ENVIRONMENTALLY FRIENDLY ENERGY SAVING MIXES

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ABSTRACT

A marked trend in road construction is the more systematic consideration of the influence of the activity not only on the environment but also on staff, road users and residents. This requires an improvement in knowledge and the more effective application of techniques accompanied by increasingly large-scale measures to reduce their overall impact. Colas is actively committed to the aims of sustainable development and in this framework has developed a procedure for manufacturing what are commonly known as warm mixes. The objective is to reduce energy consumption and greenhouse gas emissions, and also emissions of fumes which may be unpleasant for road users, residents and laying teams. This process was undertaken in a strictly-managed framework, with strong constraints on the targeted results, in particular a reduction of 40°C in the manufacturing and laying temperature of the mixes. The company has selected just two of the many technological alternatives for producing environmentally friendly energy saving mixes. Both of these are based on the control of binder rheology. The first focuses principally on the viscosity of the binder and the other mainly involves the manufacturing process. The selection of a final mix temperature in excess of 100°C and the complete elimination of water guarantees a level of performance for warm mixes which is strictly equivalent to that obtained with conventional hot mixes. Moreover, these mixes can be laid using existing industrial plant directly, which limits the investment required and facilitates their large-scale deployment. These mixes retain their workability when laid using conventional techniques. They have been tested successfully for a 3 year period under all possible worksite conditions and with intense heavy vehicle traffic. They have been monitored by the technical services of central government and their performance has proved completely satisfactory. In particular, emissions of fumes have been reduced to the great satisfaction of all involved and energy consumption measurements confirm the estimates that were made in the framework of a partial life cycle analysis of the products. The findings show a reduction in energy consumption during manufacture of at least 18% and a 20% reduction in greenhouse gas emissions.

1. INTRODUCTION

The manufacture of hot asphaltic mixes requires the aggregate to be dried and heated to a temperature of approximately 180°C before the bitumen is injected at a temperature at which its viscosity is sufficiently low to:

- Achieve complete and satisfactory coating of the dry aggregate as described in the applicable standards.
- Provide the mixes with a high degree of workability in order to lay them under normal conditions.

Therefore, asphaltic mixes are necessarily manufactured at a high temperature. For example, a temperature of at least about 160°C is required when 35/50 pen bitumen is used to manufacture the class 3 semi-coarse asphaltic concrete which is frequently used for the maintenance of pavements subjected to a large amount of HGV traffic.

At these temperatures, the mixes in question are highly workable. They can be laid with a paver in accordance with the rules of good practice and compacted without any specific difficulties.

In recent years research has been conducted into procedures that can reduce the manufacturing temperature of hot asphaltic mixes. They have led to the development of a variety of techniques that considerably reduce this temperature.

Thus, a temperature reduction of 40°C is obtained during the manufacturing and laying process while retaining mix workability which ensures the effectiveness of compaction. As a result of this, there is also a marked reduction in gaseous emissions. In fact, it is generally accepted that the production of fumes is reduced by a factor of 1.5 to 2 when the temperature is reduced by 10 to 12°C [3].

The lower working temperatures achieved with these mixes compared with a conventional mix lead to marked energy savings, which result in a reduction in greenhouse gas emissions.

However, the use of materials which have not been completely dried has been totally prohibited on the grounds that it would lead to an excessive risk with regard to the quality of coating and an inevitable reduction in mix workability as a result of water loss before laying. Of course, as the vaporization of water consumes a fixed specific amount of energy, the result could be even better if mixes were produced which still contained 2 to 3% of water.

The energy-saving mixes have been in normal use now for two years: all the projects have been successful and more than 30,000 tonnes have been manufactured. We are now able to carry out a technical and environmental evaluation of the two principal procedures based on the control of binder rheology that have been selected. This assessment provides some answers to the legitimate questions posed by road network managers concerning the benefits and the technical and environmental effectiveness of these mixes.

Lastly, the developments of the processes are described for mixes using elastomer-modified binders, for high modulus mixes and recycled mixes.

2. AN EXAMPLE OF THE PHYSICOMECHANICAL PERFORMANCE OF ENERGY-SAVING MIXES

Using 0/10 mm aggregate from the Voutré quarry, a semi-coarse asphaltic concrete mix was designed according to the applicable standards with a 35/50 pen bitumen and the binders used in the different processes.

The composition was as follows:

- 6/10 Voutré aggregate: 50%
- 2/6 Voutré aggregate: 15 %
- 0/2 Voutré aggregate: 33%
- Calcareous filler: 2 %
- 35/50 pen bitumen: 5.6% in relation to the dry aggregate – i.e. 5.4% of the mix.

Table 1 sets out the principal performance results obtained with the different processes.

Tableau 1- Performance of mixes

Type of mix		**Control Semi-course Asphaltic Concrete,** with 35/50 pen bitumen	**Energy-saving mix**
Coating temperature (° C)		**160**	**125**
GSC* % voids	after 10 gyrations	**14.5**	**14.2 to 14.8**
	after 60 gyrations	**8.1**	**7.5 to 8.4**
Duriez,	% voids	**8.2**	**6.8 to 7.5**
	Dry strength at 18°C, in Pa	**9.7**	**9.8 to 9.9**
	Wet strength/dry strength ratio	**0.78**	**0.75 to 0.80**
% rutting, at 60°C	after 30,000 cycles	**3.5**	**3.0 to 4.0**

GSC = Gyratory Shear Compactor

These results show that:

- Coating is satisfactory with all the processes.
- The workability of the mixes is maintained at a temperature of 125°C, as demonstrated by the Gyratory Shear Compactor tests.).
- The physicomechanical characteristics of the mixes are equivalent to those of conventional mixes with the same formulation, particularly with regard to stripping by water as measured by the Duriez test, and rutting.

In addition, measurements of the complex modulus and the flexural fatigue performance have shown behaviour similar to that of conventional mixes.

3. IN-SITU PERFORMANCE

To monitor this, detailed in-situ monitoring has been conducted with checks during manufacture and laying, precise temperature measurements during the different stages, verifications of the physicomechanical performance of the mixes and their in-service characteristics. Very comprehensive technical monitoring of the experimental worksite on the RN 157 was thus carried out by the technical services of central government. This pavement is subjected to daily HGV traffic of 960 vehicles (2004 estimate). In June 2005, three experimental sections of energy-saving mixes were compared to a control section consisting of Class 3 0/10 mm semi-coarse asphaltic concrete [1]. All the other worksites, which were generally smaller, were subjected to conventional monitoring.

With regard to environmental aspects, energy consumption was monitored. The gases emitted by the mixing plant were also measured and analyzed. In addition, the gases emitted during laying were analyzed in order to evaluate the impact on the use of warm mixes on laying staff and the neighbourhood around the works.

4. ASSESSMENT OF THE PROJECTS

4-1. RN 157

The RN 157 is a highly trafficked road that links Le Mans to Orléans. This is a two-way pavement, which although straight has some steep gradients with an East-West exposure. In 2004, it carried almost 7,800 vehicles per day, 25% of them HGVs, which puts it in the French category of roads with very high HGV traffic (T0).

The different processes and the control 0/10 semi-coarse asphaltic concrete were laid over an average width of 7.60 m and a length of approximately 500 m. The mixes were laid to an average thickness of 6 cm (i.e. approximately 140 kg/m²).

The control mix made with 35/50 pen bitumen used aggregate from the Voutré quarry as described in Section 1. The energy-saving mixes were manufactured with the same aggregate formula and their specific binder.

In the paver auger the temperatures of the energy-saving mixes were 40 to 45 °C lower than those of the control mixes. The temperature of these mixes was of the order of 120°C. Workability was maintained and compaction was satisfactory. The voids contents were identical, or even lower, to those obtained with the control mix, i.e. approximately 6%.

These processes resulted in an improvement in the workability of mixes, and in particular a lowering of their temperatures of use, as shown in the ratings given in Table 2 which indicate a good level of longitudinal evenness. This was evaluated by the longitudinal profile analyzer (LPA) belonging to the Angers Regional Public Works Laboratory (LRPC).

Table 2- Evenness ratings at small wavelengths before and after works

RN 157		Control section 0/10 Semi-course asphaltic concrete		Energy-saving asphaltic concrete					
				Class 1 mixes		Class 2 mixes		Class 3 mixes	
		direc +	direc -	direc +	direc -	direc +	direc -	direc +	direc -
S.W.	*Mean before works*	*7*	*6*	*8*	*7*	*5*	*7*	*6*	*5*
	Mean after works	**9**	**9**	**9**	**8**	**8**	**8**	**9**	**8**
	Minimum before works	*5*	*3*	*6*	*6*	*3*	*3*	*5*	*2*
	Minimum after works	**8**	**8**	**7**	**5**	**6**	**6**	**8**	**6**
	Mean before / Mean after	**7 / 9**	**6 / 9**	**8 / 9**	**7 / 8**	**5 / 8**	**7 / 8**	**6 / 9**	**5 / 8**

Figure 1 shows the macrotexture as measured by Mean Texture Depth (MTD). The level of macrotexture is high for this type of mix design and identical for all the mixes considered. Little change took place between the end of compaction and two months under traffic.

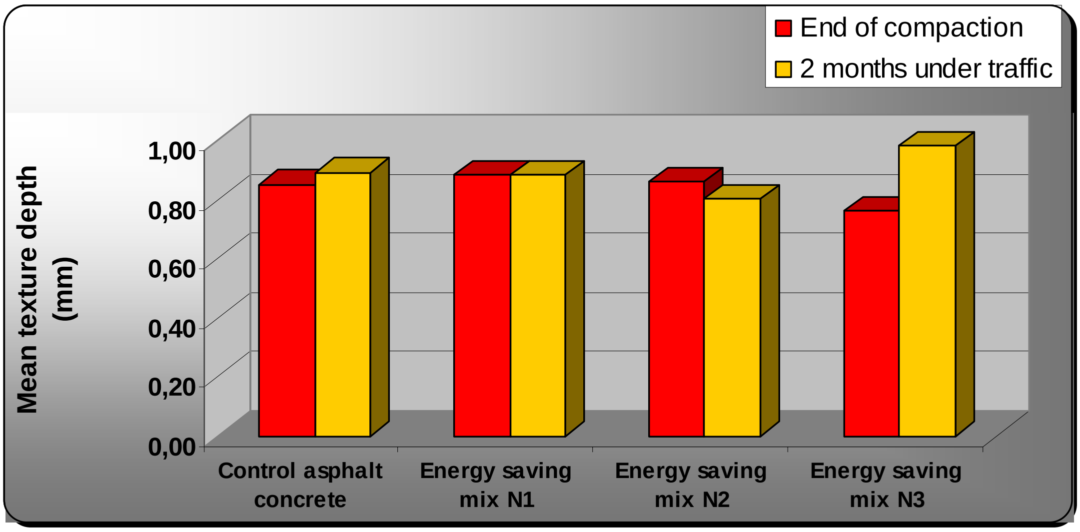

Figure 1 - Change in MTD (in mm) for the three tested processes

Mean Texture Depth values were computed on the basis of laser-guided roughness meter measurements and revealed good macrotexture and a high level of uniformity among the measurements irrespective of the traffic direction and the measurement position (the centre of the road or traffic lane) and irrespective of the section, with slightly higher values for Class 3 mixes.

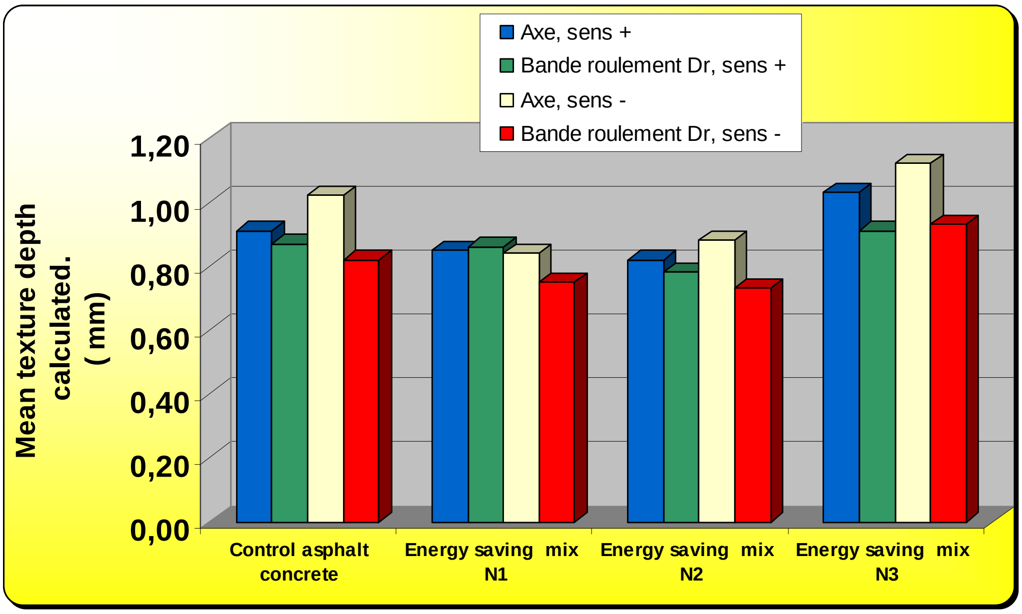

Figure 2 – Mean texture depth calculated at age 2 months for the various tested mixes

The Braking Force Coefficients (BFC) were measured on the entire worksite after 17 months of heavy traffic. The values obtained were in the middle of the national range for all surfacings and typical of 0/10 semi-coarse asphaltic concrete. At low speed, the energy-saving mixes all had the same value which was slightly higher than the control mix as shown in Figure 3. At 80 km/h, they had the highest BFCs.

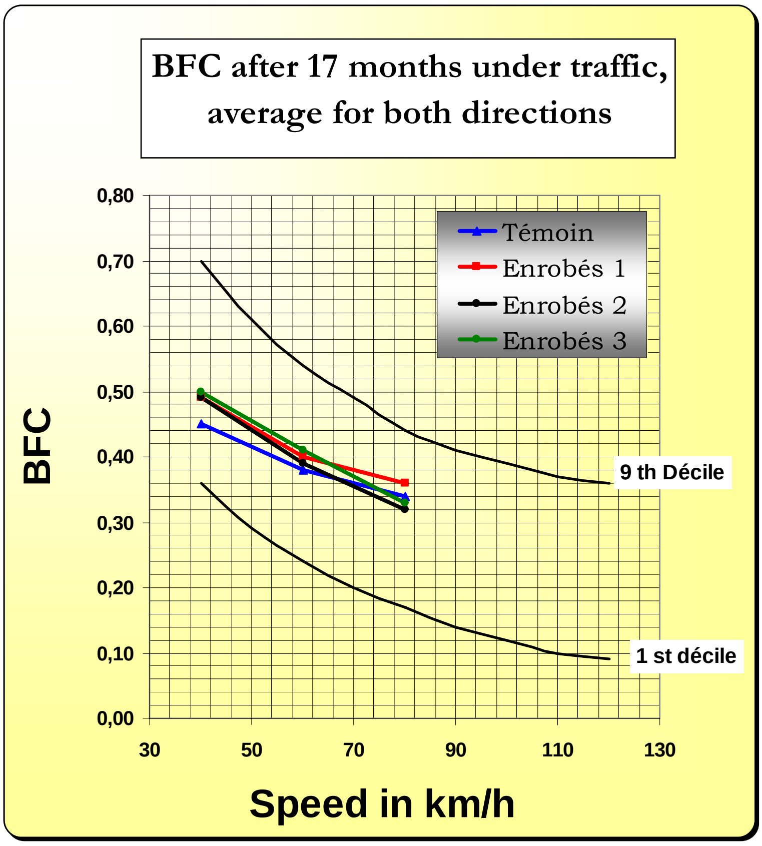

Figure 3 - BFC after 17 months under traffic, average for both directions

The level of skid resistance was therefore satisfactory for this type of mix and very similar to the control mix under heavy traffic.
Also noteworthy is the absence of any deformation in the cross-section after two hot summers and with a longitudinal profile with steep gradients exposed to the sun and subjected to intense heavy vehicle traffic.
In view of this good overall performance and the fact that the characteristics of energy-saving mixes are identical or even better than those of a control mix, and also in view of the durability after 17 months of intense traffic, the Sétra has awarded a certificate recognizing the innovation which is probative for the General Directorate of Roads.

4-2. RD 2160 La Roche sur Yon

In the framework of the maintenance contract for the county roads (RD) in Vendée, 3,000 tonnes of 0/10 semi-coarse asphaltic concrete were laid on the RD 2160, 2,650 tonnes of which were energy-saving mixes. This project was carried out at the end of November 2006 and subjected to conventional monitoring of manufacturing and laying.
The overall reduction in temperatures was 40°C. Temperatures varied from 120 to 125 °C on leaving the mixer during the 4 days of manufacture in a batch plant.
Laying was performed under traffic to a thickness of 6 cm, using a paver and 2 smooth steel vibratory roller compactors (Photo 1).
The compaction was performed at temperatures of between 110 and 80°C and the average in-situ voids content was measured as 5.6%

Photo 1 - Works on the RD 2160, laying train

The environmental impact of these works, and in particular the benefits provided by the manufacturing process were estimated using an in-house software programme that performed simulations and conducted a partial life-cycle analysis (LCA). The complexity of conducting LCAs for roadworks has already been described elsewhere [2]. Two environmental impacts, which were judged to be the most important, were considered: greenhouse gas emissions and energy consumption. The reason for the latter choice is that it is currently difficult to quantify precisely energy savings on the basis of direct measurements at the mixing plant, in view of the way such plants are configured.
Taking into account the various parameters that apply to the worksite, in particular the characteristics of the mix laid and the distances between the mixing plant and the sites where the ingredients are produced, we have evaluated that the energy-saving mixes were responsible for a reduction in energy consumption and greenhouse gas emissions of between 16 and 20% in comparison with conventional mixes.

4-3. Other developments : the use of Recycled Asphalt Pavement and elastomer-modified binders in energy-saving mixes

Recycled asphalt pavement (RAP) has been used in energy-saving mixes in the USA. Approximately 1,000 tonnes of energy-saving mix with a 20% RAP content have been laid on a section of Interstate Highway 80. The mix was manufactured at 115°C and compacted at between 80 and 110°C without any difficulty and with the same benefits as above for the worksite environment. In this case, the effects that result from saving aggregate and bitumen resources combine with those of the reduction in energy consumption during the manufacturing process. Laboratory studies of the mix formula that was laid provide further confirmation of the conclusions presented above.

The mechanical performance of the energy-saving recycled mixes was at least equivalent to that of the control mix.

These technologies have been extended with the development of thin and very thin layer overlay techniques using SBS elastomer-modified bitumens. Several construction projects were successfully carried out in 2006 in the City of Paris, on bus lanes and a variety of street surfacings.

For the last of these, the modified binders were formulated to enable manufacture and placement at the lower temperature of approximately 125°C. In all more than 15,000 square metres of these mixes have been laid. This confirms that it is possible to extend the use of this process to mix designs with elastomer-modified binders intended for highly stressed zones, particularly in very thin overlays for which the use of high performance binders is indispensable.

All the laboratory studies and the measured characteristics show a systematic equivalence in performance between the control mixes and the modified binder energy-saving mixes.

5. MEASUREMENTS OF FUMES AND INHALABLE DUST

The introduction of so-called warm mixes should lead to a significant improvement in working conditions, but also provide environmental benefits with regard to industrial gas emissions. These issues go beyond traditional concerns, but their consideration is becoming an increasingly common reflex for all industrial actors. In order to provide accurate responses, it is essential to use considerable measurement facilities. The construction projects that have been carried out have provided the opportunity to conduct sophisticated measurement campaigns whose principal conclusions are summarized below.

Reducing the temperature of mixes has the immediate effect of significantly improving the working environment for the laying staff, with a reduction in the ambient temperature at the worksite and less visible fumes during laying. This means that the works also have less impact on residents, who often object to the noise and smell caused by roadworks, particularly those for hot mixes. Thus, as can be seen in Photo 2, the windows in the dwellings near the worksite can be left open during the laying of energy-saving mixes.

Photo 2 – Less disturbance for residents.

The first important point involves gas emissions during the laying of mixes. It is generally accepted that a temperature reduction of about 12°C halves fumes emissions [3]. However, this is difficult to prove because of the low quantities that are present in the environment around the worksite. Thus, a campaign to measure inhalable dust and fumes was performed on the RN 157. To do this, it was necessary to select carefully a number of measurement points, behind the paver screed, adjacent to the paver operator and adjacent to the laying staff, as shown in Photo 3.

Photo 3 - Measurement points for fumes and dust and the weather conditions.

In spite of the care that was taken with regard to this operation, the detected quantities of gas were excessively low. They were very often below the detection thresholds of the currently available analysis techniques, and this applied too for the control mix that was laid at the conventional temperature.
In the case of inhalable dust, the levels are also very much below the average occupational exposure levels that currently apply in France, i.e. 5 mg/m3 for 8 hours of exposure and even below the level of 0.5 mg/m3 recommended by the American Conference of Governmental Industrial Hygienists (ACGIH). In the case of the energy-saving mixes, the gas emissions were even lower and the gases were very difficult to detect.
Moreover, in view of the orders of magnitude of these measurements, sensitivity to

variations in the immediate environment should be mentioned. The data may be corrupted by the slightest pollution from an external source, for example fumes from road traffic or construction plant, or simply cigarette smoke.
These results nevertheless improve our knowledge about environmental impacts.

6. GAS EMISSIONS AT THE COATING PLANTS

Measurements of gas emissions at the coating plant were made in the case of four projects. These measurements are more conventional and correspond to those which are laid down by standards for the operation of industrial plants. They were conducted at four different batch coating plants using the two manufacturing processes for energy-saving mixes. The gas emissions were collected at the mixing plant chimney as shown in Photo 4.

Photo 4 - Location of the sampling zone for the analyses of fumes at coating plants.

It is important to bear in mind that in order to be exploitable, a number of conditions must be met with regard to these measurements:

- stable weather conditions,
- identical fuel and production regime,
- the moisture level of the aggregate in the control mixes and the energy-saving mixes must be comparable.

The results are then compared for the manufacture of the same asphaltic mix. A measurement campaign which fully meets all these criteria is therefore an expensive and difficult operation.
In the case of the works on the RN 157 described in Section 3.1, the measurements were made over a period of three days. The dryer used heavy fuel oil.
In the case of the second worksite, the mixes were manufactured by a mixing plant with a gas-fired dryer. The production rates were 180 tonnes/hour for the control asphaltic concrete and 175 tonnes/hour for the energy-saving mixes, with measurements being taken over more than 2 hours of production.
In the case of the third worksite, the dryer in the plant used very low sulphur content fuel oil and the production rates were respectively 193 tonnes/hour for the control mix and 195 tonnes/hour for the energy-saving mix. Poor weather made it impossible to conduct measurements on the same day for this worksite which meant that there was variation in the water content of the aggregate.
Last, in the case of the fourth worksite, the plant dryer used very low sulphur content fuel

oil. The measurements for the conventional mixes and the energy-saving mixes were made on two different days. The production rates were respectively 90 and 110 tonnes/hour for mix designs which were strictly identical in all respects apart from their binders.
These first findings show clearly that the two selected techniques have only a slight influence on gas emissions at mixing plants. The comparison between the relative variations in CO_2 emissions at the mixing plant chimney show an effective reduction in this greenhouse gas. Table 3 shows the variations measured at the four instrumented plants.

Table 3 - Relative variations in the composition of the chimney gases at the coating plants from control mixes and energy-saving mixes.

Gas	Relative variation in emissions
CO_2	between - 5 and -30 %
O_2	between 0 and +14 %

In spite of the fairly high dispersion of the measured relative variations, a reduction in CO_2 emissions was effectively observed together with a slight increase in oxygen emissions.

7. ENERGY CONSUMPTION

On two of the above worksites, energy consumption was also measured with the equipment existing on the plants, which is not yet sufficiently accurate.
Consequently, these first results are only given for information purposes, but they do show that these new types of mixes are responsible for a clear tendency towards a reduction in energy consumption.
In the case of the gas-fired dryer, with a temperature reduction of 30°C, the average energy consumption was 5.4 m3/h for the control mix and 4.5 m3/h for the energy saving mix, with measurement durations in excess of 2 hours and the same production rate of 180 tonnes/hour. This clearly shows a reduction in gas consumption of 0.9 m3/tonne, i.e. 16.5 %.
In the second case, the consumption of very low sulphur content heavy fuel oil was also measured. Bad weather led to a considerable difference in the water content of the aggregate, which varied from 1.9 % for the control mix to 3.2% for the energy-saving mix. The production rate was 195 tonnes/hour and the measurements were made over the time required to produce virtually the same weight of both mixes (230 tonnes). Fuel consumption for the control mix was measured at 5.91 l/tonne and 5.87 l/tonne for the warm mix manufactured with considerably moister aggregate.
On the basis of a more precise thermodynamic approach, the saving in heavy fuel oil has been estimated at 0.7 l/tonne of mix for every 1% reduction in aggregate moisture content. Using this value we can estimate that with identical water content to the control, the consumption would have been 4.96 l/tonne, i.e. a reduction of the order of 16%. In a similar way, the energy saving resulting from the 30°C reduction in manufacturing temperature can be estimated. This is of the order of 0.7 l of heavy fuel oil /tonne of mix.
These tests show clearly the trend, but it is also necessary to perform calculations to evaluate the energy savings generated by the manufacturing processes used for energy-saving mixes.

8. CONCLUSION

Based on the control of binder rheology and the coating process while complying with the rules of good practice, the processes that have been developed lead to a considerable 40 to 45°C reduction in mix manufacturing and laying temperatures. The physicomechanical performance and the in-service characteristics of these mixes, which although referred to as warm mixes are in reality energy-saving mixes, are equivalent to those of traditional mixes, and frequently even better.

The close monitoring of the works on the RN157 has clearly shown the temperature gains achieved by all the tested processes. The level of density, the evenness and skid resistance of these mixes under intense heavy vehicle traffic and after two hot summers prove that the processes withstand their intended use.

Energy-saving mixes can be made with Recycled Asphalt Pavement (RAP) and used to make various types of thin and very thin overlays with modified binders with the same benefits and success.

With regard to environmental aspects, these mixes lead to a considerable reduction, of the order of 18 to 20%, in gaseous emissions, in particular greenhouse gas emissions as a result of the proven reduction in energy consumption.

At all the worksites where these mixes have been laid gaseous emissions have also been lowered to the point of becoming practically imperceptible and below the detection limit of the measurement devices.

The choice of these energy-saving mix technologies has once again been validated both with regard to the overall environmental level by the reduction in energy consumption and the production of greenhouse gases and with regard to the near environment by providing further improvements to the working conditions and safety of laying teams and road users.

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