described. Until recently, there was only a small number of design methods for cold mix, which are almost totally empirical. The tests comprised in these methods are mainly derived from tests for hot mixes. It is therefore not surprising that the specifications applicable to cold mixes are still limited and, sometimes, not fully adequate. An important research has been conducted recently. It has produced a specific design method for cold mixes. The main steps of this method are presented: coating quality, early cohesion, compactability, accelerated curing, water sensitivity, rutting resistance and stiffness modulus. The tests have been selected in order to support performance - based specifications. On the other hand, several site sections cold mix pavement and/or wearing courses have been monitored. The output of the long term monitoring has been compared to the results of laboratory evaluation. This exercise results in a more precise definition of the field of application for each type of cold mix, in terms of position in the pavement, thickness, allowable traffic, etc. Globally, the knowledge of cold mix properties has been improved. The cold mix behaviour modelling has progressed and more adequate pavement design can be performed. Complete and suitable specifications can be drafted.

KEY WORDS

COLD MIX / EMULSION / DESIGN METHOD / SPECIFICATIONS

Cold mixes have been used in a number of countries for decades. Although they are of various types, they are essentially intended for the maintenance and rehabilitation of pavements carrying light or moderate traffic. However, as a result of research conducted in various places, products with better performance have been developed. These innovations mean that the scope of application of cold mixes can be progressively extended to involve heavier traffic and new construction.

It must be admitted, however, that the specifications for cold mixes are still limited, or even embryonic, and frequently bear no relation to the material in situ behaviour.

1. - MAIN FEATURES OF COLD MIXES

It should be made clear that the cold mixes addressed in this paper are granular mixes that include bitumen in the form of an emulsion. Fluxed or cutback bitumen mixes, which are environmentally unfriendly, are not dealt with.

Emulsion cold mixes, particularly in their early age, behave in a specific manner which differs from hot mixes in numerous respects.

- The presence of water has an enormous influence on early age behaviour. Water plays a valuable role during laying as a lubricant, but then it delays the formation of a solid film of binder which means the material remains fragile until coalescence of the binder droplets is complete.

- Chemical reactions at the aggregate-emulsion interface have important impacts on the quality of coating.

- Cold mixes are evolving materials. In their initial state, some behave like unbound materials; they build up a high level of cohesion, gradually ending up as a highly bound material similar to a hot mix.

- A cold mix invariably has a higher early age voids content than an “equivalent” hot mix. Recent research has shown that the voids in a cold mix are considerably smaller than in an “equivalent” hot mix. The very small voids produced by the coalescence of bitumen droplets are embedded within the coating binder or mastic, and compactors are unable to remove them. They only disappear, very gradually, under the combined effects of curing and consolidation under traffic. The initial density does not therefore have the same significance in a cold mix as in a hot mix. With our current state of knowledge, we have to accept lower levels of initial density for cold mixes. In the long term, however, we can hope that densities approaching those of hot mixes will be achievable.

2. – THE VARIOUS MIXES

2.1 - Terminology

To improve and, in some cases, to supplement the current terminology, the following definitions are proposed:

- First, as has been stated above, it must be made clear that the term "cold mix" implies the use of an emulsion. The term cold mix will include any bituminous mix:
  . whose final preparation takes place without drying or heating,
  . which is laid at ambient temperature.

- For wearing courses, we propose systematic use of the term "cold mix asphalt concrete" (CMAC). These could be defined as follows: “Cold mixes, either non-storable or storable only for a short duration, used solely for wearing courses with 0/D or d/D particle size distribution, of which all or some of the aggregate has not been dried and in which all the aggregate particles are covered with a binder film”.

- For pavement layers we propose the following definitions:
"Grave-emulsion (GE): “a mixture of 0/D well-graded aggregate and a bitumen emulsion in which the binder is fixed preferentially to the mortar fraction. It can be used in pavement layers or for reshaping. It may be storable for the latter purpose."

“Base cold mix asphalt (BCMA): a non-storable cold mix which is used only in pavement layers, with 0/D grading in which some or all of the aggregate particles have been coated with bitumen (modified or not), in which at least some of the aggregate has not been dried and in which all the aggregate particles are covered with a film of binder”.

- Lastly, stockpile cold mixes (SMC) can be defined as follows: “cold mixes that can be stored for several weeks or months and that are intended for routine maintenance (patching, levelling, etc.) or for small jobs. They are only able to play a structural role in the pavement in the case of very light traffic (to be specified)”

These definitions can be applied to products from all types of mixing plants. Furthermore, they include mixes one of whose constituents may have been previously manufactured hot (for example aggregate from cold–recycled mixes or double-coated mixes).

Table 1 summarizes the types of cold mix and their normal ranges of thickness.

Table 1 - Types of emulsion mix and their usual thicknesses

Use	Wearing course		Pavement layers			Reshaping		Routine maintenance	Small jobs
Type	CMAC		GE		BCMA	GE		SMC	SMC
Storability	No	Yes (limited)	No	Yes (limited)	No	No	Yes	Yes	Yes
Thickness (cm)	5-8 3-5 2-3	- 3-5 2-3	6-12	6-10	6-12	0-12	0-12	N/A	Variable

2.2 - Some remarks concerning the different types of cold mix

- Cold mix asphalt concrete (CMAC) can either be dense (0/D granular composition with a high sand and fines content) or open-graded (d/D with no, or a very low, sand and fines content).

- Grave-emulsion (GE) draws some of its properties from the fact that the binder is fixed preferentially to the mortar. Its binder-rich mortar fraction and the fact that a relatively soft bitumen is used make grave-emulsion flexible, sticky and ensures it has good healing capability. This material is therefore particularly appropriate for laying in variable thicknesses, for reshaping or for laying on substrates with high deflection. However, it is not unusual for the large particles to be poorly coated.

- Base cold-mix asphalt (BCMA) differs in that the binder is more uniformly distributed between the various granular fractions and the material has a higher stiffness. This material is essentially intended for use in base or sub-base courses.

3. - MIX DESIGN METHODS FOR COLD MIXES

3.1 - The shortcomings of the current methods

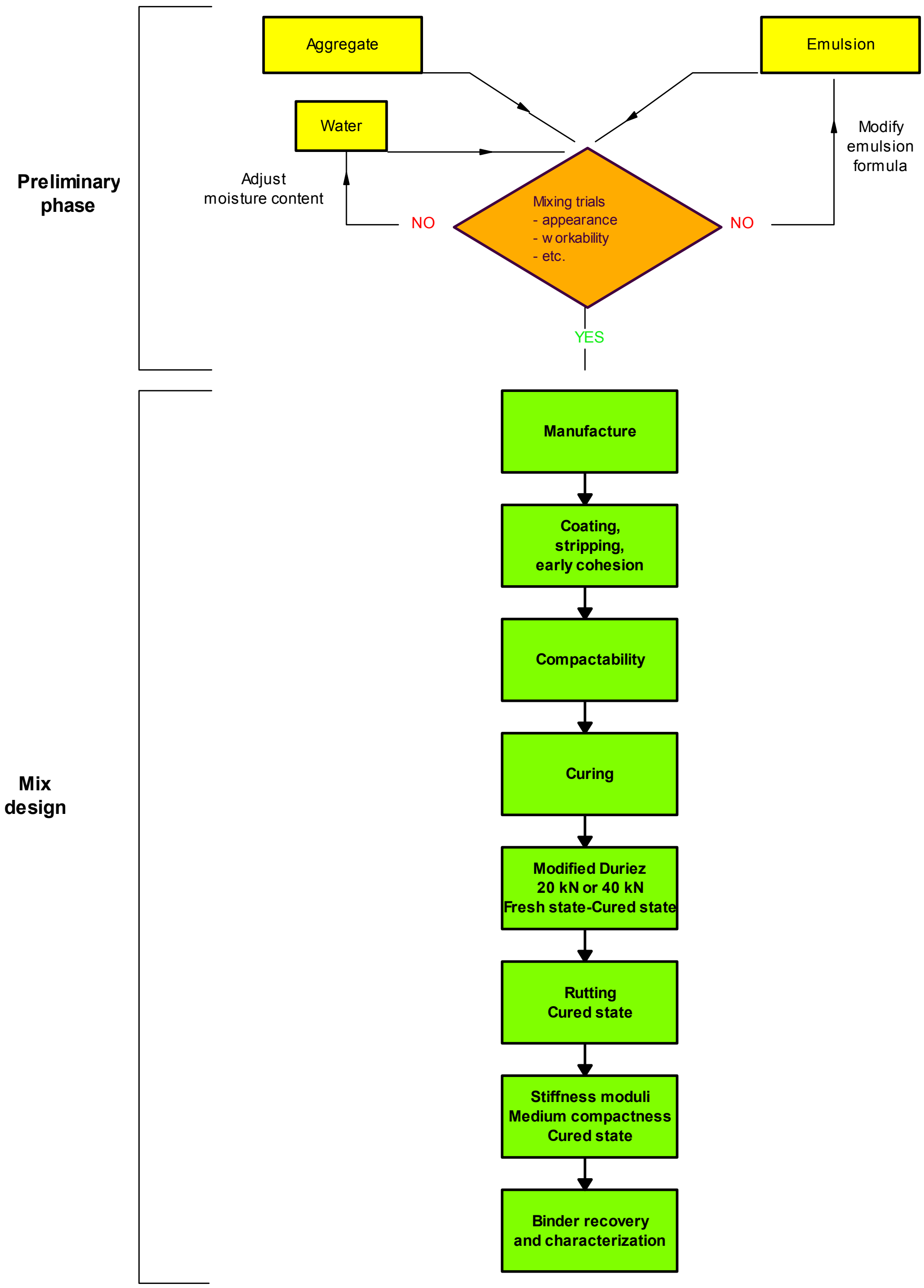
Current methods are of the “recipe” type in which the characteristics of the ingredients are specified and standard formulations are given. Generally, one or two mechanical strength tests are recommended, for example an unconfined compression test (such as the Duriez test), an indirect splitting tensile test (such as the Marshall test), Hveem stability, etc. with threshold values that aim mainly to distinguish between mixes but with no established relationship with in situ behaviour.

Accelerated curing procedures are laid down, but they are usually short and, here too, the link with likely in situ behaviour has not been demonstrated. More broadly, there is no complete appraisal method that has been recognized and validated by the technical community for cold mixes

3.2 - Proposed method

In order to fill this gap, our group launched a major research programme in 1997, that resulted at the end of 2000 in a method whose different steps are illustrated in figure 1.

Figure 1 – Flow chart showing the proposed design method



This method has been described in various publications (Serfass, 2002). When combined with observations of in-place behaviour, it should enable us to improve our knowledge of cold mixes and permit the development of performance specifications.

4. - SOME TENTATIVE SPECIFICATIONS FOR THE MIX DURING MANUFACTURE AND LAYING

4.1 - Preliminary phase: selecting and proportioning the constituents

Every country has its own specifications for aggregate selection. These are more or less justified by experience and cannot be described in detail here. Aggregate for cold mix asphalt concrete (therefore for wearing courses) is subject to the same stresses as that used in hot bituminous mixes. It must therefore meet the same specifications with regard to hardness, resistance to wear and polishing, angularity, shape, etc.

Formulation of the emulsion is essentially a matter of the manufacturer know-how. Local specifications generally specify a category of emulsion, defined in terms of breaking rate, binder content, etc. In passing, it is pointed out that the base bitumen can vary from 35/50 pen (in hot countries) to V 12 000 (in Scandinavian countries).

The aggregate grading curve is largely determined on the basis of experience. Each country using cold mixes has laid down grading envelopes. Almost all the grading curves are of the continuous 0/D type (in order to achieve immediate mechanical stability).

Starting with the data given above, the mix design is refined on the basis of manual mixing tests conducted in a bowl. Visual observation provides information about the compatibility of the ingredients, the general appearance and the consistency of the mix etc. This permits the decisions regarding the choice of constituents to be validated or modified and the water content to be adjusted. If required, the emulsion is reformulated in order to achieve an acceptable mix. This stage is empirical and based to a considerable degree on the experience of the mix designer.

4.2 - Mix manufacture

At the present time, there is no laboratory mixer that accurately replicates a mixing plant. In addition, it seems unlikely that a device of this type could be constructed at reasonable cost. We therefore need to make do with existing devices: vertical shaft - and - paddles mixers or closed twin-shaft pugmills.

Our research has demonstrated that the temperature of the materials during mixing is extremely influential. In order to eliminate any bias and facilitate comparisons, we propose that a temperature range representative of average local conditions should be specified. For temperate regions such as Western Europe, the recommended range is 18 - 25°C which is easily obtainable in all laboratories.

For other parts of the world, the manufacturing temperature needs to be adjusted in line with the probable local conditions at the time of the works. For example, a temperature of 30 - 40°C is suggested for very hot regions or 10 - 20 °C for cold regions.

4.3 - Quality of coating

Field observations have shown that the quality of coating varies a great deal depending on the constituents and technology employed. Partial coating is acceptable for materials used within the pavement, such as grave-emulsion, as it will be protected by a surfacing. However, full or almost full coating is necessary for cold mix asphalt concrete used in wearing courses, as, without it, the materials are highly sensitive to water and there is a high risk of aggregate dislodgement.

The quality of coating can be quantified by the percentage of mineral surface covered by the bituminous binder. The ideal way of measuring this is by image analysis, that quantifies the grey levels including those of the virgin aggregate. If the laboratory does not possess image analysis equipment, evaluation can be made by averaging the estimates made by three observers.

4.4 - Sensitivity to mechanical stripping

In the field, it has been observed that some cold mixes, well coated when discharged from the mixer undergo partial stripping (in particular of the large aggregate particles), as a result of the various manipulations to which they are subjected. Four successive procedures have been specified in order to evaluate sensitivity to such a problem:

Table 2 - Laboratory manipulations and simulated worksite operations

Laboratory manipulation	Simulated worksite operation
Storage in a mixing bowl, under a weight	Stockpiling
Short mixing	Loading
Cylinder moulded under a low load, then crumbled	Shear in the paver screws or under the grader blade
Pressing of a rubber disc onto the cake of mix, followed by removal	Rolling by a pneumatic-tyred wheel

After the three last manipulations, the percentage of the aggregate surface that remains coated is quantified. On the basis of our current state of knowledge, the following specifications are suggested:

Table 3 - Suggested specifications for coating quality

Type of cold mix	Minimum coated surface area after manipulations (%)
Dense-graded cold mix asphalt concrete	90
Open-graded cold mix asphalt concrete	90
Base cold mix asphalt	75
Grave-emulsion	60
Maintenance stockpile mix	90

4.5 - Compactability

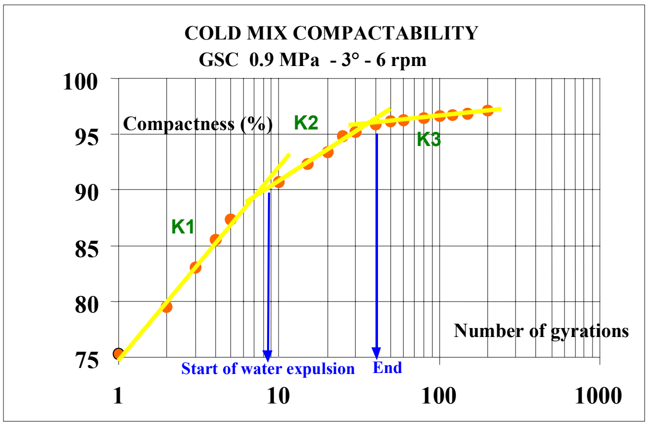
Studies conducted with the Gyratory Shear Compactor (LCPC type 1 or 2) adjusted in the normal way for a hot mix (0.6 MPa - 1°- 6 rotations/min) seem to essentially reflect the behaviour of the granular skeleton. With these settings, the Gyratory Shear Compactor is therefore not very indicative for the various cold mix formulations (Poirier, 2002).

Trials have led us to adopt different settings:

- pressure: 0.9 MPa – gyration angle: 3°- rotation speed: 6 rpm

Used in this way, the Gyratory Shear Compactor provides much more information. The densification curve (figure 2) can be broken down into three almost straight sections. The first (slope K1) corresponds to the elimination of air. The density at the point where the slope changes (intersection K1 - K2) is roughly what could be expected from well-performed worksite compaction. The second (slope K2) corresponds to expulsion of water. The third (slope K3) is almost horizontal. The density at the intersection between K2 and K3 is approximately the density the mix will reach in the long term under traffic.

Figure 2 - Densification curve using the proposed Gyratory Shear Compactor procedure



The Gyratory Shear Compactor must be fitted with a water draining and collection system. The number of rotations and the density at which water expulsion begins and ends are recorded. These two points are normally near the two points of intersection K1 - K2 and K2 - K3 respectively.

It is hoped that this test will provide a means of specifying the level of density that should be achieved after compaction. At the moment, there are too few available results for figures to be established. In addition, research is continuing in order to determine how other types of Gyratory Shear Compactor could be used for the same purpose.

5. - CURING

As the characteristics of emulsion cold mixes change considerably in the very early stages of their life, it is essential to define a laboratory curing method. This must obviously be accelerated so that the studies do not take an unreasonable amount of time.

Several curing procedures have been evaluated. The (very much summarized) conclusions are as follows:

- At low temperature (5°C), almost no curing occurs.

- Use of a high temperature (50°C) is very tempting as a means of accelerating curing. However, this option has been rejected for the following reasons:

a) This is not the temperature that prevails in most pavement layers.
b) It is considerably higher than the ring and ball softening point of the bitumens commonly used, so there is a danger of re-arrangement, giving too optimistic results.
c) It causes extremely rapid drying of the specimens, which leads the largest to crack.

- Curing of emulsion cold mixes for 14 days at 18°C and 50% relative humidity (RH) corresponds to a few months (roughly 2 to 6) of in situ curing ("the fresh state").

- Curing for 14 days at 35°C and 20% RH produces a material in a state is near that assessed in the field after 1 to 4 years in a temperate climate. We therefore suggest this procedure in order to simulate the "mature state". This choice is supported in particular by the closeness between the stiffness moduli measured in the laboratory and on core samples taken in the field (Serfass, 2003).

We have verified that this accelerated curing brings the bitumen to the same (unaged) state as the in situ evolution, that the water expulsion kinetics are realistic and that no cracking occurs.

N.B.:
1) The adopted procedures described above are for temperate climates. Different climates (tropical, Scandinavian, etc.) justify different accelerated curing conditions (to be specified).
2) These procedures are applicable to mixes whose binder contains no (or very little) flux. For mixes containing an emulsified fluxed binder, a procedure which ensures that most of the fluxing oil is expelled prior to curing still needs to be specified. Research is continuing towards this end.

6. - PROPOSED SPECIFICATIONS FOR MIXES IN THE FRESH STATE

These relate to emulsion cold mixes which have been cured for 14 days at 18°C and at 50% RH, which corresponds to the conditions laid down in the current French standard. (Other countries specify, for example, 23°C and a shorter duration).

At this stage, it is just a question of checking that the emulsion cold mix has reached an acceptable level of stability and recognizing a "category" of mix. The easiest test is the unconfined compression test. A well-tried method involves the use of statically moulded cylindrical specimens. The "Duriez" method is appropriate, as long as the specimens are moulded under lower pressure (three times less than that laid down in the current standard) to ensure the densities achieved are realistic in comparison with worksite measurements (Serfass, 2002).

Under these conditions, we can specify "dry" strength classes R_f, for example:

Grave-emulsion: $R_{f\ 14\ days - 18°C} \geq 1$ 1,5   2   ....   4 MPa (crushing at 18°C)

The appropriate class will be selected according to local conditions.

Resistance to water is evaluated by measuring the strength r_f after 7 days in the air followed by 7 days of immersion at 18°C and by calculating the ratio r_f/R_f. The following requirements can be laid down based on experience:

- Grave-emulsion	r_f/R_f	≥ 0.55
- Base cold mix asphalt		≥ 0.7
- Open-graded cold mix asphalt concrete		≥ 0.75
- Dense-graded cold mix asphalt concrete		≥ 0.75

Some countries use the splitting tensile strength. There is no reason that the same principle should not be applied to characterize materials using this type of test. The curing conditions need to be adjusted according to the local climate.

7. - PROPOSED SPECIFICATIONS FOR MIXES IN THE MATURE STATE

As said above, the curing conditions suggested for temperate zones are 14 days at 35°C and 20% relative humidity.

7.1 - Mechanical stability and water sensitivity

The approach consists in measuring (by crushing conducted at 18°C):

- the unconfined "dry" compressive strength after 14 days at 35°C – 20% RH: R_m
- the strength after curing (14 d - 35°C - 20% RH) then immersion (7 d – water at 18°C): r_m
- the ratio r_m/R_m

The classes and threshold values will be specified as results are obtained.

7.2 - Rutting resistance

The procedure consists in manufacturing a slab of emulsion cold mix at "ambient" temperature (18 to 25°C). The following day, it is subjected to post-compaction which simulates the early age densification that takes place in roads. As a result, the mix reaches a level of density close to that of the mature material in situ. The slab is then conserved 14 days at 35°C - 20% RH.

The rutting test is then performed in the same way as for hot mixes, at 60°C, on 5 or 10 cm slabs. So far the results show that:

- Rutting is essentially due to post-compaction under the wheel,

- For grave-emulsion made with 70/100 pen bitumen, the limit of 10% rutting on a 10 cm slab after 10,000 cycles at 60°C appears realistic.

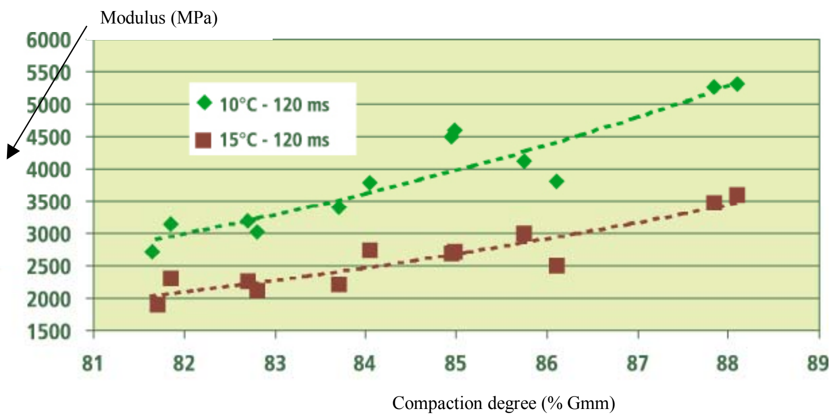
- For thin layers of dense-graded cold mix asphalt concrete, it should be possible to apply specifications that are similar to those for thin hot asphalt concrete, limiting rutting on a 5 cm slab to 15% after 3,000 cycles (light traffic), 10,000 cycles (moderate traffic) or 30,000 cycles (heavy traffic).

7.3 - Stiffness moduli

These can easily be measured by means of indirect tensile tests by applying pulsed diametral loads to cylindrical specimens. They can also be expressed or measured by direct static tensile tests using MAER equipment as a good correlation between the two tests has been established (Carbonneau, 2003).

Extensive studies have been conducted, which have, in particular, led to the choice of the above curing procedure. These studies also assessed the influence of a variety of parameters. Figure 3 shows the influence of density, which can be seen to be fundamental.

Figure 3 - Influence of compaction degree on stiffness modulus of 14 mm grave-emulsion



The results available at present show that normally the following performance can be anticipated after curing for 14 days at 35°C - 20% RH:

- Structural grave-emulsions (base course or overlay):

  . 0/10 or 0/14 mm – Bitumen content: 3.8 - 4.5 %
  . Modulus measured by indirect tensile test (10°C - 120 ms) or direct tensile test (10°C - 0.02 s):
  with 70/100 pen initial bitumen 3,000 to 5,000 MPa
  with 160/220 pen initial bitumen 2,500 to 4,000 MPa

  for compaction degrees between 85 and 92% Gmm.

- Cold mix asphalt concrete 0/10 mm – Bitumen content: 4.8 to 5.4 %

  . Modulus at 10°C - 120 ms or 10°C - 0.02 s 3,700 to 5,500 MPa
  for compaction degrees between 87 and 92% Gmm.

In view of the great influence the density exerts on the modulus, it is essential to have a forecast of in situ density, so as to manufacture test specimens with a similar density.

By applying these principles, the modulus specifications for different densities could be modified to suit local conditions.

8. - WHAT ABOUT LONG-TERM PROPERTIES?

Field monitoring has shown that, once a cold mix has achieved its mature state, it starts to behave practically like a hot mix. Once this stage is reached, it develops high cohesion, continues to be consolidated (but very slowly) and starts to be subject to the same ageing phenomena as hot mixes.

We do not consider that there is a need for specifications for aged cold mixes. By the way, there are none for hot mixes.

However, once a cold mix that has developed high cohesion plays a role in a pavement structure, its fatigue resistance must be considered. The first trials have proved that it is possible to test the fatigue resistance of cold mixed that have been well cured and consolidated. It is now necessary to obtain more results and compare them with observations of in situ performance.

9. - CONCLUSION

Local practice and experience remain often very important with regard to cold mixes. Our knowledge of certain aspects of their performance is still imperfect.

Cold mixes do, however, have certain advantages of a technical and, in particular, environmental nature. Their use is therefore certain to increase. This process will be assisted by the adoption of a universal design method. This should also help in the development of performance-based specifications suitable for different local conditions.

10. - REFERENCES

Carbonneau X. (April 2003) Evaluation of the Indirect Tensile Stiffness Modulus Test.
6th International RILEM Symposium.

Poirier J.E. (March 2002) The compactability of cold mixes. Revue Générale des Routes et des Aérodromes (R.G.R.A.), N° 804.

Serfass J.P. (January 2002) Advantages, peculiarities and mysteries of emulsion cold mixes. R.G.R.A., N° 802.

Serfass J.P. (September 2002) Emulsion cold mixes: specific features and a new design method. 3rd World Congress on Emulsions.

Serfass J.P. (April 2003) Influence of curing on cold mix mechanical performance.
6th International RILEM Symposium.