Background and positioning

The road industry has for many years been seeking to reduce the amount of energy required to manufacture HMA in order to combine energy savings and environmental benefits. To reach this goal, it first proposed cold-mix systems and more recently warm-mix asphalt processes. Despite their validity, these mixes have not yet been able to gain ground in relation to HMA.

Extensive ongoing research on the subject attests to the determination to find solutions, in particular in the area of warm mixes. This has resulted in mixtures offering a substantial reduction in manufacturing temperature (20 to 40°C) and exhibiting properties matching closely those of HMA. They use binders or combinations of binders and additives modifying the rheological properties of bitumens during mix manufacture and application.

Low-energy asphalt (LEA) with the performance of hot-mix asphalt (HMA)

The Kyoto agreements continue to divide the planet, whilst protocol signatories are defining their application conditions. Everyone is wondering what repercussions will result on their respective fields of activity and quality of life. Such is the context within which we are presenting a new aggregate coating technique, the low-energy asphalt (LEA) process, which substantially reduces energy consumption and greenhouse gas emissions (GGEs).

The LEA technique (known in French as EBE for Enrobage à basse énergie) involves the manufacture and application of asphalt mixes at a temperature lower than 100°C. These mixes offer performance equivalent to that of hot-mix asphalt (HMA). They combine the action of mixing energy, temperature and water on the components of the mix, its bitumen and aggregate skeleton. The originality of the process lies in the best use of changes in the condition of the bitumen, fluid when it is hot, ability to transform into foam or to emulsify when in contact with water. It moreover involves the moderate-temperature heating of only the chippings, the rest of the aggregate skeleton being used cold and wet. This technique yields a significant saving in mixing energy whilst reducing the resulting gas emissions. The article looks briefly into the process and sets it within its appropriate context.
To meet field application conditions, the application temperature of these mixes always remains higher than 100°C.

These seemingly appealing attempts have not made any tangible strides. They lead to complex processes often involving a combination of several binders and not yielding any immediately stable product exhibiting its final properties.

Many recent European or North American articles and papers have described and provided overviews of available techniques and their use. Temperature reductions of the order of 20 to 40°C have been obtained.

It is within this context that the low-energy asphalt (LEA) technique appeared. Its originality is characterised by an application temperature always lower than 100°C, with application conditions amenable to an even lower temperature, varying according to climatic conditions at the time of construction. Experience shows that this temperature is generally between 60 and 90°C. The study of the mechanical performance of LEA mixes shows them to be equivalent to HMA of comparable mix design.

The development of the LEA process has led to an approach differing from that of other processes. The process results from a more global approach to the principles of HMA production, thus leading to greater energy savings and better compliance with the environment by taking better into account the properties of the components used and the mix performance levels to be obtained.

The thermal properties of the components of asphalt mixes will be recalled:
• The amount of energy required for the heating of dry chippings to their coating temperature is 5 times lower than that used to raise to the same temperature an equivalent mass of water.
• The latent heat of evaporation of water represents 5 times the energy required to raise the same mass of water from 0 to 100°C. Exceeding the 100°C threshold greatly increases the heating energy expenditures.

This leads to the following remarks with regard to possible mixes:
• Possible energy savings remain small if the mixing temperature remains higher than 100°C.
• Substantial energy savings can be realised if the mixing temperature remains lower than 100°C. It is however not possible in this case to eliminate all the water contained in the aggregate skeleton, as this water is needed to ensure the workability of the mix below 100°C by allowing it to combine momentarily with the bitumen, without any effect on mix performance.
• The introduction of a surfactant enables this.
• There is nothing to be gained by drying the sand if the right coating is achieved otherwise.
• A water content of 0.5% in the final mix is favourable for compacting without affecting mechanical performance.

Based on fundamental thermal principles and customary conditions of bitumen use, the LEA process minimises the amount of energy required for complete coating of the aggregate skeleton. It results in limited heating of part of the aggregate skeleton and is based on the combined action of temperature, water and mixing energy on the components. The LEA process optimises the physical properties of the bitumen: fluidity when hot to « wet » the chippings, and «foaming» to coat the fine elements and maintain mix workability at a temperature not exceeding 80°C thanks to its combination with residual water.

After cooling, this results in mechanical performance equivalent to that of HMA.

**Genesis of the LEA technique**

The technique is the outcome of long-term, forward-looking investigations into alternative mixes capable of better meeting requirements specified by customers.

In 2002, the authors defined and checked the basic principles of the technique and its applications. This developmental work was supplemented by an energy/environment research programme with a research institute of the Ecole nationale supérieure des Arts et métiers (ENSAM) in Paris (Thermodynamics Laboratory of Professor Yves Le Goff).

In 2003, progress with the project made it eligible for a repayable loan from the national Agency.
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for the promotion of research in Industry, Agence nationale de valorisation de la recherche (ANVAR). This testifies to the validity of the process and the seriousness of studies already completed. It shows clearly the determination of the promoters to undertake the required industrial development. The ensuing steps included:

• filing of French, European and international patents,
• pursual of technical studies, in particular in the thermal and environmental areas, calling upon specialised organisations where necessary,
• completion of feasibility projects,
• design of appropriate equipment.

The French West Paris TR Labs, Laboratoire régional de l’ouest parisien (LROP) produced the first mixes in accordance with mix design standards for HMA, and performed their evaluation. The results make it possible to clearly determine laboratory test conditions and the level of mechanical performance. Industrial tests were then scheduled and completed successfully in November 2003.

In 2004, the mix-design and characterisation tests are being continued at the LROP as well as the ENSAM, where a new research programme is being carried out (Thermodynamics Laboratory of Professor Yves Le Goff and Microstructures Laboratory of Nicolas Hueber).

A new stage was reached early in 2005 with the permanent installation of a configuration using the LEA system in an Enrobés 77 hot-mix plant near Melun in the Paris region. The first industrial manufacturing operations began in April 2005.

Principle of LEA

As we pointed out above, the LEA process makes better use of available energy and optimises any additional energy required.

The objectives sought for the LEA process are the following:

• Limit additional energy requirements.
• Obtain complete coating of all components, from the finest to the coarsest.
• Ensure that the final temperature of the mix is below 100°C (between 60°C and 80°C).
• Use a single binder with no solvent.
• Have a stabilised binder at the end of application.

To achieve these goals, the LEA process consists in:

• Heating and drying only the chippings of the aggregate skeleton to less than 150°C.
• Coating the moderately heated chippings by all the bitumen of the mix to be manufactured (introduced at its normal utilisation temperature).
• Adding sand containing the fine elements of the aggregate skeleton (as is, wet and at ambient temperature).

Sequential coating (Figure 1)

1. The aggregate skeleton is separated into two fractions: one containing the chippings and sand without fines and the other containing fillered sand with fine elements.

2. Only the chippings are dried and heated, to a temperature lower than 150°C. The clean chippings and sand have a low water content and do not contain any fine elements. Heated, the chippings store calorific energy and subsequently restore it to the cold elements. Moderate heating of only the chippings leads to a reduction in the dimensions of the dryer and the dust collection system.

3. The bitumen is heated to its utilisation temperature which, depending on its grade, is between 140°C and 180°C. It is integrally provided with an anti-stripping agent to favour expansion and enable the coating of wet elements. This adhesion agent makes it possible, upon contact between water and still-warm bitumen,
to create expansion and prevent water stripping of bitumen already fixed on the chippings.

4. The chippings are then hot-coated with all the bitumen of the final mix. Hot coating leads to very good wetting of chippings by the bitumen and thorough coating of the coarsest elements. The thick and hot bitumen film clings firmly and is well distributed around the chippings brought to a similar temperature.

5. The addition of wet sand at ambient temperature leads to the complete coating of the mix:
   • spontaneous expansion of bitumen,
   • coating of sand by foamed bitumen,
   • heating of sand by contact,
   • obtaining of homogeneous mix,
   • prior addition of water, if necessary, allows for any required correction of sand moisture before introducing it into the mixer,
   • constant heat exchange taking place during the different mixing phases results in the condensation of excess water which is dispersed in part in the bitumen mass and creates the final workability of the mix at a temperature lower than 100°C.

6. Additional water can also be introduced at the end of the mixing in order to correct the workability of the mix. Water has two effects. It combines with the bitumen film in the form of fine droplets, and prevents the setting of the mix, despite the lowering of temperature.

The LEA technique allows the manufacture and application of mixes having the same properties as HMA.

At 70°C, LEAs have the appearance and characteristics of HMA:
   • They use the same bitumen grades in the same proportions.
   • They cover the entire range of HMA mix designs, from roadbase asphalt to bituminous concrete.
   • The binder content is not a limitation, unlike with mixes based on foamed bitumen.
   • The mixes, after application, exhibit their final mechanical performance.
   • Residual water content in the mixes is lower, but near 0.5%.

The technique is applicable to the recycling of asphalt by using cold recycled materials for the partial or total replacement of the sandy cold part containing the fines.

It reduces environmental disturbances substantially and improves working personnel safety:
   • mixing temperature lower than 100°C, (60°-90°C),
   • reduction of calorific energy required for manufacturing by more than half (without employing an emulsion-type binder or one using solvents),
   • reduction of greenhouse gas emissions (GGEs),
   • reduced emission of volatile organic compounds (VOCs).

Mix design, manufacture and application

Laboratory mix-design methods for HMA apply to the mix design of LEA mixes.

Laboratory procedures must be adjusted to the temperature of the mixes resulting from the process. Specimen manufacturing temperatures are between 60° and 80°C. They nevertheless allow the execution of the same types of tests used for HMA.

For these initial mix-design studies, we used mixing temperatures of 80°C. Moulding corresponding to the different tests was carried out at this temperature: Duriez specimens, mixes for gyratory shear compactor (PCG) tests, plates for rutting tests (Photos 1, 2 and 3).
Behavioural test temperatures set by standards (NF P 98-130 and NF P 98-138) are complied with.

Results of laboratory tests

The technique works with bitumen grades currently used in road building (35/50 and 50/70), but also with polymer-modified bitumens or hard binders for structuring mixes. Semi-granular bituminous concrete type mixes (French designation Béton bitumineux semi-grenu, BBSG) and Class 3 asphalt roadbase materials (French designation Grave-bitume, GB3), manufactured according to the LEA technique, make it possible to reach the same performance levels as if manufactured using the HMA technique (Tables 1 and 2).

The performance levels are reached with a manufacturing temperature of 80°C. The residual water content of LEAs, after cooling, is between 0.2% and 0.3%.

Industrial tests (November 2003)

The tests were carried out early in November 2003 in France’s Rhône-Alpes region and included mix manufacture and application with a paver-finisher. The climatic conditions corresponded to normal seasonal values, with air temperatures a few degrees above freezing in the morning. A total of 150t was manufactured and applied. LEA mixes manufactured and applied during the tests were of the BBSG and GB3 type.

The mixing plant, of the batch type, was adapted for the successive introduction of the two parts of the aggregate skeleton into the weighing system ahead of the mixer. The rest of the installation was kept untouched. The LEA leaving the mixer has the appearance of HMA. The manufactured mixes were stored in the finished product storage hopper for more than one hour. They were applied by the paver-finisher and compacted by a double-roll vibrating compactor in accordance with usual application procedures on road worksites (Photos 4 to 6).
On the other hand, the application temperature was of the order of 60/70°C.

As the difference with the ambient temperature is smaller for LEAs than for their high-temperature counterparts, the drop in temperature with weather is less significant. Note will be made of the reduced soiling of production equipment (transport or application), thus facilitating their cleaning and obviating the use of corresponding solvents.

Industrial tests showed the following (Photos 7, 8, 9):
• LEA industrial manufacturing principles are reliable.
• LEA mixes are homogeneous and reproducible.
• The operating conditions of industrial mixers are more favourable than those used for the laboratory mix-design studies.
• It is possible to store manufactured mixes in hoppers. The behaviour of manufactured LEA mixes allows worksite transport times comparable to those of HMA.
• Established feasibility of the LEA technique using the facilities and methods used for asphalt applications.
• LEA can work with an application temperature between 60°C and 80°C.
• LEA compacting conditions are identical to those of HMA.
• Mix workability is compatible with manual application.
• The LEA mix has a surface appearance comparable to that of HMA, including at joint locations.
• Less soiling of equipment is observed, thus facilitating cleaning and greatly reducing the use of solvents.
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The energy-saving and environmental advantages of LEA mixes

Their position with respect to HMA

Recent life-cycle analysis (LCA) studies on road mixes have been carried out within the industry (USRF, EUROBITUME, PIARC, COLAS). They indicate, for the road mixes used, the corresponding levels of energy consumption and GGEs.

A research programme on energy and environmental aspects accompanied the development of the process. It was carried out at the ENSAM under the direction of Professor Yves Le Goff. This study led to the development of a mathematical model simulating the energy phenomena as a function of the physical characteristics and thermal properties of the different components. It takes into account the different mix parameters and simulates the manufacturing conditions.

It may be incorporated in the operating system of the mixing plant (Figure 2).

Overall environmental balance of process

Comparative heat balance of hot – and warm-mix asphalt

Only the energy required to heat the components is taken into account in what follows.

**HMA heat balance**

**Assumptions**
- Gradation comprising 65% of 2/0 and 35% of 0/2,
- Water content of chippings: 1%,
- Water content of sand: 4%,
- Heating of aggregates to 150°C,
- Bitumen 5.6 pph at 170°C,
- Ambient temperature: 10°C.

**Calculations**

- For 1,000 kg of dry chippings:
  - Chipping heating energy
    \[ C_{\text{gran}} \times 1000 \times (150°C - 10°C) = 117180.00 \text{ kj} \]
  - Water heating energy
    \[ C_{\text{eau}} \times (1000/990 - 1) \times 1000 \times (100°C - 10°C) = 15693.75 \text{ kj} \]
  - Water evaporation energy
    \[ L_v \times (1000/990 - 1) \times 1000 = 22785.60 \text{ kj} \]
  - Water vapour heating energy
    \[ C_{\text{vap}} \times (1000/990 - 1) \times 1000 \times (150°C - 100°C) = 9218.54 \text{ kj} \]
  - Total = 127584.69 kj

- For 1,000 kg of dry mix according to following formula:
  - Chippings: 65% \times 144694,39 kj = 94051.35 kj
  - Sand: 35% \times 230686,25 kj = 80740.19 kj
  - Total, HMA, 175 MJ for one ton

**LEA heat balance**

**Assumptions**
- Gradation comprising 65% of 2/0 and 35% of 0/2,
- Water content of chippings: 1%,
- Water content of sand: 4%,
- Heating of chippings alone to 130°C,
- Bitumen 5.6 pph at 170°C,
- Ambient temperature: 10°C.

**Calculations**

- For 1,000 kg of dry chippings:
  - Chipping heating energy
    \[ C_{\text{gran}} \times 1000 \times (130°C - 10°C) = 100440.00 \text{ kj} \]
  - Water heating energy
    \[ C_{\text{eau}} \times (1000/990 - 1) \times 1000 \times (100°C - 10°C) = 10000.00 \text{ kj} \]
  - Water evaporation energy
    \[ L_v \times (1000/990 - 1) \times 1000 = 22785.60 \text{ kj} \]
  - Water vapour heating energy
    \[ C_{\text{vap}} \times (1000/990 - 1) \times 1000 \times (130°C - 100°C) = 5545.45 \text{ kj} \]
  - Total = 127584.69 kj

- For 1,000 kg of dry mix according to following formula:
  - Chippings: 65% \times 127584.69 kj = 82378.49 kj
  - Total LEA 82 Mj for one ton
Energy consumption levels involved in heating HMA and LEA (Table 3)

For HMA: 175 MJ/t for drying and heating. For LEA: 83 MJ/t for drying and heating. The heating energy, per tonne of LEA, is reduced by more than 50%.

It should be noted that the energy required for the mechanical operation of an HMA asphalt plant is of the order of 100 MJ/t. It will be less for a LEA equipped plant.

GGEs are related to fuels consumed in heating (Table 4)

An assessment of GGEs corresponding to the heating of materials shows that GGEs, per tonne of LEA, are reduced by more than 50%. NOx emissions are also halved (Table 5).

VOC emissions

VOC emissions come from bitumen fumes. Among these, polycyclic aromatic hydrocarbons (PAHs) present in small quantities have an essential impact on health. PAH emissions are proportional to mix manufacturing temperature. A reduction of 10% in mix manufacturing temperature generates a reduction of these emissions by a factor of 2. Reducing by more than 50% the application temperature of LEA reduces in considerable proportions the health risks involved.

Specificities of LEA production equipment

The dryer and dust collector are designed for the drying and heating to moderate temperature of only the chippings (maximum water content of 2.5% and absence of fine elements). This results in much smaller dimensions owing to the smaller gas quantities handled. Lower heat energy consumption makes it possible to reduce gas flow and the dimensions of the filter structure. Reduced formation of dust in the drum allows the reduction of the filtering surface, related directly to dust concentration (Table 6). The LEA technique is applicable to both batch and continuous mixing operations, being careful to comply with proper contact between components which favour heat exchanges throughout the mixing.
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The LEA technique makes it possible to:
• Obtain new plants specially designed for the manufacture of LEA mixes.
• Design kits adaptable to existing plants for the manufacture of these same mixes.
• Obtain greater mobility in movable equipment, and this, with largely improved recycling performance, and with automated operation resulting from the modelling of the process.

The LEA process is today reaching the industrial stage

The process has advanced and is ready for use in existing asphalt plants (Figure 3), enabling them, to extend their manufacturing to LEA mixes which can be used in construction projects (Photos 10 to 12).

A first AM MAN batch mixing plant in operation in the Paris region was equipped with a kit adaptable for LEA mix production at the beginning of 2005 (Photo 10). This installation is associated with a low-rate bituminous aggregate recycling system directly in the mixer.

A specific hopper allows the metering of the amount of cold sand to be introduced into the mixer via a storage bin located over it.
Also included is a device adding water to the sand. The gravelly part of the mix design follows the usual process for drying and metering the aggregate skeleton with HMA. The bitumen metering device is completed by a surfactant addition system. The mixing process has been modified to comply with the sequential mixing of the process: hot aggregate, wet sand and bitumen, and cold filler. The first projects completed confirm the reliability of the LEA process. Besides kits adaptable to existing plants, specific installations will be possible.

**Conclusions**

The studies and achievements presented show the validity and reliability of the LEA process. It is currently entering its industrial application phase, making it possible to complete the knowledge acquired and closely assess the extent of its application possibilities.

The LEA process represents an original response to today’s requirements on the scale of our planet with regard to reduced energy consumption and environmental safeguards, without generating any prohibitive extra cost as concerns its applications. It moreover improves not only the safety and working conditions of worksite personnel, but also the safety of users moving around the worksites (elimination of fog risks in rain). It is of interest to developing countries because it allows the design of less complex manufacturing systems that consume less energy while safeguarding the performance of the mixes obtained.

There is no doubt that contract awarding agencies, highway contractors, asphalt producers and equipment manufacturers respectful of the environment will be able to further the use and development of LEA process.

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