AN INNOVATIVE PLANT-BASED BINDER
FOR ROAD MIXES AND PAVEMENT SURFACINGS

M. Ballié & T. Delcroix
Colas SA, France
ballie@dt.colas.fr & delcroix@campus.colas.fr

ABSTRACT

Several years ago, a research programme started to develop a family of plant-based binders that might ultimately provide an alternative to the different grades of road bitumen. In April 2003, it resulted in the first construction project for a wearing course, in close partnership with the General Council of the Département of Côtes d'Armor in the framework of its innovation project "The Road of the Future".
With assistance from the French Energy Conservation Agency (ADEME) in-depth laboratory studies have resulted in the development of a range of plant-based binders. They are manufactured from renewable raw materials and fit in with the ideas of sustainable development. They may be used for maintenance mixes, or for surfacings which must blend harmoniously with the environment. This is because they are transparent in thin films and therefore take on the natural colour of the aggregate. They have specific rheological properties, in particular viscosity which means mixes can be manufactured at about 110 °C, or even below. They also help to reduce greenhouse gas emissions.
They give the mixes the physical and mechanical performance required for wearing courses. However, the mix design method must be adapted in view of the binder's changing properties.
Three sets of works, using a very thin layer of mix made with 0/6 mm aggregate, have been conducted on county roads in the framework of an innovation charter signed with the respective Département General Councils and the Sétra.
Monitoring of the surface characteristics of these projects has shown that their skid resistance is still very satisfactory after between 20 and 30 months of service.
The mechanical performance is also satisfactory, without rutting or deterioration even in areas where the climate requires potentially damaging winter maintenance.
The development of these plant-based binders is on-going, involving the creation of aesthetically pleasing mixes, and several examples are described.

1. The nature of the problem

Most French roads are either constructed and maintained with bituminous mixes or use bitumen in their surfacings. This bitumen is obtained by refining crude oil.

To give an idea of the quantities involved, France's annual consumption of bitumen is of the order of 3,5 million tonnes, 90% of which is used in roads. In order to make the best possible use of oil from the point of view of sustainable development, it is important at the present time to find alternatives to this use of bitumen in highway engineering.
Therefore, the development of a road binder that can be used to manufacture mixes with physicochemical characteristics similar to those of bitumen but which is made entirely of raw materials obtained from the agricultural sector is an innovative objective which is at the heart of the issues surrounding energy resources and environmental gains.
On this basis, in the last four years, large resources have been committed to research to develop a family of plant-based binders that could eventually provide an alternative to the

different grades of road bitumen. These binders are intended to be used to manufacture pavement construction and maintenance mixes, but also for aesthetically-pleasing surfacings in urban areas and other spaces where they will blend well with the architectural environment.

In-depth laboratory studies and a large number of field trials, conducted with assistance from the French Energy Conservation Agency (ADEME), have:

- established mix design rules for these plant-based binders,
- identified the appropriate aggregate mixture – binder compositions for producing what will be referred to in what follows as “plant-based binder mixes”.

The agricultural raw materials they require are already produced on an industrial scale so there is no need to create a new production channel.

Manufacture of the binder requires a special industrial unit. It is not particularly complex, but the proportioning of the constituents must be precise, the process of mixing must be controlled and it must be possible to store the raw materials and the binder produced.

Conventional bitumen mixing plants and present-day laying equipment are perfectly satisfactory. The know-how of the contractors currently operating in the sector will still be valid when working with these binders.

2. The plant-based binder

The binder is obtained by mixing a number of constituents obtained by processing raw materials of vegetable origin. The invention is protected by French and European patents.

The proportions of the constituents, the temperature and the mixing time must be strictly controlled during manufacture. The reason for this is that the binder’s final properties depend on the progression of a polymerization reaction which takes place in particular between the constituents, and probably with the aggregate and the oxygen in the air too. This process continues during manufacture and placement of the mixes and after compaction.

It is this polymerization mechanism which gives the mixes the cohesion and mechanical performance that road materials require.

The existence of this “curing” phase explains the method chosen to evaluate binder’s properties.

Consequently, although it is possible to use the same characterization tests as for road bitumens for these binders, the usual rules for selecting a binder for a given application cannot be applied to the results.

This is because it is necessary to take account of the changes caused by the polymerization which takes place after aggregate coating and mix compaction.

The binder also has specific rheological properties.

It is therefore essential to accumulate data from laboratory tests and validate them on the basis of in-situ behaviour.

This data is used to select a plant-based binder composition according to the intended use of the mix manufactured with it. A binder range has been specified in this way. It aims to match the different ways in which hydrocarbon binders are used - spraying and coating.

These binders can be emulsified. As a function of the emulsion design, different types of surfacings can be produced: surface dressings, microsurfacing and cold mixes manufactured in a central mixing plant.

This document will present those applications which are at a sufficiently advanced stage of development, i.e. hot mixes manufactured with the plant-based binder.

This research has resulted in the design of plant-based binders whose end-use properties are suitable for surfacing or foundation layers.

Table 1 presents some characteristics of the current principal classes prior to polymerization.

Class	1	2	3
Initial viscosity (Pa.s) Brookfield viscosity, (SC 4-27), 70 °C, 1.4 s^{-1}	33 to 45	16 to 24	11 to 14
Pumpability temperature (°C)	100	100	100
Density at 25°C	0.95 to 1.05	0.95 to 1.05	0.95 to 1.05
Cleveland flashpoint (°C)	> 210	> 210	> 210
Complex modulus G*(MPa) at 20 °C; 7.8Hz	>2.5	>0.8	>0.2

Table 1- Current classes and principal rheological characteristics.

On the grounds of confidentiality we will not explain in greater detail the design principles used for these binders.

3. Some of the interesting properties of the plant-based binder

The composition of the plant-based binder can be selected to make it transparent in a thin layer. It can then be used to manufacture mixes which take on the natural colour of the aggregate or which can be coloured as desired. So far, applications have primarily involved this type of plant-based binder. Photos 1 and 2 show the interesting consequences of this property on the appearance of mixes.

Photo 1-Logo without binder With and without plant-based binder With and without bitumen

Photo 2- Plant-based binder mix with the natural colour of the aggregate

The second very interesting characteristic to highlight is the viscosity of the plant-based binder. As has been stated above, the hot coating process is identical to that for bituminous mixes.

It is performed with hot dry aggregate at a temperature that depends on the viscosity of the plant-based binder and the temperature at which it can be sprayed to ensure effective coating of the aggregate particles.

Figure 1 shows that the viscosity values of the plant-based binder are considerably lower than those of the corresponding bitumen. It is therefore possible to manufacture the mixes at a lower temperature than bituminous mixes. The coating temperature can be reduced by 40 to 50°C, without any reduction in workability.

This means that energy consumption and greenhouse gas emissions will also probably be reduced.

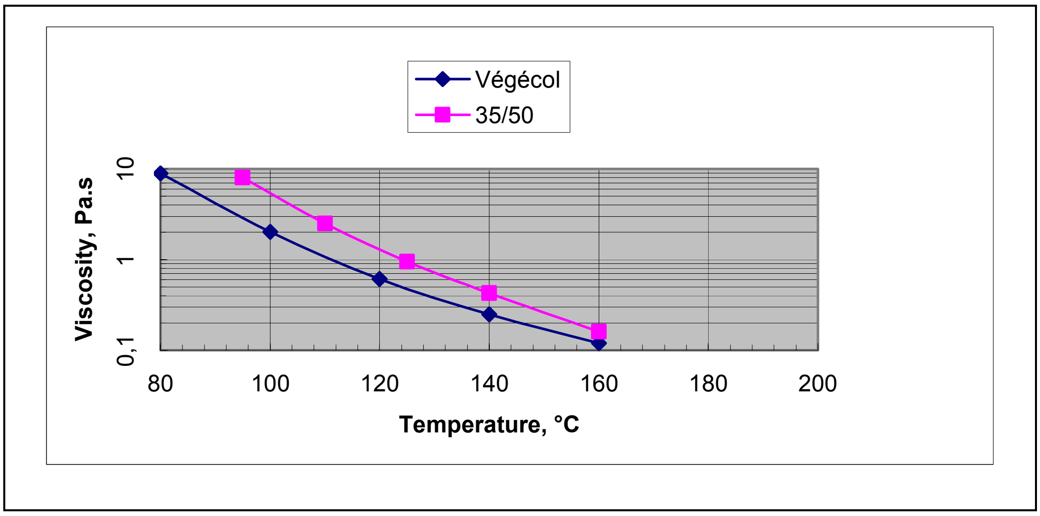

Figure 1 - Comparison between the viscosity of the plant-based binder and a 35/50 pen pure bitumen.

Photos 3 and 4 illustrate this property. Gas emissions are very low during the manufacture of plant-based binder mixes in a central mixing plant at about 110°C and when they are laid at a temperature of about 95°C.

Photos 3 and 4 - Loading a truck at the manufacturing plant and laying the same mix on a very highly trafficked county road.

Another important property, the cohesion of the binder, influences the mechanical performance of the mixes. It results from the polymerization of the binder.
Figure 2 shows a plot of cohesion against temperature obtained from a Vialit pendulum test.
This plot was obtained with a class 3 binder after RTFOT aging as specified in the normalized road bitumen test (NF EN 12607-1).

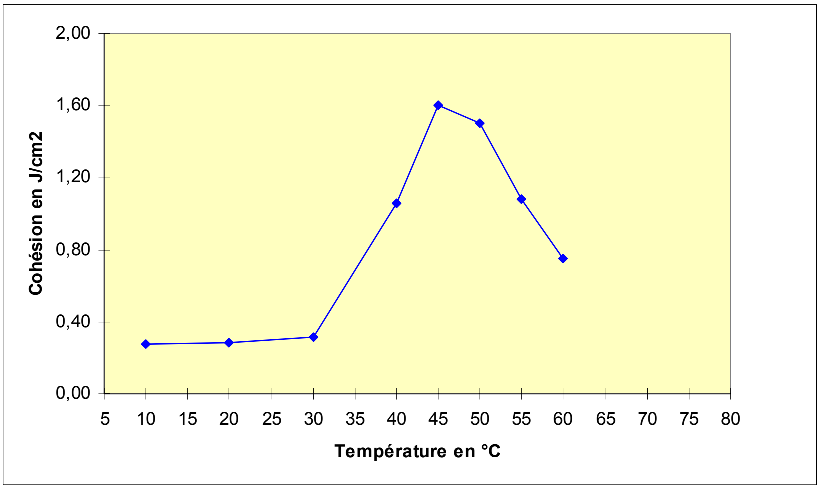

Figure : Cohesion in J/cm2, Temperature in °C
Figure 2 - Plot of the cohesion of the plant-based binder (class 3) after RTFOT aging according to temperature

4. Physicomechanical properties of the mixes

These were determined for mixes containing aggregate from the La Noubleau quarry, with 0/6 mm continuous grading and a plant-based binder content of 5.7 % in relation to the dry aggregate.

4.1 Compactability

Compactability was measured using the gyratory shear press as described in the French standard NF P 98-252. The mixes can be compacted without difficulty, even at temperatures as low as 100 °C, which explains the improved mix workability that results from the plant-based binder's lower viscosity.

4.2 Strength in air and after immersion in water

To evaluate the water resistance of the mix, the Duriez test procedure (NF 98-251-1) must be modified. Before the test the specimens are conserved at 18°C and 50% relative humidity.

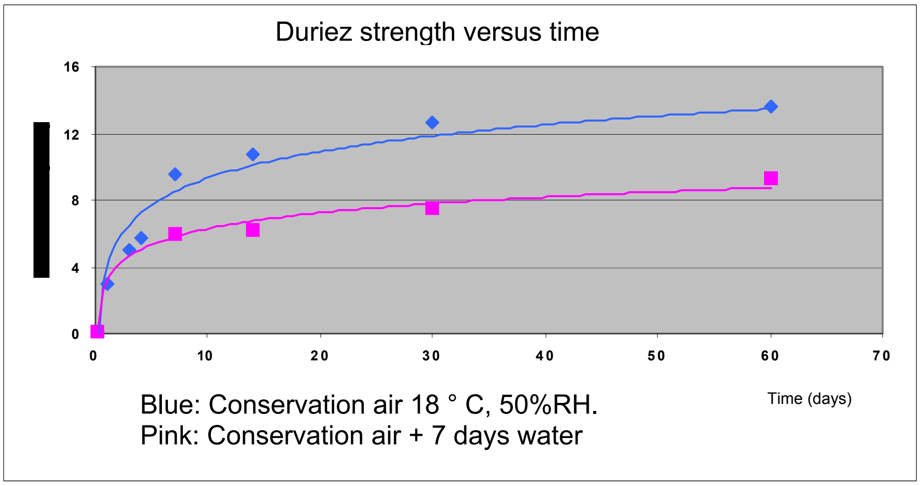

Figure 3 - Duriez strength as a function of curing time.

Under these conditions, the strength of the specimens after conservation in air at 18 °C and after immersion in water at the same temperature continue to increase during the first 60 days of curing. Their stabilization after this period marks the end of the polymerization process, as can be seen in Figure 3. The physicomechanical performance is quite satisfactory. Immersion in water slows the curing of the mixes but does not lead to binder stripping or damage to the mix specimens.

4.3 Rutting resistance

Rutting resistance was measured using the LPC rutting machine as specified in the standard NF 98-253-1. The mixes in question were intended to be laid in very thin layers. The specimens were conserved for 7 days at ambient temperature in order for the polymerization process to have an effect. Two geometric compaction values of the test plates were tested. The test was conducted at 60°C. The data are set out in Table 2 and show the good rutting resistance of the plant-based binder mixes.

Table 2 - Rutting resistance of mixes using the plant-based binder.

Number of cycles	**Low density: 85.2%**	**High density: 87.9 %**	**Specification for very thin asphaltic concrete (XP P 98-137)**
3 000	2.8 %	2.1 %	≤ 20 %
30 000	4.0 %	2.9 %	
100 000	4.4 %	3.5 %	

4.4 Stiffness modulus and fatigue strength

Table 3 presents the results of mechanical tests to establish the modulus and the flexural fatigue performance (NF P 98-260-2 et NF P 98-261-1) performed on mixes with the same composition. The binders were, respectively, a pure 50/70 pen bitumen, a binder with a high elastomer content (SBS) and the plant-based binder designed for the same type of use as the first two. The curing times of the specimens at ambient temperature were the same for all three binders, i.e. one month and nine months.

Table 3 - A comparison between the modulus and fatigue performance of the 0/6 mixes with different binders as a function of age.

	50/70		SBS modified bitumen		Plant Based Binder	
Age	1 month	9 months	1 month	9 months	1 month	9 months
Modulus 15°C,10Hz (Mpa)	3800	3800	4200	4600	5100	5600
Fatigue microdéf	110	114	122	125	129	161
Gain		+ 4 %		+3%		+25%

These values show that the 0/6 pavement surfacing mixes exhibit particularly good stiffness modulus and fatigue performance, which may be even better than those obtained with modified mixes with a very high elastomer content, and this is even more the case after nine months of curing.
The above values confirm that the mixes are completely suitable for their intended use.

5. Carrying out works and the in-situ performance of plant-based binder mixes.

5.1 The “Road of the Future” at the Ploufragan science park (Côtes D’ARMOR). April 2003 [1]

This was the very first application on a trafficked road and was conducted in partnership with the General Council of the Département of Côtes d’Armor in the framework of its innovation project “The Road of the Future”.
It provided COLAS an opportunity to conduct a full-scale test of the new mix concept on the access road to the Ploufragan Science Park.
HÉLARY, a subsidiary of COLAS Centre Ouest, laid a very thin mix wearing course with the natural colour of the aggregate on approximately half the carriageway and a similar white wearing course on the other half of the carriageway. These continuously graded 0/6 mixes with a binder content of 6% in relation to the dry aggregate proved effective with regard to skid resistance and acoustic comfort [2]. The aggregate was sourced from the Bégard quarry and met the requirements for a wearing course. The mixes were manufactured in a batch-mixing plant with a specific production line for adding and proportioning the plant-based binder.
The mixes were laid in a thickness of 2.5 cm after the application of a tack coat manufactured with conventional bitumen emulsion with the addition of a small amount of

chippings to prevent the bitumen from contaminating the plant-based binder (3 l/m² of 4/6 mm chippings).
Photo 5 shows laying of the white mix which required preliminary cleaning of the manufacturing and laying equipment. Compaction was performed by a type VT2 smooth roll tandem compactor.

Photo 5 - Laying the white plant-based binder

Principal surface characteristics of the mixes
The macrotexture of the surfacing was adequate when measured by the sand patch test, with an average sand patch value of 0.71 mm.
The average sideways force coefficient measured at 60 km/h with a SCRIM belonging to the Lyon CETE [3], was 0.69 after 4 months.
The braking force coefficient (BFC) values after 6 months and 30 months measured by the ADHERA trailer belonging to the Nord Picardie CETE [3], are displayed in Table 4.

Table 4 - BFC at different speeds as a function of age

Age	6 months	30 months
BFC at 40 Km/H	0.65	0.61
BFC at 60Km/H	0.53	0.45

The reduction in the BFC at 40 Km/h that occurs over time is small. The reduction in BFC is more marked at 60 Km/h (more traffic$ on the road in question or dirt on the surfacing?), but the level is still acceptable. This second pair of values is, in fact, at the top end of the national range for all types of surfacing. The set of measurements demonstrate very satisfactory skid resistance which is similar to that measured on SBS-modified bituminous surfacings of the same type.
With regard to photometric characteristics, measured by the Strasbourg Regional Public Works Laboratory (LRPC) the “white” section belonged to class R1 and the coloured section to class R2 as defined by the International Commission on Illumination (CIE) [4].
These values confirm the excellent performance of thes plant-based binder mixes.
Furthermore, the surface of the mix can be easily cleaned with high pressure water (about 500-600 bars) after 12 months of service. This practically restores its initial photometric characteristics without any deterioration of the mix during the cleaning process as shown in Figure 6.

Photo 6 - Appearance of surface after cleaning with high pressure water.

After 3.5 years of service, including the extremely hot summer of 2003, the wearing course still has an excellent surface appearance and its performance is completely satisfactory.
This first project was carried out in a region with a temperate climate, so for the second project a more continental climate was chosen, with large temperature variations in the winter and potentially damaging winter maintenance.

5.2 The Ligsdorf worksite (Département of Haut Rhin) October 2003

In the framework of a road maintenance contract awarded to COLAS Est's Haut Rhin Centre in Mulhouse, the General Council of the Département of Haut Rhin decided to replace a wearing course at Ligsdorf.
This project involved placing a very thin natural aggregate coloured wearing course on a pavement carrying T3 traffic (50-150 heavy lorries per day in each direction) with a bendy profile and a slight gradient.
It is located in the Jura mountains in Alsace and every year is subjected to high amplitude frost-thaw cycles for a significant length of time. This county road also has to withstand a large amount of salting and snow removal.
The mix with 0/6 continuous grading was manufactured using local aggregate from alluvial deposits in the Rhine at Blotzheim. The proportion of plant-based binder was 6% in relation to the dry aggregate. The mix was manufactured in a batch-mixing plant with a special production line for adding and proportioning the plant-based binder. The manufacturing temperature was between 110 and 120°C and the duration of transport in tarpaulin covered lorries was about one hour.
Placement was performed with a conventional asphalt laying machine and the mix was compacted with a type VT2 smooth roll tandem compactor. There was light rainfall during the laying works, but this caused no problems. Once again, the excellent workability of the mixes was observed, even at a temperature of about 80 to 90°C. Photo 8 shows laying of the mix.

Photo 8 - October 2003, laying the 0/6 mix at Ligsdorf

Principal surface characteristics of the mixes

The macrotexture of the surfacing was very satisfactory when measured by the sand patch test, with an average sand patch value of 1 mm.

The average sideways force coefficient measured at 60 Km/h with a SCRIM belonging to the Lyon CETE was 0.75 after 9 months.

The breaking force coefficient (BFC) values after 8 months and after 20 months are set out in Table 5.

After 8 and 20 months of trafficking these BFC values are placed at the upper end of the national range for all types of surfacings.

Table 5: BFC at different speeds according to age

Age	8 months	20 months
BFC 40 Km/h	0.68	0.66
BFC 60Km/h	0.57	0.59
BFC 80Km/h	0.52	0.52

Taken together, these values confirm that the skid resistance is both very satisfactory and durable. It is similar to that of surfacings of the same type manufactured with SBS elastomer-modified bitumens on a trafficked pavement exposed to severe weather.

After three fairly rigorous winters with many frost-thaw cycles and temperatures as low as -15 °C, and fairly frequent road salting and snow removal followed by hot to very hot summers, the surface appearance of the wearing course is very satisfactory.

Photo 9 shows the state of the pavement as it is now after almost 3 years of trafficking.

Photo 9- Appearance of the pavement after 30 months

5.3 Projects in 2004 -2006

In view of the good overall performance of these first projects on roads that are open to traffic, other works were performed in 2004 permitting further refinement of the mix design rules for the plant-based binder.

First, in May 2004, a path and a square in the Bois de Boulogne in Paris were surfaced using mixes with the natural colour of the aggregate (sand from the Seine).

These mixes were laid manually. Their high workability meant laying was possible at about 80°C and the “wet sand” colouring requested by the project manager was obtained.

Then in September 2004, in the framework of a Road Innovation Charter signed with the General Councils of the relevant Départmement, and the SETRA, two construction projects involving very thin mixes were undertaken.

With the same type of 0/6 mm continuously graded aggregate and a binder content of 6 % of plant-based binder in relation to the dry aggregate, these mixes were laid on fairly heavily trafficked county roads with traffic varying between approximately 150 to 750 heavy lorries per day in each direction. The works were carried out in early October 2004, in the Départements of Haut Rhin (RD 419) and Côtes d’Armor (RD 712). They were conducted under traffic and the skid resistance and general performance of the surfacings was closely monitored.

In order to cover all France’s climatic zones, in 2005, in the framework of this Charter, a third and final project was carried out, with the same 0/6 mix for the General Council of the Département of Haute Garonne on a county road (RD16) with lorry traffic of between 150 and 300 vehicles per day in each direction.

The current performance of all these surfacings is completely satisfactory and tests have confirmed their good surface characteristics, an absence of rutting and good durability as shown by this recent photo of the RD 419 (Photo 10).

Photo 10 -The RD 419 after 20 months of trafficking

There have been many projects since 2005. These have aimed to highlight the attractive natural appearance the mixes obtained as a result of the transparency of the plant-based binder which allows the colour of the aggregate to show through and blends in with the surroundings. They have principally been used for urban streets, cycle track surfacings and pedestrian or leisure zones. Photos 11 and 12 show some recent projects.

Photos 11 - Bormes Les Mimosas and the Luxembourg Palace in Paris

Photos 12 - Sainte Marie aux Mines, a cycle path in Ensisheim, Boulogne sur Mer

6. Use in the form of an emulsion

Since 2005, emulsions that use the plant-based binder have been developed.

These emulsions are used to manufacture cold mixes and provide adequate workability for the mixes to be manufactured and laid with normal techniques.
An initial test strip using a cold plant-based binder emulsion mix was laid in October 2005 with a towed mixer.
The first works using mixes of this type manufactured in a plant were performed in 2006 for urban improvements and cycle tracks. Cohesion build-up in the mixes takes a matter of hours. Their current performance is completely satisfactory.
This suggests interesting technological advances in the future, with the manufacture of mixes at ambient temperature, leading to a further reduction in energy consumption and greenhouse gas emissions.
Photos 13 and 14 show two of these promising projects.

Photo 13 and 14 – Laying cold mixes manufactured with the plant-based binder emulsion.

7. Conclusions and outlook

The innovative objective of developing a plant-based binder, which is at the heart of the issues surrounding energy resources and environmental gains, has been attained, or even exceeded. As a result of the research programme and the trials with the assistance of the French Energy Conservation Agency (ADEME), hot mixes with very satisfactory physicomechanical performance have been produced.
The road surfacings, the first of which was opened four years ago, are today performing in a very satisfactory manner under traffic.
They provide surface characteristics that are at least as good as bituminous mixes of the same class, providing a safe comfortable ride for road users.
COLAS has therefore decided to increase production of this range of coating binders and to date more than 2000 tonnes have been manufactured.
These mixes are manufactured from renewable raw materials and fit in with the ideas of sustainable development.
As the binders enable mixes to be manufactured at relatively low temperatures of around 110°C or even below, they also help reduce greenhouse gas emissions. They are recyclable and are not toxic for the environment.
So far, it is the binder's transparency which has most attracted our clients. This allows the natural colour of the aggregate to appear and make it straightforward to design pavements which integrate harmoniously with their architectural surroundings. The excellent workability of the mixes facilitates the manual laying which is frequently required for small surface areas.
Since 2006, a new application has been developed. In a water emulsion, the plant-based binder provides excellent coating of aggregate, meaning mixes can be manufactured in conventional mixing plants, which facilitates laying. The behaviour of the first projects is satisfactory suggesting the possibility of further advances in the area of energy savings and reductions in greenhouse gas emissions..
Ultimately providing an alternative to bitumen, the range of plant-based binders illustrates commitment to innovation and to sustainable development and the desire to provide appropriate responses for it.
Perhaps a new type of road?

1. Françoise Marmier (avril 2002). Sur la Route du Futur, route, véhicule et conducteur dialoguent. RGRA N° 805.
2. Michel Ballié (juin 2004). Rugosoft, une nouvelle conception de bétons bitumineux peu bruyants à adhérence élevée. RGRA N° 829.

3. CFTR. Note d'information n°11 (mars 2005). Mesures de l'adhérence des chaussées routières.
4. Sétra. Note d'information n° 92 (mars 1997). Caractéristiques photométriques des revêtements de chaussées.