Bituminous emulsions

A new generation of semi-warm emulsion asphalt concrete : feedback and field of use

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Abstract

Semi-warm bituminous mixes with emulsion have been developed by COLAS compagny for more than a decade. They are manufactured at a moderate temperature for maintenance of base and wearing courses. It combines the appearance and performance of hot mix with the advantages of cold mix which are flexibility and ease of use. Manufacturing processes have been developed. The mix can be obtained by a progressive and gentle warming of an asphalt mix previously manufactured in a cold mix plant. The mix can also be obtained by pre-heating only a part of the aggregates. The mixes are produced at a temperature between 70°C and 90°C. Those processes allow the use of high rates of reclaimed asphalt pavement until 100%. Reclaimed asphalt pavement is subject to a detailed identification. A softening agent may be used depending on the characteristics of the binder recovered from the RAP. The grade of bitumen used for manufacturing the emulsion is selected according to the volume of traffic and the constraints of the work to be performed. A comparison of the mechanical performances of these semi-warm mixes manufactured by different processes was carried out on samples taken directly at the coating plant. A complete characterization has been carried out. The various feedbacks made it possible to identify in a relevant way the field of use of this new generation of asphalt mix. Such mixes are economical in term of energy and non-renewable resources. It limits the emissions of volatile organic compounds and greenhouse gas emissions. It reduces consumption and saves non-renewable materials by using high rate of reclaimed asphalt pavement.

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INTRODUCTION:

The current range of asphalt mixes is composed of hot, warm and cold mixes. Hot and warm mixes are reserved for all traffic levels. Cold mixes are reserved for low and medium traffic levels and well adapted to flexible roads. The main disadvantage of cold mixes is the fragility at young age. A semi-warm bitumen emulsion mix is a bitumen emulsion mix that is manufactured at a moderate temperature and intended for maintenance of road base layers and wearing courses. A semi-warm bitumen emulsion mix allows to have both flexibility and resistance to fragility at young age. It partially combines the advantages of hot mixes et cold mixes. A semi-warm bitumen emulsion mix combines the appearance and performance of hot mixes with the advantages of cold mixes (flexibility, easy of laying…). It is economical in terms of the use of energy and non-renewable resources and has an impressive environmental footprint.

SEMI-WARM BITUMEN EMULSION MIX

1 Presentation of the technique

1.1 General presentation

Semi-warm bitumen emulsion mixes are laid at temperatures of under 90°C, in thick, thin or even very thin layers. They are used in sub-base and road base layers and wearing courses in new pavements, but more particularly for the maintenance of flexible pavements with low or medium traffic levels. The particle size distribution of the material ranges between 0/10 and 0/18 mm in the case of sub-base and road base layers and between 0/6 and 0/14 mm in the case of wearing courses. The aggregates and the emulsion comply with current standards and are varied according to the application. The product is consistent with a responsible development strategy that aims to limit emissions of volatile organic compounds (VOCs) and greenhouse gases (GHGs).

1.2 Manufacturing processes

Two manufacturing processes have been developed whose use depends on the local availability of manufacturing equipment. Whichever process is used, after compaction and curing, the end products have the same appearance and mechanical characteristics (this point will be explored more fully in the section of this paper on mechanical performance).

1.2.1 Process 1

The product is obtained by gradually warming a bitumen emulsion mix that has been previously manufactured in a cold mix plant. The equipment used, which is known as a “warming tube” raises the temperature of the final mix to approximately 80°C. The mix designs that are used include varying amounts of Recycled Asphalt Pavement (RAP), in some cases 50%, 75% or even 100%. Depending on the characteristics of the RAP (in particular the penetration grade of the asphalt, there are several possibilities depending on the traffic level:

- the RAP is just warmed before it is added to the binder
- the RAP is mixed with an oil- or plant-based regenerating binder before passing through the warming tube in order to remote is the binder
- there is no RAP in the mix and the product is manufactured with 100% new materials

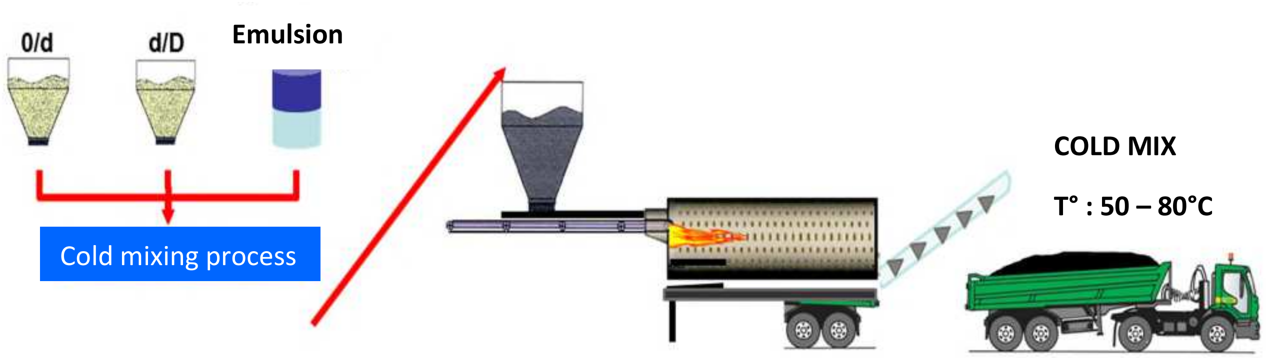

Figure 1: Diagrammatic representation of Process 1

1.2.2 Process 2

The product is obtained by coating warm chippings with emulsion, RAP and sand in a cold mixing plant. Some or all of the aggregate is heated in order to obtain an end product with a temperature of between 70 and 90°C. The mix designs may include up to 60% of RAP and may be either continuous or gap-graded in the case of thicknesses of between 2 and 4 cm. This manufacturing and laying method does not generate any bitumen fumes, just water vapour. The use of oil- or plant-based additives and/or an appropriate emulsion enables laying of the product to be delayed.

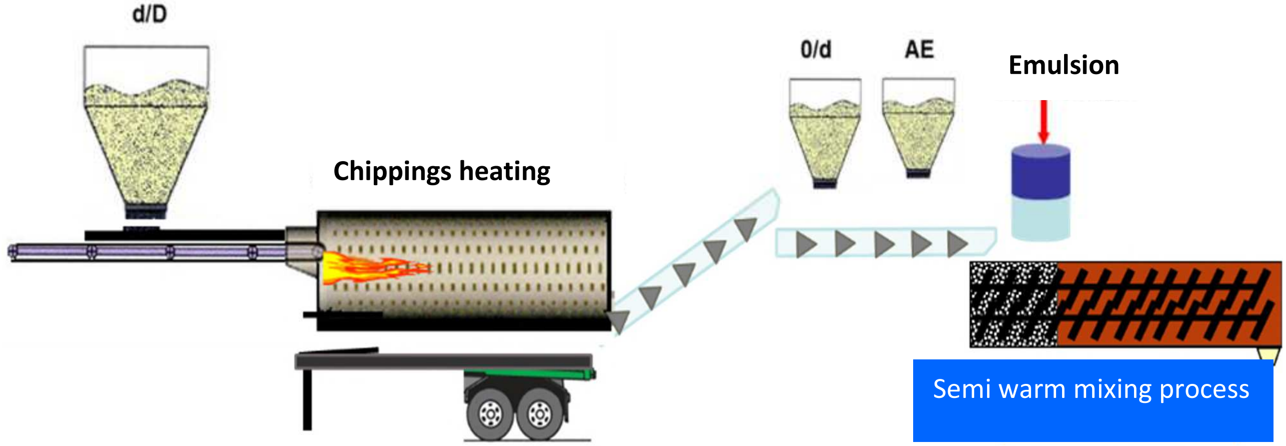

Figure 2: Diagrammatic representation of Process 2

1.3 Laying

The usual rules of good practice (NF P98-150-211) for asphalt mixes apply to this semi-warm bitumen emulsion mix. A bitumen emulsion tack coat is required. The spread rate must be adjusted to suit the substrate (between 200 and 400 g/m² of residual binder). As with any product that contains emulsion, the climatic conditions are very important (laying should be performed in the summer) with an ambient temperature of over 5°C. The product should be transported in trucks which must absolutely have a tarpaulin cover in all weather conditions in order to maintain the required moisture level and temperature during transport. Mechanical laying is performed with a paver and a compaction train which is compatible with the laying thickness and speed. For greater thicknesses (above 0.05 or 0.06 m), a rubber-tyred compactor can be added to the laying train. The surface can be re-opened to traffic fairly quickly, as soon as compaction is completed. The quality of coating and good workability mean the density of the product is very good (equivalent to that of hot mixes of the same type), resulting in higher shear strength than conventional emulsion mixes.

2 Performance of the product

As part of the follow-up of the 2 processes, performance characterizations were carried out on both laboratory mixtures and samples collected from industrial manufacturing. A test protocol was drawn up that included:

- ✓ Quality of coating as laid down the standard NF P 98-139[2] of December 2016
- ✓ Indirect Tensile Strength Ratio (ITSR) – Compressive strength – Duriez
- ✓ Rutting
- ✓ Modulus of diametral compression (specimen manufactured with a Troxler Gyratory Shear Compactor)
    - Conserved in the laboratory
    - Conserved outside
- ✓ Workability - Gyratory Shear Compactor 3
- ✓ Nynas Workability meter

2.1 Mix design

The tested mix design contained 55% of RAP and was as follows:

Table 1: Mix design of the semi-warm emulsion mix

Constituents	Process 1	Process 2
Aggregate	45%	45%
Screened RAP	55%	55%
Total residual binder	5.5%	5.5%

The grading curve was as follows:

Table 2: Grading curve of the mix

Screen (mm)	12.5	10	6.3	4.0	2.0	1.0	0.5	0.063
Passing fraction(%)	100	95	59	42	29	20	15.2	6.7

For both processes, the quality of coating as laid down in NF P 98 257-13 was class E2, i.e. at least 90% of the mineral surface was covered by binder.

2.2 Water resistance NF EN 12697-12[4]

We applied the hot mix standard NF EN 12697-12 - Procedure B, with a compaction load of 60 KN for each specimen. The test pieces were cast in the mobile laboratory after the material had been allowed to return to ambient temperature for two hours.
We applied the following two curing protocols:

- 14 days at 18°C and 50% relative humidity for the compression test in air and 7 days at 18°C and 50% relative humidity plus 7 days in water at 18°C for the compression test in water.
- 14 days at 35°C plus 7 days at 18°C and 50% relative humidity for the compression test in air and 14 days at 35°C plus 7 days in water at 18°C for the compression test in water.

In addition, we manufactured two test pieces according to NF98-251-45 procedure 2, with a load of 20KN for each specimen, to determine the bulk density of the product according to this procedure.

Table 3: ITSR results

Test	Process 1	Process 2
Bulk Density (NF EN 12697-6[6] Procedure D) (Mg/m3)	2.292	2.258
Bulk Density (NF EN 12697-6 Procedure C) (Mg/m3)	2.354	2.321
% hydrostatic voids	4.9	6.4
Dry Compressive strength (MPa)	27.8	22.7
Wey Compressive strength (MPa)	19.4	16.5
Immersion/Compression method at 18°C	**70**	**73**
Bulk Density (NF EN 12697-6 Procedure D) (Mg/m3)	2.285	2.250
Bulk Density (NF EN 12697-6 Procedure C) (Mg/m3)	2.357	2.319
% hydrostatic voids	4.7	6.5
Dry Compressive strength (MPa)	30.0	27.5
Wet compressive Strength (MPa)	24.9	20.6
Immersion/Compression method at 35°C	**83**	**75**
Method 2 NF 98-251-4		
Bulk Density (NF EN 12697-6 Procedure D) (Mg/m3)	2.084	2.039
Bulk Density (NF EN 12697-6 Procedure C) (Mg/m3)	2.243	2.203
% hydrostatic voids	9.3	11.1

The water resistance of both products complies with current standards, even with very high RAP contents.

2.3 Compactibility with the Gyratory Shear Compactor NF EN 12697-31[7] – NF EN 12697-10[8]

The tests were conducted with the Series 3 Gyratory Shear Compactor that belongs to the mobile laboratory according to the standards NF EN 12697-31 and NF EN 12697-10. The results for specimens taken from the construction sites are given below:

Table 4: Gyrator Shear Compactor

Gyratory Shear Compactor NF EN 12697-31 and 10	Process 1	Process 2
Maximum Density (NF EN 12697-5[9] Procedure A) (Mg/m3)	2.474	2.479
C1 (%)	26.3	27.4
C25 (%)	14.5	16.3
C40 (%)	12.7	14.7
C60 (%)	11.3	13.3
C200 (%)	6.8	9.2
Gradient (%)	-3.68	-3.45

Compactibility thus complies with NF P 98-139 that deals with bitumen emulsion mixes for wearing courses irrespective of the product range (very thin C25 ≤ 26%, thin C40 ≤ 20% or thick C60 ≤ 15%).

2.4 Modulus test NF EN 12697-26[10] annex C

The tests were carried out under diametral compression using a Universal Testing Machine according to standard NF EN 12697-26 annex C. The test procedure was as follows: temperature 10°C and 15°C and a loading time of 124ms with an interval of 3s between each iteration. The test pieces (diameter 100 mm and height 50 mm) were manufactured with a Gyropac, after a 2-hour cooling period. The 2 curing protocols were as follows:

- 14 days at 35°C
- 14 days outside

Table 5: Modulus

MODULUS TEST NF EN 12697-26 annex C	Process 1	Process 2
Specimen cured at 35°C		
Geometric voids content (%)	10.1	12.2
Modulus at 10°C – 124ms (MPa)	3698	2565
Modulus at 15°C – 124ms (MPa)	2266	1604
Specimen cured outside		
Geometric voids content (%)	10.4	12.0
Modulus at 10°C – 124ms (MPa)	3579	2408
Modulus at 15°C – 124ms (MPa)	2216	1458

After 6 months, 6 core samples were taken at the two worksites in order to measure their moduli under diametral compression as laid down in NF EN 12697-26 annex C. The following results were obtained:

Table 6: Modulus measured on core samples taken from worksites after 6 months

MODULUS TEST NF EN 12697-26 annex C	Process 1	Process 2
Geometric voids content (%)	20.2	17.7
% of voids determined by gamma bench	16.6	17.3
Modulus at 10°C – 124ms (MPa)	4179	4101
Modulus at 15°C – 124ms (MPa)	2701	2562

Some of the test specimens were conserved in the dark for 6 months at 18°C, and some were conserved outside, also for 6 months. The following results were obtained:

Table 7: Modulus after 6 months measured on test specimens conserved at 18°C and outside

MODULUS TEST NF EN 12697-26 annex C	Process 1	Process 2
Specimen cured at 35°C + 6 months 18°C		
Geometric voids content (%)	10.1	12.2
Modulus at 10°C – 124ms (MPa)	8295	8091
Modulus at 15°C – 124ms (MPa)	5263	5038
Specimen cured outside 15 d + 6 months		
Geometric voids content (%)	10.4	12.0
Modulus at 10°C – 124ms (MPa)	5537	6269
Modulus at 15°C – 124ms (MPa)	3583	3728

The difference measured in the modulus of the two products between the first procedures (14 days at 35°C and 14 days outdoors) was significantly reduced after 6 months of ageing in the pavement (both on site, and in the case of storage at 18°C, and outside). The measured values were in line with the initial goal for the product, namely to achieve flexibility in a bitumen emulsion mix.

2.5 Rutting resistance test NF EN 12697-22[11]

The rutting resistance of the mixes was determined with the large scale device on 5cm thick slabs as laid down in the standard NF EN 12697-22. The tests were performed at 60°C up to 30,000 cycles after curing of the plates for 15 days at 35°C. The plates were manufactured the day after the specimens were collected with the product stored in a sealed bucket and heated for 4 hours to 80°C. The results were as follows:

Table 8: Rutting

Rutting test NF EN 12697-22	Process 1	Process 2
% voids (gamma bench)	9.7	9.8
100 cycles (%)	2.5	2.4
1,000 cycles (%)	6.5	6.4
3,000 cycles (%)	7.8	6.8
10,000 cycles (%	10.1	10.0
30,000 cycles (%)	13.1	13.0
Gradient	6.36	6.11

The rutting resistance of the products is very good for a bitumen emulsion concrete, comparable to that of a thin or very thin hot mix. The main difference is the percentage of RAP (high > 30%AE) in the semi-warm bitumen emulsion mixes, which is currently not authorized in the case of hot or warm mixes.

2.6 Workability test

Workability tests were carried out in-situ on the products with the Nynas workability meter. The aim was to see if the products changed over time. For this purpose, we carried out the tests at a constant conservation temperature of 80°C, with conservation of the product in an enclosure, and after four lengths of time: 1h30, 2h30, 4h and 6h.
The first measurement was made after 1h30 for both trials because of the transport time. To carry out these tests, we modified the usual procedure. Instead of making the test piece by dropping the mix from a certain height (which results in a variable percentage of voids), the test piece was manually compacted to achieve a density which is equal to 40% of the dry density, in view of the water content. The result was the average of two tests measuring the peak shear force. The results were as follows:

Table 9: Workability

NYNAS workability	Process 1		Process 2	
Curing	Force (N)	T°(°C)	Force (N)	T°(°C)
1h30	182	65	141	70
2h30	148	73	144	70
4h00	155	73	152	73
6h00	127	80	157	76

Apart from the high value which differs from the other shear forces after 1h30 for Process 1 (the temperature was a little low compared to the other cases), it can be seen that the time that elapses prior to lay for this product will not pose a problem during laying due to ageing if the transport conditions are controlled (temperature (70 - 85°C) and the humidity level is maintained).

2.7 Summary of mechanical performance and scope of application

The results presented above allow us to draw the following conclusions:

- The water resistance of the product is within the range of standard wearing course mixes containing high percentages of RAP

- The density measured by the laboratory test (Gyratory Shear Compactor) on cores taken at the construction site, tends to demonstrate that the characteristics of this product lie between those of conventional emulsion mixes and warm or hot mixes
- The results from the rutting resistance measurements are similar to those for equivalent hot mixes (Class 1 0/10 Very Thin Asphalt Concrete and Type A Thin Bituminous Concrete or Class 2 Type C 0/10 Asphalt Concrete according to the French standard)
- The flexibility of the product has been demonstrated by the fact that the modulus measurements remain relatively low despite the high percentage of RAP

The use of moderate temperatures (<90°C) provides bitumen emulsion mixes with many advantages over cold bitumen emulsion mixes:

- Increased surface strength and reduced sensitivity to shear at early age: these aspects may cause problems in the case of conventional emulsion mixes that exhibit slow cohesion build-up and are therefore sensitive to the stresses that are generated
- The greater density of the products improves their technical performance
- Use with very high proportions of RAP

All the studies and construction site follow-up have shown very promising performance, confirming good rutting resistance combined with lower stiffness moduli than in the case of hot mix asphalt. These are currently the only processes that allow thin asphalt wearing courses to be laid with up to 100% of RAP.

Based on the mechanical performance and feedback from the construction sites, the scope of application for these products is currently as follows:

- For the maintenance of road surfacings (can also be used for new construction)
- Traffic less than or equal to T3 (≤150 HGVs/day/direction: i.e. approximately 80% of the French road network) outside built-up areas like conventional bitumen emulsion mixes but also on through-town roads due to the product's higher shear strength
- Existing flexible pavements with relatively high deflection that prevent the use of conventional hot mix techniques:
    - Existing pavement with a maximum deformation of 250 1/100th mm under a 13 tonne axle for level T5 traffic (0 - 25 HGVs/day/direction) and level T4 traffic (25 - 50 HGVs/day/direction). To give one example, the SETRA Technical Guide “Aid for the selection of maintenance techniques for the maintenance of pavement surface techniques” published in 2013[12], recommends a maximum deflection of 125 1/100th mm for use of thin asphalt concrete with level T4 traffic.
    - Existing pavement with a maximum deformation of 200 1/100th mm under a 13 tonne axle for level T3 (50 - 150 HGVs/day/direction). To give one example, the SETRA Technical Guide « Aid for the selection of maintenance techniques for the maintenance of pavement surface techniques » published in 2013[12], recommends a maximum deflection of 105 1/100th mm for use of thin asphalt concrete with level T3 traffic

In view of its good performance with level T3 traffic, the product’s scope of application will be broadened to cover heavier traffic in the years to come.

3 Reference project for the product

One of the many projects carried out using Process 2, the RD21 between St Laurent sur Gorre and St Junien, can be regarded as a reference. This 19 km long project on a road carrying 84 HGVs/day/direction traffic (traffic class T3) was completed in 2 years (2016 and 2017). The product used was a bitumen emulsion wearing course mix with 30% of RAP. It was laid with a spread rate of 70 and 75 kg/m² over the full width of the carriageway. On acceptance of the works, the average macrotexture value was 0.75 mm with a standard deviation of 0.09 mm. If we make a comparison with hot mix asphalt, the values are similar to those for thin type A asphalt concrete. The results for the longitudinal profile were as follows:

Table 10: Analysis of the longitudinal profile

	Mean value prior to works	Mean value after works
Small wavelengths	7.1	8.9
Medium wavelengths	7.0	8.5

Photo 1: End result Process 2

Since 2014, Process 1 has a strong presence in the Cher department where there are many excellent examples:

- 2014 the road through the village of Vouzeron
- 2015 RD 35 Lapan – 6 km of which 1.5 km were the subject of follow-up in the framework of an Innovation Charter signed with CEREMA
- 2017 RD 69 Saint-Baudel – 2.5 km (video available on YouTube[13])
- 2017/2018 RD 7 between Herry and la Chapelle-Montlinard – 9 km
- 2016/2018/2019 RD 18 Mareuil – 17 km
- 2018/2019 RD 925 Orval – 8 km

These projects were carried out with percentages of RAP varying from 55 to 100%. The mean laying thickness was approximately 4 cm, which corresponds to a spread rate of 80 kg/m².

Photo 2: Finished surfacing Process 1

It is also worth mentioning the RD 219 between Mauves and Les Plats in the Ardèche. This 50,000 m² section was constructed using Process 2 in 2016. The mix formulation had a RAP content of 30% and 0/10 mm aggregate and was laid in a thickness of 4cm. Mean texture depths of between 0.75 and 0.85 mm were achieved, which was the target for the rehabilitation of this section locally known as "the road with 100 bends" and which hosts the "Rallye des Coteaux" every year.

Photo 3: Finished surfacing Process 2

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