Future roads and mobility

Colored coatings with synthetic binders : how to satisfy both aesthetics and performance

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Abstract

Colored coatings are increasingly used for roads, in urban areas more specifically. They allow to create qualitative and colorful areas, to delimit places according to their different use and contribute to good visibility and lighting saving. The safety and comfort of users are therefore improved. The binder formulation requires first the selection of a pair of a resin and an oil which makes it homogeneous and possible to resist to aging. Homogeneity can be especially assessed by Light Microscopy and Atomic Force Microscopy (AFM). Then the resin/oil ratio as well as the action of other additives can complement the formulation to meet the intended applications. For instance binders can be formulated for the manufacture and application of colored pavement structures that can resist to high sollicitations such as bus lanes that are subjected to heavy, channelized and static traffic. The structure that constitutes them must integrate these damaging factors. The rutting performance has been assessed according to different conditions and meets the following specifications: o < 5% at 100 000 cycles (usual conditions) o <15% at 30 000 cycles (more severe conditions : 7 bars , 65°C , 0.1 Hz) Some feedbacks from different type of jobsites are reported . The color of the pavement contributes to the aesthetic. So it is a very important parameter to manage: simulation of UV aging is carried out in laboratory and the evolution of the color during aging is measured by a spectrophotometer which allows the determination of the L * a * b * components using the D65 illuminant (which reproduces daylight with a UV component). and an inclination of 10 °. Some recommendation will be given in order to enhance the laying, the maintenance , and the cleaning of such pavements.

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1. INTRODUCTION

Asphalt mixes formulated with a clear binder help to improve the living environment, enhance user safety by better differentiating pedestrian and cycling areas, and preserve the environment by limiting the formation of urban heat islands because of lower heat absorption.
Typical examples of development include: squares, park alleys, pedestrian and sidewalk paths, playgrounds, sports fields, schoolyards, car parks, greenways, city entrances, bicycle paths. But this list is not exhaustive. An article has been specially dedicated to the use of COLCLAIR® mixes for low traffic mode [1].
The formulation of light-colored asphalt mixes can be adapted according to the use and the desired surface appearance. It is even possible, as it will be described later, to obtain the same mechanical performance as that obtained with conventional asphalt mixes from bituminous binders.
The binder used is a synthetic asphaltene-free binder that can be modified by an elastomer and other additives to improve its performance The binder, transparent in thin film, is suitable for coloring in the mass of asphalt mixes. It allows different colors to be obtained by simply adding suitable pigments.
We will discuss successively what are the particularities of these binders compared to bituminous binders and how they can ensure the required performance. The three issues addressed in this article are respectively:
- **How to formulate age-resistant clear binders?**
- **How to formulate binders to obtain asphalt mixes with high mechanical performance?**
- **How to control the evolution over time of coatings color?**

2. HOW TO FORMULATE AGE-RESISTANT CLEAR BINDERS?

2.1. Context

It is well known that the thermal and oxydative aging induce chemical reactions that are irreversible. But the effect of ultraviolet (UV) radiation is generally not considered in laboratory aging methods. And there is very limited knowledge about the interrelated effects of moisture, oxidation, heat and solar radiation, especially for synthetic clear binders.
The study described below consists in the selection of the raw materials according to a methodology especially adapted to synthetic light-colored binders, because the conventional tests fail to perfectly simulate the field aging.

2.2. Materials

Nine binders (called ‘’Liant n°1’’to‘’Liant n°9’’) are manufactured on the base of different petroleum resins and oils. A 40/60 penetration grade is aimed. It leads to different ratios resin/oil according to the viscosity of the oil.

2.3. Laboratory tests methods

Aging methodology

The laboratory aging methodology is based on a combination of 3 tests conducted on thin films of binders: RTFOT (Rolling Thin Film Oven Test) aging, PAV (Pressurized Aging Vessel) aging and solar radiation aging using either a SEPAP UV accelerated photoaging chamber (see Figure 1), or a WOM (Weatherometer).

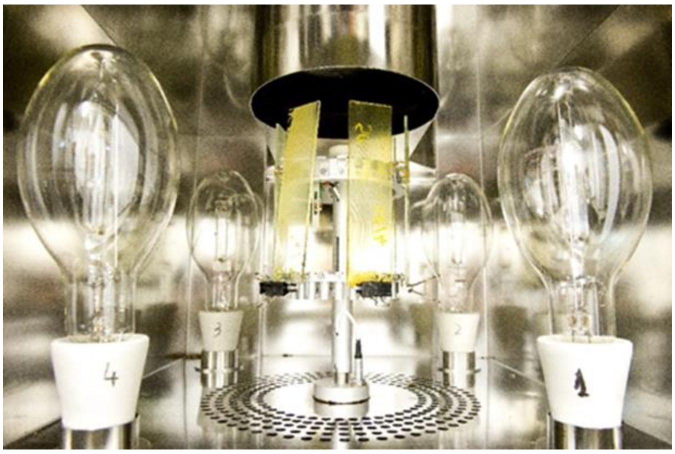

Figure 1: Clear binder samples in the SEPAP photoaging chamber

The conventional test that simulates long term aging is PAV. PAV is standardized using a single film of thickness 3,2 mm (50 g/pan), time of 20h, temperature of 100°C and pressure of 2,08 MPa. Thinner film thicknesses have also been experimented in order to get a homogeneous aging of the binder.
The methodology used only allows the practice of tests that can be carried out with a small quantity of material such as the rheological determination of the G* modulus.

Rheology methodology
Dynamic Shear Rheometer (DSR) is used to monitor the rheological viscous and elastic properties characteristics of the binder, in particular its hardening. All testing was carried out according to the EN14770 with an Anton Paar rheometer. The DSR geometry assembly was composed of 2 steel parallel plates of diameter 8mm. All testing was performed with a gap of 2mm. Strain level was 0,05% and the conditions of 15°C 10Hz have been selected. All the tests are conducted within the linear viscoelastic region as defined by the E 14770.
G* (MPa) is measured before aging (Gi*) and after aging (Gf *).
The complex modulus aging index ΔG*(%) is defined as: ΔG*(%) = [Gf *- Gi*] / Gi*.

Atomic Force Microscopy (AFM)
AFM is a local probe microscope that measures the interactions between a cantilever tip and the surface of a material. For viscous samples such as bituminous or synthetic binders the intermittent dynamic contact mode (tapping mode) is preferred. It allows to characterize the morphology of the sample up to the nanometric scale and to assess if there is a good homogeneity of the mixture. The observation is performed on the INNOVA AFM equipment from BRUKER. The products to be analysed are deposited on glass plates in a thickness of 50µm.

2.4. Results

Rheology
We base our assessment on the complex modulus aging index ΔG* criterion. Higher is ΔG*, the more pronounced is the aging level.
ΔG*(%) is measured for the 3 different levels of aging for the nine binders.
Figure 2 gathers all the results.
After RTFOT, ΔG* is in the range 15% - 31% (reference value for pure bitumen: < 30%)
After RTFOT+PAV, ΔG* is in the range 37% - 69% (reference value for pure bitumen: <60%)
After UV aging, ΔG* is > 220% (reference value for pure bitumen: <250%)
It appears that UV aging is the most important and impacts more on clear binders than black bitumens. For clear binders, based on the analysis of job sites feedback, acceptable values are considered as below 300%. Three of the binders, n°2, 6 and 7 are sensible to aging and do not meet this target. Two of them have even become very brittle. Consequently, the corresponding resin/oil blends are not validated for further studies.

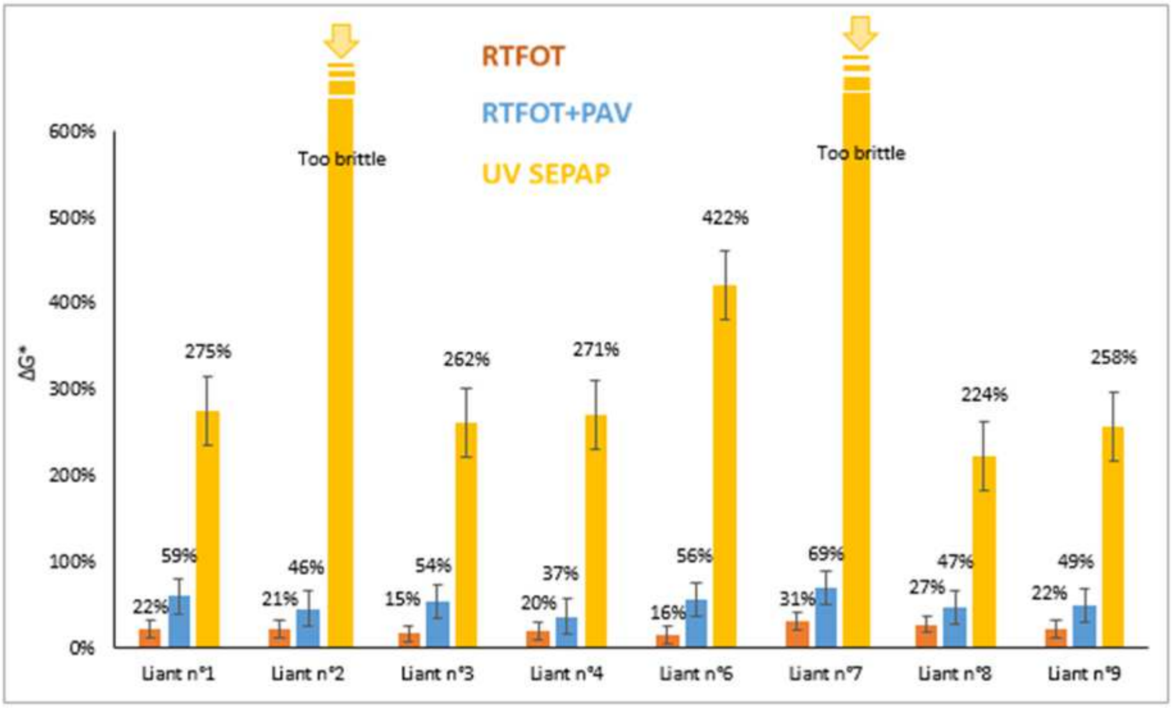

Figure 2: Evolution of G* after different types of aging: RTFOT, RTFOT+PAV, UV SEPAP

AFM

In a complementary and more fundamental way, AFM has been implemented on the samples before and after aging. First, the observation of the AFM images is used to assess if the product is homogeneous. In case of inhomogeneity two distinct phases can be seen. It may actually happen that resin/oil incompatibility cannot be detected at the macroscopic scale; in that case observation of AFM images is useful because it reveals two distinct phases. Then AFM is also used to detect if some changes in the structure happen with aging.
At this stage of the study's progress AFM measurements have not yet been done after UV aging. Figure 3 exhibits images of sample ''liant n°1''both at the initial stage and after PAV: both binders are homogeneous and no significant change happens in the structure.

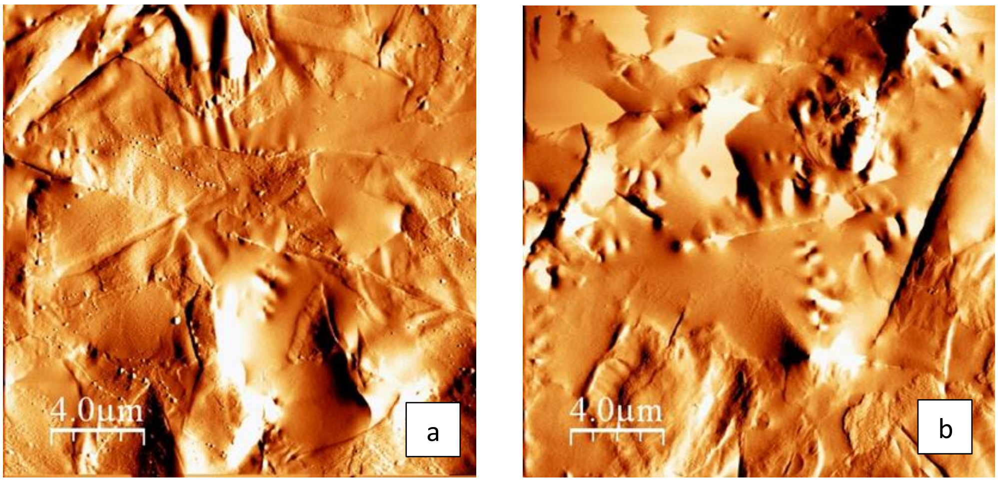

Figure 3: AFM images before aging (a) and after RTFOT+PAV aging (b) for clear binder sample

So the progressive hardening measured via rheology takes place without any change in the microstructure of the material.

2.5. Consequences

This methodology is followed as soon as there is a technico-economical opportunity to use a new resin/oil blend. It has been previously checked that the binders manufactured in the laboratory and industrially behaved in the same way.
Once the blend resin/oil has been validated, polymers and additives can then be added in order to answer to the other requirements. Also, some additives have a beneficial effect on resistance to weathering aging and help to significantly decrease the UV SEPAP aging index below 150%.
Even if these synthetic binders do not have to meet any product standard specifications, they are usually characterized with the same tests than the bituminous binders for further performance assessment, such as softening point, PG grade, elastic recovery and cohesion.

3. HOW TO FORMULATE BINDERS TO OBTAIN ASPHALT MIXES WITH HIGH MECHANICAL PERFORMANCE?

3.1. Context

Even if clear binders are mainly dedicated to low traffic pavements, we have designed a colored asphalt solution for public transport infrastructures, that is resistant to the severe and specific stresses for lanes dedicated to high service level bus lines: resistance to rutting including at low speeds on the acceleration and stopping areas, as well as excellent resistance to creep and indentation.
This technical solution will also contribute to the improvement of transport infrastructure pavements in urban and interurban areas and to the improvement of visual comfort and safety both in running lanes and in station areas.
These asphalt mixes for heavy traffic roads are an alternative to solutions made of deactivated or colored cement concrete, percolated asphalt concrete and asphalt concrete lightened by surface treatment (shot blasting, sandblasting or hydroblasting).
The present type of solution has the advantage of being immediately circulable after implementation and cooling to ambient temperature.

3.2. Formulation of high performance clear binders

To obtain the performance required to withstand the specific and severe stresses under severe operating conditions, the binders studied have been:
- formulated from a resin/oil blends that has met the aging resistance criteria described in §2.4
- adjusted to a penetrability between 20 and 30 1/10mm
- modified so that the characteristics are close to those of the best modified bitumens used in asphalt mixes intended to withstand high traffic

The binders that met those requirements have been called ''BHNS'' (voies de Bus à Haut Niveau de Service - Heavy traffic bus lanes).
Table 1 collects the characteristics of four ''BHNS'' binders obtained on the basis of the same H1 oil, 2 R1, R2 resins and 2 A1, A2 modifiers.

		BHNS -1	**BHNS-2**	**BHNS-3**	**BHNS-4**
		H1/R1/A1	**H1/R2/A1**	**H1/R1/A1/A2**	**H1/R2/A1/A2**
Penetrability (1/10mm)	EN 1427	28	22	28	27
R&B(°C)	EN 1428	66,4	66,2	88	92
FRAASS (°C)	EN 12593	-8	-8	-8	-9
Storage stability ΔR&B (°C)	EN 13999	-1	-0,6	-0,5	0
G* 15°C 10Hz (MPa)	EN 14770	70	71	52	50
Elastic recovery at 25°C (%)	EN 13398	85	86	90	91
RTFOT	EN 12607-1				
Residual pen (%) after RTFOT	EN1427	82	86	93	85
ΔR&B (°C) after RTFOT	EN1428	-1,2	-1,0	+1	+2

Table 1: Characteristics of four ''BHNS'' binders

It can be noted that:
- all binders are stable in storage
- they get very high elastic recovery: ≥ 85%
- all binders are resistant to RTFOT test
- the binders have a Fraass temperature close to -10°C
- the binders BHNS-3 and BHNS-4 formulated with the 2 additives have a softening temperature of close to 90°C, which is about 25°C higher than the binders BHNS-1 and BHNS-2
- the modulus G* at 15°C of these same two binders is lower, i.e. about 50 MPa, of the same order as pure bitumen of the same class.

In view of these results, the BHNS binder formula was validated on the basis of a double modification, as it has more favorable characteristics with regard to high temperature rutting and aging resistance.

3.3. Formulation of clear asphalt mixes for bus lanes

We focus the mixes laboratory formulations study on the rutting resistance, which is the main mechanical characteristic expected for targeted use in bus lanes. More specifically, complexes such as Base course or High Modulus Asphalt (EME 2) + Thin Asphalt Concrete (BBMC) have been tested as following:
- the conventional and standardized rutting test (60°C - 6 bar - 60 cycles per minute) with the objective of trying to obtain less than 5% rut at 100,000 cycles.
- a non-standard rutting test, more severe, developed at the COLAS Scientific and Technical Campus (CST) to better understand the risk associated with rutting and creep inherent in heavy, slow and channeled traffic. This ''severe rutting test'' is carried out at higher temperature and higher pressure.

For example, the percentage of rut obtained on a 7cm complex of Base course (GB4) R20 + 3cm of Thin Asphalt Concrete (BBMC) with clear ''BHNS'' binder is 3% at 100 000 cycles with the conventional test and 13% at 30 000 Cycles with the severe test.

Laboratory tests have been confirmed by successful feedback from road tests which shows its adaptation and durability to the most severe stresses. The works based on COLCLAIR BHNS® have recently been described in another document on the subject [2]. As an example, Figure n°4 shows a structure about 3 km long at the western entrance to the city of Saint Pierre in the Reunion Island, with a surface coating of Thin Asphalt Concrete (type C) 0/10 with clear "BHNS" binder. In total, no less than 9,000 m2 of this colored asphalt was applied in 3 cm thick.

Figure 4: COLCLAIR BHNS® bus lane in Saint-Pierre de la Réunion

3.4. New Specifications and range extension

This new binder has enriched our range of light binders, and completed the offer of clear and colorable asphalt mixes. The four main areas of use for which a clear synthetic binder could be now proposed are identified in Table 2.

Areas of use
roads with very few or no traffic, sidewalks
roads, tunnels low traffic
roads, tunnels high traffic
Bus lanes

Table 2: Areas of use for which a clear binder has been formulated and validated on site

4. HOW TO CONTROL THE EVOLUTION OVER TIME OF COATINGS COLOR?

4.1. Context

Beyond the potential color differences during manufacture, after a few months, there is a systematic gradual evolution of the coating surface. This phenomenon is more or less rapid depending on traffic but above all on the level of aggressiveness of weathering conditions. While UV-protected coatings generally keep their basic colorimetric characteristics, there is a marked action on the surfaces more exposed to the sun.

In order to objectively assess the color change over time and to be able to reliably study and compare possibilities for improvement; it is important to measure the colorimetric parameters in an analytically repeatable way [3].

At the BRCC (Belgium Road Research Center) an accelerated natural weathering method has been developed to enable to investigate the natural development of the color of mixes under the two predominant climatic agents that are sunshine and rain [4].

At the CST, trials have been carried out to perform in situ colorimetry measurements over time, in a comparative manner, under natural atmospheric conditions. They are described in this paper.

4.2. Description of sites areas

The colorimetric monitoring was carried out over a period of 2.5 years on 4 adjacent trial areas located on the CST car park and exposed to solar UV radiation:

- Area n°1: Asphalt 0/10 bitumen (reference)
- Area n°2: Asphalt 0/10 bitumen - light aggregates - hydrostripped
- Area n°3: Asphalt 0/10 red
- Area n°4: Asphalt 0/10 light binder

4.3 .Colorimetric measurements

The evolution of the color over time is measured using a spectrophotometer (X-rite model SP62). Illuminant D65 (which reproduces daylight), and a 10° inclination (observer eye) are used.

The device is set according to CIELAB color representation model, developed by the CIE (International Commission on Illumination), which correlates colorimetric measurements with visual perception.

It defines the three parameters L*, a* and b* (see Figure n°5).

- L* gives the brightness of the color:
The higher L* is, the closer the color of the substrate is to white.
- a* places the color on a green/red axis:
The higher a is, the closer the color of the support is to red.
- b* places the color on a blue / yellow axis:
The higher the b is, the closer the color of the support is to yellow.

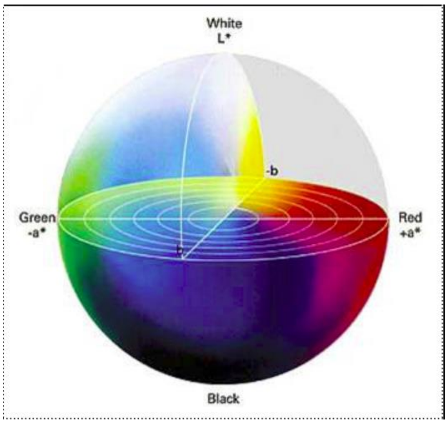

Figure 5: Representation of the colorimetric space L* a* b*

The uncertainties determined from a Robin Test on colored asphalt mixes for the three colorimetric components (L*, a* and b*) are in the order of 3% for repeatability and 9% for reproducibility.

4.4 .Results

The evolution of parameters L*, a* and b* over time is shown in Figures 6 to 8, respectively, for each of the four areas previously identified and exposed to solar UV.

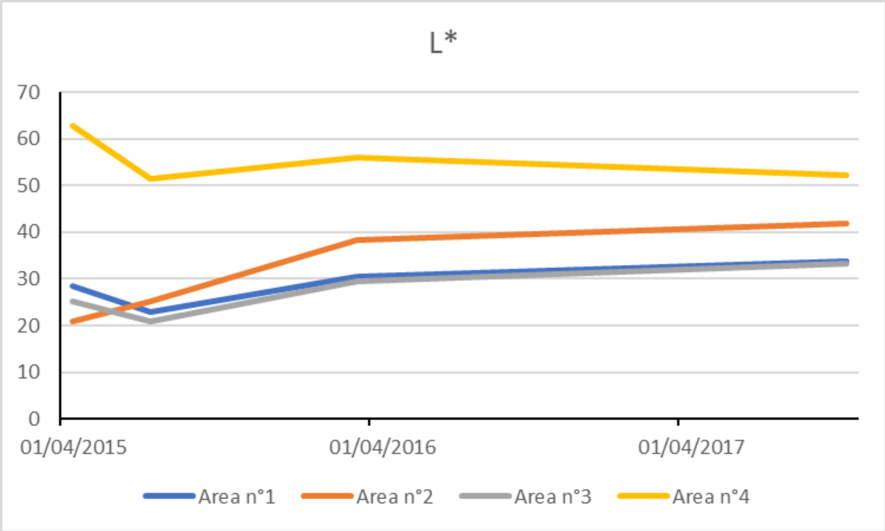

Figure 6: Evolution of L* versus time for the 4 experimental areas

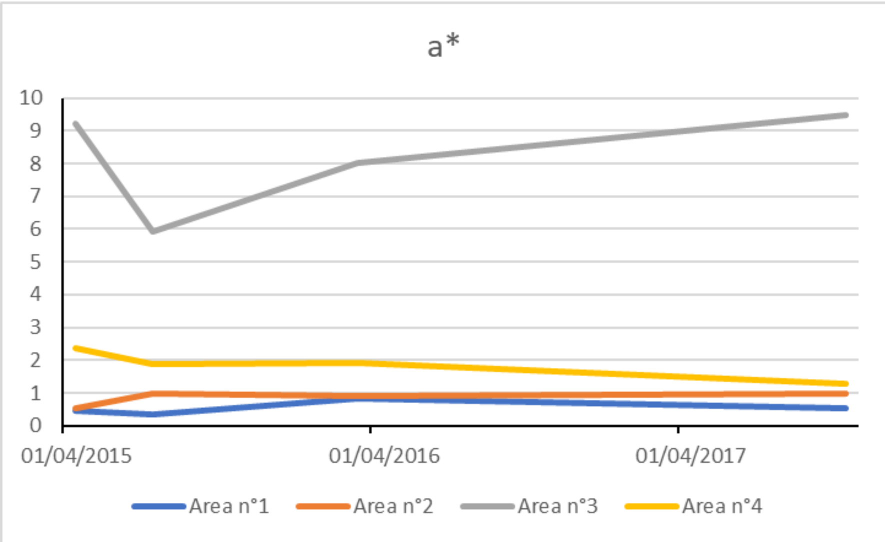

Figure 7: Evolution of a* versus time for the 4 experimental areas

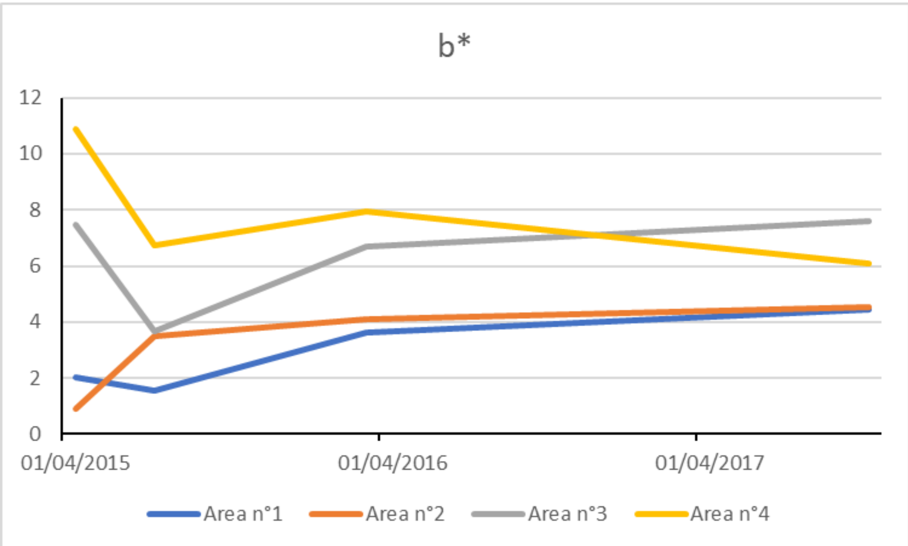

Figure 8: Evolution of a* versus time for the 4 experimental areas

It is observed after more than 2 years exposure to UV rays that:

- The level of clarity (L*) remains higher for the light-colored asphalt area (area n°4)

- The light-colored asphalt area loses its "yellow" component (b*) over time

- The hydrostripped asphalt mix formulated with light aggregates (area n°2) increases its level of clarity over time without ever reaching that of the light-colored asphalt.

- The red asphalt (area n° 3) logically has a higher red component (a*); after a slight decrease, it returns to its original level. The yellow component (b*) follows the same trend for this red area.

4.5. Interpretation and consequences

Subjected to the action of UV rays, the colorimetric characteristics of a mix formulated with a clear binder change. But this asphalt allows to maintain a high level of clarity, significantly different from the other asphalt areas.

In the medium and long term, the stripping of the binder film from the aggregate surface gradually reveals the natural color of the aggregate.

In order to preserve the aesthetic character and minimize the evolution under UV stress, it is therefore important to select not only the binder according to the evolution of its colorimetric characteristics after SEPAP UV aging, but also the aggregates which must be of a color as close as possible to the final color targeted for the mix. The CST has developed a methodology that determines an aggregate brightness index based on the measurement of the diffuse reflectance factor at 457nm, this index being strongly related to clarity L*[3].

5. CONCLUSION

Traditionally, colored paving materials have been used to provide road safety or for aesthetic reasons. Colored paving materials are also used to improve the visual appearance of surfaces particularly in urban settings, public places, or historical monuments. They also have been used in tunnels to improve photometric properties allowing better perception of obstacles and reducing the amount of lighting required for tunnel brightness. But we have also shown in this paper that we have enlarged the range of products and designed light colored paving materials that can resist to all kind of aging and to high traffic sollicitations such as buses lanes.

Our researchers also focused on verifying the environmental and societal acceptability of products: light-colored paving materials may be used to reduce the urban heat island effect taking the advantage of the particular feature of lower heat absorption. For example, a light-colored pavement has been applied in Dawson City (North of Canada) a few years ago (cf Figure 9), in order to provide a high albedo surface useful for protecting the permafrost, and it has been demonstrated that the solar heat absorption is minimized and the underlying permafrost not degraded [5].

Figure 9: Aerial View of Front Street, Dawson City, Yukon, September 2009

Moreover, environmentally speaking, the end of life of light colored pavements has been studied : it is not in the scope of this paper but the conclusions are that they can be deconstructed by milling and the aggregates thus obtained can be recycled under the same conditions as those derived from hot mixes formulated with bituminous binders, and incorporated into bituminous mixes.

ACKNOWLEDGEMENTS

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